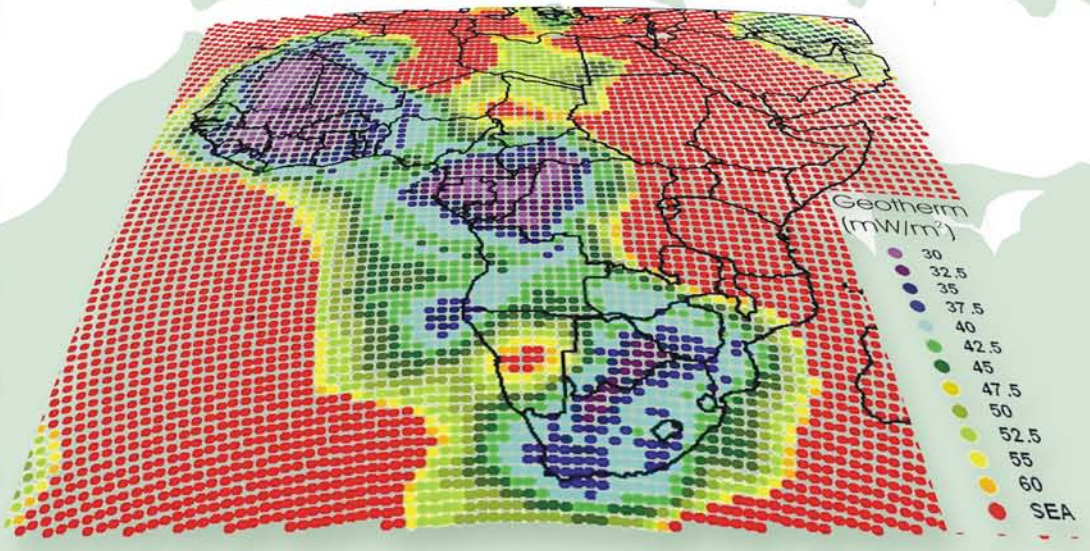
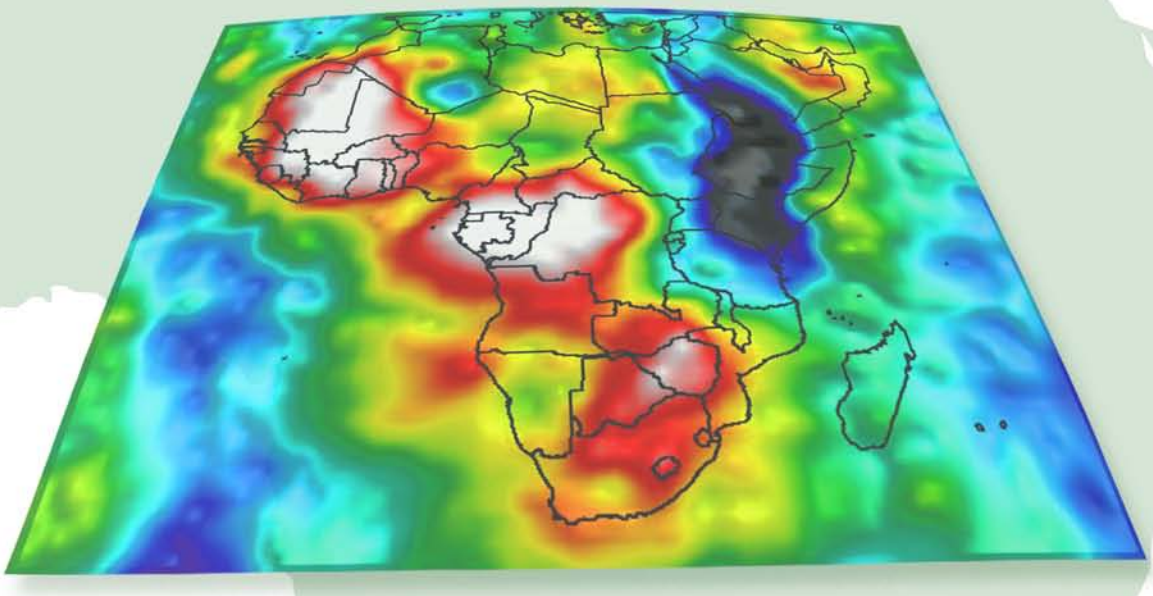




GEMOC

2005 Annual Report

ARC National Key Centre for the Geochemical Evolution and Metallogeny of Continents

MACQUARIE
UNIVERSITY~SYDNEY

- GEMOC information is accessible on WWW at: http://www.es.mq.edu.au/GEMOC/
- Contact GEMOC via email at: gemoc@mq.edu.au

Contents

GEMOC's development of methods for the inversion of seismic tomography to constrain both mantle composition and geotherms was a major advance in 2005, done in collaboration with WMC Resources. See Research Highlights (page 30), and GEMOC publication #423.

Established and supported under the Australian Research Council's Research Centres Program

Director's Preface

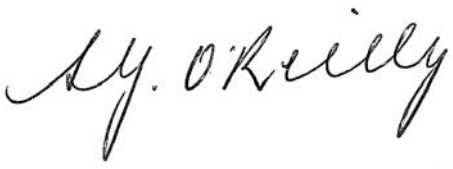
THIS REPORT summarises GEMOC's 2005 activities including research, technology development, strategic applications and industry interaction, international links and teaching (at both undergraduate and postgraduate levels). The report is required as part of GEMOC's formal annual accounting to the Australian Research Council (ARC). The ARC acknowledges GEMOC as a continuing ARC National Key Centre while GEMOC attracts sufficient income to fund its activities and achieve its annual goals, and submits an Annual Report fulfilling ARC reporting requirements.

This is the second year of a fully electronic GEMOC Annual Report available from our website (www.es.mq.edu.au/GEMOC/) as a downloadable pdf file or in html format and by mail as a CD. We have had a mixed reception to this fully digital delivery, but the costs of hard copy production are very high and we prefer to direct those resources to research support. Later this year we will have a consolidated version of all GEMOC's Research Highlights over 10 years collected together in digital form, as for the Annual Report, and we will notify you when this can be downloaded from our website.

GEMOC's second Federation Fellow, Professor Bernard Wood arrived in mid 2005 and has now set up a fully operational high-pressure experimental laboratory. This provided new and complementary resources for the Geochemical Analysis Unit in GEMOC which in many ways is the "power station" of most of GEMOC's research programs. The array of high technology instrumentation and clean laboratories (see the section on *Technology Development*) provides a wide range of geochemical (especially *in situ*) analytical capabilities. As well as serving GEMOC researchers, it hosts collaborative partner researchers from most national universities and a wide range of international research visitors.

GEMOC continues to attract a healthy annual income diversified across government competitive schemes such as the Australian Research Council, collaborative projects with partners from the mineral exploration industry (an increasing income stream), value-added consulting (for the mineral exploration industry and relevant technology development industry), strategic alliances with technology and instrument manufacturers, commercialisation ventures (such as marketing of GLITTER software with New Wave Research), and international links and alliances that provide reciprocal resources. Macquarie University has also provided significant support.

As this Report is being finalised, Macquarie's new Vice-Chancellor, Professor Steven Schwartz, has announced that GEMOC is one of five CORES (Concentrations of Research Excellence) at Macquarie University and will be allocated a significant number of new academic positions over the next year, related to our new strategic plan of research being formulated as "Earth and Planetary Evolution". 2006 promises to be the start of an exciting new phase of GEMOC.



GEMOC

http://www.es.mq.edu.au/GEMOC/

Introducing GEMOC




GEMOC'S STRATEGIC FOCUS

THE MAIN TARGETS of GEMOC's *original* activities addressed large-scale problems related to lithosphere evolution and understanding the relevance of different types of crust-mantle domains to area selection for mineral exploration. These have broadened since 2002 to involve whole-mantle perspectives of geodynamics, and far-field and feedback effects on the lithosphere that shape Earth's crust on which we live. New ways of measuring the timing of Earth processes are encapsulating the fourth dimension with increasing clarity for crust, mantle and magmatic events. New capabilities in high-pressure experimental work are simulating deep Earth conditions, another complementary perspective to probing the early history and evolution of Earth's core, mantle and crust and illuminating planetary analogues.

Industry collaboration has increased with funded large-scale projects related to lithosphere evolution and crustal generation studies, delivering new tools and a new framework of terrane analysis to the mineral exploration industry. In addition, new projects dealing with magma-related Ni deposits, plume magmatism and PGE deposits, and diamond exploration, capitalise on our depth of intellectual property about deep Earth processes from the lithosphere to the core.

Mission

- **to define the processes driving Earth's internal dynamics, and understand how these have generated the present chemical and physical structure of our planet through time, integrating petrological, geochemical and geophysical information**
- **to deliver new concepts about the spatial and temporal distribution of Earth resources to the mineral and energy industries and the next generation of students**

This Mission Statement has evolved since GEMOC commenced in 1995, to reflect the evolution of GEMOC's activities to consider Earth Geodynamics beyond the Lithosphere. Current projects are extending our horizons further to planetary composition and dynamics.

GEMOC'S CONTEXT

A SHORT HISTORY OF GEMOC: The National Key Centre for the Geochemical Evolution and Metallogeny of Continents (GEMOC) formally commenced in January 1996 and was funded under the ARC Key Centre scheme for 6 years. Under the government regulations for this round of Key Centres, there was no provision for extension of Centre funding beyond the original six-year term. A detailed business plan was required in the application to demonstrate how the Centre could continue and maintain its identity after the Commonwealth funding term. This business plan has succeeded and the evolved GEMOC started its new phase in 2002 with an independent well-funded base for the next five years.

GEMOC'S FUNDING BASE FROM 2002: This funding, like a good investment portfolio, has a healthy, risk-minimising diversity ranging across competitive traditional schemes such as those available from the Australian Research Council, to substantial industry collaborative projects. It also includes provision of value-added products to the mineral exploration industry (see the section on *Industry Interaction*) and one-off opportunities such as the competitive DEST Systemic Infrastructure Initiative in 2002 that granted over $5 million to enable GEMOC's Technology Development Program to stay at the forefront (see the section on *Technology Development*).

GEMOC'S LINKAGES AND ALLIANCES: GEMOC has significantly evolved and expanded from its original base with shifts in the original linkages and expansion in collaborations. Strong new national and international collaborative research links and programs have emerged and robust ongoing engagement with industry (mineral exploration and technology manufacturing) partners through collaborative projects has fulfilled one of GEMOC's original goals.

GEMOC's distinctiveness lies in its interdisciplinary and integrated approach to understanding how the Earth works.

SCIENTIFIC PHILOSOPHY

GEMOC's distinctiveness lies in its interdisciplinary and integrated approach to interpreting Earth's lithosphere as a 4-dimensional dynamic system (in space and time).

This approach links...

petrology and geochemistry

experimental petrology

geophysics

petrophysics

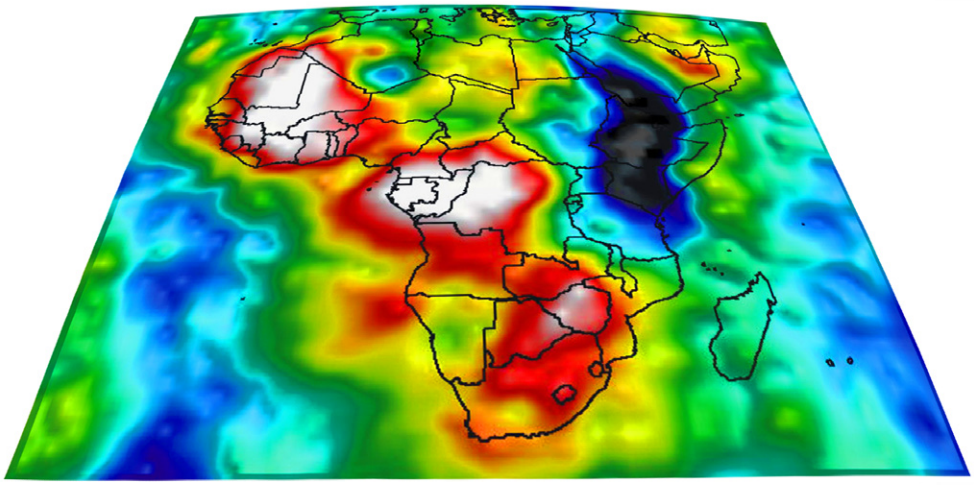
tectonics

numerical and dynamical modelling

within the important contexts of...

time (the 4th dimension) and thermal state

to understand how Earth's core-mantle system controls crustal tectonics, and the assembly and destruction of continents through time.



See Research Highlights (page 30).

STRATEGIC OUTCOMES

Our strategic goal is an integrated understanding of the evolution of the Earth and other planets. In achieving this we will deliver:

- improved understanding of the composition and structure of the Earth from the mantle to the core and the dynamics of the Earth system
- insights to planetary formation, evolution, composition and dynamics from Earth-based analogues
- fundamental insights into the processes that create and modify the continental mantle and crust and the timing and time-scales of these processes
- a better understanding of the assembly of the Australian continent and its geological architecture through work in Australia and global analogues
- results and concepts exportable to other terrains, both globally and to other potentially resource-rich areas of interest to Australian exploration companies
- an improved global framework for understanding the localisation of economic deposits
- a realistic 3-D geological framework for the interpretation of lithospheric-scale geophysical datasets
- a training program for senior undergraduate and postgraduate students (and continuing education) that will help maintain the technological edge of the Australian mineral industry and improve the industry's ability to rapidly assimilate new concepts and methodologies
- new analytical strategies for determining the chemical and isotopic compositions of geological materials (including fluids) and the timing of Earth processes and events
- new experimental petrology approaches to probing the nature of the deep Earth (core and lower mantle)
- development of *in situ* analytical methods (including dating) to maximise information encoded in mineral zoning and to enhance interpretation of data using spatial contexts
- strategic and collaborative alliances with technology manufacturers in design and application innovation

This report documents achievement of these goals

GEMOC participants

THE HOST INSTITUTION for GEMOC is Macquarie University (in the Department of Earth and Planetary Sciences).

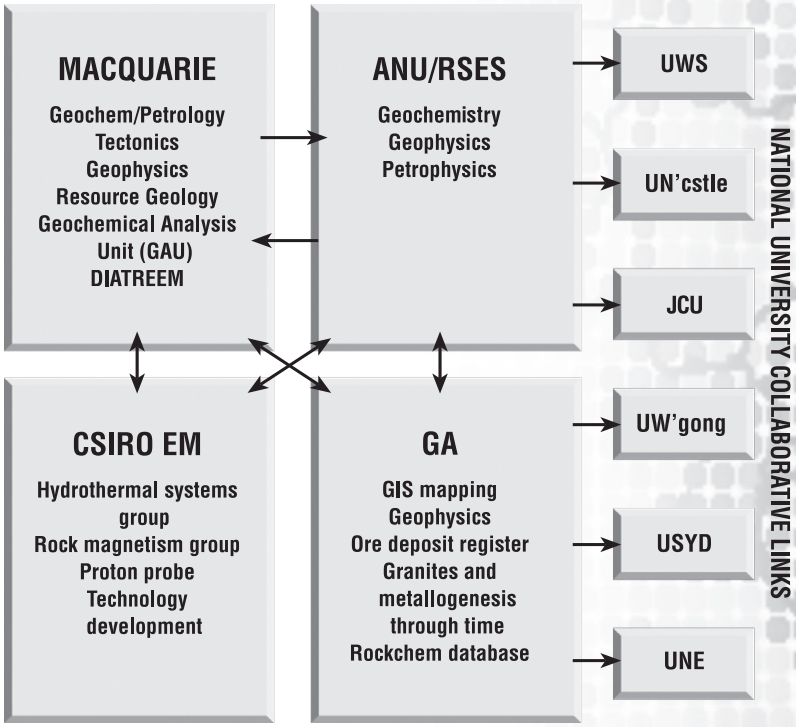
There is close collaboration with state Geological Surveys, GA (Geoscience Australia), CSIRO, ANU/RSES and several major industry concerns, across an increasingly broad range of projects.

Collaborative research, teaching and technology development links have been established with other universities nationally and internationally and these evolve as new alliances become relevant to new directions.

GEMOC has developed ongoing collaborative relationships with national and international industry and end-users such as Geological Surveys globally (eg some Australian states, Canada, Norway).

GEMOC has a wide network of international research and teaching development partners and collaborators.

A full list of GEMOC participants and their affiliations is given in Appendices 1 and 3 and at www.es.mq.edu.au/ GEMOC/



CHANGES IN 2005

Professor Bernard Wood commenced as a Federation Fellow. The project ("Origin and evolution of the Earth's chemical reservoirs") aims to understand the processes by which the Earth separated into its chemically distinct layers (core, mantle, crust, atmosphere, oceans) and to determine the nature of the continuing interactions between the surface environment in which we live and the deep interior. Experimental study of these processes involves establishment of a world-class facility for materials synthesis at high pressures and temperatures. This facility provides the means to simulate the processes occurring within the Earth and enables synthesis of new high-density materials of technological interest. This is only the second Federation Fellowship to be awarded in the Geosciences: the other one was to Professor Simon Turner, also in GEMOC in the Department of Earth and Planetary Sciences. Professor Wood has already established a world-class high-pressure experimental laboratory that includes a multi-anvil apparatus to generate pressures to 27 GPa.

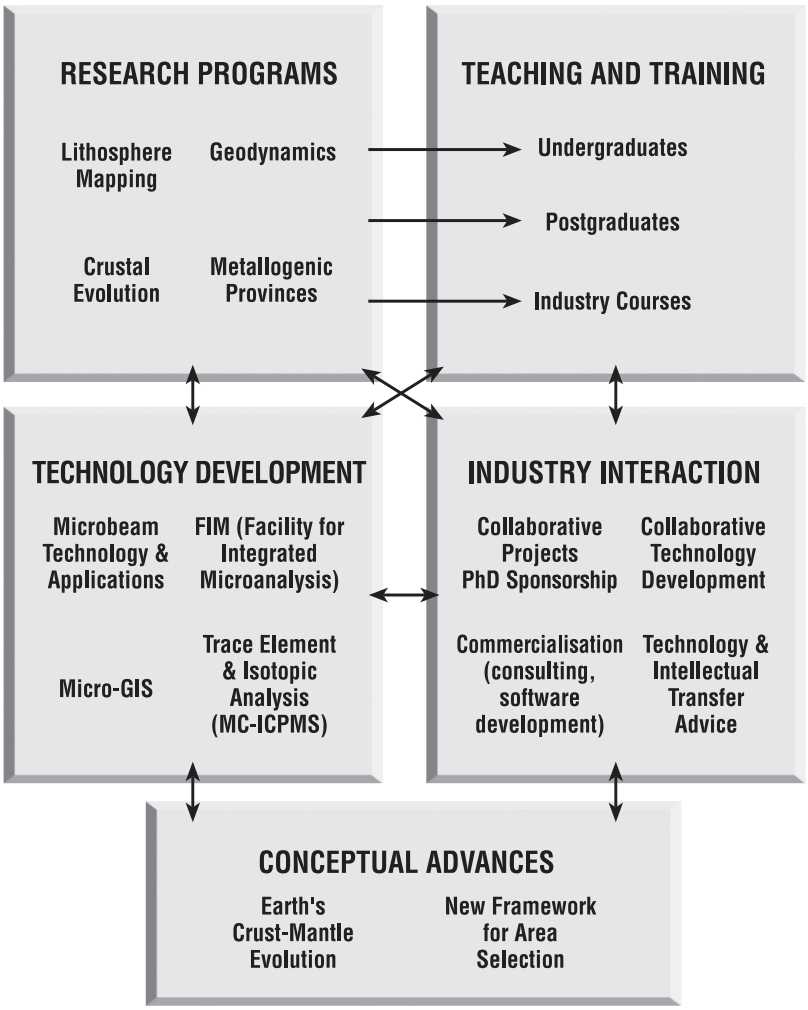
Dr Helen Williams commenced as the GEMOC-Nu Instruments Postdoctoral Fellow with funding from Nu Instruments to investigate isotopic systems relevant to the evolution and composition of the Earth, using both conventional and *in situ* analytical techniques. The initial project involved further development of the methodology for measuring iron isotopes followed by their application to unravelling mantle processes such as the evolution of oxygen in the mantle (and how this is linked to the development of the Earth's atmosphere). This complements the Mg-isotopic studies on mantle rocks and provides a new tracer for mantle metasomatic processes and fluid sources.

Dr Sune Nielsen commenced a Postdoctoral Fellowship with funding from the Danish National Science Foundation and was subsequently awarded an ARC APD. His project addresses the recycling of crustal material back into the mantle at subduction zones. This is one of the most fundamental Earth processes, but its effect on the evolution of the geochemistry of the mantle, and the ultimate fate of the subducted material, are poorly understood. This project will use the stable isotope geochemistry of thallium as a novel and sensitive tracer to follow subducted oceanic crust through the subduction process, and test for its reappearance in hot-spot volcanoes and the continental lithosphere. This project will transfer to Australia an advanced new methodology: the characterisation of thallium isotopic signatures in the mantle system during recycling of crustal material. This will allow the tracking of fluid processes in the mantle system in a completely new way and will provide significant new information about the fluids that can percolate up from subduction zones.

Dr Craig O'Neill was awarded a Macquarie University Research Fellowship for three years commencing 2006. His project will use quantitative numerical modelling to evaluate the links between episodes of intense mantle convection and the production of the continental crust that we live on. These models will assess the degree of melt production and crustal generation resulting from different styles of episodic mantle convection, and will determine which types of mantle evolution through time could produce the age distribution observed in the continental crust worldwide. The research addresses a critical shortcoming in our understanding of the formation and evolution of continents, with important implications for the distribution of major mineral and energy resources.

GEMOC programs

GEMOC'S PROGRAMS are set up to be interactive. Basic research strands are supported by parallel applied collaborative research with industry partners: these provide the impetus for technology development. This is, in turn, supported by strategic alliances with front-line instrument designers and manufacturers (eg Nu Instruments, Agilent Technologies, New Wave Research). Teaching and training benefit directly from these new advances. Technology development has been transferred to relevant end-users, applied in postgraduate research programs, and is the essential core that provides the data underpinning the conceptual advances about lithosphere architecture and evolution in GEMOC.



GEMOC structure

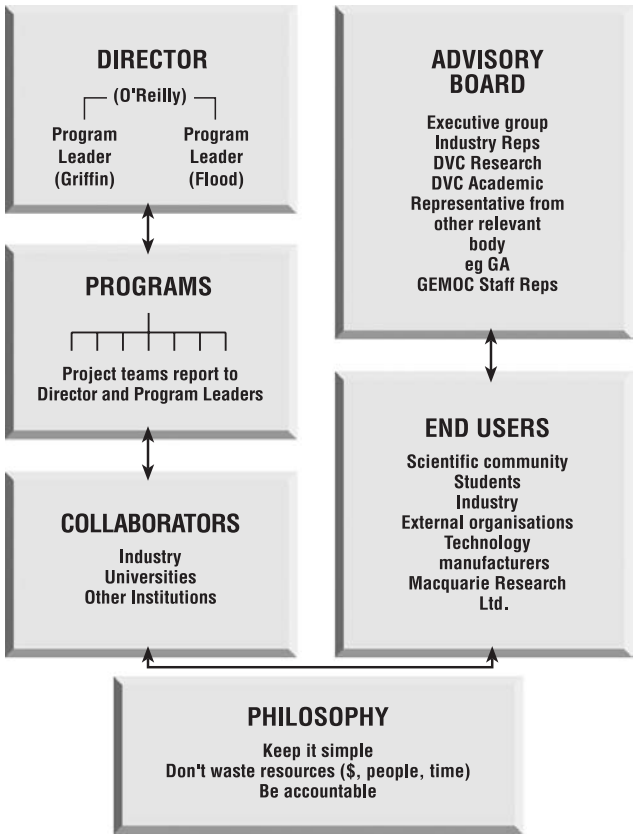
THE ORGANISATIONAL STRUCTURE of GEMOC is designed for efficiency, flexibility and interaction. The financial management operates within Macquarie University's Finance System and within AccessMQ for commercialised products, consulting and some strategic collaborative research projects. The Teaching Program is incorporated into the teaching activities and strategies of the Department of Earth and Planetary Sciences at Macquarie to ensure that GEMOC interfaces in a positive way with the existing structures while retaining a clear identity and funding unit.

GEMOC has been reconfirmed as a Centre of Excellence and research concentration within Macquarie University, and three designated Areas of Excellence within Macquarie University's Research and Research Teaching Management Plan lie within GEMOC:

- lithosphere and planetary evolution and metallogeny
- isotopic and global geochemistry
- paleomagnetism, geodynamics and geophysical modelling

All of these align with GEMOC's mainstream foci. This University recognition allows for ongoing appropriate staffing and support arrangements.

MANAGEMENT STRUCTURE



2005 MANAGEMENT ROLES

Professor Suzanne O'Reilly is Director of GEMOC.

Ms Nikki Bohan is GEMOC Administrator.

Dr Richard Flood is the coordinator of Teaching Programs at Macquarie and Head of the Department of Earth and Planetary Sciences from December 1999.

Professor William Griffin is Adjunct Professor at Macquarie University and is the Program Leader responsible for Technology Development and Industry Interaction.

Professor Bernard Wood leads experimental petrology programs.

Professor Simon Turner leads the U-Series Geochemical Program.

Dr Norman Pearson is Manager of the Geochemical Analysis Unit at Macquarie.

Dr Kelsie Dadd is responsible for implementation of GIS-based teaching methodology in the Teaching Program and for promotional activities to attract students.

Dr Simon Jackson assists with ICPMS and laser microprobe development at Macquarie.

Ms Sally-Ann Hodgekiss is the GEMOC graphics and design consultant at Macquarie.

ADVISORY BOARD MEMBERS (2005)

Board Members at Macquarie

Professor Suzanne O'Reilly (Director) – *EPS Macquarie*

Professor William Griffin (Program Leader: Technology Development) – *EPS Macquarie*

Dr Richard Flood (Program Leader: Teaching) – *EPS Macquarie*

Professor Jim Piper – Deputy Vice-Chancellor (Research), *Macquarie*

Professor John Loxton – Deputy Vice-Chancellor (Academic), *Macquarie*

Dr Kelsie Dadd – *GEMOC, EPS Macquarie*

Federation Fellows Professors Bernard Wood and Simon Turner *and*

GAU Manager Dr Norman Pearson are ex officio members

External Board Members

Adjunct Professor Michael Etheridge – Leader, Risk Assessment Group, interfaces with GEMOC's Tectonic Research program and the Predictive Mineral CRC, links with the Exploration Industry and Management Roles, *EPS Macquarie*

Dr Russell Korsch – *representative of Geoscience Australia (GA)*

Dr Richard Glen – *representative of Geological Survey of New South Wales*

Dr Paul Heitherseay – *representative of PIRSA*

Dr Jon Hronsky – *industry member BHP-Billiton (Perth)*

Dr Steve Walters – *industry member GeoDiscovery*

Dr Simon Shee – *industry member DeBeers Australia Exploration Ltd*

GEMOC communications 2005




GEMOC WEB RESOURCES provide past Annual Reports, updated details on methods for new analytical advances and software updates (GLITTER), activities of research teams within GEMOC, synthesised summaries of selected research outcomes and items for secondary school resources. In addition, undergraduate teaching is web-based. Annual Reports from 2003 are available as downloadable pdf files on the GEMOC website as well as in html format. All previous Annual Reports are available in html format.

The Terranechron® team accepts the Macquarie Innovations Award for 2005.

"Annual Reports from 2003 are available as downloadable pdf files on the GEMOC website as well as in html format. All previous Annual Reports are available in html format."

AWARD

GEMOC teams were finalists in three categories of the Macquarie Innovations Awards for 2005: *Innovation in Research* (*Terranechron®*), *Commercial Innovation* (the GLITTER Data Reduction Software System), and *Postgraduate Innovation* (Diamond Fingerprinting). *Terranechron®* won the Innovation in Research Award and the trophy now watches over the *Terranechron®* Team in the LAM-ICPMS laboratory.

PARTICIPATION IN WORKSHOPS, CONFERENCES AND INTERNATIONAL MEETINGS IN 2005 (AND BEYOND)

GEMOC staff and postgraduates increased their profile at peak metallogenic, geodynamic and geochemical conferences as convenors or invited speakers, or presenters, with more than 50 presentations. International fora included: the GACMAC Meeting (Halifax, Canada), the 15th V. M. Goldschmidt Conference (Idaho), the AGU 2005 Joint Assembly (New Orleans), AOGS Asia Oceania Geosciences Society 2nd Annual Meeting (Singapore), the IUGS-SECE International Workshop on the Subcontinental Lithosphere (Beijing), 8TH Biennial SGA Meeting on Mineral Deposit Research: Meeting the Global Challenge (Beijing), and the American Geophysical Union Fall Meeting (San Franscisco). A full list of abstract titles for Conferences and Workshops attended is given in *Appendix 4* and on the GEMOC website where full-text versions of most of the abstracts can also be found.

Professor Simon Turner continued to lead the organisation of the 2006 International Goldschmidt Conference to be held in Melbourne (see *Appendices 8 and 9*).

Professor Sue O'Reilly gave a Keynote talk at the SGA Meeting on Mineral Deposit Research: Meeting the Global Challenge (Beijing) and an invited talk at the IUGS-SECE International Workshop on the Subcontinental Lithosphere (Beijing).

Professor Bill Griffin gave invited talks at the IUGS-SECE International Workshop on the Subcontinental Lithosphere (Beijing) and the SGA Meeting on Mineral Deposit Research: Meeting the Global Challenge (Beijing).

Dr Norman Pearson co-convened a session at the 2nd European Geosciences Union Meeting, Vienna, April 2005 (VGMP Symposium 20 "MC-ICP-MS and the understanding of mantle structure") and a session at the 15th Goldschmidt Conference, Moscow, Idaho, May 2005 (SS41 "Isotopic ratio measurement using microbeam methods: Where do we stand and where are we going?").

Dr Norman Pearson gave a Keynote talk at the European Geoscience Union Meeting in Vienna and invited talks at the 15th Annual Goldschmidt Conference.

Dr Sonja Aulbach presented an invited talk at the 15th Annual Goldschmidt Conference in Moscow (Idaho, USA).

Dr Simon Jackson and Ms Suzy Elhlou gave an invited demonstration on laser-ablation techniques for ICPMS at the 2005 Agilent ICP-MS User Group Meeting in Adelaide.

GEMOC participants enjoying pre-Award drinks at the Innovation Awards.

Professor Sue O'Reilly continued as a member of the organising committee for the International Geological Congress (IGC) to be held in Brisbane in 2012 after the successful bid by Australia at the 32nd IGC in Florence (by the Australian Bid Committee of which she was a member).

Professor Bill Griffin is a member of the program committee for the Goldschmidt Conference to be held in Melbourne in August 2006.

A conference on "Sheared Magmas in Nature and Experiment" was organised in honour of Professor Ron Vernon at Kloster Seeon, Bavaria.

Professor Bernie Wood gave an invited talk at the Fall American Geophysical Union Meeting in December 2005 - "Kelvin revisited: cooling and core formation after the giant impact."

VISITORS

GEMOC fosters links nationally and internationally through visits of collaborators to undertake defined short-term projects or short-term visits to give lectures and seminar sessions. Formal collaborative arrangements are facilitated by ARC Linkage grants with reciprocal funding from international collaborators.

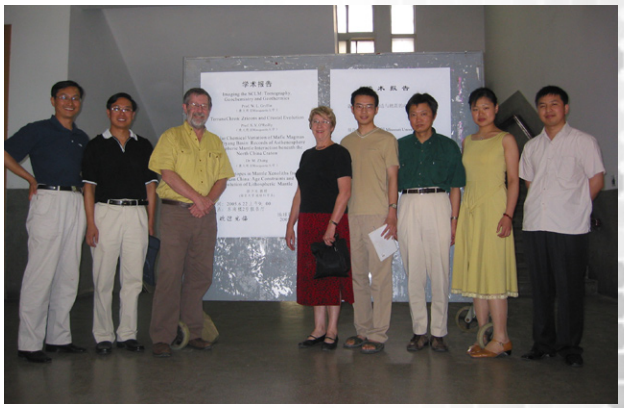
All Australian and international visitors are listed in *Appendix 3*.
They have participated in:

collaborative research

technology exchange

seminars, discussions and joint publications

collaboration in postgraduate programs



Bill Griffin, Sue O'Reilly and Ming Zhang with Nanjing University Colleagues in front of their lecture announcement.

Is GEMOC making a difference?

> "Tools are now developed to address long-standing fundamental questions about Earth's geological evolution and to inform area selection in exploration"

RESEARCH EXAMPLES:

- Unique methodology for geochemical imaging of the lithosphere (4-D Lithosphere Mapping) developed to maturity and now being extended to whole-mantle perspectives. This has given a new understanding of lithosphere formation mechanisms and changes through time, and has delivered new concepts for exploration targeting to the mineral exploration industry
- Unique methodologies developed for dating mantle formation events (from 4.6 billion years ago) and times of overprinting tectonic events (Re-Os *in situ* dating of mantle sulfides and *TerraneChron*® using zircon geochemical fingerprints)
- Two Federation Fellows in Geoscience attracted to Australia
- Establishment of world-class U-series isotope facility
- Revitalisation of high-pressure experimental petrology in Australia and establishment of new world-class facility

❄ *Unique methods for testing mantle and crust coupling over Earth history have emerged – and these are also keys to new exploration methods*

HIGHLIGHTS OF TECHNOLOGY DEVELOPMENT OUTCOMES:

- Focus on *in situ* analysis of important elements to parts per billion
- Unique method (*in situ* Re-Os) to date mantle events
- Unique method to track crustal histories (U-Pb dating and Lu-Hf and trace-element fingerprinting of zircons, rutiles): ***TerraneChron***®
- Delivery of rapid, cost-effective and user-friendly new methodologies and software in geochemical analysis (eg GLITTER)
- Establishing the rates of geological processes both for the deep Earth and for surface processes using Uranium decay series dating

❄ *Unique geochemical analysis infrastructure built up over last decade (see Technology Development section).*

❄ *Tools are now developed to address long-standing fundamental questions about Earth's geological evolution and to inform area selection in exploration*

HIGHLIGHTS OF TEACHING OUTCOMES:

- Industry-standard training with development of new degree programs (eg Environmental Geoscience, Marine Geoscience)
- Hands-on undergraduate training in use of state-of-the-art techniques (GIS databases, imaging, geochemical techniques, geophysical measurements) with industry-standard instrumentation
- Vigorous postgraduate group with active international postgraduate exchange programs: (eg China, France, Norway, Italy)
- Short-course programs for end-user information and technology exchange

HIGHLIGHTS OF INDUSTRY INTERACTION OUTCOMES:

- Changing the mineral exploration paradigm by delivering new concepts for exploration globally and in Australia derived from basic research and technology development
- Development of active partnerships in strategic and applied research with industry (exploration companies and technology manufacturers)
- Funded industry initiatives (eg GEMOC-Nu Instruments 3-year Fellowship - see *Industry Interaction*)
- Development of value-added consultancies and collaborative research programs using GEMOC's geochemical technologies and database

GEMOC's research program

GEMOC aims to achieve an integrated understanding of the evolution of the Earth and other planets

The research aims

- to understand how Earth's core-mantle system controls crustal tectonics, and the assembly and destruction of continents through time
- to map the spatial and temporal distribution of elements, rock types and physical and chemical conditions within this system
- to constrain the processes responsible for the evolution of Earth's chemical reservoirs
- to define the systematics of element redistribution in the mantle and crust during the critical liquid-crystal and vapour-liquid separation events
- to quantify the transport of crustal material into the deep Earth, and its ultimate contribution to mantle plumes and the subcontinental lithosphere
- to advance the modelling of the crust and lithospheric mantle from geophysical datasets, through integration of geophysical, petrological and geochemical information
- to understand from the "bottom-up" the processes that control the generation and modification of the crust-mantle system and to define the tectonic and geochemical processes that have created different crustal and mantle domains through time
- to produce and interpret maps of lithosphere thickness and lithospheric mantle type at the present day and for selected time (and location) slices through Earth's geological evolution
- to produce and interpret chemical tomography sections of lithospheric mantle in time and space where global datasets can be constructed
- to provide a new framework for area selection for a wide spectrum of economic deposits, by linking these models and processes to the formation of metallogenic provinces
- to define the timing of events and processes in the crust and mantle to understand crust-mantle linkages
- to develop collaborative links with international institutions and researchers relevant to GEMOC's goals

SCIENTIFIC CONTEXT

THERMAL ENERGY transmitted from the deep Earth (core and convecting mantle) provides the energy to drive lithosphere-scale processes. Mantle-derived fluids and the tectonic environment control element transfer across the crust-mantle boundary and control commodity distribution in the accessible crust. The nature of mantle heat transmission reveals information on fundamental deep Earth processes from the core-mantle boundary to the surface. The Earth's lithosphere can be mapped for rock types and their relationships using fragments of deep materials such as mantle rocks and diamonds, and the compositions of mantle-derived magmas. Timescales can be unravelled from billions of years to tens of years.

What drives the heat engine that powers the Earth's magnetic field and drives mantle convection? We do not clearly understand this, because we do not know the contents of heat-producing radioactive elements (K, U, Th) in the lower mantle and the core, and how these may have changed with Earth's evolution. Experimental

studies of Earth materials at extreme conditions will provide new constraints for modelling of the mantle and the evolution of the early Earth.

The focus of GEMOC's research programs is the driving role of the convecting mantle in Earth processes and its control of element concentration and distribution in the accessible crust. This bottom-up approach involves:

- Understanding Earth's internal dynamics and the generation of the present chemical and physical structure of our planet through time
- Understanding the location of different types of metallogenic provinces by defining the links between:
  - mantle evolution, type and processes
  - crustal generation
  - large-scale tectonics
  - heat, fluid and element transport
- Integration of information across disciplines, especially petrology, geochemistry, geodynamics, geophysics and tectonics

RESEARCH PROGRAM

The *Research Highlights* section gives an overview of major progress in 2005.

The Research Program for 2006 follows the topics of the funded projects listed in *Appendix 5*. Summaries of funded basic research projects are listed below and some of the collaborative industry research projects are summarised in the section on *Industry Interaction*.

The research program for the first six years focused on four strands: the current Research Program is pushing into new conceptual and technology frontiers, building on our intellectual capital from the first phase of GEMOC.

• Mantle Dynamics and Composition

will form the framework for advancing our knowledge of Earth's geochemical and physical evolution. The thermal output driving Earth's "engine" has declined exponentially through time, and the distribution of heat sources must have changed with the geochemical evolution of Earth. How has this secular cooling of Earth affected the internal driving forces, and what does this imply about changes in Earth dynamics through time? When did subduction processes begin? Novel approaches using redox-sensitive metal-isotope systems will be used to examine changes in the mantle's oxidation state, potentially linked to the initiation of subduction. Modelling of Earth's thermal history, incorporating information about the present and past distribution of heat-producing elements and processes will be used to test conceptual models for Earth's internal dynamics through time. High-pressure experimental approaches will advance our understanding of deep Earth structure and properties.

Lithosphere Mapping provides the fundamental data for defining lithospheric mantle domains in terms of composition, structure and thermal state. Lithosphere profiles

"Modelling of Earth's thermal history, incorporating information about the present and past distribution of heat-producing elements and processes will be used to test conceptual models for Earth's internal dynamics through time."

built up by this information are interpreted in the context of geophysical datasets (especially seismic tomography) to extrapolate laterally. Relating lithospheric domains to refined models of tectonic evolution will help to define the large-scale evolution of mantle processes through time, and their influence on the development of the crust and metallogenic provinces. The nature of mantle fluids and the mantle residence and abundances of siderophile, chalcophile and noble elements, sulfur, carbon, oxygen and nitrogen and timescales of magmatic processes are keys to understanding the transfer of mineralising elements into the crust.

- **Geodynamics**

uses stratigraphic, tectonic, and geophysical data to interpret the history and causes of continental assembly and disruption, with a special focus on Australia, East Asia and major cratons (Siberia, Africa, Canada, South America, India). It provides the fundamental framework to link the research on crustal and mantle processes with the localisation and development of metallogenic provinces. Numerical Modelling is a new direction and is being used to test a range of different Earth models.

- **Crustal Generation Processes**

seeks to understand the large-scale processes that have created and modified continental crust, how these processes may have changed through time, and how crustal processes influence the concentration and localisation of economically important elements. The role of crust-mantle interaction in granite genesis, coupled crust-mantle formation and its influence on tectonism, and transport of elements across the crust-mantle boundary link to the Mantle Dynamics and Composition and Metallogenesis strands.

- **Metallogenic Provinces**

seeks to define the mantle and crustal reservoirs of economically important elements, the mechanisms by which elements can be extracted from the mantle and transported into the crust, and the mechanisms of fluid transfer in the crust and mantle. The emphasis is on understanding processes of regional scale, and relating these processes to the tectonic framework and the processes of mantle and crustal generation.

RESEARCH PROJECTS FEEDING MAJOR PROGRAMS

Mantle Dynamics and Composition

Lithosphere mapping: Geochemical structure and evolution of continental lithosphere and interpretation of geophysical data Research Highlights

U-series applications to timescales of lithosphere processes Research Highlights

Experimental studies of mantle minerals: high pressure partition coefficients; role of accessory minerals in controlling mantle fluid compositions

Mantle terranes and cratonic roots: Canada, USA, southern Africa, Siberia, eastern China, Australia, Brazil, India, Spitsbergen Research Highlights

Gravity modelling of lithosphere terranes (regional elastic thickness)

The composition of Earth's core and timing of core formation

Interpretation of deep seismic tomography Research Highlights

Evolution of oceanic lithosphere: Kerguelen Plateau, Hawaii, Crozet Islands, abyssal peridotites Research Highlights

Diamonds: origin and clues to deep mantle and lithosphere evolution and structure; Canada, Siberia, South Africa Research Highlights

Seismic imaging of Moho structure and integration with petrological data: Indian Ocean, Kerguelen Plateau

Basalts as lithosphere/asthenosphere probes

Plume compositions, sources and origins

Thermal framework of the lithosphere: paleogeotherms, heat production, conductivity, thermal evolution

Lithosphere extension processes and consequences in East Asia: Taiwan and eastern China Research Highlights

Constraints on the timing of depletion and fluid movements in lithospheric mantle of different ages, using a range of isotopic and trace-element methods, including Re-Os in mantle sulfides Research Highlights

Metal isotopes as tracers of lithosphere processes and Earth evolution

Crustal Evolution and Crustal Processes

Timescales and mechanisms of magmatic processes and movement (U-series applications) Research Highlights

U-series analysis of weathering and erosion processes Research Highlights

Dating lower crust domains and tracking extent of Archean crust

Role of oceanic plateaus in the formation of oceanic and continental crust: Kerguelen

Tracers of magmatic processes; trace elements in accessory minerals

Hf-isotopic signatures of zircons (*in situ* LAM-ICPMS) as tracers of crust-mantle interaction in granites

Integrated U-Pb, Hf-isotope and trace-element *in situ* analysis of detrital zircons to characterise the magmatic history of major crustal terrains ("Event Signatures"): applications of *TerraneChron*®, South America, Canada, South Africa, Australia, India, Norway Research Highlights

Studies of detrital zircons in Paleozoic sediments: origins of terranes in Lachlan Fold Belt

Metallogenesis

Risk management in exploration

U-series applications to timescales of fluid movement

Metal isotope applications to ore genesis

Geochemistry of mantle sulfides Research Highlights

Area selection and evaluation for diamond exploration

Lithosphere domains through time and location of ore deposits

Effect of deep mantle processes on lithosphere evolution and structure

Identification of plume types fertile for Ni and PGE mineralisation

Crust-mantle interaction, granites and metallogenesis through time

Sulfide and PGE budget of the mantle

Re-Os dating of mantle sulfides *in situ* and timing of mantle processes Research Highlights

Highly siderophile element (including platinum group element) concentrations in sulfides (LAM-ICPMS) Research Highlights

Stable-isotope ratios of some important commodity elements (eg Cu, Fe, Zn, Mo) in a range of ore minerals and deposit types

Trace elements in diamonds - fingerprinting and possible genetic indicators?

Geodynamics

Influence of mantle processes on crustal geology and topography - regional geotectonic analysis: Slave Craton (Canada), Siberia, eastern China, Australia, Kaapvaal Craton, India Research Highlights

Tasman Fold Belt: terrane analysis

Paleomagnetic studies of the northern New England Orogen

Antarctic seismic studies Research Highlights

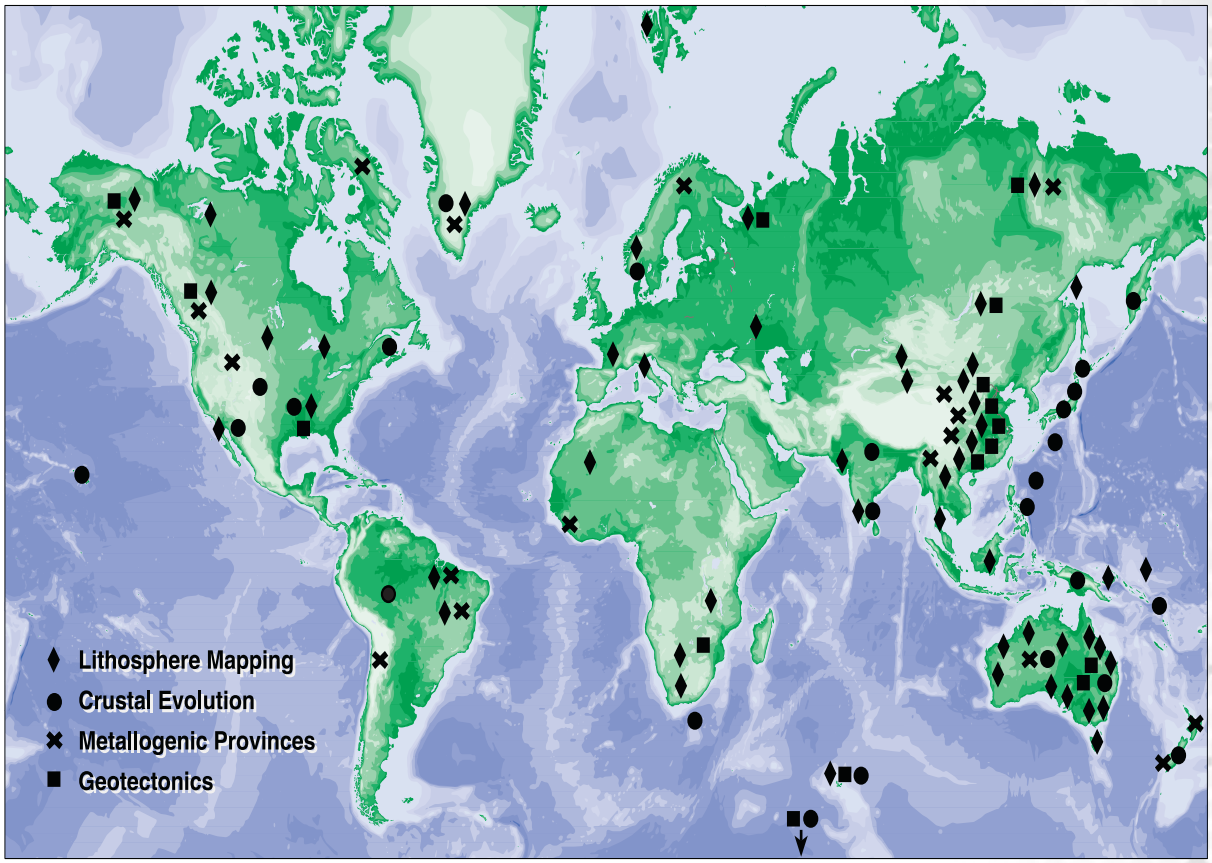
Deep crustal processes (New Zealand)

Plate margin processes (Papua New Guinea, Macquarie Island)

Geodynamic modelling of large-scale processes, integrating constraints from 4-D Lithosphere Mapping

Evolution of lithospheric composition and Earth geodynamics through time

WHERE IN THE WORLD IS GEMOC?



Funded basic research projects for 2006

Funded research projects within GEMOC are formulated to contribute to the long-term, large-scale strategic goals and determine the short-term Research Plan. Summaries of these projects for 2006 are given here.

The behaviour of geochemical tracers during differentiation of the Earth

Bernard Wood: Supported by ARC Discovery

Summary: The aims of this project are to understand the processes by which the Earth separated its metallic core, to test models of how it developed 'enriched' and 'depleted' mantle components and to constrain the nature of continuing interactions between near-surface geochemical reservoirs and Earth's deep interior. These processes have traditionally been followed using chemical tracers, but lack of understanding of chemical behaviour under the conditions of the deep Earth limits their application. This project is aimed at filling the gap, by determining experimentally, at high pressures and temperatures, the chemical behaviour of those trace elements which are central to our understanding of geochemical processes in Earth's interior. The project is aimed at providing fundamental data which Earth Scientists will use to understand the processes by which Earth separated into its chemically-distinct layers (core, mantle, crust, atmosphere, oceans) and to determine the nature of the continuing interactions between the surface environment in which we live and the deep interior.

Episodicity in mantle convection: effects on continent formation and metallogenesis

Craig O'Neill: Supported by Maquarie University Research Fellowship

Summary: Quantitative numerical modelling will be used to evaluate the links between episodes of intense mantle convection and the production of the continental crust that we live on. These models will assess the degree of melt production and crustal generation resulting from different styles of episodic mantle convection, and will determine which types of mantle evolution through time could produce the age distribution observed in the continental crust worldwide. The research addresses a critical shortcoming in our understanding of the formation and evolution of continents, with important implications for the distribution of major mineral and energy resources.

Isotopic fractionation of the ore minerals (Cu, Fe, Zn): A new window on ore-forming processes

Simon Jackson and Bruce Mountain: Supported by ARC Discovery

Summary: Stable isotopes of common ore metals (eg copper and iron) are new tools for investigating ore deposits. Our data suggest that metal isotopic variations can provide new insights into mechanisms operative during formation of ore deposits. Stable metal isotopes also show promise as a new exploration tool for identifying the location of economic mineralisation within large prospective terrains; eg weakly vs strongly mineralised zones in a volcanic belt.
This project will provide fundamental baseline data that will help elucidate the processes that cause metal isotope variations. This will allow stable metal isotopes to be used much more effectively by the mining and exploration industries.

Spreading ridge sedimentation processes: a novel approach using Macquarie Island as a natural laboratory

Nathan Daczko and Julie Dickinson (University of Sydney): Supported by ARC Discovery

Summary: This project is the first that aims to understand the generation, deposition and lithification of sedimentary rocks at mid-ocean spreading ridges. It will improve our understanding of the construction of significant volumes of oceanic crust that commonly host important economic resources such as cupriferous sulfides. The project will examine spreading-related sedimentary

rocks, including processes relating to their depositional system, utilising unique exposures on Macquarie Island, where *in situ* oceanic crust still lies within the basin in which it formed.

A new approach to understanding the mechanism and deep crustal controls of continental rifting

Nathan Daczko: Supported by ARC Discovery

Summary: **The Papuan Peninsula region of Papua New Guinea represents an active plate boundary on the northern Australian margin that is presently rifting. This project will develop models that detail how the rifting is accommodated in continental rocks and compare and contrast this with oceanic rocks. The project aims to understand the tectonics of rifting by examining this active tectonic region, thus investigating a fundamental plate tectonic process that is critical to understanding Earth evolution. Expected outcomes include a deeper understanding of plate tectonics, with special focus on deep Earth processes.**

Global lithosphere architecture mapping

Sue O'Reilly and Bill Griffin: Supported by ARC Linkage Project and WMC Resources

Summary: **Compositional domains in the subcontinental lithospheric mantle reflect the processes of continental assembly and breakup through Earth's history. Their boundaries may focus the fluid movements that produce giant ore deposits. Mapping these boundaries will provide fundamental insights into Earth processes and a basis for the targeting of mineral exploration. We will integrate mantle petrology, tectonic synthesis and geophysical analysis to produce the first maps of the architecture of the continental lithosphere, to depths of ca 250 km. These maps will provide a unique perspective on global dynamics and continental evolution, and on the relationships between lithosphere domains and large-scale mineralisation.**

Toward the use of metal stable isotopes in geosciences

Olivier Alard: Supported by ARC Discovery

Summary: **Metal stable isotopes (MSI: Mg, Fe, Cu, Zn, Ga) have enormous potential applications (basic and applied) in Geosciences and beyond. However the use of these elements as geochemical tracers and petrogenetic tools requires: (i) the definition of their isotopic composition in Earth's key reservoirs and in reference materials such as the chondritic meteorites; (ii) understanding and quantification of the causes of MSI fractionations during geological processes. By a unique combination of *in situ* and solution geochemical analytical techniques available now through frontier technology and method development, we aim to establish a conceptual and theoretical framework for the use of metal stable isotopes in Geosciences.**

Crustal Evolution in Australia: Ancient and Young Terrains

Elena Belousova: Supported by ARC Discovery

Summary: **The mechanisms of crustal growth and the processes of crust-mantle interaction will be studied in selected Archean, Proterozoic and Phanerozoic terrains in Australia, using a newly developed approach: the integrated, *in situ* microanalysis of Hf and Pb isotopic composition and trace-element patterns in zircons from sediments and selected igneous bodies. The results will provide new information on the evolution of the Australian crust, with wider implications for the development of global crust and mantle reservoirs. The outcomes will define crustal evolution signatures related to regional-scale mineralisation, and thus will be highly relevant to mineral exploration in Australia and offshore.**

How has continental lithosphere evolved? Processes of assembly, growth, transformation and destruction

Sue O'Reilly and Bill Griffin (with 5 partner investigators): Supported by ARC Discovery and Linkage International

Summary: **We will use new *in situ* analytical techniques, developed in-house, to date the formation and modification of specific volumes of the subcontinental lithospheric mantle, and to define the temporal and genetic relationships between mantle events and crustal formation. Quantitative modelling will investigate the geodynamic consequences of spatial and temporal variations in lithosphere composition and thermal state. Magmatic products will be used to assess the roles of mantle plumes and delamination in construction of the lithosphere, and xenolith studies will investigate the evolution of oceanic plateaus. The results will provide a framework for interpreting the architecture of lithospheric terranes and their boundaries.**

The timescales of magmatic and erosional cycles

Simon Turner (with 4 partner investigators): Supported by ARC Discovery

Summary: **Precise information on time scales and rates of change is fundamental to understanding natural processes and the development and testing of quantitative physical models in the Earth Sciences. Uranium decay-series isotope studies are revolutionising this field by providing time information in the range 100-100,000 years, similar to that of many important Earth processes. This project is to establish a dedicated Uranium-series research laboratory and to investigate (1) the processes and time scales of magma formation, transport and differentiation beneath western Pacific island arc volcanoes, (2) the time scales and relative roles of physical and chemical erosion in Australian river basins.**

Mantle Melting Dynamics and the influence of recycled components

Simon Turner: Supported by Macquarie University Development Grant

Summary: **This proposal aims to use U-series isotopes to constrain the rates of mantle melting and residual porosity. Precise information on the time scales and rates of change is fundamental to understanding natural processes and central to developing and testing physical models in the earth sciences. Uranium series isotopes have revolutionised the way we think about time scales because they can date processes which occurred in the last 10-350 000 years. By contrasting normal and enriched basalts we will constrain the effect of heterogeneities, including volatiles on mantle melting. This will radically improve our understanding of mantle melting which powers Earth's dynamics.**

The oxidation state of the early Earth mantle: new clues from iron isotopes

Helen Williams: Supported by Macquarie University New Staff Grant and Industry (Nu Instruments)

Summary: **This project's goal is to understand how the Earth's atmosphere became oxygen-rich. Oxygen stored in the Earth's deep interior (the mantle) was probably released to the surface as water and CO_2, allowing the growth of free oxygen in the atmosphere to a significant level by ~2.4 Ga (billion years ago). These processes, and the distribution of oxygen in the mantle, are poorly understood. This project will use iron and chromium isotopes as oxygen tracers in 3.3-2.1 Ga mantle rocks to understand the evolution of oxygen in the mantle and how this is linked to the development of the Earth's atmosphere.**