The Allen Consulting Group

Review of Australia's participation in the Integrated Ocean Drilling Program

Final report

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Report to the ANZIC IODP Governing Council

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Acronyms

ANU	The Australian National University
ANZIC	Australia-New Zealand IODP Consortium
ARC	Australian Research Council
CMO	Central Management Organization
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCCEE	Department of Climate Change and Energy Efficiency
DFAT	Department of Foreign Affairs and Trade
DIISRTE	Department of Industry, Innovation, Science, Research and Tertiary Education
DRET	Department of Resources, Energy and Tourism
DSDP	Deep-Sea Drilling Project (1968-1984)
ECORD	European Consortium for Ocean Research Drilling
ERA	Excellence in Research Australia
ESO	ECORD Science Operator
FGB	Facility Governing Board
FIB	Facility Implementation Board
GA	Geoscience Australia
IODP	Integrated Ocean Drilling Program (2003-2013)
IODP (2)	International Ocean Discovery Program (2013-2023)
IODP-MI	IODP Management International
IOs	Implementing Organisations
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
LIEF	Linkage, Infrastructure, Equipment and Facilities program
MEXT	Japan's Ministry of Education, Culture, Sports, Science and Technology
MoU	Memorandum of Understanding
MSP	Mission-Specific Platforms
NERC	UK Natural Environment Research Council

NRC	US National Research Council
NRIP	National Research Investment Plan 2012
NSF	US National Science Foundation
ODP	Ocean Drilling Program (1985-2002)
OPSAG	Oceans Policy Science Advisory Group
PM&C	Department of the Prime Minister and Cabinet
POCs	Program Operating Costs
QUT	Queensland University of Technology
SAS	Science Advisory Structure
SEDIS	Scientific Earth Drilling Information System
SOCs	Science Operating Costs
UK	United Kingdom

Key Facts on Australia's Participation in IODP

- *IODP (2003-2013) is the world's largest international collaborative Earth sciences research program with 26 members, including Australia's largest trading partners.*
- *The oceans cover around 71% of the Earth's surface and scientific ocean drilling is crucial to the understanding of the fundamental processes and geological history of the planet.*
- *Australia has one of largest marine jurisdiction on Earth totaling about 10 million square kilometers (excluding the territory of Antarctica), much more than its land mass of about 7.6 million square kilometers.*
- *The resources in Australia's marine jurisdiction contributed about $44 billion to Australia's economy in 2011 and this is expected to increase to $100 billion by 2025.*
- *Through its membership of IODP Australia has access to major scientific drilling and equipment with an estimated value of $US 1 billion, and annual operating costs of about $US 170 million.*
- *IODP continues more than 40 years of ocean drilling in which Australian scientists have been involved.*
- *Australia's annual IODP membership fees are $US 1.4 million, with the total direct and indirect costs of participation in IODP over the 2008-2013 period estimated at $AUD 14.8 million.*
- *The ANZIC IODP consortium is itself a major scientific collaboration involving some 16 universities and several publicly funded research agencies across Australia and New Zealand.*
- *ANZIC has secured berths on nearly all IODP scientific expeditions since 2008 and a number of influential voting and non-voting positions on key IODP scientific committees, including for the 2013-23 Science Plan.*
- *Australian scientists have been authors of 8.9% of the 7,135 peer reviewed publications resulting from ocean drilling from 2003 to 2012, with further publications in preparation.*
- *Analysis of citations by country shows that the average citation rate of Australian authored ocean drilling related papers of 20 is significantly above the world average of 17.*
- *Analysis of citations by scientific journal shows that average citation rates for Australian authored ocean drilling related papers for five leading journals is above both that for other IODP-related papers and for the journal as a whole.*
- *A global map of collaborations based on jointly authored ocean drilling papers between 1996 and 2011 shows that Australian scientists are very well connected with leading international researchers and institutions.*
- *Leading university scientists making substantial use of ocean drilling material have been awarded $7 million in various ARC grants over the course of the IODP*
- *The results of ocean drilling in Australian waters have helped inform the geological assessments undertaken to support the Government's Offshore Petroleum Exploration Acreage Release Program.*
- *Some petroleum companies working in Australia's territorial waters have also used data from scientific ocean drilling to help inform and de-risk their exploration activities.*
- *Australian involvement in ocean drilling activities has helped train a number of PhD students, given post-doctoral researchers valuable experience and informed the teaching and research of academic staff.*

Executive summary

The Integrated Ocean Drilling Program (IODP) is a 10 year (2003-2013) international scientific collaboration to explore the history and structure of the Earth as recorded in the ocean basins. The IODP aims to solve global scientific problems by taking continuous core of rocks and sediments at a great variety of sites. IODP carries out deep scientific coring in all the world's oceans using a variety of platforms, and provides 'ground truthing' of scientific theories.

With a total marine jurisdiction of around 10 million square kilometres, which is considerably greater than the Australian mainland (7.69 million square kilometres) Australia has one of the largest Exclusive Economic Zones in the World. The oceans surrounding Australia hold answers to issues of fundamental importance to the nation's future, including: climate change; environmental sustainability; economic growth; national security; energy security and food security.

The IODP and predecessor programs

The IODP builds on the results of the previous Deep-Sea Drilling Project (DSDP) and the Ocean Drilling Program (ODP). The IODP is the world's largest Earth sciences collaboration, being supported by 26 countries and funded by eight entities acting as international partners.

Scientific expeditions are accomplished using three types of drilling platforms funded by the USA, Japan, and the European Consortium for Ocean Drilling Research (ECORD):

- *D/V JOIDES Resolution* operated by the US Implementing Organization;
- *D/V Chikyu* operated by Japan Agency for Marine-Earth Science and Technology (JAMSTEC) Center for Deep Earth Exploration; and
- Mission-specific platforms, operated by the ECORD Science Operator (ESO).

Australia joined the IODP in 2008, investing $US 1.4 million per annum for 25 per cent of a membership unit, while New Zealand has five per cent of a membership unit. The Australian arm of ANZIC was initially funded for 5 years through the Australian Research Council's (ARC) Linkage, Infrastructure, Equipment and Facilities (LIEF) grant scheme, and was subsequently awarded additional funding for 2013 (a total of $8.95 million). The ARC funding has been supplemented through contributions from consortium member universities and research institutions.

A new IODP Science Plan for 2013-2023, *Illuminating Earth through Subseafloor Sampling, Observation and Experimentation*, was published in 2011 with significant input from Australian scientists. The Plan highlights four main research themes: Climate and Ocean Change; Biosphere Frontiers; Earth Connections; and Earth in Motion. It identifies 14 major scientific challenges related to those themes.

A new management structure and business model is also being put in place to achieve economic efficiencies through lower program administrative costs, control of vessel scheduling, and direct contributions from international partners, ultimately leading to more months at sea.

The performance of IODP

The US, UK and Europe have each reviewed the IODP. These reviews have commented favourably on the performance of both the IODP and its predecessor programs, finding that the program has lead to a diverse range of valuable scientific and other benefits.

There are substantial lead times between scientific drilling proposals being developed and actual drilling occurring; and again between a drilling expedition taking place and the publication of general expedition reports and refereed scientific papers. Consequently it is often not practical to link IODP drilling expeditions explicitly to scientific outcomes published during the same period. Further, the experience, networks and collaborations developed through ocean drilling expeditions can last a lifetime for the scientists involved.

Benefits of Australia's investment

As with all science, some of the value of IODP would flow in due course to Australia, even if we were not a subscribing member. However it is clear that the magnitude, nature, scale and timing of benefits to Australia would be demonstrably different without direct participation.

It is well established that international collaboration is essential to remain in touch with leading researchers and scientific research. This is particularly the case where Australia wishes to remain at the leading edge or is seeking to build capability in new and emerging areas. Direct participation in IODP provides engagement with leading researchers in a wide range of fields, exposure to new techniques and use of ocean drilling research platforms and equipment with an estimated value of about $US 1 billion.

With a marine jurisdiction, if Antarctica is included, roughly double Australia's land mass, development and maintenance of a broad marine science capability is important in terms of understanding, managing and exploiting that jurisdiction, including huge energy resources, as well as contributing solutions for global issues such as climate change and natural hazards such as earthquakes and tsunamis.

The scientific outcomes from Australia's participation in ocean drilling are impressive in terms of productivity, quality and scientific impact. This is evidenced by the volume and citations of publications in high quality peer-reviewed scientific journals, the quality of science as reflected in the ratings achieved under the Excellence in Research Australia (ERA) process, ARC grants and contributions to the IODP scientific reports and publications. For example analyses undertaken by the Australian National University (ANU), which was drawn on for this project, show that:

- the ratings of ocean drilling university researchers in the ERA process indicates that 84 per cent are associated with fields of research, which have been evaluated to be 4 (above world standard) or 5 (well above world standard) in quality;
- of the ocean drilling publications in the Scopus database (1996 to 2011) the 203 papers published by Australian authors had an average citation rate of 20, significantly above the global average of 17;

- Australian authored papers in the *Geochimica et Cosmochimica*, the *Journal of Petrology*, *Organic Geochemistry*, the *JOIDES Journal* and *Island Arc* are cited above both the IODP and journal average. For a further nine journals, including *Nature*, Australian authored papers overall are cited above the journal averages. This is a further demonstration of the quality and impact of Australian scientists across a broad range of disciplines; and
- Australian scientists authored 8.9% of the 7,135 peer reviewed publications recorded by IODP from 2003 to 2012, with further papers in preparation.

The scientific outcomes of Australia's investment in IODP have been further built upon through leading researchers, who are making substantial use of ocean drilling materials, winning various competitive ARC grants totalling $7 million.

Government and industry end user impact is more indirect but includes some evidence of:

- IODP drilling providing valuable early stage geological information about prospective and non-prospective areas within Australia's offshore marine jurisdiction;
- use of relevant scientific drilling results to help inform the geological assessment of Australia's offshore petroleum acreage release program; and
- use of IODP drill core repositories to help inform and derisk commercial exploration activities.

Australia's participation in IODP provides valuable scientific spin-offs, including berths on drilling ship expeditions not in Australian waters and the work of international scientific teams on issues of direct interest to Australia. Scientific ocean drilling can add important new data and insights across a range of areas of key national interest such as climate change, earthquakes and tsunamis, how mineral deposits form and their exploration.

For expeditions in the Australian region, such as the IODP expeditions in the Great Barrier Reef or Wilkes Land off Antarctica, at least 30 foreign scientists are devoting time at sea and afterward working on scientific problems of direct interest to us. This has a significant multiplier effect on the work of the 2-3 Australian shipboard scientists involved.

Australia's membership of IODP also provides opportunities for participation in the governing structure and key committees of the IODP. Through such participation Australian scientists can influence directly the governance, strategic direction and work program of the IODP.

Australia's membership of IODP is consistent with the emphasis on building core capabilities articulated in the *2011 Strategic Roadmap for Australian Research Infrastructure* and the policy underpinning the *2012 National Research Investment Plan*.

There are a number of direct economic benefits to the Australian economy from membership of IODP derived predominately from port visits by consortium drilling vessels, but also from international investment in drilling in Australian waters and areas of interest in our region, as well as IODP-related workshops and conferences held in Australia.

Costs of Australia's participation

In considering the costs of Australia's membership it is important to account for both direct (e.g. membership fees) and indirect (e.g. support provided by host institutions) costs. Also some costs incurred in one phase of scientific ocean drilling (e.g. the work done on the 2013-2023 Science Plan) may well benefit a subsequent phase.

The direct cost of Australia's membership of IODP have totalled just under $AUD 11.8 million over the life of ANZIC participation (2008-2013). The associated indirect costs borne by researchers' institutions are estimated to be approximately $AUD 3.0 million. In total, it is therefore estimated that Australia's participation in IODP from 2008-2013 has cost approximately $AUD 14.8 million.

Conclusions

The key conclusions of the review are that the benefits to Australia of direct membership of the IODP consortium far exceed the modest costs of participation. Moreover it would be detrimental to Australia's interests not to be a member of the next phase of scientific ocean drilling. Participation in this next phase is well aligned with current government policy as articulated in the *2012 National Science Investment Plan*, the aspirations of the *Australia in the Asian Century White Paper* and Australia's policy of fostering international scientific collaborations.

Based on the expected benefits and costs of membership of the International Ocean Discovery Program (2013-2023), there is a strong case for Australia to become a member of all three ocean drilling consortia (US, Japan and Europe). At this time, the ARC LIEF program remains an appropriate source of funding and the Australian IODP consortium funding bid should emphasise the productivity, quality, multi-disciplinary nature and end uses of scientific ocean drilling. It should ideally include greater leverage from contributing institutions and a currency movement strategy. It would be sensible for Australia to continue to work closely in partnership with New Zealand counterparts.

Looking further forward, the Australian consortium should continue to ensure that maximum benefits flow to Australia from membership of the International Ocean Discovery Program, including to potential government and industry end users. It will be important that relevant data and information on the inputs, outputs and outcomes, including end-use, of Australia's membership be recorded on a systematic basis to facilitate monitoring of performance and future evaluations. There are advantages in the Australian IODP office continuing to be hosted by the ANU and for appropriate resourcing and succession planning to be put in place to ensure continuity and maintenance of corporate memory.

In addition, a more sophisticated communications campaign should be developed and implemented by the Consortium to ensure there is a broader understanding of the benefits of scientific ocean drilling among relevant Ministers, Departments, parliamentarians and science journalists.

Finally, it would be prudent for representations to be made to the Australian Government to have funding of membership of such an important international collaboration placed on a more sustainable and long-term basis beyond the LIEF program.

Chapter 1

This study

The Integrated Ocean Drilling Program (IODP) is a 10 year (2003-2013) international partnership to explore the history and structure of the Earth as recorded in the ocean basins. The IODP aims to solve global scientific problems by taking continuous cores of rocks and sediments at a great variety of sites. IODP carries out deep scientific coring in all the World's oceans using a variety of platforms, and provides 'ground truthing' of scientific theories that are based largely on remote sensing techniques. Australia joined the IODP in 2008.

The Australia-New Zealand IODP Consortium (ANZIC) commissioned the Allen Consulting Group to undertake a review of Australia's participation in the IODP. The Australian component of IODP research is currently funded until 2013. It is intended that the results of this study will help support a case for funding Australia's participation in the next decade of ocean drilling, titled the *International Ocean Discovery Program*. This requires a continued demonstration of the societal relevance and impact of IODP-related research.

1.1 Methodology

The review examines both the past performance of the IODP as well as likely future outcomes. It considers what has been achieved and is in train and what is proposed and likely to be achieved from the successor program.

The review has been informed by:

- a desktop review of existing information, including other reviews of the IODP;
- targeted consultations with key scientific, research and government stakeholders (a list is provided in Appendix A);
- selected case studies related to scientific ocean drilling;
- productivity, quality and impact indicators for IODP-related science;
- other benefits resulting from Australia's participation;
- the direct and indirect costs of participation; and
- an assessment of overall benefits and costs for Australia.

The Allen Consulting Group has worked closely with Professor Neville Exon and Catherine Beasley of the ANZIC office and Dr Paul Wong and Brett Cuthbertson from the Research Services Division, Office of Research Excellence of the Australian National University in undertaking this review and has also received assistance from the Australian Research Council. The Allen Consulting Group would like to thank all those involved in contributing to this review for their generous assistance.

1.2 Structure of the report

The remainder of this report is structured as follows:

- Chapter 2 discusses scientific ocean drilling and IODP as a background to the review;
- Chapter 3 describes the key achievements of the IODP and the findings of previous overseas reviews of the IODP and the science plan for the next phase of ocean drilling;
- Chapter 4 details the benefits of Australia's investment in IODP;
- Chapter 5 examines the costs of Australia's participation in IODP;
- Chapter 6 outlines the main conclusions of the review; and
- The Appendices provide additional detailed information, including on consultations, case studies, and Australian expeditioners and students involved in IODP.

Chapter 2

40 Years of Drilling - The IODP and Predecessor Programs

This chapter provides a background to the review of IODP. It explains scientific ocean drilling, explores the IODP and Australia's involvement in the IODP, as well as outlining the future science plan and operational arrangements for the next phase of scientific ocean drilling.

2.1 Scientific ocean drilling

Scientific ocean drilling involves taking continuous cores of rocks and sentiments, reaching several kilometres below the seabed. The broad aim is to explore how the Earth has worked in the past and is working now (ANZIC 2011).

For more than 40 years, results from scientific ocean drilling have contributed to global understanding of Earth's biological, chemical, geological, and physical processes and feedback mechanisms (NRC 2011). Research on deep-sea drill cores tells a story of profound climate and environmental change of the past that helps us to better understand the nature, mechanisms and driving forces behind such changes (IODP 2012b). Further information about ocean drilling is outlined in Box 2.1.

Box 2.1

SCIENTIFIC OCEAN DRILLING

All parts of the Earth system—the solid Earth, hydrosphere, atmosphere, cryosphere, and biosphere—are linked through flows of mass, energy, and life. Interactions between these realms have affected the development and evolution of our planet, and ultimately determined its habitability through time.

Buried beneath the ocean floor are records of millions of years of Earth's climatic, biological, chemical, and geological history. Scientific ocean drilling permits researchers to access these records and explore, analyse, theorize, and test models that describe how Earth works. Scientific ocean drilling also enables collection of subseafloor fluids, microbes, and geophysical and geochemical data by instrumenting boreholes, and using networks of boreholes for active experiments to resolve important properties and processes.

As a growing global population demands more resources and a better understanding of geological hazards and ongoing and future climate change, access to data and samples acquired through scientific ocean drilling is essential.

Source: IODP 2011, *IODP Science Plan for 2013-2023*, *Illuminating Earth through Subseafloor Sampling, Observation and Experimentation.*

2.2 The Integrated Ocean Drilling Program

The IODP is an international marine research program that explores Earth's history and structure recorded in seafloor sediments and rocks, and monitors subseafloor environments. The IODP's vision is:

> To provide vital information of the Earth system with which humankind has increasing interaction, through exciting expeditions to "inner space" realized by multiple-platform scientific drilling.
>
> IODP 2012b, International IODP web page.

The IODP builds on the scientific results of the earlier Deep-Sea Drilling Project (DSDP) initiated in 1968 and the Ocean Drilling Program (ODP), which succeeded the DSDP in 1985, and the encouragement that the United Nations Convention on the Law of the Sea has provided to international cooperation in marine scientific research (IODP 2009). Box 2.2 outlines the history of scientific ocean drilling.

Box 2.2

THE HISTORY OF SCIENTIFIC OCEAN DRILLING

In 1961, when the *CUSS* successfully used drilling technology to recover the first sample of oceanic crust, scientific drilling took root as a new scientific discipline. This Project Mohole led by the American Miscellaneous Society with funding from the National Science Foundation was an ambitious attempt to drill through the Earth's crust into the Mohorovičić discontinuity and to provide an Earth science complement to the high profile Space Race.

The next phrase of scientific ocean drilling, the DSDP, began in 1966 and operated using the *D/V Glomar Challenger*. This pioneer vessel for DSDP conducted drilling and coring operations in the Atlantic, Pacific and Indian oceans as well as the Mediterranean and Red Seas. The *Glomar Challenger* also advanced the technology of deep-ocean drilling.

In 1985, *D/V JOIDES Resolution,* a larger and more advanced drilling ship, replaced the *Glomar Challenger* at the start of a new program, the ODP. The ODP was truly an international cooperative effort to explore and study the composition and structure of the Earth's subseafloors. During ODP, the *JOIDES Resolution* was used to conduct 110 expeditions with 2000 holes from major geological features located throughout the ocean basins of the world.

The IODP builds upon earlier successes of the DSDP and the ODP to revolutionize our view of Earth history and global processes through ocean basin exploration. The program distinguishes itself from its legacy programs by employing multiple drilling platforms, the US *JOIDES Resolution*, the Japanese *D/V Chikyu* and European *Mission-Specific-Platforms* and collaborating with 26 worldwide nations.

Source: IODP 2012b, International IODP web page, accessed at http://iodp.org/history.

The IODP advances scientific understanding of the Earth by monitoring, drilling, sampling, and analysing subseafloor environments. It (IODP 2012b):

- deploys state-of-the-art ocean drilling technologies as its essential tool of discovery;
- unifies the international research community to explore Earth as a system;
- advances future research and discovery through dissemination of data and samples from global archives; and
- provides scientific context for global awareness of geohazards and environmental change.

The IODP's *Initial Science Plan* (IODP 2001) outlines three key research areas associated with the program. These areas have a number of potential benefits for the international science community, including:

- *The deep biosphere and subseafloor ocean* — microbes that inhabit these extreme environments are now widely considered to be a potential source of new biomaterials and are the basis of ideas for new biotechnical applications;
- *Environmental change, processes and effects* — new sediment samples, combined with drilling results from a global array of sites, allow a more sophisticated analysis of the causes, rates, sequencing and severity of change in the Earth's climate system over all time scales; and
- *Solid Earth cycles and geodynamics* — new technologies for sampling and monitoring regions of the seafloor will potentially provide answers to long-standing questions relating to oceanic crust formation and deformation, thereby contributing significantly to our understanding of earthquake generation.

The *Initial Science Plan* also acknowledges that while IODP's central mission focuses on fundamental scientific research, there is an important role for educational outreach (IODP 2001).

Current structure of IODP

The IODP is supported by 26 countries and is funded by eight entities acting as international partners, as outlined further in Box 2.3. IODP's initial 10-year, $US1.5 billion program was funded by the lead agencies — Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the US National Science Foundation (NSF). The IODP's Annual Program Plan (2013) budget identifies a total program cost of just over $US167 million for the US 2013 financial year (IODP 2012d).

Box 2.3

IODP FUNDING AGENCIES

National consortia and government funding agencies support IODP science and drilling platform operations. Participation in IODP is proportional to investment in the program.

Lead Agencies

Two lead agencies formally established IODP. In April 2003, officials from Japan's MEXT and the NSF signed a memorandum of understanding in which they agreed to form and jointly operate the Integrated Ocean Drilling Program.

Contributing Member

The European Consortium for Ocean Research Drilling (ECORD) was established with 12 European countries to maximize the impact of European scientists in IODP. The consortium has since grown into a collaborative group of European nations and Canada that together comprise an IODP funding agency, the European Consortium for Ocean Research Drilling (ECORD). Working alongside Japan and the United States, ECORD provides the IODP scientific community with access to mission-specific platforms (MSP) chosen to fulfil a particular challenging drilling environment.

Associate Members

In April 2004, the People's Republic of China joined IODP as an Associate Member through sponsorship of China's Ministry of Science and Technology. China's participation in IODP has given the Chinese marine science community new impetus and increased opportunity for deep-sea research. Chinese scientists participate in research expeditions and represent China's interests in the IODP Science Advisory Structure.

The Republic of Korea joined IODP as an Associate Member in June 2006 through the sponsorship of the Korea Institute of Geoscience and Mineral Resources.

In 2008, Australia and New Zealand formed the ANZIC and joined IODP as an Associate Member.

In 2009, a Memorandum of Understanding (MoU) brought India into IODP as an Associate Member, supported by India's Ministry of Earth Sciences. In 2012 Brazil also joined IODP as an Associate Member.

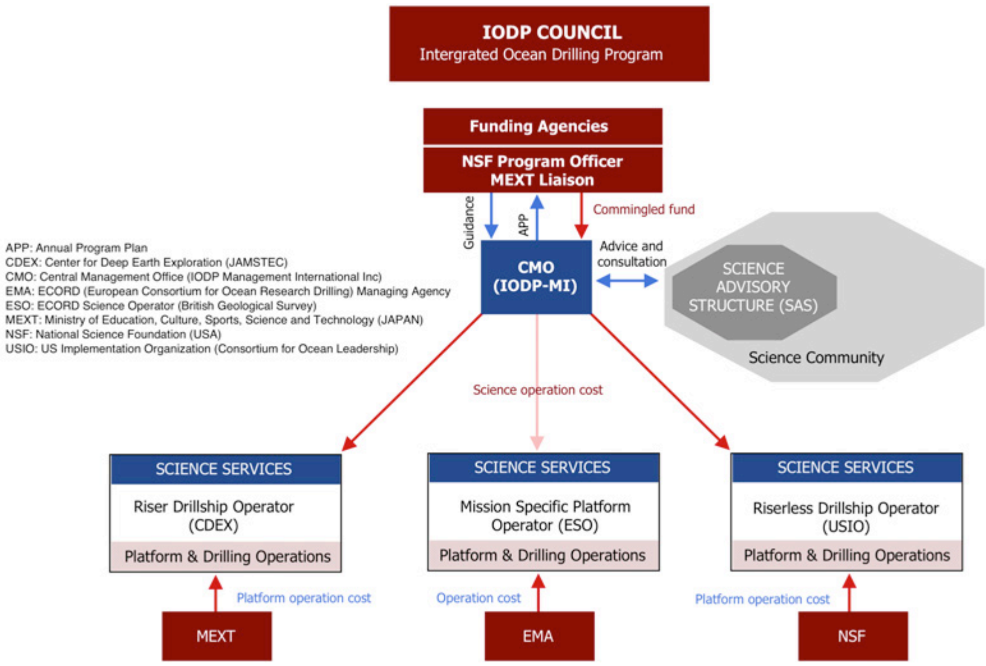
Source: IODP 2012c, *The integrated ocean drilling program*

In addition to the IODP members that comprise the governing IODP Council, the IODP operations are based on three structural elements (IODP 2012d):

- the Central Management Organization (CMO), IODP Management International (IODP-MI), which is responsible for overall management of the program;
- the three Implementing Organisations (IOs), which are responsible for operation of the platforms; and
- the Science Advisory Structure (SAS), comprising scientists, engineers, and technologists designated by IODP member organizations, which is responsible for assessing and determining drilling expeditions proposals.

The IODP structure is shown in Figure 2.1.

Figure 2.1
IODP STRUCTURE



Source: IODP 2012d, *Annual Program Plan 2013*, Integrated Ocean Drilling Program, accessed at http://www.iodp.org/program-document

IODP program costs are defined as either Science Operating Costs (SOCs) or Program Operating Costs (POCs). Funds for SOCs are collected from IODP members by the US NSF and provided through contract to IODP-MI, which in turn distributes them to the Implementing Organizations and other subcontractors according to the budgets outlined in the Annual Program Plan (IODP 2012d). POCs, which represent far larger costs, are supplied directly to the Implementing Organizations from the funding agencies of the countries or consortia responsible for the IODP drilling platforms. The IODP Council is the forum in which the sponsoring financial partners (IODP members) fund and guide the Program.

Drilling platforms

Scientific expeditions are accomplished on three distinct drilling platforms funded by IODP members USA, Japan, and ECORD and operated by Implementing Organizations. These platforms and Implementing Organizations are:

- *D/V JOIDES Resolution* (a riserless drilling vessel), operated by the US Implementing Organization;
- *D/V Chikyu* (a riser drilling vessel), operated by Japan Agency for Marine-Earth Science and Technology (JAMSTEC) Center for Deep Earth Exploration; and
- Mission-specific platforms, operated by the ECORD Science Operator (ESO).

Table 2.1 outlines the different platforms and vessels capabilities. Figure 2.2 provides a schematic of the different IODP platforms and vessels.

Table 2.1

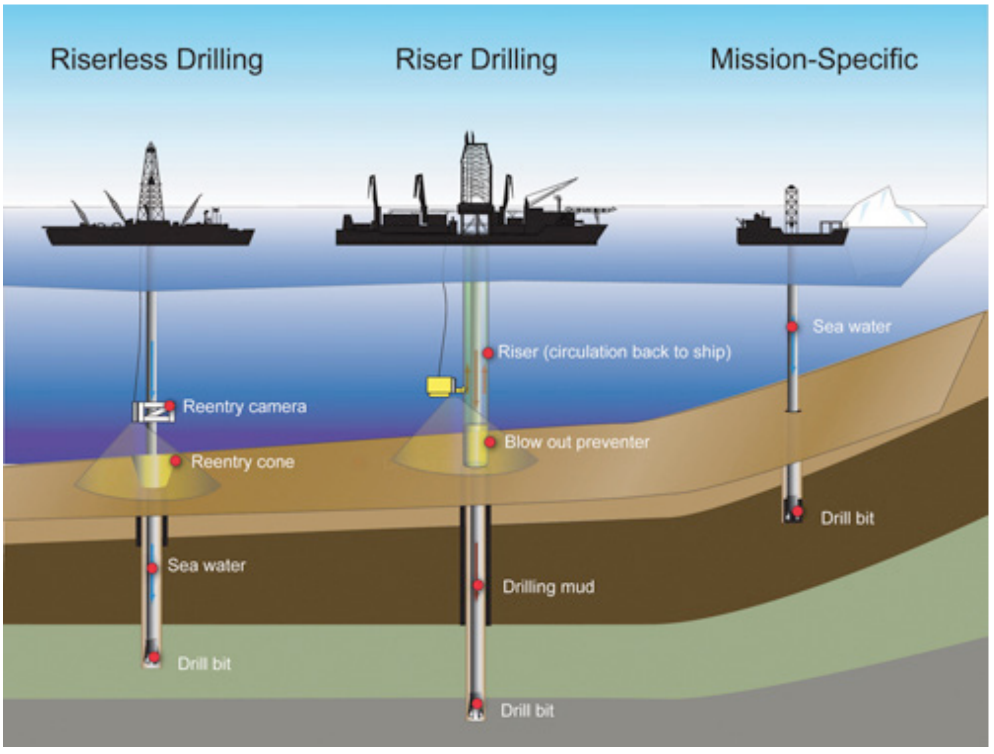
IODP PLATFORM AND VESSEL CAPABILITY

Ship/Platform	Capability	Description
JOIDES Resolution	Riserless drilling	In riserless drilling, seawater is circulated downward through the drill pipe and upward through the open hole. If needed, mud can be pumped through the drill pipe to clean the hole, but it cannot be returned to the platform and reused. Open-hole drilling typically can be initiated within hours or one day upon arrival at the site. Riserless drilling needs to avoid geological structures that are likely to contain hydrocarbon reservoirs in order to avoid the possibility of a blow-out and consequent environmental and other damage.
Chikyu	Riser drilling	In riser drilling, a large-diameter steel pipe (riser) is connected to the drilling platform and the seabed, with the drill pipe run within the riser. Drilling mud is pumped down the drill pipe and returned outside of the drill pipe contained by the riser. Mud density is controlled to keep the hole from collapsing by balancing formation pressure. Mud use can also improve core recovery and keep the hole clean by lifting drilling fragments (“cuttings”) to the surface. These cuttings can be used for scientific examination, however, in most applications, cuttings cannot substitute for cores. Riser drilling is needed for deep holes and for difficult formations (e.g. salt, zones that are over pressured). If a hole has any risk of containing hydrocarbons, the riser technique allows for the deployment of a blow-out preventer. Setting up a deepwater riser can take many days to weeks, and is sensitive to weather and sea conditions. Thus, a riser system would not be used for multiple shallow holes.
Mission-specific platforms	Various	Some scientific targets critical to accomplishing the goals of this science plan are located in regions characterized by geological formations that are difficult to drill or by extreme environmental conditions. Such targets require the use of MSPs. MSPs are chartered from industry according to the specific needs.

Source: IODP 2011, IODP Science Plan for 2013-2023, Illuminating Earth through Subseafloor Sampling, Observation and Experimentation.

Figure 2.2

IODP PLATFORMS AND VESSELS



Source: IODP 2012b, International IODP web page, accessed at **http://iodp.org**.

Core Repositories and access to data

The various ocean drilling core repositories represent a valuable resource for current and future scientific investigation. Access is available after a one year moratorium to all scientists (not just IODP members) with a convincing science plan.

There are three IODP Core Repositories:

- the Gulf Coast Repository in College Station in Texas;
- the Bremen Core Repository in Germany; and
- the Kochi Core Centre in Japan.

The Gulf Coast Repository (including the Rutgers repository) contains cores from the Eastern Pacific and Southern Oceans, the Caribbean Sea and the Gulf of Mexico. It holds about 131 km of drill cores. The direct core curation cost is about $US 500,000 per year, and involves an average (since 2004) of about 185 post-post-cruise moratorium requests for 23,000 samples per year. This is in addition to early post-cruise sampling parties (about one per year) which can take anywhere from 10,000 to 70,000 samples.

The Bremen Core Repository is for material from the Atlantic Ocean; the Mediterranean, Black and Arctic Seas; and all the Mission Specific Platform cores. It holds about 151 km of core, and provides about 50,000 samples to scientific investigators each year.

The costs for running the IODP Bremen Core Repository are in the order of $US 375,000 per year. In addition there is also an added value of MARUM, University of Bremen, providing the core repository part of the building, the amortisation costs of which are in the order of $US 160,000 per year. There are also amortization costs for providing access to MARUM equipment of approximately $US 150,000 per year.

The Kochi Core Centre store holds 93 km of cores from the Western Pacific and Indian Oceans. On an average, the Kochi Core Centre ships around 8000 samples annually for scientific investigation. The direct cost of IODP core curation at the Kochi Core Centre is about $US 400,000, which does not include 30 per cent indirect costs.

In total the three ocean drilling core repositories hold a valuable geological record comprising 375 km of core material. A measure of their importance is that between 81,000 and 140,000 samples are provided for further scientific investigation each year.

IODP also maintains an integrated data and publications portal, the Scientific Earth Drilling Information System (SEDIS), which serves as a one-stop-shop for discovery, searching and accessing (ANZIC 2012b):

- post-moratorium data and metadata from all IODP and legacy program data systems;
- publications and publications metadata from IODP/ODP/DSDP and the open literature related to scientific ocean drilling; and

- post-expedition data and metadata from post-cruise data capture projects and voluntarily submitted post-expedition data sets.

For data sets, SEDIS provides multiple discovery and search capabilities, including geospatial searching, keyword searching, and controlled vocabulary searching. For publications, SEDIS offers full-text searching of most articles, as well as geospatial and controlled vocabulary searching.

2.3 Australia's involvement in the IODP

Australia joined the IODP in 2008 with 25 per cent of a membership stake, while New Zealand has five per cent of a membership stake. The Memorandum of Understanding (MOU) between the Australian Research Council (ARC), NSF and MEXT covers the period 1 January 2008 to 30 September 2013. The Australian membership fees amount to $US 1.4 million per annum, and New Zealand contributed $US 375,000 per annum up to 2011. A full member pays U$US 5.6 million per annum.

The Australian arm of ANZIC was awarded initial annual funding of $AUD 1.2 million by the ARC for a five-year period (i.e. until the end of 2012) under the Linkage, Infrastructure, Equipment and Facilities (LIEF) grant scheme, and secured $AUD 570,000 per annum from scientific partners. This was supplemented by additional funding in 2009 to meet large fluctuations in the Australia-US dollar exchange rate — comprising an additional $AUD 350,000 per annum from the ARC and an additional $AUD 60,000 per annum from partners.

In early 2011 the Australian arm of the ANZIC consortium was awarded a further $1.55 million by the ARC for 2013. As the Consortium had benefited financially from the appreciation of the Australian dollar the amount sought from Australian scientific partners was reduced to a total of $AUD 180,000 for 2013. The ANZIC IODP income flows are outlined in Table 2.2.

Table 2.2

ANZIC IODP INCOME, $AUD

Funding Source	2008[1]	2009[1]	2010[1]	2011[1]	2012[1]	2013[2]	Total
ARC Grant funding	1,200,000	1,550,000	1,550,000	3,100,000	1,550,000	0	**8,950,000**
Contribution from scientific partners	570,000	570,000	680,000	630,000	770,000	180,000	**3,400,000**
Other	(66,531)	66,531	0	(97,358)	128,646	44,000	**75,288**
Total	**1,703,469**	**2,186,531**	**2,230,000**	**3,632,642**	**2,448,646**	**224,000**	**12,425,288**

Notes: 1. Actual expenditure. 2. Budgeted expenditure
Source: Statements of Income and expenditure (2008-2012), provided by the ANZIC IODP office and the IODP Grant – Financial report December 2012, provided by the ANZIC IODP office.

Membership of the Australian arm of ANZIC has varied somewhat over time. It now comprises 16 universities, five government agencies, and one marine geoscience peak body, as outlined in Box 2.4. The involvement of several New Zealand institutions in 2008, forming the ANZIC Consortium, increased the Consortium's IODP contribution to 30 per cent of a membership stake. The ARC, NSF and MEXT agreed to a MOU in 2009 which entitles ANZIC to a specified number of scientific positions on drilling expeditions per year, and to several voting and non-voting positions in IODP committees.

Box 2.4

ANZIC MEMBERS IN 2013

Australian IODP partners:

- Australian National University
- CSIRO Petroleum Division and Exploration & Mining Division
- Macquarie University
- James Cook University
- Curtin University of Technology
- Geoscience Australia
- Monash University
- University of Melbourne
- University of New England
- University of Queensland
- Queensland University of Technology
- University of Sydney
- University of Tasmania
- University of Western Australia
- University of Wollongong
- Australian Institute of Marine Science
- Australian Nuclear Science and Technology Organisation
- MARGO (Marine Geoscience Office)

New Zealand IODP partners:

- GNS (Geological and Nuclear Sciences Ltd)
- Otago University
- Victoria University of Wellington
- University of Auckland

Source: ANZIC 2012a, ANZIC IODP webpage.

In 2012, due to New Zealand government budget constraints, New Zealand could no longer pay its $US375,000 per annum fee to NSF, so the New Zealand institutions were invited on a short-term basis to become paying members of the Australian consortium, which has enabled their continued participation without detriment to pre-existing arrangements.

The rationale for Australian involvement

Australia has one of the largest marine jurisdictions on Earth totalling about 10 million square kilometres (excluding the territory of Antarctica), much more than its land mass of about 7.6 million square kilometers (Australian Government 2012g). The resources in Australia's marine jurisdiction contributed about $44 billion to Australia's economy in 2011 and this is expected to increase to $100 billion by 2025 (OPSAG 2012).

The Prime Minister the Hon Julia Gillard, has acknowledged the importance of the 'blue economy' stating:

> the oceans are the foundation of livelihoods, economies and cultures

and

> the ocean is of profound innate value to Australians
>
> PM Address to the Rio+20 Nature Conservancy "Blue and Green Economy" Breakfast, Rio de Janerio

Following submissions to the UN Commission on the Limits of the Continental Shelf, Australia's seabed jurisdiction has been extended significantly beyond the 200-nautical mile limit established under international law. Exploration of this additional territory will require a significant research effort.

However, as noted by Exon (2010, p. 37), this research requires 'more scientists than we have, specialised equipment that we do not have, and vessels with capabilities that Australian research agencies do not and will not possess'. The capabilities of the IODP therefore provide important tools that will benefit Australian marine research, for example through the use of coring technology that allows for the sampling of sub-surface environments hundreds of metres below the sea floor.

Australia's new deep water research vessel, *RV Investigator*, a national facility operated by CSIRO, will have piston coring capability of 25 metres but will not be able to undertake deep subseafloor drilling. The scientific research undertaken by the *RV Investigator* will assist in providing the necessary site survey work needed to support future IODP drilling proposals.

Australia is able to benefit from significant synergies in the use of the capital assets of the IODP — worth approximately $US 1 billion — for research in the Asia-Pacific region. For example, the 2010 expeditions to the Great Barrier Reef and Wilkes Land (Australian Antarctic Territory) yielded data of particular relevance to the Australian scientific community. The IODP may also play a future role in further researching the geological features surrounding Lord Howe Island, which could complement work already being undertaken by Geoscience Australia. There is thus significant potential for Australia to leverage existing and planned IODP research to improve scientific knowledge of national geological assets.

IODP data may also have important domestic commercial applications, for example in the energy and mineral resources industries. Woodside Petroleum Limited, one of Australia's largest oil and gas companies, has previously obtained access to cores obtained by a Japanese IODP vessel from the Exmouth Plateau off the coast of Western Australia, to help inform its exploration activities.

Membership of the IODP offers:

- the Australian scientific community an opportunity to participate in the forefront of global geoscience research;
- Australian scientists benefit through participating in shipboard and post-cruise research as well as in land-based support teams for expeditions by building partnerships with overseas scientists, by steering research programs and outputs, and through early access to key samples and data; and
- unique training opportunities for doctoral and post-doctoral students in marine science.

There are also direct economic benefits from visits by IODP ships to Australian ports and from IODP related workshops held in Australia when they occur.

The benefits to Australia of participation in IODP are discussed in more detail later in this report at Chapter 4.

Alignment with other research programs

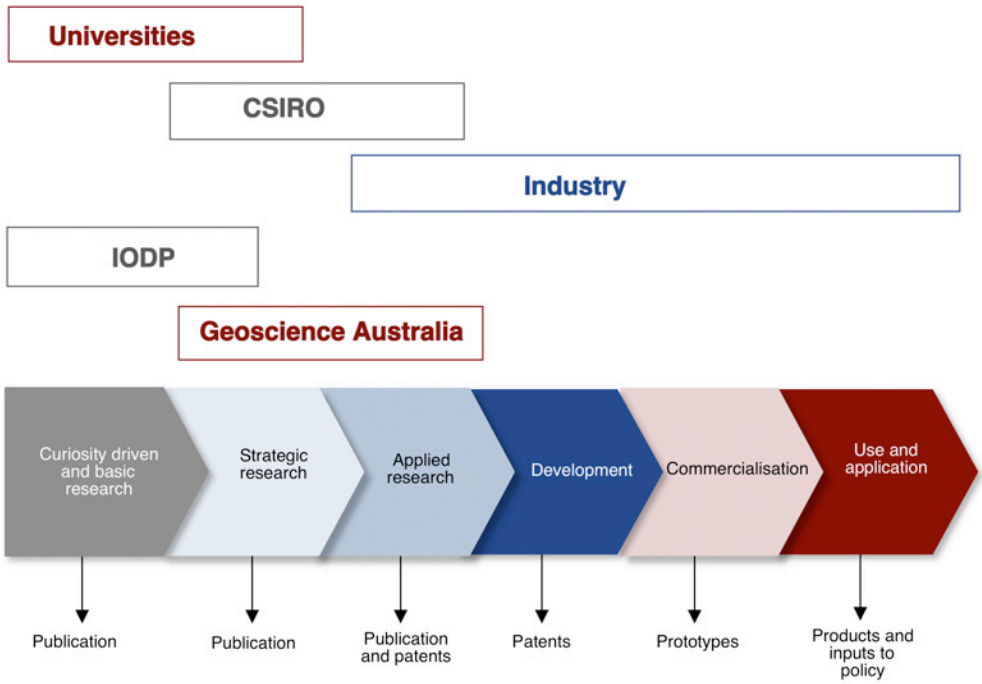
Scientific ocean drilling is basic science designed to provide new data and insights into the fundamental processes and history of the Earth. The research undertaken through the IODP is determined by a competitive peer review processes. This ensures that only the most worthwhile proposals are pursued. The IODP is therefore somewhat akin to the Australian Research Council's (ARC) curiosity driven Discovery Program.

The successor International Ocean Discovery Program is planned to be more focussed and strategic in nature while still basic science.

While not wanting to imply that there is a linear progression from basic research, through to its application, Figure 2.3 below illustrates the spectrum of different types of research and commercialisation and shows (approximately) where various research performing organisations sit and how these activities fit in the broader R&D/innovation environment. Examples of the dominant outputs from each part of the spectrum are also shown.

Figure 2.3

RESEARCH SPECTRUM



Source: Allen Consulting Group

IODP is demonstrably different to the strategic basic and applied science undertaken by CSIRO through its Flagships program and to the applied science undertaken by Geoscience Australia. However, the results of scientific ocean drilling will inform subsequent research undertaken within universities and publicly funded research agencies and, in a general sense, commercial exploration activities. It also informs policy making processes and decisions as well as providing potentially valuable information for industry.

The National Research Investment Plan (NRIP) (Australian Government 2012a) makes a number of points that are relevant to Australian participation in IODP. The NRIP emphasises the importance of international collaboration and the need to fund activities such as IODP on a sustainable and ongoing basis. More specifically, IODP addresses three of the Research Investment Principles in that document:

- Principle 3 – increase the stock of knowledge;
- Principle 4 - support global quality and scale; and
- Principle 5 - deliver a strong cohesive research fabric.

Principle 6 (Create a sustainable capability) is also important in relation to Australia's continuing commitment to the IODP. This Principle states:

> Investment should be made with a view to sustaining the long term viability of Australia's research and innovation capability. Funding for core research and innovation programs should be ongoing and predictable.
>
> National Research Investment Plan, 2012, page 60.

A further report, *APS200 Project: The Place of Science in Policy Development in the Public Service* (Australian Government 2012b) recognises the important use of science in policy making. IODP contributes to policy making through knowledge gained and scientific analysis undertaken from IODP exploration in areas of interest to Australia.

2.4 The future of scientific ocean drilling

Planning for the next ten-year phase of IODP is already well underway, with significant input from Australian scientists. A new scientific ocean drilling Science Plan for 2013-2023, *Illuminating Earth through Subseafloor Sampling, Observation and Experimentation*, has been developed and published. This Science Plan for the International Ocean Discovery Program is intended to guide multidisciplinary, international collaboration in scientific ocean drilling during the period 2013 to 2023 (IODP 2011). The Plan highlights four main research themes:

- Climate and Ocean Change;
- Biosphere Frontiers;
- Earth Connections; and
- Earth in Motion.

Each of these themes identifies a number of high-priority challenges as outlined in Box 2.5.

The Science Plan also explores aspects of education, outreach and implementation, acknowledging that education and outreach will be crucial components of the International Ocean Discovery Program. Education and outreach activities will place special emphasis on three outreach initiatives (IODP 2011):

- training the next generation of scientists — by providing opportunities for shipboard and shore-based participation alongside international teams of scientists and engineers, the International Ocean Discovery Program will serve as a technical and scientific training ground for early-career scientists, graduate students, and undergraduates. As environmental challenges increasingly require global solutions, the multidisciplinary, international training acquired through participation in the drilling program will be invaluable to the future scientific leaders in the private sector, academia, and governments around the world.
- fostering stewards of the planet — the International Ocean Discovery Program will provide access to resources and help educators develop materials for teaching geoscience, bioscience, and related disciplines to children of all ages. It will also offer opportunities for educators to participate in hands-on activities at sea and at core repositories, where they can work with scientists on real samples and data, and develop educational activities for the classroom.
- informing and inspiring the public — the International Ocean Discovery Program will build and maintain a vibrant public communication program, using print, audio, and video media, public institutions, and social networking to inform, influence, and inspire citizens about Earth systems and life science.

Box 2.5

RESEARCH THEMES AND CHALLENGES

Climate and ocean change: reading the past, informing the future

1. How does Earth's climate system respond to elevated levels of atmospheric CO2?
2. How do ice sheets and sea level respond to a warming climate?
3. What controls regional patterns of precipitation, such as those associated with monsoons or El Niño?
4. How resilient is the ocean to chemical perturbations?

Biosphere frontiers: deep life, Biodiversity, and environmental forcing of ecosystems

5. What are the origin, composition, and global significance of subseafloor communities?
6. What are the limits of life in the subseafloor?
7. How sensitive are ecosystems and biodiversity to environmental change?

Earth connections: deep processes and Their impact on earth's surface environment

8. What are the composition, structure, and dynamics of Earth's upper mantle?
9. How are seafloor spreading and mantle melting linked to ocean crustal architecture?
10. What are the mechanisms, magnitude, and history of chemical exchanges between the oceanic crust and seawater?
11. How do subduction zones initiate, cycle volatiles, and generate continental crust?

Earth in motion: processes and hazards on human time scales

12. What mechanisms control the occurrence of destructive earthquakes, landslides, and tsunami?
13. What properties and processes govern the flow and storage of carbon in the subseafloor?
14. How do fluids link subseafloor tectonic, thermal, and biogeochemical processes?

Source: IODP 2011, IODP Science Plan for 2013-2023, Illuminating Earth through Subseafloor Sampling, Observation and Experimentation

Funding for the next ten-year phase of ocean drilling is yet to be formally confirmed but there are grounds to be very optimistic that the NSF, MEXT and European Union will continue their support.

The research undertaken through the IODP remains relevant for future global and domestic scientific purposes. ANZIC (2009) noted that Australia and New Zealand were unique among the members of the IODP in that they are the only countries representing the Southern Hemisphere, and their jurisdictions incorporate the climatologically vital Southern Ocean and the active tectonic margins of the Southwest Pacific and Indian Oceans. Australia therefore has an important role to play in contributing to the post-2013 planning process and to the future ocean drilling research effort. Brazil joined IODP in 2012 and adds a third Southern Hemisphere country to the grouping.

A new framework for the International Ocean Discovery Program

The IODP's international partners, platform operators and the scientific leadership of the Science Advisory Structure have designed a new management structure and business model for future operations. The new framework will be a guiding document for the platform providers to develop more specific MOUs with their international partners for the new International Ocean Discovery Program (IODP 2012a).

In addition to changes to the administration of the Program under the new framework, the NSF, ECORD and MEXT/JAMSTEC will operate as independent Platform Providers, rather than having two Co-Lead Agencies. Each Platform Provider will have its own Facility Board that will be responsible for the effective delivery of the Facility's contribution to the IODP Science Plan (IODP 2012a). Each Platform Provider will independently solicit contributions from international partners. The major changes are summarised in Box 2.6.

Box 2.6

THE NEW FRAMEWORK

The key aspects of the new framework are:

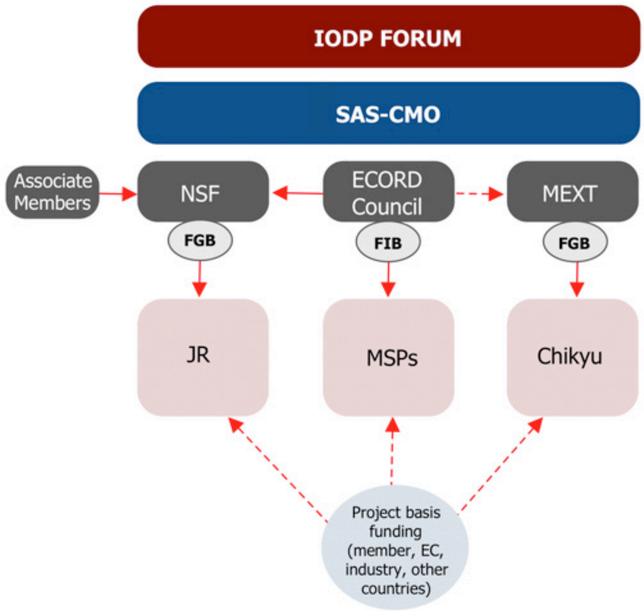
- The IODP Forum will be the overarching international umbrella of the programme. All funding agencies contributing to the programme will be represented. The IODP Forum will develop a long-term strategic view. The Chair of the Forum will be a well-recognised senior scientist, who will be the face of the programme, interact with other international science initiatives, and promote the programme internationally.
- The international SAS will evaluate all proposals for all platforms. A "Support Office" will help to deal with the proposals. The future SAS will have a simpler structure than that of the current programme.
- Platform providers will be completely responsible for funding the operations, and will in turn have more independence. Each of them will rely on its own board, the Facility Governing Board in the case of NSF and MEXT, and the Facility Implementation Board (FIB) in the case of ECORD, to schedule their platforms based on the positively evaluated proposals forwarded by the SAS. The ECORD Facility Implementation Board will include leading scientists, representatives of the funding agencies, the ECORD Managing Agency and the ESO.
- The programme will have the flexibility in its funding sources to allow it to seek additional funding from industry, the EC or other countries. Funding from IODP members on a project basis will be also encouraged and facilitated.

Source: ECORD 2012, *The future of ECORD:2012-2023.*

The new governance and operating structure is outlined in Figure 2.4.

Figure 2.4

NEW FRAMEWORK STRUCTURE



Source: ECORD 2012, *The future of ECORD: 2012-2023.*

The benefits of this new model are stated to include economic efficiencies gained by reductions in program administrative costs, control of vessel scheduling, and direct contributions from international partners, ultimately leading to more months at sea (NSF 2012). A high level of cooperation and collaboration between the parties will be required to ensure effective coordination and delivery of the new Science Plan.

2.5 Conclusions

International collaboration in scientific ocean drilling has had a long history and each successive phase (DSDP, ODP, IODP) has achieved significant scientific and technical results. The major platform operators (US, Japan and Europe) have made a very substantial investment in drilling vessels and equipment. There is a strong rationale for Australia to be a member of the IODP consortium in terms of the access to key infrastructure, the scientific outcomes and the strong alignment with other research programs and the National Research Investment Plan.

Planning is well advanced for the next phase of scientific ocean drilling, the *International Ocean Discovery Program*, with a science plan for 2013-2023 already published and new governance and operational arrangements being put in place.

Chapter 3

Illuminating the Past - Results of IODP

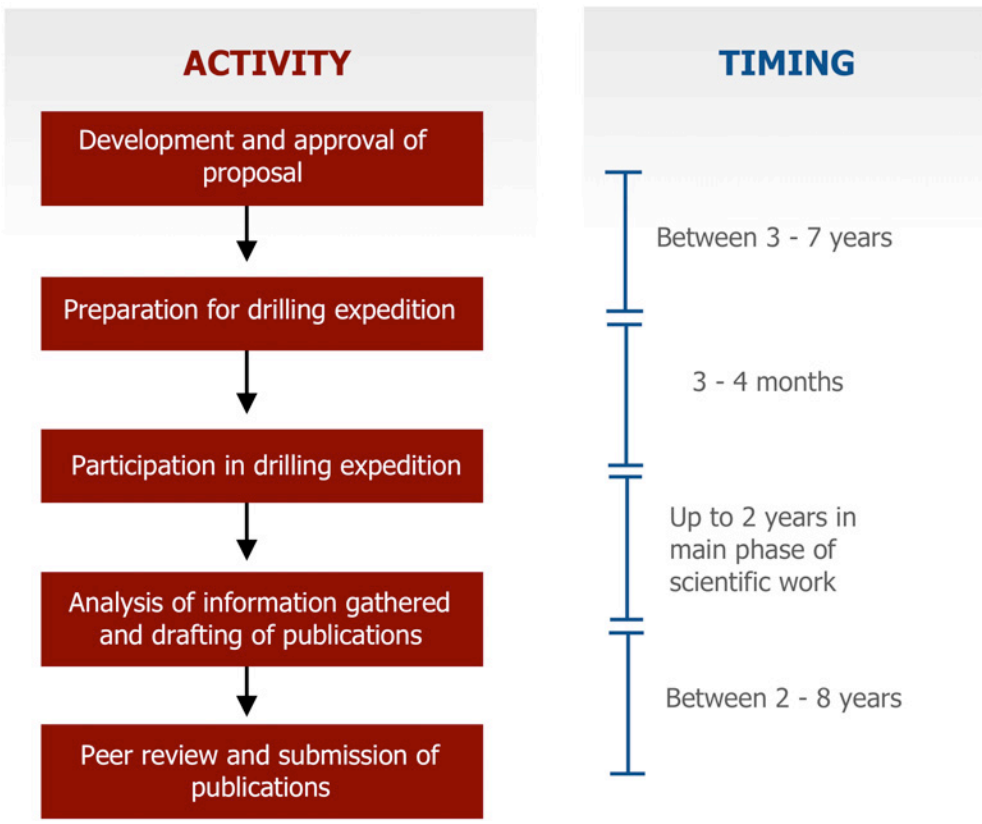
Over the lifetime of the IODP, as well as its predecessor programs, significant scientific accomplishments have been realised. This chapter outlines the work of the IODP to date. It explores the key achievements of the IODP and the findings of recent overseas reviews of the IODP, as well as the IODP Science Plan for 2013-2023, noting the considerable time lags between drilling activity and the publication and utilisation of the results.

3.1 Time lags between scientific ocean drilling and utilisation

Due to the scientific review process and platform scheduling, there can be substantial lead times between proposals being developed, actual drilling taking place, and the publication and utilisation of results. The entire process can take up to 15 years. The process of participating in an expedition and the timing between each activity is summarised in Figure 3.1. Importantly, the experience, networks and collaborations developed through ocean drilling expeditions will continue for many years, if not decades, for the individual scientists involved. The process is described in further detail in Chapter 4.

Figure 3.1

ACTIVITIES ASOCIATED WITH PARTICIPATION IN AN IODP EXPEDITION



Source: The Allen Consulting Group, based on information provided by stakeholders

Consequently in many cases it is not practical to link IODP drilling expeditions explicitly to scientific outcomes published during the funding period of the program. Scientific outcomes will reflect activity and knowledge gained during predecessor programs (DSDP and ODP) as well as through the period of the IODP itself. The impact of IODP builds on the earlier ocean drilling programs and will continue into the follow-on International Ocean Discovery Program. In short, scientific results from ocean drilling will continue to emerge long after a particular program of work is complete.

3.2 Key achievements of the IODP

Scientific deep ocean drilling ships allow scientists to access some of Earth's most challenging environments, collecting data and samples of sediment, rock, fluids, and living organisms from below the seafloor (IODP 2011). From 2003 to 2010, a total of 2,638 sample requests were made for IODP materials with 617,535 samples provided to the scientific community (IODP 2011).

The IODP has (IODP 2011):

- transformed understanding of our planet by addressing some of the most fundamental questions about Earth's dynamic history, processes, and structure;
- lead to the development of tools and methodologies that are now used across the terrestrial and marine geosciences, and in the private sector;
- fostered enduring international scientific collaborations;
- trained new generations of multidisciplinary students and scientists; and
- engaged the public worldwide in scientific discovery.

Scientific ocean drilling has also contributed to resolving a number of important questions. Examples of these are outlined in Box 3.1.

Box 3.1

CONTRIBUTIONS BY SCIENTIFIC OCEAN DRILLING

Examples of major contributions by scientific ocean drilling to resolving important questions include:

- Scientific ocean drilling tested and confirmed the theory of plate tectonics, which revolutionized geological sciences in the late 20th century.
- Drilling provided the first samples of intact volcanic crust below thick layers of marine sediment, revealing the complexity of crustal construction processes.
- Drilling recovered extensive layers of salt deposits deep below the bottom of the Mediterranean Sea, proving that it had dried out repeatedly in the past.
- Drilling helped to define and refine the geologic time scale, as determined through the study of paleomagnetic records, radiometric dating, and the layering of marine microfossils.
- Drilling extended the marine sedimentary record from the present day back to nearly 200 million years ago, allowing reconstruction of planetary history and life at high resolution during periods of tremendous change and adaptation.
- Samples collected from ocean drilling cores have linked Earth's orbital variability to long-term climate changes.
- Sediment and coral samples recovered by drilling allowed construction of a 100-million-year history of global sea level change, showing how quickly ice sheets have melted and how sea level rise was globally distributed.
- Ocean drilling has permitted shallow sampling of large igneous provinces, vast outpourings of lava that may have had a catastrophic influence on Earth's climate, and that serve as windows into deep Earth processes.
- Drilling has revolutionized understanding of continental breakup, faulting, rifting, and associated magmatism.
- Scientific ocean drilling researchers and engineers have developed the first sub-seafloor borehole observatory systems, generating long-term samples and data records used to explore remote environments and processes.
- Drilling allowed an initial assessment of what materials are recycled by subducting plates at convergent margins.
- Drilling has begun to illuminate fault zone behaviour and related tectonic processes at active plate boundaries where Earth's largest earthquakes and tsunami are generated.
- Scientific ocean drilling revealed large flows of fluids through virtually all parts of the seafloor, from mid-ocean ridges to deep-sea trenches.
- Drilling demonstrated that a previously unknown biosphere exists within sediments as deep as 1.6 km below the sea-floor, and within the volcanic carapace of the oceanic crust.

Source: IODP Science Plan for 2013-2023, Illuminating Earth through Subseafloor Sampling, Observation and Experimentation.

In addition, scientific ocean drilling has had a significant impact on a number of research fields and resulted in a large number of peer-reviewed publications in major scientific journals as outlined in Table 3.1.

Table 3.1

PEER REVIEWED SCIENTIFIC OCEAN DRILLING PUBLICATIONS

Publication date	• Nature • Science • Nature Geoscience*	• Earth and Planetary Science Letters • Geology • Geophysical Research • Letters • Journal of Geophysical • Research • Micropaleontology • Palaeoclimatology • Palaeoecology • Palaeogeography • Paleoceanography	All peer-reviewed publications
1968-1974	18	14	1,582
1975-1981	69	124	3,616
1982-1988	95	163	4,474
1989-1995	63	415	5,835
1996-2002	75	568	5,840
2003-2010	117	840	5,464
Total	**437**	**2,124**	**26,811**

* Nature Geoscience began publication in 2008

Source: IODP Science Plan for 2013-2023, Illuminating Earth through Subseafloor Sampling, Observation and Experimentation

3.3 Previous reviews of IODP

In recent years there have been a number of reviews by IODP consortium member countries of the IODP and its predecessor programs. These reviews have commented favourably on the performance of both the IODP and the previous programs — DSDP and ODP.

United States Review

In 2011, a Committee of the US National Research Council (NRC) of the National Academies reviewed the activities of scientific ocean drilling. The Committee's report looked backward, at significant scientific accomplishments enabled by scientific ocean drilling, and also forward to the next phase of scientific ocean drilling.

The committee found that:

> the US-supported scientific ocean drilling programs (DSDP, ODP, and IODP) have been very successful, contributing significantly to a broad range of scientific accomplishments in a number of Earth science disciplines. In addition, the programs' technological innovations have strongly influenced these scientific advances. To a large extent, the success of IODP and prior scientific ocean drilling programs has been a result of strong international collaboration.
>
> NRC 2011

Following the broad themes in the IODP Initial Science Plan (2001), the Committee identified three general areas in which there have been significant accomplishments: solid Earth cycles; fluids, flow, and life in the subseafloor; and Earth's climate history (NRC 2011). Several of the scientific achievements that could not have been accomplished without scientific ocean drilling are listed in Box 3.2.

Box 3.2

SCIENTIFIC ACCOMPLISHMENTS DEPENDENT ON SCIENTIFIC OCEAN DRILLING

The NRC committee identified three general areas in which there have been significant accomplishments. These areas and their associated accomplishments are:

- Solid Earth Cycles:
  - Verification of the seafloor spreading hypothesis and plate tectonic theory.
  - Development of an accurate geological time scale for the past 150 million years.
  - Confirmation that the structure of oceanic lithosphere is related to the spreading rate.
  - Exploration of the emplacement history of submarine large igneous provinces.
  - Contribution to a new paradigm for continental breakup due to studies of rifted margins.
  - Definition of subduction zone inputs and confirmation of subduction erosion.
- Fluids, Flow, and Life in the Subseafloor:
  - In situ investigation of fluid flow processes, permeability and porosity in ocean sediments and basement rocks.
  - Characterization of the sediment- and rock- hosted subseafloor microbial biosphere
  - Study of subseafloor water-rock interactions and the formation of seafloor massive sulfide deposits in active hydrothermal systems.
  - Examination of the distribution and dynamics of gas hydrates in ocean sediments.
- Earth's Climate History:
  - Reconstruction of global climate history for the past 65 million years, based on ocean sediments.
  - Development and refinement of the Astronomical Geomagnetic Polarity Timescale.
  - Documentation of the pervasive nature of orbital forcing on global climate variability.
  - Recognition of past geological analogs (for example, the Paleocene-Eocene Thermal Maximum) for Earth's response to increases in atmospheric carbon dioxide.
  - Discovery of the history of polar ice sheet initiation, growth and variability, and their influence on fluctuations in global sea level.

Source: NRC 2011, Scientific Ocean Drilling - Accomplishments and challenges, Committee on the Review of the Scientific Accomplishments and Assessment of the Potential for Future Transformative Discoveries with US-Supported Scientific Ocean Drilling, Ocean Studies Board Division on Earth and Life Studies, National Research Council

The report also found that scientific ocean drilling had (NRC 2011):

- fundamentally advanced the fields of plate tectonics, paleomagnetism, geomagnetism, and geochronology;
- been critical to understanding connections between subseafloor fluid flow, microbial communities, and massive sulfide deposits;

- pioneered technology that has enabled the recovery of intact gas hydrates, strongly influencing the understanding of gas hydrate distribution for economic and geohazard objectives;
- been integral to the study of continental breakup, in conjunction with onshore and offshore geophysical and geologic exploration and geodynamic modelling;
- contributed to increased understanding of lithospheric formation and structure, and to connecting the occurrence of submarine large igneous provinces with volcanic eruption-related climate change;
- played a central role in deciphering the relationship between atmospheric carbon dioxide and global surface temperatures, glacial-interglacial cycles, global sea level change, ocean anoxia events, and the discovery of large climate excursions and abrupt climate change; and
- lent credence to the meteorite impact hypothesis as a paradigm for global extinction processes, a mainstay of modern Earth science education.

In addition, the report notes that scientific ocean drilling programs have also had important education and community outreach benefits.

The review also examined the new 2013-2023 science plan, with the Committee's findings discussed further below.

United Kingdom review

The Natural Environment Research Council (NERC) of the United Kingdom (UK) undertook a review of the UK IODP in December 2010, reporting on its findings in early 2011. The panel found that (NERC 2011):

- the programme has delivered excellent science with high impact that is strongly aligned with many of the science themes and the People and Partnerships themes of the NERC Strategy;
- successive ocean drilling programmes have continued to be highly effective and relevant not withstanding numerous changes of NERC strategy, and the panel expects that effectiveness to continue; and
- all three present platform types (riser drilling - *Chikyu*, non-riser drilling - *JOIDES Resolution*, and Mission Specific Platforms) provide complementary and unique sea floor sampling opportunities.

The panel recommended that the NERC maintain the subscription and Research Programme at levels that secure the quantum of benefits to the UK that have been delivered thus far.

ECORD Evaluation report

In 2011, the ECORD Evaluation Committee was set up to evaluate, from the point of view of ECORD, the results to date of the first phase of IODP and the plans for the new phase. This evaluation involved two tasks:

- conducting an evaluation of the role of ECORD in the scientific achievements of IODP (2004-present); and

- assessing the new science plan for the future ocean drilling programme, post 2013, and in particular the need for a strong MSP programme to address the scientific objectives.

The evaluation found that ECORD has been a great success, and the ECORD Evaluation Committee recommended that ECORD continue with a funding and activity level higher than the present programme (ECORD 2011). Additional findings of the evaluation are outlined in Box 3.3.

Box 3.3

ECORD EVALUATION FINDINGS

The ECORD evaluation found that:

- ECORD has provided members with the opportunity to contribute to scientific research of global importance and to access major operational infrastructures and data that would have otherwise been impossible as individual countries.
- ECORD scientists have been very active in many aspects of IODP science. They have contributed to a large number of proposals (and have participated in a large number of expeditions). ECORD scientists have also contributed to more than 2600 peer-reviewed papers, many of which have been published in high-ranking journals such as *Nature* and *Science*.
- The mission-specific platform concept has shown, through their work on four expeditions to the Arctic, Tahiti, New Jersey (USA) and the Australian Great Barrier Reef, that these flexible platform facilities provide scientists with the facilities to solve specific problems.
- MSP operations are a valuable contribution to IODP ocean-drilling and monitoring operations that complement the JOIDES Resolution and Chikyu. Providing IODP with the capability to drill in the Arctic and other challenging environments clearly demonstrates the value of MSP operations and the enormous scientific and societal benefits that ECORD contributes to the programme.

In addition, the ECORD Evaluation Committee recognised that some aspects can be improved, and individual recommendations were made where appropriate.

Source: ECORD 2011, *ECORD Evaluation Report*.

3.4 Findings in relation to the IODP Science Plan for 2013-2023

The 2011 NRC review included an assessment of the IODP's Science Plan for 2013-2023. The committee found (NRC 2011) that:

- Each of the four themes within the science plan identifies compelling challenges with potential for transformative science that can only be addressed by scientific ocean drilling. Some challenges within these themes appear to have greater potential for transformative science than others.
- There was a need for data in under-represented regions such as high latitudes and for deeper sampling into intact ocean crust. The themes and challenges identified in the science plan were well justified and timely, although there was a lack of guidance as to which challenges were most important.
- Using legacy data and samples to their maximum capabilities will continue to increase the scientific value of the scientific ocean drilling programs. Expanded use of legacy materials could help, for example, with prioritization of drilling objectives in the next phase of scientific ocean drilling.

In relation to the Science Plan for 2013-2023 it recommended (NRC 2011) that:

- The scientific ocean drilling community should establish a mechanism to prioritize the challenges outlined in the science plan in a manner that complements the existing peer-review process.
- From the earliest stages of proposal development and evaluation, possibilities for increasing program efficiency through integration of multiple objectives into single expeditions should be considered by proponents and panels.
- Pathways for innovations in technology should be encouraged. In addition, setting aside some resources specifically to promote technological research and development could increase the potential for transformative science.

In its evaluation, ECORD (2011) found that the new Science Plan introduces new scientific methods and models that clearly identify cutting-edge research opportunities in the future. Further, the evaluation committee suggested that the scientific and societal challenges are enormous, emphasising the need for more Earth-system science as societies become increasingly vulnerable to changes in our natural environment (ECORD 2011).

3.5 Conclusions

These scientific reviews all viewed the IODP favourably, finding that the IODP program has been successful and has lead to a diverse range of scientific and other (e.g. technological, outreach) benefits. The tenor of the NRC report is that scientific ocean drilling should be continued, while both the UK and ECORD studies recommended that funding should be maintained for the Program[1]. In addition, both the NRC and ECORD supported the IODP Science Plan for 2013-2023.

While each review focused on the benefits of the IODP from their particular perspective, the consistency of the findings indicates that internationally the IODP has achieved significant scientific outcomes and is highly valued. Moreover there is support for the new Science Plan, which will guide the next phase of scientific ocean drilling, and for continued funding.

[1] A decision to seek the approval of the National Science Board for a renewal of scientific drilling will be made in the near future (NSF 2012).

Chapter 4

The benefits of Australia's investment in IODP

The previous Chapter shows the value of scientific ocean drilling programs and the value of IODP as demonstrated by reviews undertaken by leading science organisations in the US, UK and Europe. As some of the value of the science outcomes would flow in due course to Australia through scientific publications, conferences, scientific networks and the like, a key issue is the additional benefits that accrue to Australia through direct participation in IODP and its successor program. Chapter 2 (section 2.3) included a discussion of the rationale for Australia's involvement in scientific ocean drilling. This chapter outlines in more detail the benefits to Australia. While mainly longer term in nature and difficult to quantify, the benefits are nevertheless real and important.

Benefits which flow to non-consortium nations

Non-member nation scientists working in fields covered by IODP activities can in effect 'free ride' to a limited extent. This is because ocean drilling protocols are such that scientists in nations where drilling is taking place in their territorial waters are offered a place on the relevant expedition. Also, the results of IODP drilling expeditions will be available after a lag through published expedition reports, peer-reviewed scientific publications, relevant conferences and scientific networks.

Importantly however, non-member nation scientists do not receive automatic access to berths on drilling expeditions outside their territorial waters, they are not involved in IODP governance and science committees and hence are unable to influence its scientific direction, and they miss the opportunities of close engagement with the science and many learning and networking opportunities.

Arguably, New Zealand scientists benefited disproportionally (relative to other non-member countries) through being observers on ODP expeditions in their waters. While Australian scientists could also benefit to a limited extent if we were to withdraw, the benefits would only apply to expeditions in our waters, and would be constrained as compared to the benefits obtained through membership of IODP.

Direct benefits of Australia's membership

Australia has Associate Member status of the IODP through the ANZIC partnership. ANZIC is entitled to put up to six scientists aboard IODP expeditions each year, the bulk of these being on the *JOIDES Resolution*. However, ANZIC scientists also obtain berths on the *Chikyu* and some MSP expeditions. In 2012, for example, ANZIC had participants on all expeditions that took place. Over the 2008 to 2013 period a total of 26 Australian scientists have or will participate in IODP expeditions. As an Associate Member, ANZIC also has rights to participate on most IODP science panels.

The direct benefits of Australia's membership are discussed in further detail in the following sections.

4.1 Scientific outputs

There are a number of well-recognised ways of measuring the scientific outputs from a program such as IODP. These include measures of productivity (publications per scientist), quality (standing of the scientific journal in which publications appear); and impact (number of citations relative to the relevant benchmark in the field).

Table 4.1 provides an indication of the productivity of Australian researchers and the quality of their published work. It is important to recognise that there is typically a delay of about three years between participation in an ocean drilling expedition and the publication of resultant journal articles. Moreover, publication numbers are variable over time depending on whether or not Australia was a member of the ocean drilling programs. Australia was a member of ODP from 1989 to 2002 and that is reflected in the figures. However, as Australia was not a member of IODP for the five years between 2003 and 2008 it could be expected that this would impact on the number of publications by Australian scientists over the 2003-2012 period.

Table 4.1

TOP TIER PUBLICATIONS STATISTICS FOR ANZIC RESEARCHERS

Date of Publication	***Nature, Science, Nature Geoscience***			**Other major geoscience journals***			**All Peer-Reviewed Publications**		
	New Zealand	**Australia**	***World***	**New Zealand**	**Australia**	***World***	**New Zealand**	**Australia**	***World***
1968-1974	0	0	18	0	0	14	79	122	1,584
1975-1981	0	0	69	0	0	124	19	21	3,617
1982-1988	3	5	95	4	0	163	88	94	4,476
1989-1995	0	8	63	3	10	415	37	1,099	5,918
1996-2002	0	5	75	6	22	568	81	963	5,906
2003-2012	5	7	152	49	75	1,490	216	632	7,135
Total: 1968-2012	**8**	**25**	**472**	**62**	**107**	**2,774**	**520**	**2,931**	**28,636**

* Other major geoscience journals include Geology, Journal of Geophysical Research, Geophysical Research Letters, Earth and Planetary Science Letters, Micropaleontology, Paleoceanography, Palaeogeography, Palaeoclimatology, Palaeoecology.
Notes: The criteria for the country-specific queries were the date ranges listed and institutional affiliation containing the words "Australia" or "New Zealand". Statistics for 2012 are reported as entered to the IODP publications database by December 2012 and are incomplete.
Source: Basic figures provided in January 2013 by Jamus Collier, Data and Publications Manager at IODP-MI.

As demonstrated in the above table, over the history of ocean drilling programs, Australian scientists have authored 10.2 per cent of all IODP related peer-reviewed journal papers. Since the commencement of IODP Australians have authored 8.9 per cent of such papers.

The above table relates to papers where Australian and New Zealand scientists are authors. Co-authorship of papers is the norm in scientific journals to reflect the contribution of all collaborating scientists. The 2012 Drilling Citation Index produced by IODP Publication Services[2] and available on the web, covering 1969 through 2011, cites 333 non-Program publications first-authored by Australian scientists and 187 by New Zealand scientists over that period (IODP 2012e).

An analysis of the ratings of IODP researchers in the ARC Excellence in Research Australia process indicates that 81 (or 84 per cent) out of a large sample of 96 IODP researchers from the university sector are associated with fields of research, which have been evaluated to be 4 (above world standard) or 5 (well above world standard) in quality. Taken together with the IODP publications data, these figures indicate that Australian scientists are producing world class research.

The Research Services Division of the ANU has undertaken a sophisticated citation analysis for this project. The analysis is based on matching IODP publications data between 1996 and 2011 (inclusive) with the Elsevier SCOPUS data set using publication title and publication year[3]. Further details of this analysis are outlined in Appendix F.

Of the 12,902 IODP publications during this time, some 4,480 were able to be matched. While not a complete coverage, the matched publications provide a good basis for analysis.

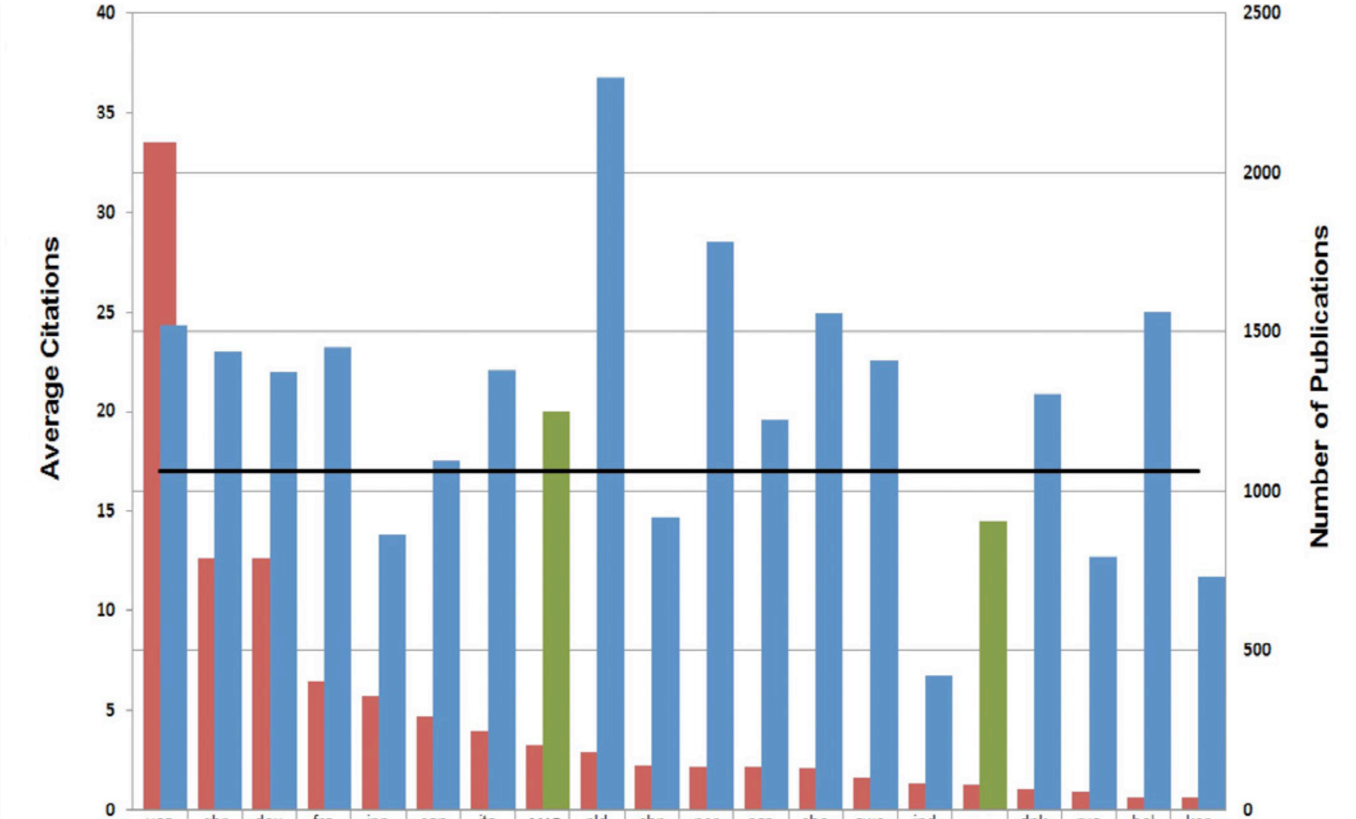
The analysis of citations by country over the 1996 to 2011 period shows that the average citation rate of Australian authored IODP related papers of 20 is above the world average of 17, as shown in Figure 4.1. The higher citation rates recorded by a number of countries with lower volumes of publications can in most cases be attributed to a small number of high quality papers from participation in ocean drilling legs.

[2] See http://iodp.tamu.edu/publications/AGI_studies/AGI_study_2012.pdf

[3] SCOPUS is the World's largest abstract and citation database of peer review literature.

Figure 4.1

IODP PUBLICATIONS AND CITATIONS BY COUNTRY 1996-2011



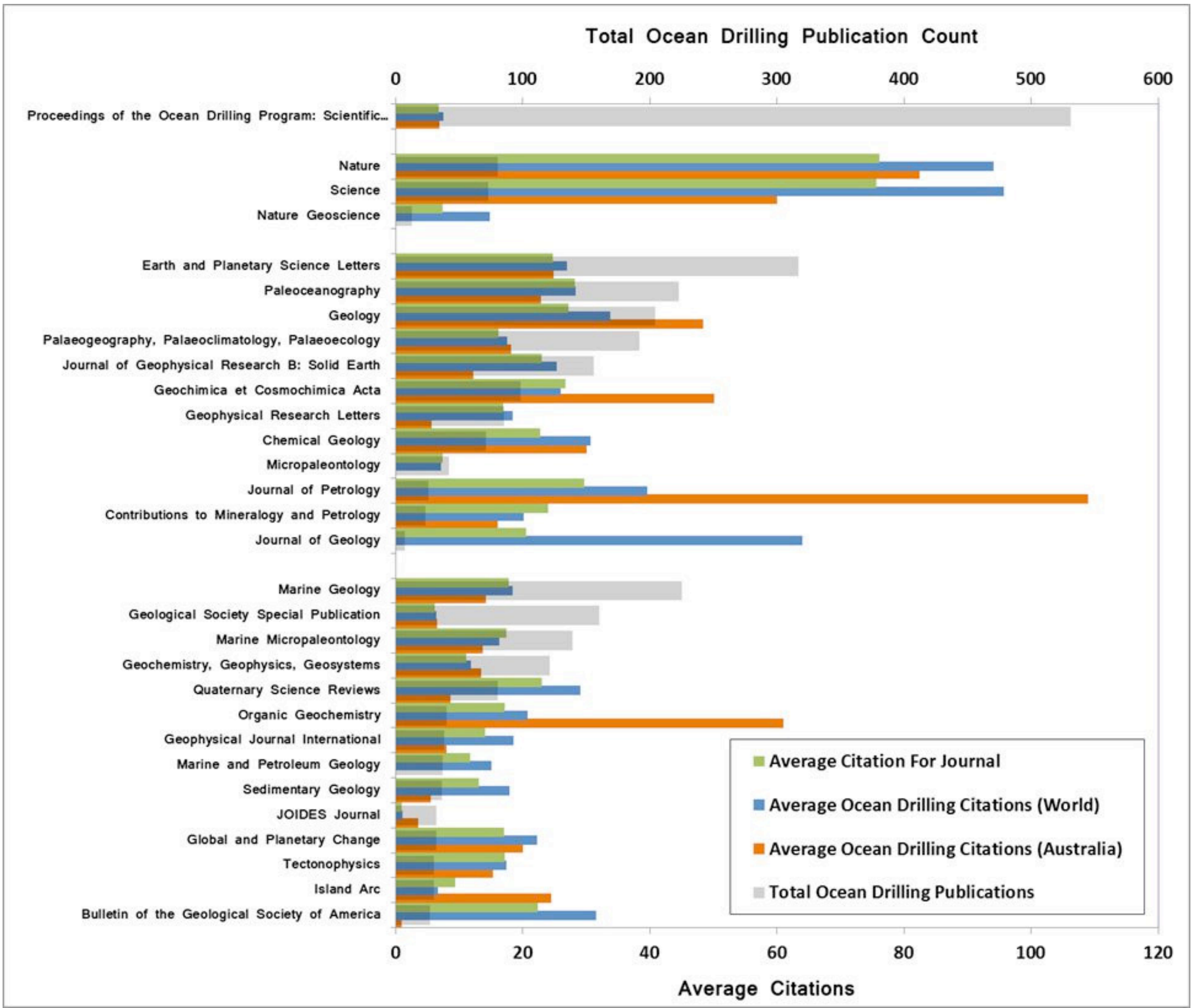
	usa	gbr	deu	fra	jpn	can	ita	**AUS**	nld	chn	nor	esp	che	swe	ind	**NZL**	dnk	rus	bel	kor
Total Pub	2097	790	789	405	357	292	245	**203**	180	136	134	132	130	101	81	**76**	67	55	40	40
Avg World	17.0	17.0	17.0	17.0	17.0	17.0	17.0	**17.0**	17.0	17.0	17.0	17.0	17.0	17.0	17.0	**17.0**	17.0	17.0	17.0	17.0
Avg Citation	24.3	23.1	22.0	23.2	13.8	17.5	22.0	**20.0**	36.8	14.7	28.6	19.6	25.0	22.5	6.7	**14.5**	20.9	12.7	25.1	11.7

Note: The horizontal bar refers to the world average citation number of 17.
Source: Research Services Division, Office of Research Excellence of the Australian National University based on matching IODP and SCOPUS data from 1996 to 2011. Further details of this analysis are outlined in Appendix F.

A further analysis of citations by scientific journal (Figure 4.2) shows that Australian authored papers in the *Geochimica et Cosmochimica*, the *Journal of Petrology*, *Organic Geochemistry*, the *JOIDES Journal* and *Island Arc* are cited above both the IODP and journal average. For a further nine journals overall, including *Nature*, Australian authored papers are cited above the journal averages. This is a further demonstration of the quality and impact of Australian scientists across a broad range of disciplines.

Figure 4.2

TOTAL OCEAN DRILLING PUBLICATION COUNT, 1996-2011



Source: Research Services Division, Office of Research Excellence of the Australian National University based on matching IODP and SCOPUS data from 1996 to 2011. Further details of this analysis are outlined in Appendix F.

A further indicator of research quality is that a number of Australian scientists have won ARC grants to undertake post ocean drilling expedition research, including in relation to work done on the Great Barrier Reef. In total Australian scientists making substantial use of ocean drilling material have won $7 million in various ARC competitive grants over the period of IODP (as outlined in Appendix D). This research builds on the investment made in IODP itself.

In addition to scientific journal papers, Australian and New Zealand scientists contribute to the scientific reports and publications on the IODP expeditions in which they participate. IODP supports a number of publications including:

- a series of preliminary expedition reports that provide a summary of the technical and scientific results of the drilling undertaken;

- a publication series, *Proceedings of the Integrated Ocean Drilling Program: Initial Reports*, which provide more detailed summary results and data;
- another publication series, *Proceedings of the Integrated Ocean Drilling Program: Scientific Results*, which includes peer-reviewed data reports and synthesis papers; and
- a program journal, *Scientific Drilling*, which includes brief scientific expedition and project reports, technical and scientific review articles and news related to scientific drilling.

These publications contain important data and information, which can often provide new insights and lead to further scientific investigation.

A number of ANZIC scientists also contribute articles to scientific magazines, which are designed for a more general audience. Typical examples in Australia include magazines such as *COSMOS* and *Australasian Science*. Reliable data on such 'grey literature' has not been compiled.

Australia's participation in IODP provides valuable scientific spin-offs, including berths on drilling ship expeditions not in Australian waters. This is important because it not only provides opportunities to build expertise for the individual scientist but also to study, directly with other international experts, geological and other processes with global significance and hence applicability to Australia's interests.

Information on prizes and awards that may be attributable, at least in large part, to participation in IODP has not been collected. However the participation of Australian and New Zealand scientists in the governing structure and key IODP committees is discussed in the next section. The roles being played by Australian and New Zealand scientists is arguably greater than might be expected and reflects their standing in the scientific community.

In addition to scientific inputs involving Australian scientists, it should be noted that, for expeditions in the Australian region, like the IODP expeditions in the Great Barrier Reef or Wilkes Land off Antarctica, at least 30 foreign scientists are devoting time at sea and afterward working on scientific problems of direct interest to us. This has a huge multiplier effect on the work of the 2-3 Australian scientists initially involved in such an expedition.

4.2 Influencing the scientific agenda

Australia's membership of IODP provides opportunities for participation in the governing structure and key committees of the IODP. Through such participation Australian scientists can influence directly the governance, strategic direction and work program of the IODP.

ANZIC scientists, as the only representatives from outside the North America, Europe and Japan on the fourteen-person New Science Plan Writing Committee, arguably played a disproportionate role in the development and writing of the 2013-2023 ocean drilling plan, *Illuminating Earth's Past, Present, and Future*. It is significant that while the three ocean drilling consortia are more independent under the new structure for the next phase of IODP, they are all committed to the new Science Plan. The areas of focus of the new Science Plan discussed in Chapter 2 are of great relevance to Australia, for example, the theme on climate and ocean change.

A number of ANZIC scientists have also accepted additional responsibilities beyond their committee or panel membership, including chairing key sub-committees. It is significant that leading ANZIC scientists are playing major roles in the Proposal Evaluation Panel, the key scientific committee, as voting members of the Earth Connections, and Climate and Ocean Change sub-committees. An Australian chairs the Earth Connections sub-committee. Members of such committees have a major influence on what scientific drilling proposals go forward, but are also exposed to leading scientists and scientific thinking across a range of disciplines, whether the proposals are successful or not.

The various roles Australian and New Zealand scientists undertake is summarised in Box 4.1.

Box 4.1

IODP COMMITTEES AND ANZIC REPRESENTATIVES

The following IODP committees and panels currently have ANZIC representation. These committees and panels form part of the Science Advisory Structure of IODP.

- Science Implementation and Policy Committee (the top administrative and planning panel). The ANZIC (non-voting) representative is Dr. Chris Yeats from CSIRO.
- Proposal Evaluation Panel (PEP) is the top science committee, which has a four sub-committees focussed on particular science themes. ANZIC has had two members, rather than the normal Associate Member's one position, on PEP since mid-2012 when it was formed. Prof Richard Arculus of ANU on the Earth Connections Sub-committee, with Dr Ingo Pecher of GNS Science as the alternate; Dr Jody Webster of Sydney University on the Climate and Ocean Change Sub-committee with Dr. Zanna Chase of the University of Tasmania as the alternate.
- The Site Characterisation Panel. Dr. Ben Clennell of CSIRO, with Dr. Andrew Gorman of the University of Otago as the alternate, fills the ANZIC voting position.
- The Science and Technology Panel. Dr. Denise Kulhanek of GNS Science, with Dr. Leanne Armand of Macquarie University as the alternate, fills the ANZIC voting position.

In addition, a number of ANZIC scientists served on the earlier panels, most recently Dr Chris Yeats (CSIRO), Dr Jody Webster (Sydney University), Associate Professor Stephen Gallagher (Melbourne University), Dr Stuart Henrys (GNS Science) and Dr Martin Young (CSIRO).

ANZIC scientists have also filled special roles in ANZIC committees, because of their particular capabilities, as follows:

- Dr Geoff Garrett AO, who was later to become ANZIC Chairman, was the only one from outside the US, Europe and Japan on the key IODP Triennial Review Committee in 2009-2010. This Committee investigated how well the scientific arrangements in IODP had worked in the past, and made suggestions for the future, many of which were used in a new simplified IODP structure. Dr Garrett played a lead role on the committee.
- Professor Richard Arculus of ANU and Professor Peter Barrett of Victoria University of Wellington were the only scientists from outside the US, Europe and Japan on the fourteen-person New Science Plan Writing Committee in 2010. That led to the new plan published in 2011 - *Illuminating Earth's Past, Present, and Future* - which is the basis for the next phase of IODP.
- Dr Chris Yeats of CSIRO was the only scientist from outside the US, Europe and Japan, on the International Working Group Plus subcommittee of the IODP SASEC executive committee from 2009 to 2011. He represented the other IODP associate members (China, Korea and India) on the International Working Group Plus. The purpose of this Working Group was to frame a new multinational program architecture that promotes delivery of the best possible and most exciting and relevant science to the broad science community and the public through scientific ocean drilling. Dr Yeats' played a key role in the overall planning of the future IODP.

Source: ANZIC IODP office

Importantly for Australia and New Zealand, the new ocean drilling plan and the scientific proposals already agreed and coming forward are expected to result in a greater concentration of effort on the southwest Pacific Ocean and Indian Ocean over the next few years. If funding for the next phase of ocean drilling were sufficient for ANZIC to be a member of all three consortia (US, Japan and Europe) and the D/V *Chikyu* started to undertake deep drilling expeditions outside Japanese waters the potential benefits are considerable. Australia has a particular interest in scientific drilling on the Lord Howe Rise, which is likely to be prospective for hydrocarbons. New Zealand has a great interest in deep drilling in the Hikurangi subduction zone, where fault movements have produced past tsunamis.

Consultations with international IODP member representatives suggested that Australia is an extremely valuable partner in terms of intellectual contribution, driving ideas and undertaking quality science. It was suggested that Australia's scientists are up there with the world's leading scientists in their respective fields and they make a important contribution on advisory panels and have a significant influence on the science being undertaken.

4.3 Enhancing international linkages

As Australia accounts for around 3 per cent of the World's published research outputs (Australian Government 2011a), international collaboration is essential to remain in touch with leading researchers and scientific research. This is particularly the case where Australian wishes to remain at the leading edge or is seeking to build capability in new and emerging areas of interest.

Australian scientists being allocated places on IODP scientific expeditions both within and outside Australian waters, typically involve about two months on a drilling ship in the company of around 30 other leading researchers. This provides a unique opportunity for advancing their own areas of interest and also provides a highly stimulating and multi-disciplinary scientific environment for cross fertilisation of ideas, exposure to new methods and new perspectives. The scientific and career-enhancing benefits provided by ocean drilling expeditions were a constant theme that emerged in the consultation process.

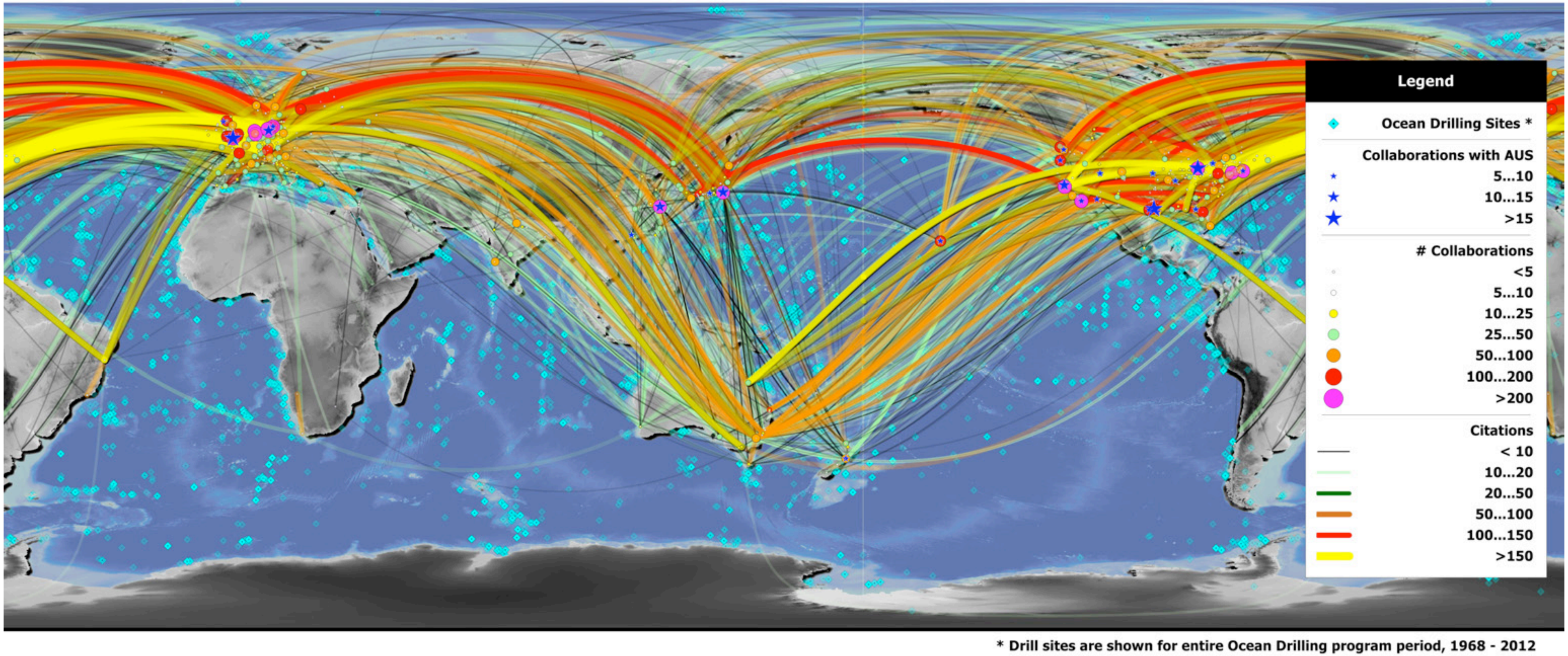
In the science world, the success or otherwise of researchers is highly influenced by the nature and quality of their scientific networks and the interaction with peers. Establishing a network of scientific colleagues is an essential step in building longer-term informal and formal collaborations. Given the limited size of the Australian scientific community, international networks are of huge importance. Stakeholders noted that the IODP is the largest geoscience collaboration in the World and it is therefore highly important that Australian scientists have the opportunity to be involved in the Program.

Clearly participation in the IODP related activities provides valuable opportunities for both early career researchers and more experienced scientists to build and strengthen their international networks. Such activities include participation in IODP related conferences and workshops, joint development of drilling proposals, participation in committees, membership of expeditions, post expedition analysis, and working on expedition reports and jointly authored publications of various kinds.

The ANU extended its analysis of citations by geocoding the locations of author's home institutions to produce a global map of IODP related collaborations. Figure 4.3 shows the result of this work. It can be clearly seen that Australian researchers are very well connected into the global IODP related network, with major centres of collaboration in North America, North East Asia and Europe. It is also apparent that Australia's participation is important in terms of its Southern Hemisphere location.

Figure 4.3

OCEAN DRILLING COLLABORATION NETWORK, 1996-2011



Source: Research Services Division, Office of Research Excellence of the Australian National University based on matching IODP and SCOPUS data from 1996 to 2011. Further details of this analysis are outlined in Appendix F.

To further illustrate this point Table 4.2 shows the top ten World and Australian institutions for IODP collaborations. It is notable that Australia has strong collaborations with World-leading research institutions evidenced by the fact that seven of the top ten IODP collaborating institutions in the World are also in Australia's top ten overseas IODP collaborating institutions.

Table 4.2

TOP TEN WORLD INSTITUTIONS FOR IODP COLLABORATIONS

IODP organisation	Total number of collaborations	IODP organisation	Total number of collaborations with Australia
University of Bremen	491	Department of Geology, University of Southampton	15
University of California	481	Texas A and M University	15
Woods Hole Oceanographic Institution	391	University of California	14
GEOMAR Forschungszentrum für marine Geowissenschaft	345	Laboratory of Marine Geology, Tongji University	14
Department of Geology, Faculty of Earth Sciences Utrecht University, Netherlands	293	Deep Sea Research Department, Japan Marine Science and Technology Center	11
Lamont-Doherty Earth Observatory, Columbia University	275	Ocean Research Institute, University of Tokyo	11
Laboratory of Marine Geology, Tongji University	266	Geophysics Department, Stanford University	11
Department of Geology, University of Southampton	262	University of Bremen	10
Scripps Institution of Oceanography	259	Woods Hole Oceanographic Institution	9
Deep Sea Research Department, Japan Marine Science and Technology Center	240	GEOMAR Forschungszentrum für marine Geowissenschaft	9

Source: Research Services Division, Office of Research Excellence of the Australian National University based on matching IODP and SCOPUS data from 1996 to 2011. Further details of this analysis are outlined in Appendix F.

4.4 Facilitating domestic collaboration

Involvement in IODP also has an important role in facilitating and enhancing domestic collaboration. In short international collaboration can strengthen domestic collaboration and vice versa. In addition, as noted earlier in this report, currently the ANZIC Consortium is made up of 22 organisations. The exposure, relationships and interaction of these Australian and New Zealand institutes, is another key benefit of participation in IODP.

Stakeholders suggested that interaction between members within the ANZIC consortium is a valuable aspect of involvement and has lead to synergies, better relationships and cross fertilisation of ideas. Fostering collaboration between institutions in science and research can be difficult given the competitive environment of research funding. As noted in *Herding Cats* 'unfortunately the prevailing culture, largely, is not supportive of extensive collaboration' (Garrett, G. and Davies, G. 2010).

4.5 Multidisciplinary science

The preceding discussion of the breadth of research fields and research institutions involved in IODP reinforces the fact that it is fundamentally a multidisciplinary program. Australian scientists working on IODP are involved in a range of disciplines and have a variety of areas of expertise including sedimentology, geochemistry, micropaleontology, microbiology, paleoclimate geochemistry, igneous petrology, sulphide petrology, structural geology, paleomagnetism and coal geology. With many new scientific developments occurring at the interface of disciplines, the multidisciplinary nature of the program and the diversity of the disciplines engaged in related science is a key benefit of the program.

A comprehensive list of ocean drilling expeditions and Australian researcher participation is at Appendix C. Notable features are the senior roles often played, the broad range of fields of research involved and the range of host institutions.

4.6 Increasing marine science capability

Development and maintenance of a broad marine science capability is important in terms of understanding and contributing solutions for global issues such as climate change and natural hazards and in having the wherewithal to deal with issues within Australia's national jurisdiction, including natural resources. With one of the largest and least explored marine jurisdictions in the World, Australia has a major national interest in building its marine science capability. While IODP is not specifically mentioned, building our marine science capability is recognised in the *2011 Strategic Roadmap for Australian Research Infrastructure* (Australian Government 2011b) and IODP is clearly within the scope of the *2012 National Research Investment Plan* (Australian Government 2012a).

A report being prepared by the Oceans Policy Scientific Advisory Group (OPSAG), *Marine Nation 2025: Marine Science to Support a Blue Economy* (Australian Government 2012c), outlines five grand challenges facing Australia, namely sovereignty; security and natural hazards; energy security; food security; protection of biodiversity; and dealing with climate change. OPSAG identifies skills, infrastructure and relationships as the key foundations of Australia's marine science capability.

In this context OPSAG notes the importance of training, collaboration and international links and cooperation. Not only does building international engagement help keep Australian marine science current and globally relevant but also it can also provide the catalyst for building national partnerships. The IODP is instanced as one of the international programs that facilitate such partnerships.

The strategy pursued by the Queensland University of Technology (QUT) in building on its membership of the ANZIC consortium to enhance its marine sciences capability is an example of how the opportunities offered by IODP can be leveraged, as outlined in Box 4.2.

Box 4.2

BUILDING SCIENCE CAPABILITY

Over the past twenty years, QUT has pursued a goal to build its national and international research profile. QUT's membership of the ANZIC (through the School of Earth, Environmental and Biological Sciences) over the past 6 years has significantly contributed to this goal through developing scientific collaborations with and beyond Australia and building scientific networks that will persist into the future.

For a modest annual financial contribution, three of QUT's academic staff members (Professor Gary Huftile, Dr David Murphy, and Dr Craig Sloss) have been shipboard scientists on the *D/V Chikyu* and *D/V JOIDES Resolution*. Their participation on separate IODP drilling expeditions was through a peer-reviewed, competitive process. They have also participated as voyage–related shore-based scientists. As a result of their involvement in IODP, they have interacted both aboard ship, and subsequently during the study of recovered samples and reporting of results in the international literature, with some of the world's leading Earth scientists.

The beneficial impacts of QUT's membership have extended to the whole School; the exciting scientific results reported both from staff involvement as well as those from other expeditions, has informed all staff, post-graduate, Honours and undergraduate students. QUT has become engaged with the current results of the cutting-edge, multi-disciplinary, societally important research being pursued by IODP. The involvement of undergraduates through postgraduate students in IODP research is significant and rewarding.

Although QUT has had long-term research interests in coastal environments, both from scientific as well as management and engineering points of view, it did not have a national or international engagement with research in most of the world's oceans. QUT has built upon its IODP experience, using it to refocus and build marine science strengths.

Membership of ANZIC has given QUT a means for its relatively small School of Earth, Environmental and Biological Sciences to "play on a much larger stage", with dramatically positive results from research and teaching points of view. A less tangible but important benefit has been the lifting of the School's national profile among all the other members of the ANZIC.

Source: Professor David A. Gust, Head of School, Science and Engineering Faculty, Earth, Environmental and Biological Sciences, Queensland University of Technology

It also makes sense for Australia to leverage off international investments in essential major scientific infrastructure that any one country could not afford to develop, build and operate. As noted earlier in the report, Australia's participation allows access to the significant capital assets of the IODP — worth approximately $US 1 billion, with running costs of just over $US 167 million for the 2013 financial year (IODP 2012d). This allows Australian scientists to access world-class research infrastructure on a scale and of a quality that would not be possible without IODP membership. Furthermore, membership fees pay for some operating costs only. Australia is not required to pay for the capital cost or amortisation of the infrastructure involved. Effectively Australian researchers gain the use of this very expensive infrastructure and equipment at a very modest cost.

Direct participation in IODP not only allows for access to this infrastructure, but also provides engagement with leading researchers in a variety of fields and exposure to new scientific techniques.

Australia's participation also enables scientists to access the various ocean drilling core repositories. These repositories are a valuable resource for current and future scientific investigation. The repositories allow researchers to access cores from previous expeditions and these historical cores can provide important insights into current research, as demonstrated in Box 4.3.

Box 4.3

ACCESSING REPOSITORY CORES

The cores that have been recovered by the scientific ocean drilling programs represent an immensely valuable global resource, available for further research as established analytical and imaging techniques improve, and radically new methods of investigation are developed. While every drilling leg has been staffed as far as possible with a range of experts appropriate for anticipated recoveries, it is a fact that additional investigation post-expedition is often vital.

During an expedition, which was focused on examining a volcanic rock called boninite, hundreds of volcanic ash layers were recovered. As the expedition was focused on the recovery of boninite the ship was heavily staffed with igneous petrologists, as well as sedimentary petrologic and palaeontologic expertise. The ship therefore did not contain the expertise to analyse this ash, however it was clear to the scientists involved that, as a result of the finding they could reconstruct, for the first time, the 50 million years of geochemical evolution of the island arcs under investigation.

A scientist from this expedition travelled to the North American repository to sample ash-containing cores that had been recovered from a previous expedition. The results from the two expeditions were then used to form the basis for two Australian PhD students. This lead to the development of several published papers in peer-reviewed literature.

The results of this work have fundamentally altered perspectives on the way plate tectonics has recycled oceanic lithosphere through subduction zone systems of the western Pacific, as well as stimulating further deep sea drilling.

Source: Adapted from material provided by Professor Richard Arculus (Australian National University)

In addition, stakeholders noted that IODP participation provides an important training ground for researchers and provides PhD students and early career researchers (i.e. post-doctoral fellows) with valuable opportunities to work in a range of fields and thus strengthen the scientific workforce. While a complete list of Australian and New Zealand students involved in IODP-related projects is not readily available, research by the ANZIC IODP office indicates that more than 30 Australian and New Zealand students, including Masters, PhD students and Post-Doctoral Fellows have participated in IODP projects. Appendix E lists those students who have been able to be identified. Assuming the societal value of a PhD student is equivalent to the stipend paid under the Higher Education Research Training Scheme, the value of Australian PhD students alone is estimated at around $1.3 million[4].

Consultations with leading scientists and administrators of the IODP program based in the US, Japan and Europe, consistently elicited the view that Australian scientists' participation in IODP was highly valued in terms of their scientific and broader intellectual contribution to the strategic direction of the program, their focus on outcomes from committees and workshops, and the leadership shown on expeditions. It seems clear that Australia's participation in IODP has enhanced the reputation of Australian scientists. The Excellence in Research Australia ratings suggests that host institutions have also benefited from the high quality research that results. It would be reasonable to expect that, other things being equal, science students, particularly post-graduates, would be attracted to those institutions as a result.

Consultations with leading researchers also suggest that there are substantial long-term career benefits from scientists participating in international ocean drilling projects. One senior academic described participation in an ocean drilling expedition in 1990 as a seminal experience on which this researcher is still building some decades later.

It is reasonable to conclude that in the absence of direct participation in IODP Australia's marine science and general geoscience base would be smaller and of overall lower quality than currently exists.

4.7 Contributing to Government policy and national interests

Australia's membership of IODP is consistent with the emphasis on building core capabilities articulated in the *2011 Strategic Roadmap for Australian Research Infrastructure* and the policy underpinning the *2012 National Research Investment Plan*. Scientific ocean drilling can add important new data and insights across arrange of areas of key national interest such as climate change, earthquakes and tsunamis, how mineral deposits form and their exploration.

The results of IODP drilling can have unexpected benefits, including to gain a better understanding of terrestrial deposits, as outlined in Box 4.4.

[4] This is based on the 2013 Australian Postgraduate Awards stipend rate of $24,653 per year, for 13 PhD students each undertaking PhDs for four years.

Box 4.4

APPLICATION OF OCEAN DRILLING TO TERRESTRIAL ORE DEPOSITS

The results of ocean drilling have been used to gain a greater understanding of terrestrial mineral deposits. During one ODP expedition in the Indian Ocean in 1997, instead of encountering the expected results from drilling, the leg encountered iron-rich, often foliated gabbroic rocks. It revealed a previously undocumented process whereby movements in a slow spreading ridge concentrated iron-rich mineralisation. At the time, this discovery was reported to have had no real consequence.

However, subsequent research into Broken Hill lead, zinc and silver deposits showed that there were also iron-rich mineralisations along the line of the ridge. This led to the development of a new model for the Broken Hill mineralization that has received widespread interest, and strong support from a number of the key industry and academic researchers.

Without exposure to new developments in igneous petrology and geochemistry deriving directly from ODP, researchers would not have been aware of the existence of the key processes and products that played a significant role in forming the Broken Hill deposit.

In addition to helping to explain the formation of Broken Hill, the work has significant exploration spin-offs, which may help focus exploration for new examples of this important mineralization style.

Further details of the application of ocean drilling to terrestrial environments are provided in Appendix B.

Source: Adapted from material provided by Professor Tony Crawford (University of Tasmania)

In addition, IODP drilling provides valuable early stage geological information about prospective and non-prospective areas within Australia's large offshore marine jurisdiction. The data and information gained is used by Australian scientific agencies, especially Geoscience Australia (GA) and CSIRO, to enhance their understanding of basin geology and inform further scientific research.

In the case of GA, ocean drilling results can point the way to where additional pre-competitive work may be required, such as seismic studies ground-truthed by the new boreholes, to provide sufficient base data and information to attract commercial interest. Equally, ocean-drilling results may save expenditure, by companies not undertaking expensive further work in areas which are clearly not prospective. In short, ocean drilling adds valuable basic science data and information to the store of knowledge about Australia's offshore jurisdiction.

There are potentially large resource discovery benefits where GA utilise ocean drilling results to help explain and inform the geology and likely prospectively of areas being considered under the offshore petroleum acreage release program (see Box 4.5).

Box 4.5

OCEAN DRILLING INFORMING PETROLEUM EXPLORATION

Ocean drilling has played an important role in understanding the geology and petroleum potential of the Exmouth Plateau off Western Australia.

In the mid-1970s the Bureau of Mineral Resources (BMR) undertook work to build a geological picture of the Plateau and its petroleum potential. In the late 1970s the Government released exploration licenses on the plateau. Exploration companies spent $200 million on seismic exploration and drilling a dozen wells on the plateau in 1979-80, looking for oil. The wells confirmed that there was gas in the area and the giant Scarborough Gas Field was discovered. Developing these finds was not profitable at the time, so company interest declined.

In 1989 an ODP expedition on the Plateau recovered thousands of metres of cores of sedimentary marine rock sequences. Two outcomes were of great interest to the petroleum industry. One was the discovery, for the first time in Australia, of buried Triassic reefs, which host petroleum elsewhere in the world. The other was the recovery of about 1000 m of cores of Early Cretaceous (140 million year old) sedimentary rocks, continuous with those of the Scarborough gas field to the east. These cores provide details of rock types that complement information from the sparsely cored petroleum exploration wells.

In considering deep drilling for similar targets, companies have studied the ODP cores of the Triassic reefs, and a geologist from Woodside Exploration visited the Japanese core repository in 2011 to examine the cores as part of his assessment of Woodside's related drilling program.

Further details of the significance of ocean drilling to petroleum exploration are provided in Appendix B.

Source: Adapted from material provided by Professor Neville Exon (Australian National University)

Table 4.3 shows how relevant ocean drilling results have been used in recent years to help inform offshore petroleum acreage releases.

Table 4.3

RECENT AUSTRALIAN OFFSHORE PETROLEUM ACREAGE RELEASES USING OCEAN DRILLING HOLES

Year	Release Name	Release Areas	Holes	State
2009	Northern Exmouth Plateau	W09 - 6, 7 & 8	ODP 759-61, 764 (1998)	Western Australia
2010	Mentelle Basin	W10 - 26	DSDP 258 & 264 (1972)	Western Australia
2011	Southern Carnarvon Basin	W11 - 16 & 17	DSDP 263 (1972)	Western Australia
2012	Sorell Basin	T12 - 2	ODP 1168 (2000)	Tasmania

Source: Geoscience Australia

A striking feature of the table is that it takes a long period of time (in some cases decades) from when the scientific drilling is done to when sufficient additional data, information and analysis is completed to support a offshore petroleum acreage release. It can be expected that in due course the results of IODP drilling expeditions will also be used by Australian scientific agencies for similar purposes. This is illustrated in the case study outlined in Box 4.6, which discusses drilling in the Mentelle Basin.

Box 4.6

OCEAN DRILLING AND EXPLORATION ACREAGES RELEASES

The results of the various international scientific ocean drilling programs not only improve understanding of geological structures and processes generally but can inform directly the understanding of the geology of offshore areas released by the Australian Government for commercial petroleum exploration activities. The Mentelle Basin, located in deep water southwest of Perth, which was released for exploration activity in 2010, is a case in point.

Geological knowledge of the Mentelle Basin area is based on two deep sea project wells drilled in 1972 under the DSDP program and 1 060 kilometres of industry standard seismic data acquired across the Mentelle Basin in 2004 (GA seismic survey 280) and 2 570 kilometres in 2008-09 (GA seismic survey 310).

As no exploration wells had been drilled in the Mentelle Basin, two DSDP stratigraphic wells and exploration wells in a nearby Basin were used to assist the interpretation of its geology. Both DSDP wells had been drilled to collect marine sediment cores for basic science purposes, including to improve the understanding of the age and early history of the Indian Ocean and, the breakup of Gondwana, the initiation of the Circumpolar current and to collect more data for biostratigrahic analysis.

Subsequently Geoscience Australia used one DSDP stratigraphic well, DSDP 258, drilled on the boundary of the Basin, to develop seismic stratigraphic correlations and understanding of the geological structure of the Basin. This work added to the body of knowledge about the Basin.

The information provided from the DSDP wells, increased the basic information about the Mentelle Basin and contributed to its release for exploration activity in 2010.

Source: Summarised from Australian Government (2010), *Mentelle Basin, Release Area W10-26: Offshore Petroleum Acreage Release*, Department of Resources, Energy and Tourism and Geoscience Australia, Canberra.

The historical record revealed by ocean paleo-sediments provides a clear picture of past climate change, including whether current circumstances have occurred before or are unprecedented, what the drivers of change might have been, and the past conditions of the climate system. In this context the ocean sediment record ties in well with the ice-core record from Antarctica.

Consultations indicate that ocean drilling results are not used directly for the purposes of climate change modelling or policy developments. Climate change models are mathematical representations of key processes in the oceans, atmosphere and climate and are populated by observational data. However, the paleo record is one form of ground truthing such models. Ocean drilling has also been used to gain a greater understanding of the movement of the Australian continent and the associated climatic changes, as outlined in Box 4.7.

Box 4.7

UNDERSTANDING MOVEMENT OF THE AUSTRALIAN CONTINENT

Ocean drilling is a key source of information for understanding the Australian continent's movement northward and its coincident warming and drying periods.

Seafloor spreading is the process in which new oceanic crust (basalt) forms when two tectonic plates move apart. The process of seafloor spreading means that older rocks are found further away from the spreading zone, with younger rocks found closer to this zone.

In the 1960s ocean drilling as part of DSDP helped prove the seafloor spreading theory through coring and dating the age of sediments directly above the ocean crust. The results of the program also helped us understand the separation of Australia and Antarctica through the process of seafloor spreading. Ocean drilling further supported this theory by demonstrating that the Tasman Seaway between the new continents first fully opened 33 million years ago as Australia moved northwards.

More focused drilling during ODP added to the understanding of this continental separation and the climatic changes it caused. As a result of ocean drilling it is now known that before full separation, near tropical conditions existed on both sides of the gulf. The separation and the onset of strong currents between the two continents coincided with rapid Antarctic cooling and the initial build-up of a major Antarctic ice sheet. Continued northward movement of Australia widened the circum-Antarctic seaway and further isolated Antarctica, which continued to reinforce a global cooling and drying trend including that of Australia.

In addition to understanding the movement of Australia, the knowledge of the extremes that have affected Australia in the past can assist with planning for a future of increasing greenhouse gasses, warmth and sea level rise.

Further details of the influence of ocean drilling on the understanding of the movement of the Australian continent are provided in Appendix B.

Source: Adapted from material provided by Professor Neville Exon (Australian National University) and Professor James Kennett (University of California at Santa Barbara)

Ocean drilling has also enabled scientists to obtain a greater understanding of sea-level change and define sea surface temperature variations and the impact of these on reef growth, as outlined in Box 4.8.

Box 4.8

UNLOCKING THE HISTORY OF REEF GROWTH AND DEMISE

Ocean drilling has helped gain a greater knowledge of the Great Barrier Reef's history and changes over time.

An IODP expedition between January and April 2010 investigated a succession of submerged fossil reefs on the shelf edge of the Reef, with the scientific objective of establishing the course of sea-level change and defining sea-surface temperature variations, as well as analysing the impact of these environmental changes on reef growth for the last 20,000 years.

The expedition provided:

- new knowledge about changes in the sea level for the period 30,000- 10,000 years ago;
- new information on sea surface temperatures and other oceanography parameters from 30,000- 10,000 years ago;
- a unique recording in the Great Barrier Reef of past environmental stresses similar to current scenarios of future climate change; and
- a new record of upper-slope sedimentation in water shallower than 160 m that spans the last 300,000 years.

The expedition improved the understanding of how the geometry, composition and development of the Great Barrier Reef responded to repeated and major environmental disturbances over the last 30,000 years. This has broad management implications as modern reefs around the world face an uncertain future.

Source: Adapted from material provided by Dr. Jody M. Webster (University of Sydney)

4.8 Direct economic benefits

The direct economic benefits to the Australian economy from membership of IODP derive predominately from port visits by consortium drilling vessels. Over the course of the IODP there were four port visits. The *JOIDES Resolution* made port calls in Townsville in October 2009 and in Hobart in March 2010, while the European-chartered alternative drilling platform *Greatship Maya* made port calls in Townsville in January and March 2010. Consultations with senior IODP administrators indicate that expenditure on fuel, provisions and other requirements totals US $1.5 to 1.9 million per port visit. Hence, it is estimated that expenditure on port visits has totalled between $AUD 4.4 million and $AUD 5.5 million during IODP[5].

With a greater focus on the south-western Pacific and the Indian Ocean over the next few years, further port visits by scientific ocean drilling vessels are likely.

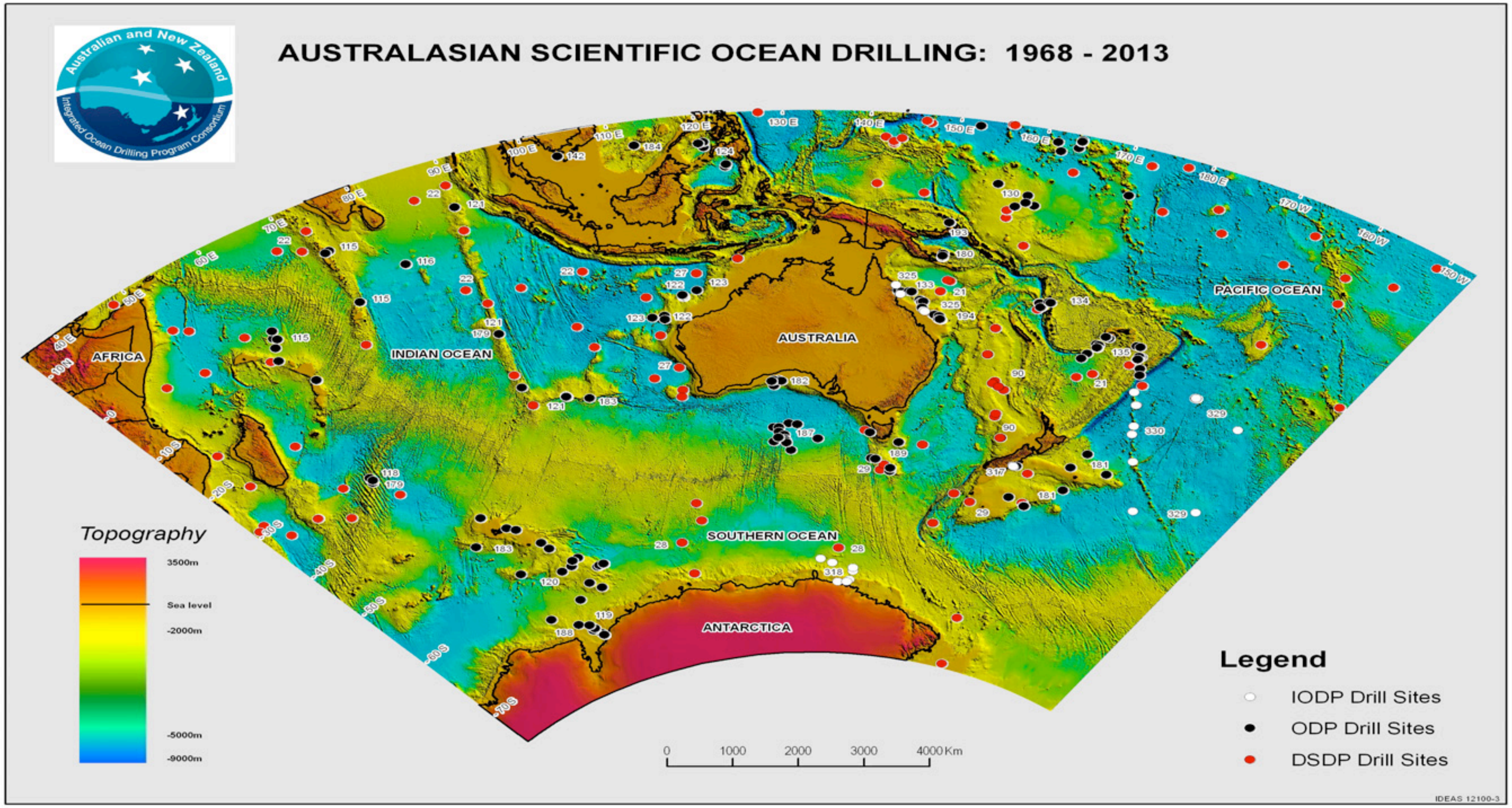
Australia also benefits in the form of better scientific knowledge from the international investment in drilling in Australian waters and areas of interest in our region. The value of drilling undertaken by IODP and predecessor programs in Australian waters is around $US 8 million per expedition[6]. During IODP, two expeditions have occurred in Australian and Australian Antarctic waters, while numerous expeditions occurred in the previous programs, as can be seen in Figure 4.4. Arguably Australia may also have benefited from this investment in the form of budgetary savings, although if they were to be funded from its own resources, Australia may have chosen to use the funds in other ways.

[5] Exchange rates based on Reserve Bank of Australia exchange rate data (RBA 2012)

[6] Based on information provided during stakeholder consultations.

Figure 4.4

AUSTRALASIAN SCIENTIFIC OCEAN DRILLING: 1968 - 2013



Source: Geoscience Australia

The Australian economy also benefits directly whenever IODP workshops or IODP related conferences are held in Australia. For example, a Southwest Pacific Ocean IODP Workshop was held in Sydney over four days in October 2012, which attracted a diverse group of 80 Australian and overseas scientists. The workshop attracted 35 foreign and 10 interstate scientists for an average of three nights. Based on Australian Government visitor expenditure figures[7], this is anticipated to have benefited the NSW economy by approximately $AUD 12,000.

An IODP Symposium was held as part of the International Geological Congress in Brisbane during August 2012. The 13 symposium presentations attracted audiences of 40 to 70 scientists. While the attendees had chosen to attend the Congress for various reasons, the level of interest shown in the Symposium indicates that it was a factor in the success of the Congress, including its economic benefits.

4.9 Geopolitical impacts

A little recognised aspect of Australia's membership of IODP is its contribution to the role of science in diplomacy and our place in the World with resultant geopolitical benefits. Australia has formal Science and Technology cooperation agreements with over 30 countries including major IODP consortium partners (e.g. USA, Japan, EU) and newer and increasingly important participants (e.g. China, India, Brazil). Participation in IODP is one element in helping support the intent of such agreements.

In light of decisions in recent years of China and India to join the IODP consortium, Australia's membership of IODP is also consistent with the policy of strengthening research and training links with the region as articulated in the *Australia in The Asian Century White Paper*.

It is notable in this regard that an Indian Ocean IODP Workshop in Goa, during October 2011, was initiated and planned by ANZIC and India-IODP. The workshop was an important step towards more IODP drilling in the Indian Ocean, of particular interest to Australia, as well as enhancing international cooperation.

4.10 Education and outreach

Education and outreach forms an important aspect of IODP. In addition to linking with IODP international education and outreach activities ANZIC has undertaken, or intend to undertake, the following education and outreach activities:

- Tours during port calls:
  - The *JOIDES Resolution* hosted one day of tours when it visited Townsville in November 2009 and three days of tours when it visited Hobart in March 2010. These tours included students from local High Schools and Universities as well as researchers, employees of Government agencies and staff from both the member organisations and the government. Between 200-300 visitors participated in these tours.
- Distinguished Lecturers:
  - Each year, ANZIC funds lectures to promote the diverse work of the program. In 2012 these included Dr Craig Sloss of QUT, who spoke in

[7] Australian Government 2012e and Australian Government 2012f.

Hobart about the results expected from the Mediterranean Outflow expedition, and climate modeller, Professor Matthew Huber of Purdue University, Indiana, who spoke in Sydney, Canberra and Melbourne about the unique climate evidence obtained from IODP material.

- Masterclass:
  - ANZIC is offering funding for each ANZIC member university to nominate one high performing undergraduate for a Masterclass each year beginning in 2013. The masterclass will showcase the skills and opportunities involved in IODP work. This year the Masterclass will be hosted by CSIRO, UWA and Curtin in Perth in December. It includes four days of seminars and activities with experts in different fields followed up by a daylong, shipboard field trip on a local research vessel.
- Questacon exhibit:
  - ANZIC is contributing to Questacon's Deep Oceans exhibit in 2013, supplying information displays, activities and guest speakers. The displays will include details of on-board activities, the science outcomes and replica cores.
- Expedition 341 education activities:
  - Expedition 341 will be embarking in May for the Southern Alaskan Margin. ANZIC has part-funded one of the Education Officers on this expedition in addition to two scientists. ANZIC is aiming to promote extensive activities in schools through the CSIRO Double Helix Club and Scientists in Schools Program. In addition, Questacon is proposing to relay a broadcast for remote area schools.

Broader awareness of IODP

Despite the long history of collaborative scientific ocean drilling and a range of international and domestic IODP communication, education and outreach activities being undertaken, consultations with key stakeholders, particularly Australian government departments and research agencies, indicate a low awareness of the program outside the scientists and the few policy advisers directly involved. Moreover, the knowledge of IODP science and its contribution to understanding key issues such as climate change is thinly spread.

While probably not a major issue for the ARC, the lack of awareness among senior policy advisers of IODP and the benefits that accrue from Australia's participation is a matter of concern and should be addressed through an enhanced and targeted communication strategy. Promoting the value of IODP participation to relevant Ministers' offices and government departments more broadly (especially key policy areas in departments such as DIISTRE, DRET, DCCEE, DFAT and PM&C) would increase its profile and assist in laying the underpinning policy and analytical groundwork for government consideration of a new collaborative research infrastructure funding program beyond the ARC LIEF program bid.

4.11 Continued involvement in the program

Stakeholder consultations demonstrated that the program is highly valued by those involved and there was strong support for Australia's continued involvement in the future. This support was voiced from both domestic and international stakeholders alike.

It is also important to note that a number of stakeholders suggested that the next phase of the program (IODP2) is likely to have even greater benefits for Australia than IODP. It was suggested that Australian researchers are now fully involved in the program, and have a significant influence on the program's direction and this would enable Australia to benefit to a greater extent. Further, it is anticipated that over the next few years there will be a greater concentration of expeditions in the region, in particular the South Western Pacific than in the past.

A leading Australian scientist, Prof Richard Arculus, is the lead proponent of the IODP2 expedition 352 scheduled for August 2014. Professor Arculus has recently been invited to be a co-chief of the expedition, which is a prestigious appointment. A co-chief has significant responsibilities and scientific influence prior to, during and after the expedition concludes. However, if Australia did not continue its part membership stake in IODP2 it would not be entitled to a co-chief position and Professor Arculus' participation in the expedition would be dependent on a member nation being prepared to offer him a berth.

Another Australian scientist is the lead proponent on a highly valued proposal to drill on Australia's Northwest Shelf, which is likely to occur in 2015. This scientist could also be offered a co-chief role. It is unlikely that this expedition would occur without Australia's direct participation in IODP2 and a potential co-chief position would not be forthcoming. There is the possibility of a third such opportunity for an Australian scientist around 2017.

Stakeholders noted that research related to ocean drilling will remain highly relevant and seek to address key topical global issues. Many stakeholders suggested that there is still a great deal of research to be done in the field to gain a greater understanding of a wide variety of issues. For example, ocean drilling is seen as having a key role in petroleum exploration in the future, as discussed further in Box 4.9.

Box 4.9

THE IMPORTANCE OF FURTHER OCEAN DRILLING

The Lord Howe Rise region is one of the world's largest remaining offshore frontier areas. The submerged continental landmass covers an area of over 1,500,000 km^2 and its geological history is not well known, despite the fact that the region holds the key to some of the global-scale plate tectonic events and environmental changes during the Mesozoic and Cenozoic Eras.

In order to better understand the region's geology and petroleum prospectivity, Geoscience Australia and its predecessors, GNS Science and its predecessors, and the New Caledonian and French governments have completed a series of data (largely seismic) acquisition surveys and studies since the 1970s. Despite expenditure of tens of millions of Australian dollars on these surveys, a lack of sufficiently deep stratigraphic drilling poses a major roadblock to furthering geologic knowledge and attracting exploration interest.

Initial scientific investigations, including those undertaken by DSDP, established the tectonic and stratigraphic framework of the region. The data from DSDP sites remain the only existing drilling data sets in the region, but the oldest section penetrated is Late Maastrichtian (i.e. latest Cretaceous). Consequently, most of the Late Cretaceous, as well as the older successions, which are the most prospective sections for petroleum, remain untested.

Ocean drilling into the pre-Late Cretaceous sedimentary succession would provide essential information to unlock the geological history of the region and contribute to an assessment of resource potential. Drilling would target basins with the most regionally representative and complete stratigraphy, as identified from the latest studies. The Lord Howe Rise is a region where the IODP could bring about a significant scientific breakthrough, as well as potential economic benefits through opening up of a large frontier region to resource exploration.

Whether IODP drilling would provide vital missing information for the petroleum assessment of the region that would lead to petroleum exploration would depend on the geology revealed through the drilling. However, without direct sampling of sedimentary rocks from the potential target sequences, major petroleum exploration companies are unlikely to invest in large-scale exploration in the region.

Further details of the importance of further ocean drilling are provided in Appendix B.

Source: Adapted from material provided by Dr Takehiko (Riko) Hashimoto (Geoscience Australia).

4.12 Conclusions

To the extent that scientific ocean drilling occurs within Australian waters, Australia scientists would have the opportunity to be involved in those expeditions. Further, some of the value of IODP science outcomes would flow in due course to Australian researchers and research institutions through access to scientific publications, conferences, scientific networks and the like.

However, were Australia not to be a member of IODP Australian scientists would generally not have access to berths on expeditions outside Australian waters, not have positions on IODP governance and scientific committees, could only access the scientific results after considerable delay, would miss the valuable additional scientific insights and networking opportunities associated with being part of an expedition, and find it more difficult to remain at the forefront of their scientific disciplines. The loss of such opportunities would be particularly detrimental to the training of the next generation of Australian scientists.

If Australian does join IODP2, an Australian scientist will be the co-chief of an expedition in 2014. Further, it is likely that another Australian scientist will co-chief an expedition in 2015, with the possibility of another in 2017. These are prestigious and influential opportunities from a scientific perspective.

While most of the additional benefits to Australia from participation in IODP cannot be quantified in monetary terms they are nevertheless very considerable. A fair qualitative assessment would suggest that significant scientific benefits in terms of enhancing our science base, remaining at the leading edge of basic international science, additions to our store of knowledge and breakthroughs in published scientific papers, influence on the direction of a major and long term scientific effort, leveraging the international investment made in drilling platforms, and working on issues of direct national interest are a direct result of Australian membership.

The direct economic benefits from port calls and workshops are modest but should the release of petroleum exploration acreage, which has been informed by scientific ocean drilling, result in a significant commercial discovery the potential benefits to Australia are huge. The geopolitical benefits and education activities are also worth noting.

Chapter 5

The costs of Australia's participation in IODP

As discussed earlier in this report Australia has had a long history of association with international ocean drilling programs, having been involved in both DSDP and ODP. It is recognised that the attribution of costs and benefits to particular programs is difficult given the time lags involved. Some of the benefits discussed in this report have resulted from Australia's involvement in these previous programs. Further, some costs incurred in this phase, such as input into the future structure of the program, will result in future benefits. In order to make a robust assessment of the benefits compared to the costs, the cost of involvement in the successive scientific ocean drilling programs would need to be calculated[8].

While the total cost of this involvement cannot be readily established, the direct cost of Australia's membership of ODP from 1989-2003 was approximately $20 million (Australian ODP 2003). Membership of DSDP was free and scientists' participation was a result of invitation by the host organisation.

This chapter explores the costs of Australia's participation in IODP. In addition to the direct costs of the participation, such as the membership fees paid to be part of IODP and administrative costs, the indirect costs of participation, including the costs associated with the effort of researchers who participate in expeditions and Australian representatives on IODP panels and committees, are also examined.

5.1 IODP expenditure

The direct cost of Australia's participation in IODP to date relates to the various expenses incurred. As can be seen in Table 5.1, a range of expenses are incurred including:

- IODP membership fees;
- administrative expenses;
- travel expenses;
- post-cruise funding; and
- expenditure on other activities.

To date, the direct costs of participation in IODP have totalled just under $11.8 million. Importantly, this includes membership fees for 2013 and other budgeted expenses in this year.

[8] A full analysis of the costs and benefits of the successive scientific ocean drilling programs is beyond the scope of this project.

Table 5.1

IODP EXPENDITURE, $AUD

Expense	2008[1]	2009[1]	2010[1]	2011[1]	2012[1]	2013[2]	Total
IODP membership fees	1,092,385	1,775,759	1,905,299	2,806,637	975,517	0	**8,555,597**
Administrative expenses	83,881	100,307	132,282	142,142	152,402	157,000	**768,014**
Travel expenses	35,528	84,490	90,944	99,900	139,430	76,000	**526,292**
Post-cruise funding	0	0	49,296	145,012	209,753	285,000	**689,061**
Other activities	157,157	1,022	18,046	40,894	79,423	934,093	**1,230,635**
Total	**1,368,951**	**1,961,578**	**2,195,867**	**3,234,585**	**1,556,525**	**1,452,093**	**11,769,599**

Notes: 1. Actual expenditure. 2. Budgeted expenditure
Source: Statements of Income and expenditure (2008-2012), provided by the ANZIC IODP office and the IODP Grant – Financial report December 2012, provided by the ANZIC IODP office.

Membership fees

Australia contributes US $1.4 million per annum, which represents a 25 per cent share of a full membership of the IODP consortium. Up to 2011 New Zealand contributed a further 5 per cent share, giving the ANZIC consortium 30 per cent of a full membership in total. However currency fluctuations relating to changes in the value of the Australian dollar against the US dollar influence the cost of membership.

In 2009, additional funding from the ARC and partners was required to meet large fluctuations in the dollar. However, the subsequent favourable movement of the Australian currency benefited the Consortium and the amount sought from Australian scientific partners was reduced.

Since 2008, IODP membership fees have totalled just over $8.5 million. This figure includes a prepayment of 2013 membership fees.

Administrative expenses

The running of the Australian IODP Office, based at the Research School of Earth Sciences at the Australian National University, incurs administrative costs. These costs relate to the salary of staff and related expenses, as well as the cost of non-capital equipment and utilities and maintenance.

Travel expenses

The ANZIC IODP office pays the travel expenses of researchers on expeditions, as well as the travel expenses for Australian members of IODP committees and panels. The office also holds various workshops, conferences and meetings. A total of just over $526,000 is expected to be expended on these activities from 2008-2013.

Post cruise funding

In September 2009, a variation to the ARC LIEF funding arrangements (agreed by ARC but funded by members) provided up to $20,000 each for immediate post-cruise data analysis by Australian IODP participants. This acknowledged the difficulty for such scientists to get adequate initial post-cruise science funding, to reap the full benefits of participation in the IODP, because there is only a one-year moratorium on expedition data. The funding covered the period 2009 to 2012.

In November 2010, the ANZIC Governing Council decided that additional funding of $20,000 could increase the sum available per scientist to up to $40,000. The additional funding covered the period 2010 to 2012. In general, this additional funding is not to be used for researchers salaries or on-costs.

In February 2012, both the ANZIC Science Committee and the ANZIC Governing Council discussed how to encourage additional Australian and New Zealand scientists to carry out work on ocean drilling material, in order to achieve better value from our membership of IODP by filling gaps in existing research. This would increase the number and quality of publications within the life of the Program. It was decided to offer a funding package of up to $25,000 each to researchers to carry out analytical work on shipboard data/samples for a specific task. The offers could be distributed among contributing organisations. Thirteen grants were made in late 2012.

In 2012, $150,000 was spent on Post Cruise Special Analytical Funding, and it is estimated that this will increase to $285,000 in 2013.

In total, just under $690,000 has been spent of post-cruise funding to date.

Other activities

There are a range of other expenses incurred by the ANZIC IODP Consortium which include foreign exchange losses, bank charges, postage and freight charges and miscellaneous operating expenses.

5.2 Indirect costs

In addition to the direct costs of participation in IODP outlined above, a range of indirect and opportunity costs are incurred. This section explores the cost associated with researcher's effort, through the participation in expeditions, as well as the cost associated with membership of various IODP committees and panels.

Researcher effort

In addition to paying annual membership fees ANZIC member institutions may provide additional support for scientists to participate in IODP through researchers time and effort associated with being part of IODP expeditions. In some cases the home institution may also incur opportunity costs in terms of the researchers absence from other institutional activities, including teaching.

The process of participating in an expedition and the timing between each activity was summarised earlier in Figure 3.1. The cost of this support is borne by the institution that employs the researcher. The researcher effort associated with each of the activities associated with participation in an IODP expedition is outlined below.

Preparation of a drilling proposal entails a number of steps. These involve the development of an initial proposal, which is submitted to the IODP proposal evaluation panel for consideration. Strong proposals are then usually sent back to the proponent for revision. Once the proposal has been revised, it is then sent out for external review. Following external review there is generally one additional round of changes made by the proponents. The lead proponent organises and takes the lead in the revision.

Following the approval of a proposal, researchers are then able to participate in a drilling expedition. Stakeholders suggested that the lead-time between proposal development and participation in an expedition could be between three to seven years.

Prior to an expedition, work is required to prepare for the voyage. This includes site surveying, which involves assembling the geophysical and geological information for the drilling to occur. Stakeholders suggested that IODP researchers have varying levels of involvement in this process. In some instances required data and information has already been collected and limited effort is involved. However, in others significant time and resources are required and associated effort can range from between 24 to 52 weeks of time. Researchers are however, required to assemble the information obtained and provide it to the IODP, which ensures it is adequate. Researchers also have to prepare information for, and one of them is interviewed by, the Pollution Prevention and Safety Panel to ensure there are no safety or pollution hazards.

Researchers then participate in the drilling expeditions. The drilling expeditions usually last for approximately eight weeks, with another week of time associated with pre and post expedition activities.

Subsequent to the drilling expedition, researchers undertake analysis of the information gathered and the activities undertaken on the vessel and drafting of publications. It was suggested that final results from each cruise could take approximately two years to produce and involve some months of work.

These publications are then subject to peer review. Finally, the publications appear in scientific journals, which normally takes two to four years after the expedition. It was noted that publications are still emerging from predecessor drilling programs and can therefore have apparent lag times of up to ten years.

The entire process can take up to 15 years. The researcher effort associated with this process is summarised in Table 5.2. It is estimated that from the initial drafting of a drilling proposal to the submission of publications approximately 37 weeks of a researcher's time is required, while for chief scientists, this could be up to 91 weeks.

Table 5.2

RESEARCHERS TIME ASSOCIATED WITH PARTICIPATING IN AN IODP EXPEDITION

Aspect	Researcher effort
Pre-cruise surveys and their assessment	Varies[1]
Development and revision of proposal	8 weeks
Preparation for drilling expedition	2 weeks (4 weeks for co-chief Scientist)
Participation in drilling expedition	9 weeks
Analysis of information gathered and drafting publications	16 weeks (52 weeks for chief scientists)
Peer review and submission of publications	2 weeks
Total	**37 weeks** **(Up to 91 weeks for co-chief scientists)**

Note: 1. The amount of effort spent on site surveys varies considerable on a case-by-case basis depending on site survey needs and available information. Stakeholders suggested it can vary from very little effort to between 24 weeks and 52 weeks of researchers effort. Due to this variability the cost associated with site surveys has not been quantified.
Source: The Allen Consulting Group, based on information provided by stakeholders

Cost associated with researcher effort

Based on the analysis of researcher effort, an approximation of the cost borne by the host institution in supporting researcher effort in the IODP can be calculated.

It is conservatively estimated that the researcher effort associated with IODP has a total cost of just over $2.5 million. This conservative estimate is based on the following assumptions and data:

- a total of 26 Australian researchers involved in IODP expeditions (including one co-chief scientist);
- an average of 37 weeks of researcher effort for each researcher involved (and 91 weeks for the co-chief scientist);
- on-costs of 28 per cent as outlined in the ARC's salary and stipend rates for Discovery and Linkage 2013; and
- estimated salaries based on the Australian National University Enterprise agreement 2010-2012.

Table 5.3 provides further detail of the cost associated with researcher effort.

Table 5.3

COST ASSOCIATED WITH RESEARCHER EFFORT

Personnel level	Estimated salary[2] (A$, annual)	On-cost[3] (A$, annual)	Total cost (A$), annual	Proportion of costs related to IODP[4]	Number of researchers[1]	Total cost (A$)
Professor	150,675	42,189	192,864	137,230	5	686,151
Senior Lecturer, Principal Researcher, Senior Researcher	107,044	29,972	137,016	97,492	7	682,447
Lecturer	89,591	25,085	114,676	81,597	7	571,177
Lecturer (co-chief)	89,591	25,085	114,676	81,597	1	200,684
Tutor, PhD student, Post-doctoral researcher	66,900	18,732	85,632	60,930	6	365,583
Total					**26**	**2,506,041**

Source: Allen Consulting Group analysis
1. Based on information supplied by the ANZIC IODP office (see Appendix C)
2. Based on the Australian National University Enterprise agreement 2010-2012
3. Based on ARC salary and stipend rates for Discovery and Linkage 2013
4. Based on 37 weeks of effort for scientists (and 91 weeks of effort for co-chief) as calculated above.

Membership of committees and panels

The membership of committees also results in indirect costs of participation in IODP which are also borne by host institutions. As noted in Chapter 4, ANZIC has representation on the:

- Science Implementation and Policy Committee (1 member);
- Proposal Evaluation Panel (2 members);
- Site Characterisation Panel (1 member); and
- Science and Technology Panel (1 member).

Stakeholder consultations suggested that, on average, the various panels meet twice a year. Meetings generally last for 3-4 days and total effort associated with each meeting is estimated to be around 2.5 weeks, including meeting preparation.

With ANZIC having five representatives on four committees and panels, the total effort associated with such representation is estimated to be 25 weeks per year.

Cost associated with membership of committees

Based on the effort associated with committee and panel membership, an approximation of the cost borne by the host institution in supporting researcher effort in the IODP can be calculated.

It is conservatively estimated that the effort associated with IODP committee and panel membership has a total cost of nearly $556,000. This estimate is based on the following assumptions and data:

- a total of five ANZIC representatives on committees and panels each year;
- an average of five weeks of effort for each committee or panel per year;

- a similar level of yearly involvement from 2008-2013;
- on-costs of 28 per cent as outlined in the ARC's salary and stipend rates for Discovery and Linkage 2013; and
- an estimated annual salary of $150,675, based on the Australian National University Enterprise agreement 2010-2012.

5.3 Cost of participation in the next phase of ocean drilling

The Australian IODP consortium intend to bid for a further round of ARC LIEF funding for five years from 2014. The Australian National University is leading this bid. Consultations indicate that the Australian IODP consortium intend to seek sufficient funding to increase annual membership payments for the US (*JOIDES Resolution*), and European (MSPs) consortiums and to pay Japan for access to the *Chikyu*. Under the new framework for the International Ocean Discovery Program this will ensure Australian scientists have access to all expeditions on all three platforms, a better situation than at present. The nominal annual budget for the first five years of participation is outlined in Table 5.4.

Table 5.4

DIRECT COST OF PARTICIPATION IN THE NEXT PHASE OF OCEAN DRILLING

Item	Annual expenditure ($AUD)
NSF-European Membership $US1.5 million*	1,580,000
Japanese membership	316,000
Salaries and related costs (2 part-time)	170,000
General administrative costs	90,000
Supporting scientific activities**	440,000
Total	**2,596,000**

* Estimated sum, based on assumed exchange rate of $1A = $US0.95
**Post-cruise science funding, student master classes etc.
Source: ANZIC IODP office

If Australia continues to play a substantial role in IODP2, the indirect costs of participation could be expected to be around the same order of magnitude as for IODP. However, should Australian scientists be offered more co-chief roles as discussed in the previous chapter (there was only one during IODP) the indirect costs would be relatively higher due to the higher time commitments involved.

5.4 Conclusions

The direct costs of Australia's membership of IODP have totalled just under $11.8 million over the life of ANZIC participation (2008-2013). The associated indirect costs borne by researcher institutions are estimated to be approximately $3.0 million.

In total, it is therefore estimated that Australia's participation in six years of IODP from 2008-2013 has cost approximately $14.8 million.

Based on the Australian IODP consortium's intended bid for a further round of ARC LIEF funding, Australia's participation in the forthcoming International Ocean Discovery Program for ten years (2013-2023) would be around $26 million in current dollar terms (based on an assumed exchange rate of $1A=$US0.95). If Australia continues to play a similar role in IODP2 as it does currently, the indirect costs of participation could be expected to be around the same order of magnitude as for IODP.

Chapter 6

Conclusion and Recommendations

This chapter outlines the key findings of the review, including a summary of the benefits and costs of Australia's participation in the IODP. It also discusses a number of issues, which were bought to the attention of the review team during the course of this study. Finally, it comments on Australia's future involvement in the International Ocean Discovery Program.

6.1 Key findings of the review

Each successive phase of scientific ocean drilling (DSDP, ODP and IODP) has achieved significant scientific and technical results. This has been confirmed by reviews undertaken in the US, UK and Europe and by this study. Planning is already well underway for the next phase, the International Ocean Discovery Program, and a new Science Plan is agreed and revised operational arrangements are being put in place.

In assessing the benefits and costs of IODP it is important to recognise that there are significant lags between the initiation of a proposal, actual drilling taking place, the analysis of results and publication of scientific papers. This means that during the period of IODP, benefits will arise that are attributable (in part or in whole) to previous phases and similarly the benefit of work done during IODP will flow through to the successive phase.

It is also important to recognise that as with all science, a range of benefits from IODP would flow to Australia, usually with some lags, even if Australia was not a participating member. However, it is clear from this study that the nature, scale and timing of benefits to Australia would be quantifiably and qualitatively less.

Within the constraints of the data and information available, and recognising the issues of attribution and additionality associated with membership, it is clear that Australia's direct participation in IODP has generated a range of collaboration, capability building, scientific outputs, economic impacts and broader national interest benefits. These are summarised in Table 6.1.

Table 6.1

THE QUANTITATIVE AND QUALITATIVE BENEFITS OF AUSTRALIA'S PARTICIPATION IN IODP

Benefit	Description
Enhancing linkages	Participation of 26 Australian scientists (one as Co-Chief) on IODP expeditions provides a unique opportunity for advancing their areas of interest and provides a highly stimulating and multi-disciplinary scientific environment for cross fertilisation of ideas, exposure to new methods and new perspectives.
Extensive international collaborations	Australian researchers are very well connected into the global IODP related network, with major centres of collaboration in North America, North East Asia and Europe.
Access to infrastructure	Through participation in IODP Australian researchers have access to ocean drilling infrastructure valued at around $US 1 billion and with operating costs of around $US 170 million.
Increasing marine science capability	Direct participation in IODP provides engagement with leading researchers in a variety of fields, exposure to new techniques and effectively free use of expensive ocean drilling research platforms and equipment. 30 Australian and New Zealand students, including Masters, PhD students and Post-Doctoral Fellows have participated in IODP projects. The societal value of Australian PhD students alone is estimated at around $1.3 million. In the absence of direct participation in IODP Australia's marine science base would be smaller and of lower quality than currently exists.
High quality scientific outputs	The scientific outcomes are impressive in terms of publications in high quality peer-reviewed scientific journals and quality of science as reflected in the ratings achieved under the Excellence in Research Australia (ERA) process and additional competitive ARC grants totalling $AUD 7 million. The average citation rate of 20 for the 203 Australian authored papers on the SCOPUS database was above the global average of 17 (between 1996 and 2011).
High productivity	Australian scientists have contributed to 2,931 peer reviewed IODP and previous ocean drilling publications from 1968-2012, or 10.2 per cent of the World total (8.9 per cent during IODP to 2012). They have also contributed to many IODP program reports and publications.
Funding leverage	Australian researchers' host institutions have provided in kind support conservatively estimated at $3.0 million to support IODP-related research.
Influencing the scientific agenda	Membership provides opportunities for participation in the governing structure and key committees of the IODP, whereby Australian scientists can influence directly the governance, strategic direction and work program of the IODP. ANZIC scientists are members of four key IODP committees as well as the 2013-2023 Science Plan Writing Committee.
Scientific legacy	The three core repositories (located in the USA, Japan and Europe) and SEDIS database are a valuable resource for further scientific research and are growing as further expeditions take place.
Contributing to Government policy and national interests	Membership is consistent with Australian Government policy and can add important new data and insights across arrange of areas of key national interest such as climate change, earthquakes and tsunamis, how mineral deposits form and their exploration.
Direct economic benefits	The direct economic benefits to the Australian economy from membership of IODP derive predominately from port visits by consortium drilling vessels, estimated to total between $4.4 million and $5.5 million during IODP. The Australian economy also benefits directly whenever IODP workshops or IODP related conferences are held in Australia.
International investment	Australia benefits from the international investment in drilling in Australian waters and areas of interest in our region. The two expeditions undertaken in Australian waters during IODP represent an investment of $US 16 million. Arguably Australia also benefits in the form of potential budgetary savings.
Indirect economic benefits	Use by the oil and gas industry to de-risk exploration activities.
Geopolitical impacts	IODP contributes to the role of science in diplomacy and Australia's place in the World.
Education and outreach	These activities contribute to a more scientific literate community and to generating student interest in science.

Source: The Allen Consulting Group, based on stakeholder input and broader research.

In considering the costs of Australia's membership it is important to account for both direct (e.g. membership fees) and indirect (e.g. support provided by host institutions) costs. Although not practical to quantify, some costs incurred in one phase of scientific ocean drilling (e.g. the work done during IODP on the 2013-2013 Science Plan) may well benefit a successor phase. Putting the attribution issues aside, the direct and indirect costs of IODP are summarised in Table 6.2.

In total, it is estimated that the direct and indirect costs of Australia's participation in IODP from 2008-2013 totals approximately $14.8 million. Of this amount $3.0 million is in the form of in-kind contributions from researchers' host institutions that can also be regarded as leverage on the ARC grants for IODP membership, over and above the member institutions' ANZIC consortium fees.

Table 6.2

THE ACTUAL AND PROJECTED COSTS OF AUSTRALIA'S PARTICIPATION IN IODP

Cost	Description
IODP membership fees	Over six years from 2008, membership fees have totalled just over $8.5 million, including a prepayment of 2013 membership fees.
Administrative expenses	Actual and budgeted expenses of running the Australian IODP Office, at the Australian National University are estimated to total approximately $768,000.
Travel expenses	Actual and budgeted expenditure on travel expenses workshops, conferences and meetings is estimated to total just over $526,000.
Post-cruise funding	Actual and budgeted funding immediate post-cruise data science by Australian IODP participants and funding to researchers to carry out analytical work on shipboard data/samples for a specific task is estimated to total just under $690,000.
Other activities	Other expenses incurred by the ANZIC IODP Consortium, including foreign exchange losses, bank charges, postage and freight charges and miscellaneous operating expenses are projected to total $1.23 million.
Researcher effort	The costs borne by ANZIC member institutions by way of support for scientists to participate in IODP through researchers' time and effort associated with being part of IODP expeditions is estimated to be approximately 37 weeks of a researchers time and up to 91 weeks for chief scientists. It is conservatively estimated that the researcher effort associated with IODP has a total cost of just over $2.5 million.
Membership of committees and panels	The membership of committees also results in indirect costs of participation in IODP, estimated to total $556,000.
Total costs	The total costs of Australia's participation in IODP over the 2008-2013 period are estimated to be $14.8 million.

Source: The Allen Consulting Group, based on stakeholder input and broader research.

6.2 Overall assessment of benefits and costs

It is not practicable to quantify in dollar terms the net additional benefit to Australia of IODP membership because there are no robust and generally accepted indicators and/or methodology to do so. Attempting to calculate a standard cost-benefit ratio is therefore not appropriate.

In considering the value of the benefits to Australia it is important to recognise that:

- the nature and impact of the benefits are very diverse, ranging from those of a public good nature (e.g. increased knowledge) to those which are commercial (e.g. exploration industry use);
- many of the benefits are longer term and cumulative in nature (e.g. networks, collaborations and enhanced human capital);
- the direct (e.g. port visits) and indirect (e.g. industry use) benefits are quite significant in their own right; and
- the potential benefits (e.g. a better understanding of natural hazards, discovery of hydrocarbon resources) are huge.

In summary, the assessment is whether the benefits of membership sufficiently outweigh the costs to justify the investment in IODP and the successor International Ocean Discovery Program.

The overall conclusion of the review is that quantifiable and unquantifiable benefits to Australia of direct membership of the IODP consortium far exceed the modest costs of participation. Moreover it would be detrimental to Australia's interests not to be a member of IODP and such participation is well aligned with current government policy as articulated in the *2012 National Science Investment Plan*, the aspirations of the *Australia in the Asian Century White Paper* and Australia's policy of fostering international scientific collaborations.

The review has also concluded that based on the value to Australia of participation in IODP and the expected benefits and costs of membership of the International Ocean Discovery Program there is a strong case for continuing direct Australian membership.

6.3 The way forward

In considering the way forward in ensuring the benefits of Australia's direct participation in the International Ocean Discovery Program are recognised by the ARC, as a key funding body, and the government more broadly there are a number of key issues which should be taken into account.

It is recognised in the *2012 National Research Investment Plan* that:

> 'Investment should be made with a view to sustaining the long-term viability of Australia's research and innovation capability. Funding for core research and innovation programs should be ongoing and predictable.'
>
> Australian Government 2012a, *2012 National Research Investment Plan*, Department of Industry, Innovation, Science, Research and Tertiary Education

In this context, while not originally designed for this purpose, the ARC LIEF program is an appropriate source of funding for IODP. This is because the membership fee provides access to ocean drilling infrastructure and participation in the World's largest geoscience collaboration, which is important for Australian science and national interests and would otherwise be unavailable.

In light of the LIEF funding rules for 2013 and with little prospect that the LIEF budget will be significantly increased, an ANZIC bid for a further round of LIEF funding carries some risk. This is because with a total LIEF budget of about $30 million per annum and around 170 applications for each funding round, ARC Selection Committees are focussed on achieving best value for money. Scientific ocean drilling is expensive science and, in the LIEF context, justifying a five year grant of $2.6 million per annum for the next phase of international collaborative ocean drilling could be challenging.

Nevertheless in the absence of alternative funding sources such as a further National Collaborative Research Infrastructure Strategy (NCRIS) style program, which is unlikely before 2014, the ANZIC IODP Governing Council has little option than to submit a further application for ARC LIEF funding.

Clearly demonstrating as strongly as possible the scientific outputs and broader benefits of Australia's membership of IODP will be crucial. This includes use by scientific agencies and policy departments. This report has sought to garner as much information as practicable and it is important that the benefits are articulated clearly not only in the bid to the ARC but to relevant Ministers and Government Departments more broadly in order to both improve the currently low visibility of the importance of scientific ocean drilling and to help lay the groundwork for funding under any new collaborative research infrastructure program.

Consultations suggest that it would be prudent for the new ARC LIEF funding application to have some different parameters to the previous bid and with a clear emphasise on demonstrating value for money, including demonstrating the scientific outputs and outcomes. Importantly, obtaining a larger proportion of total funding from existing and new participating institutions or other parties would achieve a higher leverage ratio and strengthen the case for further LIEF investment. However it is recognised that due to their own funding issues, obtaining more funds from universities will be difficult to achieve.

In addition, past adverse movements in the $US/$AUD exchange rate have had to be met through additional contributions from participating institutions and also the ARC. As further exchange rate movements are bound to occur over the next five years, it would again be prudent for an explicit strategy to be included in a new LIEF bid. Given Commonwealth Government policy prohibits currency hedging, an appropriate strategy may include seeking as much funding as practicable from all parties up front so that future IODP membership subscriptions can be paid while the exchange rate is favourable.

In a world of many competing demands, a focused publicity strategy that not only involves representations and presentations to Ministers and Departments, but seeks to engage Parliamentarians more generally and influential science journalists, would help to build a broader constituency of supporters. Ideally this should be timed to coincide with the release of the 2012 ANZIC Annual Report with follow up after the ARC LIEF bid is submitted.

Post the ARC bid, consultations indicate that it is recognised within some government departments and the scientific community that it is preferable to find another way to fund IODP, rather than further rely on the ARC competitive Linkage Infrastructure, Equipment and Facilities (LIEF) funding program. The LIEF program was not designed to fund long-term international collaborations as such and continuing to be able to fund programs for more than five years is problematic. Establishment of a new program to fund major international research collaborations would be an ideal outcome.

Appendix A

Consultations

Targeted consultations were undertaken with a range of key stakeholders to inform the review. The table below outlines the stakeholders consulted for this project.

Name	Organisation
Dr Andrew Heap	Geoscience Australia
Ms Anne Baly	Department of Industry, Innovation, Science, Research and Tertiary Education
Professor Annette George	University of Western Australia
Dr. Brad Clement	IODP US Implementing Organisation, USA
Dr. Chris Hollis	GNS Science, NZ
Dr. Chris Yeats	CSIRO
Ms Clare McLaughlin	Department of Industry, Innovation, Science, Research and Tertiary Education
Dr. Clinton Foster	Geoscience Australia
Dr. David Divins	Ocean Drilling Programs Consortium for Ocean Leadership, USA
Dr David Falvey	Palatine Energy Pty Ltd
Dr. David Whitford	CSIRO
Professor Gilbert Camoin	ECORD Management Agency, France
Dr Geoff Garrett, AO	Queensland Chief Scientist and ANZIC Governing Council chairperson
Professor James Kennett	University of California at Santa Barbara
Professor Janet Hergt	Melbourne University
Ms Josephine Mummery	Department of Climate Change and Energy Efficiency
Dr. Jody Webster	University of Sydney
Mr John Gunn	AIMS and OPSAG
Ms Leanne Harvey	Executive General Manager, Australian Research Council
Mr Martin Squire	Department of Resources, Energy and Tourism
Professor Mike Coffin	University of Tasmania
Professor Richard Arculus	Australian National University
Professor Richard Coleman	University of Tasmania
Dr. Shingo Shibata	MEXT, Japan
Dr. Simon Lang	Woodside Energy Ltd
Associate Professor Stephen Gallagher	University of Melbourne
Professor Tony Crawford	Formerly of University of Tasmania
Dr. Tony Worby	CSIRO
Dr. Will Howard	Office of the Chief Scientist
Professor Will Steffen	Australian National University

Appendix B

Detailed case studies

This Appendix provides further details on some of the case studies included in the body of the document.

Box B.1

UNDERSTANDING MOVEMENT OF THE AUSTRALIAN CONTINENT

The basis for the theories of seafloor spreading and plate tectonics depends on a number of factors, including the broad magnetic stripes in oceanic basalts that are caused by the periodic flipping of north and south magnetic poles. Very early in the history of ocean drilling, in the late 1960s, the Deep Sea Drilling Project (DSDP) proved seafloor spreading by showing that the theoretical ages of the magnetic stripes in the Atlantic Ocean were correct through coring and dating the sediments directly above the oceanic crust.

The separation of Australia and Antarctica by seafloor spreading was reasonably understood in the early 1970s from the magnetic stripes between them (reference 1), and properly dated by DSDP Leg 28 drilling. DSDP Leg 29 further supported theory by demonstrating that the Tasman Seaway between the new continents first opened about 33 million years ago (Ma) as Australia moved northwards, and that strong currents poured through the gap to the east as the precursor of the present Antarctic Circumpolar Current (reference 2).

More focused drilling on the facing continental margins, during Ocean Drilling Program Legs 187 and 189 and Integrated Ocean Drilling Program Expedition 318, has added greatly to the understanding of this continental separation and the climatic changes it caused (references 3 & 4). Separation began by rifting in the Late Cretaceous, and basalt seafloor started to form between the two new continents later, about 80 Ma. However this spreading started in the west and was very slow – a gulf formed that was limited to the east by a land bridge consisting of what are now Tasmania and the more southerly South Tasman Rise. Spreading accelerated in the Eocene at about 43 Ma, and water leaked across the land bridge, but only with full separation at 33 Ma did strong currents begin to flow and separate the climatic regimes of Australia and Antarctica.

From ocean drilling it is now known that in Eocene times, before full separation, near-tropical conditions existed on both sides of the gulf, with palm trees and baobabs growing on the Antarctic coast. The separation and the onset of strong currents between the two continents coincided with rapid Antarctic cooling and the initial build-up of a major Antarctic ice sheet at the onset of the Oligocene (33 Ma). Many argue that this ice sheet expansion was in response to the disruption of southward-flowing warm currents that until then had bathed the Antarctic margin. Antarctica began to become thermally isolated in the Early Oligocene and ocean circulation underwent fundamental changes that led to major transfer of CO2 out of the atmosphere and into the ocean, thus reinforcing the cooling trend. This represents the transition from a Greenhouse to an Icehouse Earth.

Continued northward movement of Australia widened the circum-Antarctic seaway and further isolated Antarctica, which continued to reinforce a global cooling and drying trend including that of Australia well documented as a result of ocean drilling. Australia consequently became one of the driest continents on Earth. The Earth eventually entered into the classic ice age period well known for its pronounced glacial-interglacial fluctuations. This period has featured not only considerable temperature variations related to the accumulation and melting of ice sheets in the Northern Hemisphere, but also global sea level variations of more than 100 m.

Ocean drilling is a key source of information for understanding Australia's movement northward and its coincident warming and drying periods. The knowledge of the extremes that have affected us in the past can help us better plan for a future of increasing greenhouse gasses, warmth and sea level rise. Such planning is critical for a prosperous Australian future.

Source: Written by Professor Neville Exon (Australian National University) and Professor James Kennett (University of California at Santa Barbara).

References:

1) Weissel, J.K. and Hayes, D.E., 1972. Magnetic anomalies in the Southeast Indian Ocean. In Antarctic Oceanography II: The Australian-New Zealand sector, Antarctic Research Series 19, p. 165-196, American Geophysical Union, Washington, D.C.

2) Kennett, J.P. and others, 1972. Australian-Antarctic continental drift, paleo-circulation change and Oligocene deep-sea erosion. Nature 239, 51-55.

3) Exon, N., Kennett, J.P, and Malone M., 2004. The Cenozoic Southern Ocean: tectonics, sedimentation, and climate change between Australia and Antarctica. American Geophysical Union Geophysical Monograph 151, 367 p.

4) Escutia, C., Brinkhuis, H., Klaus. A. and others, 2011. IODP Expedition 318: from Greenhouse to Icehouse at the Wilkes Land Antarctic Margin. Scientific Drilling 12, p.15-23.

Box B.2

APPLICATION OF OCEAN DRILLING TO TERRESTRIAL ORE DEPOSITS

As the foundation supervising Scientist of ODP Australia when we joined ODP (Ocean Drilling Program) jointly with Canada in late 1988, I spent 3 years attending all International Planning Committee meetings and was well versed in the innovative science outcomes deriving from this premier global Earth science program. I particularly followed developments in my own field of igneous petrology and geochemistry.

One important drilling Leg with respect to petrology and geochemistry was Leg 176, during which an attempt was made to drill deep oceanic crust exposed alongside an ultra-slow spreading mid-ocean ridge, the SW Indian Ridge. Instead of encountering the expected 'layer-cake' cumulate gabbros and related rocks such as had been drilled at other sites investigating the lower oceanic crust, this Leg yielded remarkable Fe-rich, often foliated gabbroic rocks (ferrogabbros). The Chief Scientists invoked a heretofore undocumented process, synkinematic fraction, to explain these rocks, Essentially, this involves movements of the slow–spreading ridge 'pumping' or 'vacuuming' very Fe-rich interstitial melt in the cooling crystal mush pile into fractures to form the ferrogabbros and related rocks.

In many respects, this may have seemed a rather esoteric process, with the resultant rocks having little more than curiosity value. However, after shifting my research interests to ore deposit geology in the ARC Centre of Excellence in Ore Deposits (CODES) in Hobart, I was exposed to the mysteries of the supergiant Broken Hill Pb-Zn-Ag deposits, which have been mined for 120 years. The formation of the Broken Hill deposits always has been, and remains, an exceptionally controversial topic. Most research has concentrated on structural and metamorphic aspects of the deposit as well as the ores themselves, with very little attention paid to the associated igneous rocks.

I commenced a study of the abundant mafic sills around the Broken Hill deposit in 2003, and it became immediately obvious that (1) the mafic magmas along the line of lode were extremely Fe-rich compared with those more than 500-1000m away from the line of lode, and (2) that this Fe-enrichment was demonstrably magmatic and not an alteration or metasomatic feature. This led to the development of a new model for the Broken Hill mineralization (Crawford and Maas, 2009) that has received widespread interest, and strong support from a number of the key industry and academic researchers on Broken Hill mineralization. In particular, it argued that the ore-forming fluids ultimately derived not from the metasedimentary host rocks, but from very Fe-enriched mafic magmas formed by synkinematic fractionation along the line of lode detachment system. New very detailed Pb isotope data acquired by Dr Roland Maas at the University of Melbourne showed that the mafic magmas and ore deposit Pb are identical isotopically, strongly supporting the viability of this model.

Clearly, without exposure to new developments in igneous petrology and geochemistry deriving directly from ODP, I would not have been aware of the existence of the key processes and products that played a key role in forming the Broken Hill deposit. In addition to providing a satisfying explanation for the formation of this globally important deposit, it has significant exploration spin-offs which may help focus exploration for new examples of this important mineralization style. This provides an excellent example of how curiosity-driven research can provide unexpected benefits that help direct more pragmatic research, such as that in locating and understanding ore deposits, which underpin a large proportion of Australia's sovereign wealth and future prosperity.

Source: Written by Professor Tony Crawford (University of Tasmania)

Reference: Crawford A.J. and Maas, R., 2009. A Magmatic – Hydrothermal Origin for the Giant Broken Hill Pb-Zn Deposit. In: Korsch R.J. (Ed.) Abstracts of the Broken Hill Exploration Initiative 2009 Conference. *Geoscience Australia Record* 2009/28, 28-30.

Box B.3

OCEAN DRILLING INFORMING PETROLEUM EXPLORATION

Australia was associated with the Ocean Drilling Program (ODP) through its life, and the role of ODP Leg 122 in understanding the geology and petroleum potential of the Exmouth Plateau is important. The sequence of events in developing an understanding of the plateau is illuminating.

1) The Bureau of Mineral Resources (BMR) reviewed all existing seismic profiles and other geophysical data on the virtually unknown deepwater plateau in the mid-1970s and, by tying the plateau data back to wells on the Northwest Shelf, built up a geological picture of the plateau and its petroleum potential (References 1 & 2) that interested major companies in the plateau. BMR and its successors (AGSO and GA) continued to work on the plateau (in partnership with German geologists and ships, and using AGSO's vessel Rig Seismic) for many years by running deep seismic profiles and by dredging ancient rocks from the margin of the plateau.

2) The Government released exploration leases on the plateau in the late 1970s, and exploration companies spent $200 million on seismic exploration, and drilling a dozen wells on the plateau in 1979-80. The hunt was for oil, but the wells confirmed that there was gas in the huge Triassic fault blocks, and the giant Scarborough Gas Field was discovered in a Lower Cretaceous basin-floor fan on the culmination of the plateau. Developing these finds was not profitable at the time, so company interest declined. However, the Scarborough Gas Field is still held under a production lease and, with improving technology and gas value, is being considered for development.

3) ODP Leg 122 in 1989 was the result of a proposal led largely by BMR scientists. It investigated the nature of the marine sediments on the southeast margin of the broad Mesozoic Tethyan Ocean as part of a global scientific study. Thousands of metres of core (References 3 & 4) were recovered of sedimentary marine rock sequences as old as Late Triassic (230 million years ago). Two outcomes were of great interest to the petroleum industry. One was the discovery of buried Triassic reefs, which host petroleum elsewhere in the world, for the first time in Australia. The other was the recovery of about 1000 m of cores of Early Cretaceous (140 m.y. ago) sedimentary rocks continuous with those of the Scarborough gas field to the east. These cores provide details of rock types that complement information from the sparsely cored petroleum exploration well.

4) AGSO and its successor Geoscience Australia have continued their work on the Exmouth Plateau as have exploration companies. The result is ongoing company interest in the plateau, with much seismic data acquisition and the drilling of deep wells in exploration leases. ODP 122 cores of the Triassic reefs were used by companies in considering deep drilling for similar targets, and a geologist from Woodside Exploration visited the Japanese core repository in 2011 to examine the cores as part of his assessment of Woodside's related drilling program at Tiberius No. 1 well.

5) The Petroleum Geological Summary for the Exmouth Plateau, as part of the 2012 petroleum acreage release (www.petroleum-acreage.gov.com), states that "The plateau hosts numerous supergiant gas fields and has recently become Australia's premier deepwater gas exploration province..." The phase of drilling for gas started in the mid 1990s with initial exploration in the east near the Rankin Platform where the producing fields of the North West Shelf Venture are located. Since then it has spread across the plateau and about 30 gas finds have been made. Scientific ocean drilling has played its part in these discoveries of large-scale Australian resources.

Source: Written by Professor Neville Exon (Australian National University)

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Box B.4

THE IMPORTANCE OF FURTHER OCEAN DRILLING

The Lord Howe Rise region is one of the world's largest remaining offshore frontier areas. The submerged continental landmass covers an area of over 1,500,000 km2 and its geological history is not well known, despite the fact that the region holds the key to some of the global-scale plate tectonic events and environmental changes during the Mesozoic and Cenozoic. In order to better understand the region's geology and petroleum prospectivity, Geoscience Australia and its predecessors, GNS Science and its predecessors, and the New Caledonian and French governments have completed a series of data (largely seismic) acquisition surveys and studies since the 1970s. Despite expenditure of tens of millions of Australian dollars on these surveys, a lack of sufficiently deep stratigraphic drilling poses a major roadblock to furthering our geologic knowledge and attracting exploration interest.

Initial scientific investigations of seismic reflection surveys in the 1960s and 1970s established the tectonic and stratigraphic framework of the region. In particular, investigations by the Deep Sea Drilling Project (DSDP) during 1971 (Burns et al. 1973), and again in 1982 (Kennett et al. 1986), provided a stratigraphic benchmark for the post-Late Cretaceous succession in all subsequent studies undertaken in the region. In addition, industry reconnaissance during the 1970s, encouraged by the rising global energy demand and major hydrocarbon discoveries in the nearby Taranaki and Gippsland basins, resulted in the acquisition of a few seismic reflection transects. However, exploration interest diminished as oil prices declined and further large hydrocarbon discoveries were made elsewhere in offshore Australia.

During the 1990s and early 2000s, geoscientific interest in the Lord Howe Rise region re-emerged, as the governments of Australia, New Zealand and France (New Caledonia) commenced data acquisition and interpretation to support maritime territorial claims under the United Nations Convention on the Law of the Sea 1982 (UNCLOS). A series of surveys, several undertaken collaboratively by the governments of the region, helped to build up a geoscientific data set of regional-scale reflection seismic, potential field and bathymetric data, limited rock and sediment samples, and associated geologic interpretations (e.g. Stagg et al., 2002). The interpretation of reflection seismic data led to speculations of vast gas hydrate deposits underlying the Lord Howe Rise and adjacent basins (e.g. Auzende et al., 2000).

These interpretations contributed to a resurgence in petroleum exploration interest in the region during the 2000s, which has been maintained despite the fact that subsequent work has found the regional occurrence of gas hydrates to be unlikely (Nouzé et al., 2009). Government initiatives were designed to promote frontier offshore exploration in basins such as the Capel, Faust, Fairway and Reinga basins, which had been identified as potentially having the region's highest prospectivity. For example, the Australian Government invested over $AUD 9 million in the acquisition of high-quality reflection seismic, gravity, magnetic, bathymetry and geologic sampling data over the Capel and Faust basins under the New Petroleum (2003–2006) and Offshore Energy Security (2006–2011) programs (e.g. Colwell et al., 2006).

In order to facilitate the synthesis of scientific results and data access across the Australian, New Zealand and New Caledonian jurisdictions, the Tasman Frontier project, an ongoing regional collaboration led by GNS Science, Geoscience Australia and Service Géologique de Nouvelle-Calédonie, was initiated. The project released the Tasman Frontier Database in 2012, a first-ever, cross-jurisdictional compilation of open-file seismic reflection data (Sutherland et al., 2012), as an initial step to further encourage scientific and industry interest in the region.

The latest phase of assessments has improved our understanding of the geologic evolution the Lord Howe Rise region from the Early Cretaceous to the present, and indicated that some basins are likely to host petroleum systems and are capable of generating oil or gas (e.g. Norvick et al., 2008; Collot et al., 2009; Stagpoole et al., 2009; Colwell et al., 2010). However, the major barrier to further scientific understanding and promoting exploration interest in the region has been the complete lack of pre-Late Cretaceous stratigraphic control, which would serve to ground-truth the existing interpretations that are largely inferred from tectonic reconstructions and basin analogues. The data from DSDP sites 206–208 and 587–592 remain the only existing drilling data sets in the region, but the oldest section penetrated is Late Maastrichtian (i.e. latest Cretaceous). As such, most of the Late Cretaceous, as well as the older successions, which are the most prospective sections for petroleum, remain untested.

Ocean drilling into the pre-Late Cretaceous sedimentary succession will provide essential information to unlock the geological history of the region and contribute to an assessment of resource potential. Reflection seismic data indicate a few locations within the Lord Howe Rise region where the pre-Late Cretaceous succession onlaps structural highs at depths of less than 2000 m from the seafloor. Some of these locations are constrained by two or more recent high-quality reflection seismic lines, reducing the scope of pre-drilling (largely seismic) site surveys. Drilling would target basins with the most regionally representative and complete stratigraphy, as identified from the latest studies. As such, the Lord Howe Rise is a region where the IODP could bring about a significant scientific breakthrough, as well as potential economic benefits through opening up of a large frontier region to resource exploration. IODP's Complementary Project Proposal (CPP) model would involve a third party providing at least 70% of the platform operating costs for this joint effort.

It should be noted that, although such IODP drilling would provide vital missing information for the petroleum assessment of the region, whether this will lead to petroleum exploration depends on the geology revealed through the drilling. However, without direct sampling of sedimentary rocks from the potential target sequences, which are believed to be Cretaceous or older in age, major petroleum exploration companies are unlikely to invest in large scale exploration in the region. There are currently no samples to indicate the existence of potential petroleum source, reservoir and seal rocks—a fundamental prerequisite for exploration. Resource exploration in the region will also fast-track the growth of geoscientific knowledge, as exploration companies acquire and interpret a growing body of data for their work programs. These industry-acquired data, in combination with the IODP drilling, could enable some major scientific questions regarding continental breakup, ocean basin formation and associated climatic and biospheric effects to be finally answered.

Source: Written by Dr. Takehiko (Riko) Hashimoto (Geoscience Australia)

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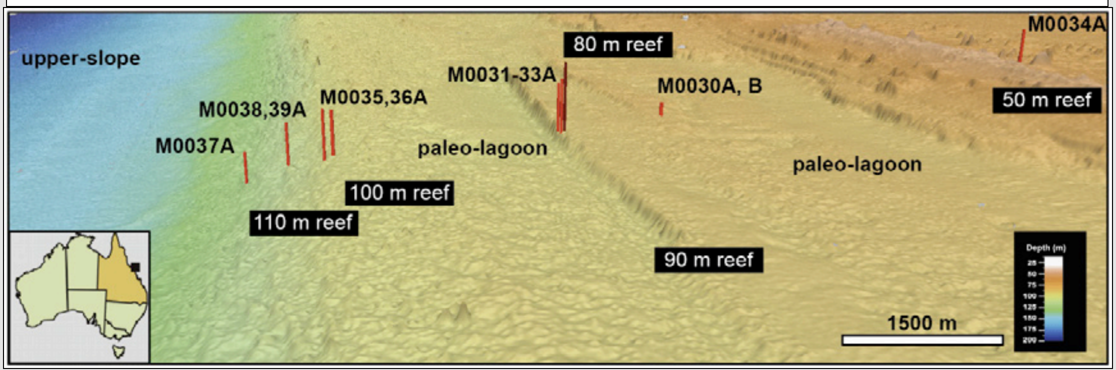
Box 6.1

UNLOCKING THE HISTORY OF REEF GROWTH AND DEMISE

- Predicting how the Great Barrier Reef (GBR) will respond to future global climate changes, and over what time frame, is crucial.
- Fossil reefs record critical data on the geomorphic and ecological consequences of both long-term and abrupt centennial-millennial scale environmental changes.
- The Integrated Ocean Drilling Program (IODP) Expedition 325 investigated a succession of submerged fossil reefs on the shelf edge of the GBR between January and April 2010. The scientific objectives were to establish the course of sea-level change and define sea-surface temperature variations, but also to analyse the impact of these environmental changes on reef growth since the Last Glacial Maximum (LGM).
- Thirty-four boreholes were cored from 17 sites along four transects at three locations (Hydrographers Passage, Noggin Pass and Ribbon Reef) in water depths between 42 and 167 m.
- Some scientific highlights from Expedition 325 include:
  - A robust new sea level curve spanning the periods from 30 to 10 ka (thousand years ago). This includes comprehensive new coverage of the crucial but poorly constrained LGM (19-23 ka), and through the post glacial sea level rise.
  - New constraints on sea surface temperatures and other oceanography parameters from 30 to10 ka.
  - A unique recording in the GBR to past environmental stresses similar to current scenarios of future climate change (i.e. changing sea-levels, SST's, water quality). The new data document a dynamic coral reef system that grew, drowned, and back-stepped repeatedly up-slope as sea level rose 130 m since the LGM.
  - A new record of upper-slope sedimentation in water shallower than 160 m that spans the last 300 ka. This will provide important new information about margin sedimentation and paleoceanographic changes over this period.
- Expedition 325 has improved our understanding of how the geometry, composition and development of the GBR responded to repeated and major environmental disturbances over the last 30 ka. This has broader management implications as modern reefs around the world face an uncertain future.

Figure 2. High-resolution multibeam image of Hydrographers Passage transect HYD-01C (multibeam data after Bridge et al., 2011; Abbey et al., submitted). The bathymetry data is gridded at 5 m, and the vertical red lines represent the positions and approximate penetration depths of sites M0030A–39A.



Source: Yokoyama, Y., Webster, J.M., Cotterill, C., Braga, J.C., Jovane, L., Mills, H., Morgan, S., Suzuki, A., Scientists, and expeditioners, 2011. IODP Expedition 325: Great Barrier Reefs reveals past sea-level, climate and environmental changes during the end of the last Ice age. Scientific Drilling 12, 32-45.

Source: Written by Dr. Jody M. Webster, IODP Expedition 325 Scientists and collaborators, Geocoastal Research Group, School of Geosciences, The University of Sydney, NSW, Australia

Box 6.2

ACCESSING REPOSITORY CORES

The cores that have been recovered by the scientific ocean drilling programs represent an immensely valuable global resource, available for further research as established analytical and imaging techniques improve, and radically new methods of investigation are developed. The cores are expertly stored and archived in three major repositories in North America, Europe, and Japan.

While every drilling leg has been staffed as far as possible with a range of experts appropriate for anticipated recoveries, it is a fact that additional investigation post-expedition is often vital. One such example originated on Ocean Drilling Program Leg 125 in 1988 to the Izu-Bonin-Mariana island arcs, that stretch southwards about 2000 km from Japan. The Leg was heavily staffed with igneous petrologists keen to examine an unusual volcanic rock called boninite, named after the type locality of Chichijima in the Bonin Islands as it was anticipated the leg would recover extensive samples of this rock type between the currently active volcanic chains and adjacent deep-sea trenches.

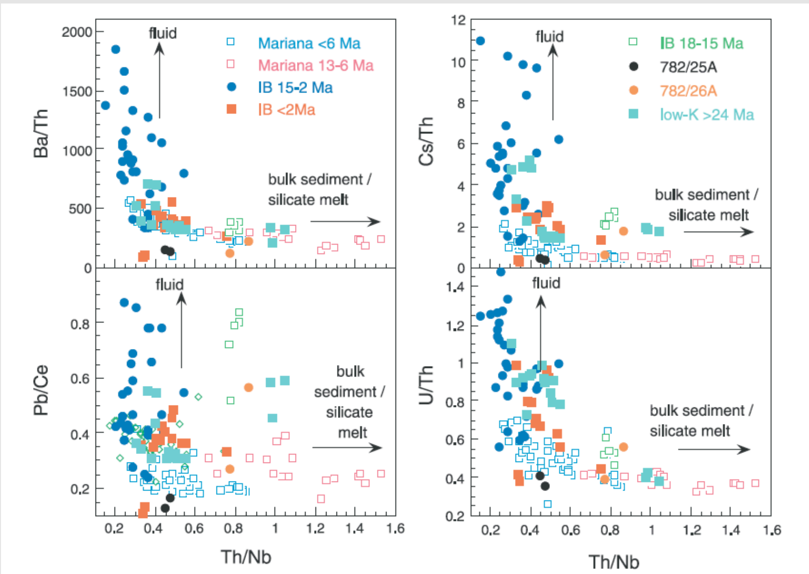
The boninites were erupted at the inception of these arcs some 50 million years ago, and have since been overlain by sediments in the forearc regions explored by our drilling expedition. At each of the drilling sites, scientists recovered cores of sedimentary material several hundred meters thick en route to the older boninite lavas forming so-called "basement". Scientists with sedimentary petrologic and paleontologic expertise were on board the ship, but were not prepared for the recovery of hundreds of volcanic ash layers derived from the adjacent volcanoes of the arcs.

These ashes comprise quenched magma fragments including glass and a variety of minerals. It was clear that scientists could reconstruct for the first time, the 50 million years of geochemical evolution of the arcs using these materials. The advent of micro-analytical (~20 to 50 μm diameter spot resolution) laser ablation inductively coupled plasma source mass spectrometry (LA-ICP-MS) made this research possible.

Post-leg 125, a scientist travelled to the North American repository to sample ash-containing cores that had been recovered during Leg 60 of the Deep Sea Drilling Project in 1978, adjacent to the Mariana Arc volcanoes. The repository provided every assistance for the sampling effort, with strict protocols and recording of position and amounts removed.

The combined Leg 60 and 125 ashes formed the research materials for two Australian PhD students, leading to several published papers in the international peer-reviewed literature. Several other groups worldwide have been pursuing similar research with the latest generation of high-resolution analytical equipment. The results have fundamentally altered our perspectives on the way plate tectonics has recycled oceanic lithosphere through subduction zone systems of the western Pacific, and has stimulated a new round of deep sea drilling in the Iu-Bonin Arc scheduled for 2014.

The figure below shows variation in ratios of critical trace element abundances, determined by LA-ICP-MS, for glass fragments in ashes recovered during deep sea drilling in the Izu-Bonin-Mariana (IB and M respectively) arcs. Samples are grouped in age ranges; of many important features, the high "melt component" derived from the subducting Pacific Plate in the 13-6 million years (Ma) of the Mariana Arc (open pink square symbols) is coincident with cessation of tectonic extension in the arc basement for that time period.



Source: C.J. Bryant et al., 2003, Geochemistry, Geophysics, Geosystems, 4, doi:10.1029/2002GC000427.

Source: Written by Professor Richard Arculus, The Australian National University

Appendix C

Australian Expeditioners

Table C.1

AUSTRALIAN EXPEDITIONERS: ODP AND IODP EXPEDITIONS (INCLUDING ECORD SCIENCE PARTIES)

Leg	Year	Description	Person	Organisation	Status	Expertise
ODP						
119*	1988	Kerguelen Plateau and Prydz Bay	Chris Jenkins	Sydney University	Lecturer	Sedimentologist
120*	1988	Central Kerguelen Plateau	Mike Coffin	Bureau Mineral Resources	Geophysics	Geophysics
120*	1988	Central Kerguelen Plateau	Patrick Quilty	Australian Antarctic Division	Senior scientist	Micropaleontology
121*	1988	Broken Ridge, Ninetyeast Ridge	Chris Klootwijik	Bureau Mineral Resources	Senior Research Scientist	Paleomagnetism
122*	1988	Exmouth Plateau	Neville Exon	Bureau Mineral Resources	Principal Research Scientist	Sedimentologist and Lead Proponent
122*	1988	Exmouth Plateau	Paul Williamson	Bureau Mineral Resources	Principal Research Scientist	Geophysics
122*	1988	Exmouth Plateau	Ron Boyd	Newcastle University	Lecturer	Sedimentologist
123*	1988	Argo Abyssal Plain	David Haig	University of Western Australia	Lecturer	Micropaleontology
123*	1989	Argo Abyssal Plain	David Heggie	Bureau Mineral Resources	Senior Research Scientist	Sedimentologist
123*	1989	Argo Abyssal Plain	Andrew McMinn	University of NSW	Lecturer	Palynology
125	1989	Bonin-Mariana Region	Richard Arculus	University of New England	Lecturer	Igneous petrology
125	1989	Bonin-Mariana Region	Greg Milner	University of Western Australia	PhD student	Micropaleontology
126	1989	Izu-Bonin Arc-Trench system	Ian Aitchison	University New England	Lecturer	Structural geologist
127	1989	Japan Sea	Kathy Stewart	University of Adelaide		Igneous petrologist
130*	1990	Ontong Java Plateau	Bob Musgrave	University of Tasmania		Paleomagnetism
133*	1990	Northeast Australia margin	Peter Davies	Bureau of Mineral Resources	Senior Research Scientist	Co-Chief Scientist: carbonate petrologist
133*	1990	Northeast Australia margin	David Feary	David Feary	Research Scientist	Sedimentologist
133*	1990	Northeast Australia margin	Chris Pigram	Chris Pigram	Senior Research Scientist	Sedimentologist

Leg	Year	Description	Person	Organisation	Status	Expertise
ODP (cont.)						
133*	1990	Northeast Australia margin	Chris Pigram	Chris Pigram	Senior Research Scientist	Sedimentologist
133*	1990	Northeast Australia margin	Phil Symonds	Phil Symonds	Senior Research Scientist	Geophysicist
134*	1990	Vanuatu	Ignacio Martinez	Australian National University		Micropaleontology
134*	1990	Vanuatu	Russell Perembo	University of Western Australia	PhD student	Micropaleontology
135*	1991	Lau Basin	George Chapronier e	Bureau of Mineral Resources	Senior Research Scientist	Micropaleontology
135*	1991	Lau Basin	Anthony Ewart	University of Queensland	Lecturer	Igneous petrologist
140	1991	Costa Rica Rift	Andrew McNeill	University of Tasmania	PhD student	Igneous petrologist
143	1992	Northwest Pacific Atolls	Peter Flood	University of New England	Lecturer	Sedimentologist
145	1992	North Pacific Transect	Barrie McKelvey	University of New England	Lecturer	Sedimentologist
147	1992	Hess Deep Rift Valley	Trevor Falloon	University of Tasmania	PhD student	Igneous petrologist
148	1993	Costa Rica Rift	Andrew McNeill	University of Tasmania		Igneous petrologist
150	1993	New Jersey Sea Level Transect	Stuart McCracken	University of Western Australia		Sedimentologist
153	1993	Mid Atlantic Ridge	Christopher Stephens	University of Queensland		Igneous petrologist
155	1994	Amazon Deep-Sea Fan	Simon Haberle	Australian National University		Palynologist
156	1994	Barbados Ridge Prism	Evan Leitch	University of Technology Sydney	Lecturer	Structural geologist
157	1994	Gran Canaria and Madeira Abyssal Plain	Richard Howe	University of Western Australia		Nannofossils
158	1994	TAG Hydrothermal Mound	Bruce Gemmell	University of Tasmania	Lecturer	Igneous petrologist
159	1995	Côte d'Ivoire Transform Margin	Samir Shafik	Australian Geological Survey Organisation	Senior Research Scientist	Nannofossils
160	1995	Mediterranean Sea	Edgar Frankel	University of Technology Sydney	Lecturer	Sedimentologist
161	1995	Mediterranean Sea II	Greg Skilbeck	University of Technology Sydney	Lecturer	Sedimentologist
163	1995	Southeast Greenland Margin	Yaoling Niu	University of Queensland		Igneous petrologist

Leg	Year	Description	Person	Organisation	Status	Expertise
ODP (cont.)						
164	1995	Blake Ridge and Caroline Rise	Bob Musgrave	La Trobe University	Lecturer	Paleomagnetism
166	1996	Bahama Transect	Alexandra Isern	University of Sydney	Lecturer	Physical properties
169	1996	Sedimented ridges: NE Pacific	Rowena Duckworth	James Cook University	Lecturer	Igneous petrologist
172	1997	NW Atlantic Sediment Drifts	Gavin Dunbar	James Cook University	Lecturer	Physical properties
173	1997	Return to Iberia	Mike Rubenach	James Cook University	Lecturer	Petrologist
176	1997	Return to Hole 735B	Yaoling Niu	University of Queensland	Lecturer	Igneous petrologist
177	1998	Southern Ocean Paleoceanogra-phy	Will Howard	Antarctic CRC	Research scientist	Sedimentologist
178*	1998	Antarctic Glacial History	James Daniels	University of Melbourne		Sedimentologist
180*	1998	Woodlark Basin	Tim Sharpe	University of Technology Sydney		Sedimentologist
181*	1998	SW Pacific Gateways	Robert Carter	James Cook University	Professor	Co-Chief Scientist: sedimentologist
181*	1998	SW Pacific Gateways	Katherine Grant	James Cook University	PhD student	
182*	1998	Great Australian Bight Carbonates	David Feary	Australian Geological Survey Organisation	Senior Research Scientist	Co-Chief Scientist: sedimentologist
182*	1998	Great Australian Bight Carbonates	Alexandra Isern	University of Sydney	Lecturer	Logging scientist
182*	1998	Great Australian Bight Carbonates	Samir Shafik	Australian Geological Survey Organisation	Senior Research Scientist	Nannofossils
182*	1998	Great Australian Bight Carbonates	Qianyu Li	University of Adelaide		Foraminifera
183*	1999	Kerguelen Plateau and Broken Ridge	Dietmar Müller	University of Sydney	Lecturer	Logging scientist
183*	1999	Kerguelen Plateau and Broken Ridge	Leah Moore	Australian National University	PhD student	Physical properties
188*	2000	Prydz Bay	Philip O'Brien	Australian Geological Survey Organisation	Senior Research Scientist	Co-Chief Scientist: sedimentologist
188*	2000	Prydz Bay	Patrick Quilty	University of Tasmania	Senior Lecturer	Foraminifera
188*	2000	Prydz Bay	Alex Kaiko	Curtin University	PhD student	Sedimentologist
189*	2000	Tasmanian Gateway	Neville Exon	Australian Geological Survey Organisation	Senior Principal Research Scientist	Co-Chief Scientist: sedimentologist

Leg	Year	Description	Person	Organisation	Status	Expertise
ODP (cont.)						
189*	2000	Tasmanian Gateway	George Chapronier e	Australian Geological Survey Organisation	Principal Research Scientist	Foraminifera
189*	2000	Tasmanian Gateway	Peter Hill	Australian Geological Survey Organisation	Research Scientist	Stratigraphic correlator
190	2000	Nankai Trough Accretionary Prism	Christopher Fergusson	University of Wollongong	Senior Lecturer	Sedimentologist
193*	2000	Manus Basin Hydrothermal System	Raymond Binns	CSIRO	Senior Principal Research Scientist	Co-Chief Scientist: ore deposit geologist
193*	2000	Manus Basin Hydrothermal System	Christopher Yeats	CSIRO	Senior Research Scientist	Sulphide petrologist
193*	2000	Manus Basin Hydrothermal System	Ian Warden	Nautilus Minerals and University NSW		Observer
194*	2001	Marion Plateau	Alexandra Isern	University of Sydney	Senior Lecturer	Co-Chief Scientist: sedimentologist
198	2001	Shatsky Rise Cretaceous climate	Tracy Frank	University of Queensland	Lecturer	Inorganic geochemist
201	2002	Microbial communities: E Equatorial Pacific	Gregory Skilbeck	University of Technology Sydney	Senior Lecturer	Physical properties
206	2002	Fast Spreading Crust (Guatemala Basin)	Rachel Sandwell	Macquarie University	Student	Undergraduate trainee
207	2003	Demerara Rise	Helen Bostock	Australian National University	PhD student	Sedimentologist
209	2003	Mid-Atlantic Ridge	Ulrich Faul	Australian National University		Petrologist
IODP						
316	2008	NanTroSEIZE 1, Nankai Trough	Christopher Fergusson	University of Wollongong	Senior Lecturer	Sedimentologist
317*	2009	Canterbury Basin Sea Level Change	Robert Carter	James Cook University	Professor	Sedimentologist
317*	2009	Canterbury Basin Sea Level Change	Simon George	Macquarie Unversity	Senior Lecturer	Geochemist
318*	2010	Wilkes Land Climate Change	Kevin Welsh	University of Queensland	Lecturer	Sedimentologist
319	2009	NanTroSEIZE 2, Nankai Trough Observatory	Gary Huftile	Queensland University of Technology	Professor	Structural Geologist
322	2009	NanTroSEIZE 2, Nankai Trough Subduction	John Moreau	University of Melbourne	Lecturer	Microbiologist
323	2009	Bering Sea oceanography	Kelsie Dadd	Macquarie University	Professor	Sedimentologist - volcanologist
324	2009	Shatsky Rise volcanic buildup	David Murphy	Queensland University of Technology	Lecturer	Igneous Petrologist

Leg	Year	Description	Person	Organisation	Status	Expertise
IODP (cont.)						
325*	2010	Great Barrier Reef Environmental Change	Tezer Esat	ANSTO and Australian National University	Senior Researcher	Paleoclimate geochemist
325*	2010	Great Barrier Reef Environmental Change	Jody Webster	University of Sydney	Lecturer	Co-Chief Scientist: carbonate sedimentologist
325*	2010	Great Barrier Reef Environmental Change	Michael Gagan	Australian National University	Senior Researcher	Paleoclimate geochemist
329*	2010	South Pacific oceanic gyre microbiology	Jill Lynch	University of Melbourne	PhD student	Microbiologist
330*	2011	Louisville Seamount Trail geodynamics	Ben Cohen	University of Queensland	Post-doctoral researcher	Igneous petrologist
330*	2011	Louisville Seamount Trail geodynamics	David Buchs	Australian National University	Post-doctoral researcher	Igneous petrologist
331	2010	Hot Deep Biosphere Okinawa Trough	Christopher Yeats	CSIRO	Principal Research Scientist	Sulphide petrology
334	2011	Costa Rica Seismogenesis Project	Gary Huftile	Queensland University of Technology	Professor	Structural Geologist
335	2011	Superfast Spreading Rate Crust 4 E Pacific	Graham Baines	Adelaide University	Lecturer	Igneous petrologist
337	2012	Coalbed Biosphere Shimokita	Rita Susaliwati	University of Queensland	PhD student	Coal geologist
338	2012	NantroSEIZE Plate Boundary Deep Riser	Lionel Esteban	CSIRO	Senior Research Scientist	Structural geologist/Sedimentologist /Physical Property Specialist
339	2011	Mediterranean Outflow	Craig Sloss	Queensland University of Technology	Lecturer	Sedimentologist
341	2013	South Alaska Margin	Maureen Davies	Australian National University	Post-doctoral researcher	Physical properties
342	2012	Paleogene Newfoundland Drifts	Brad Opdyke	Australian National University	Senior Lecturer	Sedimentologist
344	2012	Costa Rica Seismogenesis Project 2	Alan Baxter	University of New England	Lecturer	Nannofossils
345	2013	Hess Deep Plutonic Crust	Trevor Falloon	University of Tasmania	Researcher	Igneous petrologist
346	2013	Asian Monsoon Japan Sea	Stephen Gallagher	University of Melbourne	Associate Professor	Foraminifera
347	2013	Baltic Sea Paleoenvironment	Craig Sloss	Queensland University of Technology	Lecturer	Sedimentologist

* In Australasian region
Source: ANZIC IODP office

Appendix D

ARC grants for researchers making substantial use of ocean drilling material

The following table outlines recent ARC grants for researchers making substantial use of ocean drilling material, derived from information provided by the ARC Data Analysis Unit. The table does not include the LIEF funding for Australia's membership of the IODP.

The information shown is limited to that which was current at the time research proposals were approved for funding and accordingly excludes any post-award variations that may subsequently have been approved.

Funding for 2013 is not complete. A number of ARC scheme rounds are still open for proposals or under consideration for funding approval.

Project data was retrieved from the ARC database using keywords to search from Project Title, Abstract and National Benefit. Projects were not vetted for relevance to IODP.

The direct relationship between substantial use of ocean drilling material and the ARC grant was subsequently confirmed directly with grant recipients by Professor Neville Exon, ANZIC Program Scientist, ANU.

Table 6.3

RECENT ARC GRANTS FOR RESEARCHERS MAKING SUBSTANTIAL USE OF OCEAN DRILLING MATERIAL

Project ID	Lead Org.	Lead investigator	Start year	Scheme	Project title	$ Total
DP 120103980	ANU	Dr John Mavrogenes	2012	Discovery	Magnetite and metal-rich sulphides in arc magmas	135,000
DP 120104240	ANU	Prof Richard Arculus	2012	Discovery	The oxidation state of mantle-derived arc magmas	510,000
DP 1110103668	Melbourne University	Dr John Moreau	2011	Discovery	Anaerobic methane oxidation in the deep sub-seafloor microbial biosphere	150,000
DP 1094001	Sydney University	Dr Jody Webster	2010	Discovery	Integrated Ocean Drilling Program (IODP) in the Great Barrier Reef: unlocking the causes, rates and consequences of abrupt sea level and climate change	372,000
FS100100076[1]	ANU	Prof Andrew Roberts	2010	Super Science Fellowship s	Novel dating methods for marine sediments of relevance to determining past climate changes	278,400
DP 0986377	Sydney University	Prof Dietmar Müller	2009	Discovery	Planet-scale reorganizations of the plate-mantle system	300,000
DP 0987713	Sydney University	Prof Dietmar Müller	2009	Discovery	The Subduction Reference Framework: unravelling the causes of long-term sea-level changes	310,000
FL 0992245	Sydney University	Prof Dietmar Müller	2009	Australian Laureate Fellowship	The Virtual Geological Observatory: a four dimensional view into the Earth through deep-time data-mining	3,088,350
LP 0989312	Sydney University	Prof Dietmar Müller	2009	Linkage	Integrating deep-earth and surface processes for frontier-basin exploration	525,000
LE 0989731	ANU	Stephen Eggins	2009	LIEF	Instrumentation for Innovative Marine Biogeochemistry	700,000
DP 0880010	ANU	Dr Stephen Eggins	2008	Discovery	Atmospheric CO2, global temperature, and surface ocean acidity response to fossil carbon burning	313,000
DP 0773236	ANU	Dr John Mavrogenes	2007	Discovery	Magmatic processes, volatiles and ore formation	140,000
DP 0559471	Sydney University	Dr Y You	2005	Discovery	Simulating the evolution of the Southern Ocean and Australia's Palaeo-environment over 14 million years	180,000
Total						**7,001,750**

Note: 1. This grant was awarded to Prof Leslie Fifield and Prof Andrew Roberts who supervised two students. Prof Andrew Roberts supervised Alexandra Abrajevich, who used ocean drilling material. As a result half of the FS100100076 grant has been included in this table.
Source: ARC Data Analysis Unit; prepared 21/02/2013. Checked with the researchers by Professor Neville Exon in March.

Appendix E

Australian and New Zealand students involved in IODP

The following table outlines some of the Australian and New Zealand students involved in IODP. The table is not a complete list of Australian and New Zealand students, but is indicative of the range of host institutions and use of ODP and IODP material.

Table 6.4

AUSTRALIAN AND NEW ZEALAND STUDENTS WORKING ON OCEAN DRILLING MATERIAL

Student	Degree	Year	University	Supervisors	Material	Time %
Australia						
Alexandra Abrajevitch	Post-doc	2012	ANU	Andrew Roberts	ODP 120	100%
Lizzie Ingham	PhD	Started 2010	ANU	Andrew Roberts, David Heslop	ODP 181	20%
C.J Bryant	PhD	1997-1999	ANU	Richard Arculus	ODP125	100%
W. Chen	PhD	1991-1994	UNE	Richard Arculus	ODP125	100%
L. Cao	PhD	1991-1994	UNE	Richard Arculus	ODP125	100%
Sophia Bratenkov	PhD	Starting 2013	Macquarie	Simon George	IODP 317	
Amy Chen	PhD	Started 2012	Macquarie	Paul Hesse	ODP 174AX IODP 342	
Irina Romanova	Post-doc	2012	QUT	David Murphy	IODP 324	
Rita Susilawati	PhD	Started 2012	Queensland	Joan Esterle	IODP 337	
Jill Lynch	PhD	Started 2012	Melbourne	Malcolm Wallace	IODP 329	
Elizabeth Abbey	Honours	2007	JCU	Jody Webster	IODP 310	100%
Elizabeth Abbey	PhD	Completed 2012	Sydney	Jody Webster	ODP 310 & 325	70%
Robert Campbell	PhD	Completed 2003	Western Australia	D. Haig A.D. George N. Marshall J. Rexilius	ODP 122	5%
Marjorie Apthorpe	PhD	Completed 2003	Western Australia	David Haig	ODP 122	10%
Paul Massara	Honours	Completed 2010	Curtin	Lindsay Collins	ODP 122	
M.C Watson	Honours	2003	UTS		ODP Leg 201	100%

Student	Degree	Year	University	Supervisors	Material	Time %
Australia (cont.)						
Angel Puga-Bernabeu	Post-doc	2013	USYD/Univ. Granada	Jody Webster	ODP 325	20%
Tom Bridge	PhD	2012	JCU	Jody Webster	ODP 310 & 325	50%
Patrick Moss	PhD	1999	Monash	Peter Kershaw	ODP 133	90%
New Zealand						
Lueer, Vanessa	PhD	2007	Bremen	C Hollis	Leg 181, 1123, 1124	100%
Creech, John	MSc	2010	VUW	J Baker	Leg 181, 1121	10%
Bolton, Annette	PhD	2011	VUW	L Carter, G Dunbar, J Baker	Leg 181, 1123	30%
Taylor, Kyle	PhD	2011	Bristol	C Hollis	Leg 181, 1121	10%
Hutchison, Courtney	BSc project	2011	Canterbury U	G Cortese	Leg 28	30%
Duncan, Bella	MSc	2012	VUW	L Carter, G Dunbar	Leg 181, 1120	40%
Prebble, Joe	PhD	2012	VUW	L Carter, E Crouch, G Cortese	Leg 90	30%
Grant, Georgia	MSc	2012	VUW	R McKay, T Naish	Exp 318	100%
van Kerckhoven, Liesbeth	PhD	current	Auckland	K Campbell, B Hayward	Sites 689, 690, 865, 1211	100%
Patterson, Molly	PhD	current	VUW	R McKay, T Naish	Exp 318	70%
Pascher, Kristina	PhD	Starting 2013	VUW	C Hollis, G Cortese, R McKay	Exp 342 & many more	90%

Source: ANZIC IODP office based on information provided by lead researchers

Appendix F

Citation analysis and methodology

The Research Services Division of the ANU undertook a sophisticated citation analysis as part of this project. The analysis is based on matching IODP publications data between 1996 and 2011 (inclusive) with the Elsevier SCOPUS data set using publication title and publication year. This appendix outlines the data sources and methods used for the citation analysis.

SciVerse SCOPUS is the world's largest abstract and citation database of peer-reviewed literature. SCOPUS has had a particular focus on the life, social, physical and natural sciences but more recently has added the Arts and Humanities. The citation counts are based on snapshot of Scopus Data as of 25 July 2011.

F.1 Data Sources

The citation analysis is based on the following data sources:

- IODP Publication Records sourced from : http://odp.georef.org/;
- Elsevier SCOPUS data 1996 – 2011; and
- ANU Institutional Geocode Database.

F.2 Data Methods

The following steps were used in the citation analysis:

1. IODP Publication data between 1996 and 2011 (inclusive) were matched to the SCOPUS dataset [Extracted April 2012] using publication title and publication year.

2. Publication matches were manually checked for erroneous matches.

3. Citation counts from the SCOPUS dataset for each matched IODP publication were extracted.

4. Author affiliation data from the SCOPUS dataset for each matched IODP publication were extracted.

5. Affiliation ID's were matched to the ANU Institutional Geocode Database to provide Latitude and Longitude coordinates for each author.

6. Figures were produced showing the collaboration network from the data obtained from the process detailed in steps 1-5.

7. Excel Data Tables were produced from the data obtained from the process above.

In addition, Drill sites were extracted from the FULL IODP dataset 1968 - 2012.

Not all IODP publications in the period 1996 - 2011 were successfully matched to SCOPUS. The total number of IODP publications between 1996 and 2011 was 12,902, of these a total of 4,480 were matched to the SCOPUS database. The IODP database includes refereed journal publications, books, book chapters, conference proceedings and PhD theses.

The SCOPUS database provides good coverage of journals, and to a lesser degree conference proceedings, with poor coverage of books, book chapters and no coverage of PhD theses.

Of the 8,422 IODP publications that were unsuccessfully matched to SCOPUS:

- 2,538 were PhD Theses;
- 223 were meetings;
- 33 were IODP Preliminary Reports;
- 462 were IODP Initial Reports;
- 465 were Conference Proceedings;
- 821 were IODP special scientific results;
- 93 were technical reports;
- 1267 were Journal supplements and special publications;
- 182 were books;
- 237 were Abstracts with Programs;
- 119 were IODP Scientific Prospectus; and
- 160 were Geophysics Research Abstracts.

The remaining 1,733 unmatched publications were a mix of specialised journals, newsletters and publications that were unable to be matched to a SCOPUS record. It is noted that this will introduce some uncertainty in the citation analysis.

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