GEMOC

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

2004 GEMOC Annual Report

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

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Front Cover: The hazards of Arctic fieldwork – the GEMOC team under attack by angry Arctic terns, on their way to collect xenoliths on the Sverrefjell volcano, NW Spitsbergen. See Research Highlights for more on the 2004 Arctic Mars Analog Svalbard Expedition (AMASE).

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

Director's Preface

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

THIS REPORT summarises GEMOC's 2004 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.

Last year we experimented with new ways of presenting the Report and we sent, with all our posted copies, a questionnaire inviting your feedback on your preferences for delivery of our report, with choices including web access only, CD, traditional hard copy, hard copy of Research Highlights, and with composite combinations. The overwhelming response was to keep the hard copy distribution and post a web copy as well. This was also our preference, but the increasing costs of hard copy production (a large proportion of a postdoctoral salary) have made it prudent to go fully electronic. We have prepared the 2004 Report as a CD which we can mail to you, and it is posted on our website (www.es.mq.edu.au/GEMOC/) both in downloadable pdf format and as an html version.

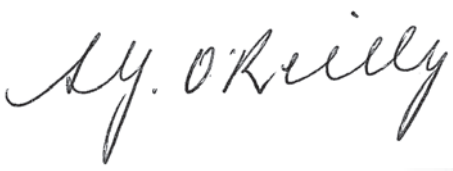
GEMOC's funding continued to access a wide portfolio of income sources ranging from traditional research sources such as the Australian Research Council schemes, non-ARC government sources, delivery of value-added consulting to the mineral exploration industry, industry collaborative projects (both mineral exploration and technology development industries), 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. The latter included significant funding from the Johnson Space Centre, NASA and the Carnegie Institution through the AMASE (Arctic Mars Analogue Svalbard Expedition) Project in the Centre for Physics of Geological Processes at the University of Oslo. Four GEMOC researchers participated in the AMASE program in Spitsbergen in September 2004 (see *Research Highlights* and front cover).

The suite of new instrument rooms and clean geochemical laboratories for GEMOC is now fully operational and provides a world-class facility that, along with the extensive instrument array (see the text and photos in the section on *Technology Development*), attracts many national and international researchers. A successful LIEF bid resulted in the purchase of a Triton Thermal Ionisation Mass Spectrometer to complement the capabilities of the Nu Multi-collector Inductively Coupled Plasma Mass Spectrometers. GEMOC's strategy of driving basic research with parallel strategic and applied goals, requires our high-technology facilities to deliver the relevant developments in technology and analytical methodologies.

GEMOC has achieved tremendous advances in understanding the nature of Earth's lithosphere and its processes and we now plan to plunge deeper and explore the whole mantle and core-mantle interaction with the same interdisciplinary approach, integrating geochemical, geophysical and tectonic information. This new direction will align with the planned experimental studies of deep Earth processes which will be a part of the research program of Professor Bernard Wood, the second Federation Fellow to join GEMOC, who will arrive mid 2005.

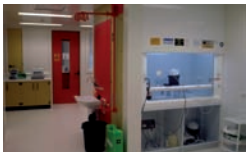
Throughout 2004, Macquarie University continued to provide a supportive research framework for GEMOC to operate within.

We look forward to expanding beyond the lithosphere to explore Earth's deeper regions through 2005.



Introducing GEMOC



This Mission Statement has been revised to reflect the evolution of GEMOC's activities to consider Earth Geodynamics beyond the Lithosphere.

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

GEMOC'S STRATEGIC FOCUS

THE MAIN TARGETS of GEMOC's founding activities were defined to be 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 to involve whole-mantle perspectives of geodynamics, and far-field and feedback effects involving the lithosphere.

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 minerals exploration industry. In addition, we have undertaken new projects related to magma-related Ni deposits and to diamond exploration, capitalising on our depth of intellectual property about the lithosphere and deep Earth processes.

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, 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*).

The hazards of Arctic fieldwork – the GEMOC team under attack by angry Arctic terns, on their way to collect xenoliths on the Sverrefjell volcano, NW Spitsbergen (cover photo).

GEMOC'S LINKAGES AND ALLIANCES: GEMOC was initially based on the pre-1995 collective profiles of the core participants at Macquarie and the networked group at ANU (Faculties), with collaborative links to CSIRO, AGSO (now Geoscience Australia (GA)) and colleagues at other Australian universities. GEMOC has significantly evolved and expanded from its original base with shifts in the original linkages and expansion in collaborations. Interaction with CSIRO and GA has grown and transformed over the six years. 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.

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 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.

"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)"

STRATEGIC OUTCOMES

These are modified from the founding strategic aims in 1995 as our understanding and development of novel methodologies to address these aims have evolved.

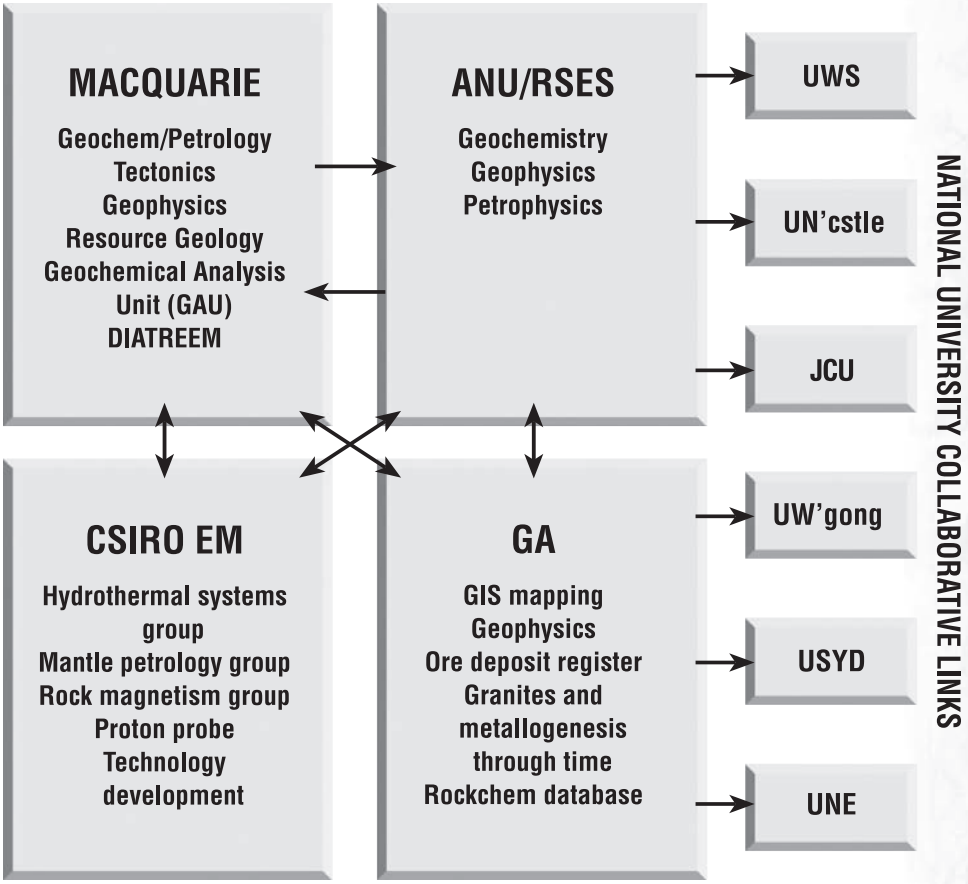
- **fundamental insights into the processes that create and modify the continental mantle and crust through time**
- **a better understanding of the assembly of the Australian continent and its geological architecture through work in Australia and global analogues**
- **results and concepts exportable to other terrains, globally and other potentially resource-rich areas of interest to Australian exploration companies**
- **a new conceptual framework for understanding the localisation of economic deposits, that will influence exploration strategies for world-class ore deposits, and improve the competitiveness of the Australian exploration industry both on- and off-shore**
- **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)**
- **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 a close collaboration with CSIRO Exploration and Mining (EM) (North Ryde), State Geological Surveys, GA (Geoscience Australia) and ANU/RSES across an increasingly broad range of projects.



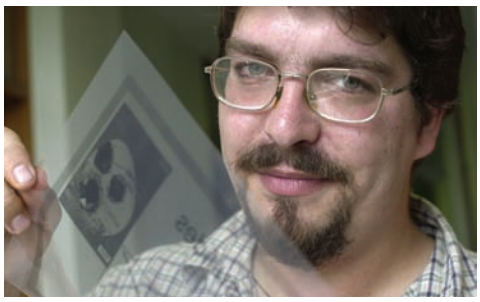
Collaborative research, teaching and technology development links have been established with other universities nationally and internationally and these evolve as new alliances become relevant to new directions.

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

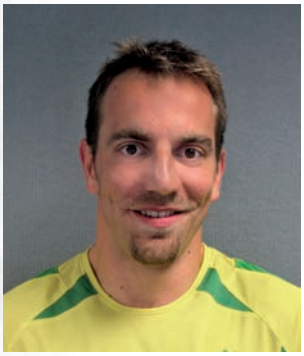
GEMOC has a wide network of international research and teaching development partners and collaborators.

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

CHANGES IN 2004



Dr Olivier Alard commenced an ARC Postdoctoral Fellowship. This project will develop novel methods for analysing metal stable isotopes (MSI: Mg, Fe, Cu, Zn, Ga) and applying these to define their isotopic composition in Earth's key reservoirs and in reference materials such as the chondritic meteorites; and to quantify and understand the causes of MSI fractionations during geological processes. A unique combination of in-situ and solution techniques will be aimed at establishing a conceptual and theoretical framework for the use of MSI in geosciences.



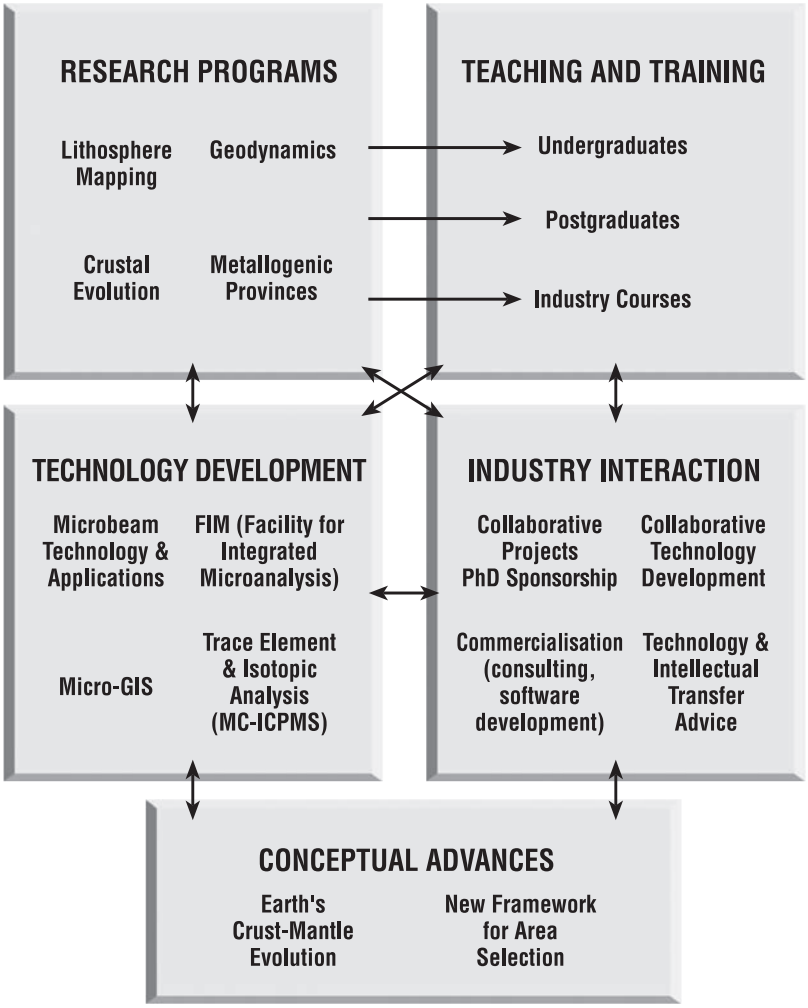
Dr Anthony Dosseto commenced an ARC Postdoctoral position. He is currently using U-series disequilibria to study Australian river systems and soils. The objective is to better understand how soils develop and sediments are transferred under the various conditions that consitute the Australian climate: from desert to wet tropical. Other projects are under way in the Carribbean Islands and South American river systems.

Dr Helen Williams was appointed the GEMOC-Nu Fellow (commencing 2005) with 3-year 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.

Professor Bernard Wood was awarded a Federation Fellowship. 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 will involve establishment of a world-class facility for materials synthesis at high pressures and temperatures. This facility will provide the means to simulate the processes occurring within the Earth and will enable synthesis of new high-density materials of technological interest. This is only the second Federation Fellowship to be awarded in the Geosciences and the other one was to Professor Simon Turner, also in GEMOC in the Department of Earth and Planetary Sciences.

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

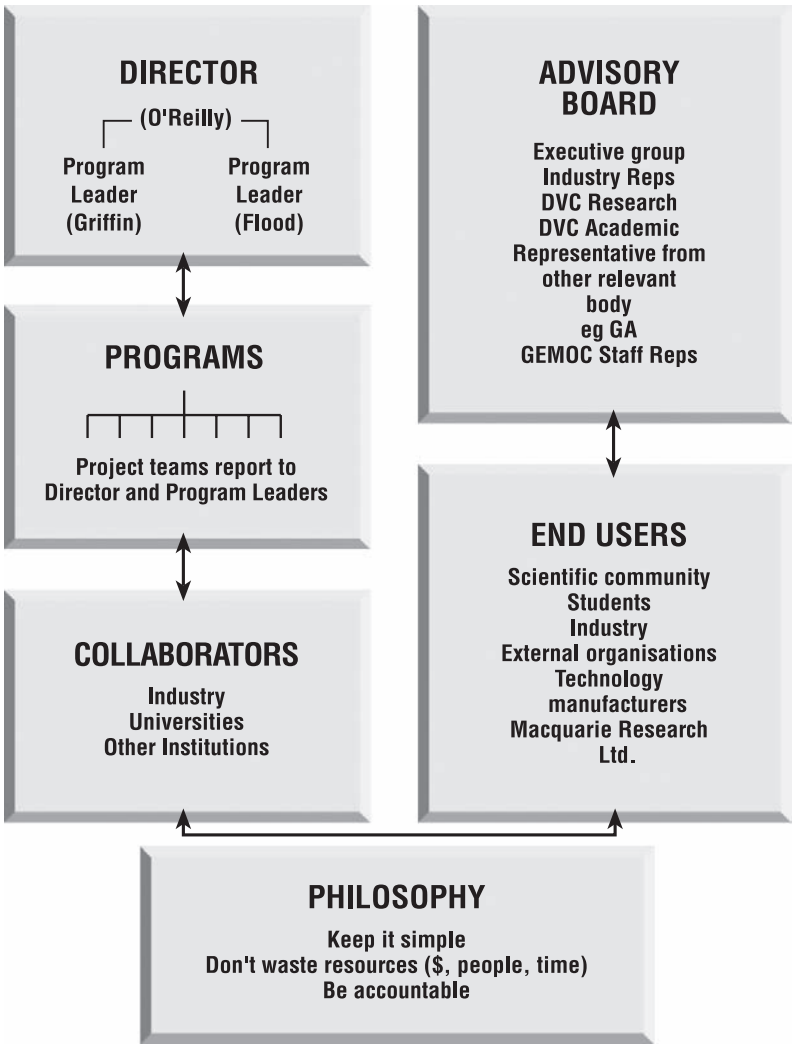
THE ORGANISATIONAL STRUCTURE of GEMOC is designed for efficiency, flexibility and interaction. The financial management operates within Macquarie University's Finance System and within Access Macquarie for commercialised products, consulting and some strategic collaborative research projects. The Teaching 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



2004 MANAGEMENT ROLES

Professor Suzanne O'Reilly is Director of GEMOC.

Ms Leigh Newton was 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 (re-elected in 2002).

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

Professor Simon Turner leads the development of 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

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*

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*

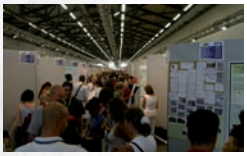
Dr Paul Heitherseay – *representative of PIRSA*

Dr Jon Hronsky – *industry member WMC (Perth)*

Dr Steve Walters – *industry member GeoDiscovery*

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

GEMOC communications 2004




GEMOC WEB RESOURCES provide past Annual Reports, updated details on methods for new analytical advances and software updates (GLITTER), synthesised summaries of selected research outcomes (eg studies of eastern China lithosphere) and items for secondary school resources on the lithosphere and on diamond occurrence. In addition, undergraduate teaching is web-based. From 2003 the Annual Reports 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.

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PARTICIPATION IN WORKSHOPS, CONFERENCES AND INTERNATIONAL MEETINGS IN 2004 (and beyond)

GEMOC staff and postgraduates increased their profile at peak metallogenic, geodynamic and geochemical conferences as convenors or invited speakers, or presenters, with 50 presentations. International fora included: the AGU Joint Assembly in Montreal, the 32nd Geological Congress in Florence, the 14th V. M. Goldschmidt Conference, the de Beers International Diamond Workshop in Warwick, the 2004 Western Pacific Geophysics Meeting in Hawaii, the 2004 IAVCEI General Assembly, the International Society of Economic Geologists (SEG) 2004 Predictive Discovery Undercover Conference in Perth and the American Geophysical Union Fall Meeting. 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 *Appendix 8*).

Professors Sue O'Reilly and Bill Griffin were co-convenors for the Special Session "Geophysical and geochemical imaging and modelling of continental roots and beyond: implications for the formation and evolution of continents" at the International Geological Conference in Florence in 2004. They were also invited speakers in the session on mantle geochemistry.

Professor Bill Griffin gave a keynote talk at the Symposium on "Seismic heterogeneity in the Earth's mantle: thermo-petrologic and tectonic implications" in Copenhagen in February 2004.

Professors Bill Griffin and Sue O'Reilly (with Sonal Rege) gave an invited account of GEMOC's work on diamond trace-element analysis at the de Beers' International Diamond Workshop in Warwick, UK in June 2004.

Dr Norman Pearson gave a Plenary Talk at the "Inaugural Symposium Celebrating the Opening of the W.M. Keck Isotope Laboratory", University of California, Santa Cruz in June, titled " More ions in the fire: developments in *in situ* high-precision isotope ratio measurement using laser ablation MC-ICPMS".

Professor Bill Griffin presented a two-day workshop on the *TerraneChron*™ methodology and its application to crustal evolution, at the request of WMC Resources (Perth).

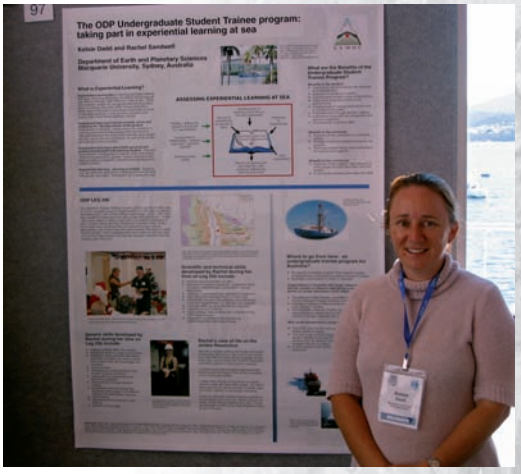
Sonja Aulbach discussing her popular poster presentation at the IGC held in Florence.

Professor Mike Etheridge gave an invited keynote talk on "Improving Exploration Performance" and Professor Sue O'Reilly presented an invited keynote talk on *TerraneChron*™ at the International Society of Economic Geologists meeting in Perth in September 2004, both in the session on "Research, Exploration and Predictive Mineral Discovery".

Professor Sue O'Reilly accepted nomination to the organising committee for the International Geological Congress (IGC) to be held in Brisbane in 2012 after the successful bid by Australia at the 32 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 2006.

A highlight in 2004 was the invitation to four GEMOC researchers (O'Reilly, Griffin, Pearson, Powell) to join the international AMASE (Arctic Mars Analogue Svalbard Expedition) team (with members from the University of Oslo, the Carnegie Institution and the Jet Propulsion Laboratory) on the Arctic island of Spitsbergen to unravel the significance of deepseated fluids detected in volcanic rocks and in mantle xenoliths. Carbonate minerals formed in the xenoliths and in volcanic vents at the surface form tiny round structures very similar to those seen in some Martian meteorites and controversially described as evidence for life on Mars (see *Research Highlights*).



Kelsie Dadd at the 17th AGC conference held in February 2004.

Dr Norman Pearson is convenor of the symposium "European Geosciences Union" for the European Geosciences Union (EUG) Conference in Vienna, April 2005. He is also a Keynote Speaker at this conference.

Dr Norman Pearson is convenor of the session "Isotopic ratio measurement using microbeam methods: Where do we stand and where are we going?" for the 15th Annual Goldschmidt Conference in Moscow (Idaho , USA), 2005.

Dr Simon Jackson is the presenter of a Short Course on laser ablation techniques at the Agilent ICP-MS User Group Meeting, Adelaide, April 2005.

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.

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.

Elena Belousova and fellow attendees at the 17th AGC.

Is GEMOC making a difference?

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

❄ *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

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

GEMOC's research program

The research aims

- 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 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 the 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 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 develop collaborative links with international institutions and researchers relevant to GEMOC's goals
- to define the timing of events and processes in the crust and mantle to understand crust-mantle linkages

"The nature of mantle heat transmission reveals information on fundamental deep Earth processes from the core-mantle boundary to the surface."

SCIENTIFIC CONTEXT

THERMAL ENERGY transmitted through the mantle provides the energy to drive lithosphere 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 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 2004.

The Research Program for 2005 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. *Additional details on the Research Programs are given at www.es.mq.edu.au/GEMOC/*

View from the MS - Polarsyssel on the way into Bockfjord, NW Spitsbergen.

• 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 built up by this information are interpreted in the context of geophysical datsets (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.

• 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 Lithosphere Mapping 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.

"Mantle dynamics and composition will form the framework for advancing our knowledge of Earth's geochemical and physical evolution."

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

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)

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

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

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

Basalts as lithosphere/asthenosphere probes

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

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

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

The nature of lithospheric mantle in arc regions (Japan, Kamchatka, Philippines, Solomon Islands)

Tracking mantle plumes through time

Metal isotopes as tracers of lithosphere processes and Earth evolution

Crustal Evolution

Role of oceanic plateaus in oceanic and continental crustal formation: Kerguelen

Crustal evolution and metallogenesis, southeastern China

Evolution of continental crust: central Queensland; San Francisco Volcanic Field, Arizona; Peninsular Ranges batholith of Baja California, Mexico; western Norway Research Highlights

Origin of granites and crustal genesis at continental margins: eastern Australia, southeastern China Research Highlights

Metamorphic reactions and mineral growth; microstructural processes in metamorphic rocks

Oceanic crust evolution Research Highlights

Tracers of magmatic processes; trace elements in accessory minerals

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

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

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

Metallogenesis

Risk management in exploration Research Highlights

U-series applications to timescales of fluid movement

Metal isotope applications to ore genesis

Geochemistry of mantle sulfides Research Highlights

Chromite chemistry in mantle-derived magmas and residues

Resistate minerals and mineral exploration Research Highlights

Area selection and evaluation for diamond exploration

Lithosphere domains through time and location of ore deposits

Crust-mantle interaction, granites and metallogenesis through time Research Highlights

Sulfide and PGE budget of the mantle Research Highlights

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

Zircon composition in mineral exploration Research Highlights

Groundwater geochemistry and aquifer lithology

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 - 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

Neoproterozoic earth history of Australia: Tectonics, isotope-, volcanic- and bio-stratigraphy

Tasman Fold Belt tectonism and regional volcanology

Paleomagnetic studies of the northern New England Orogen

Antarctic seismic studies Research Highlights

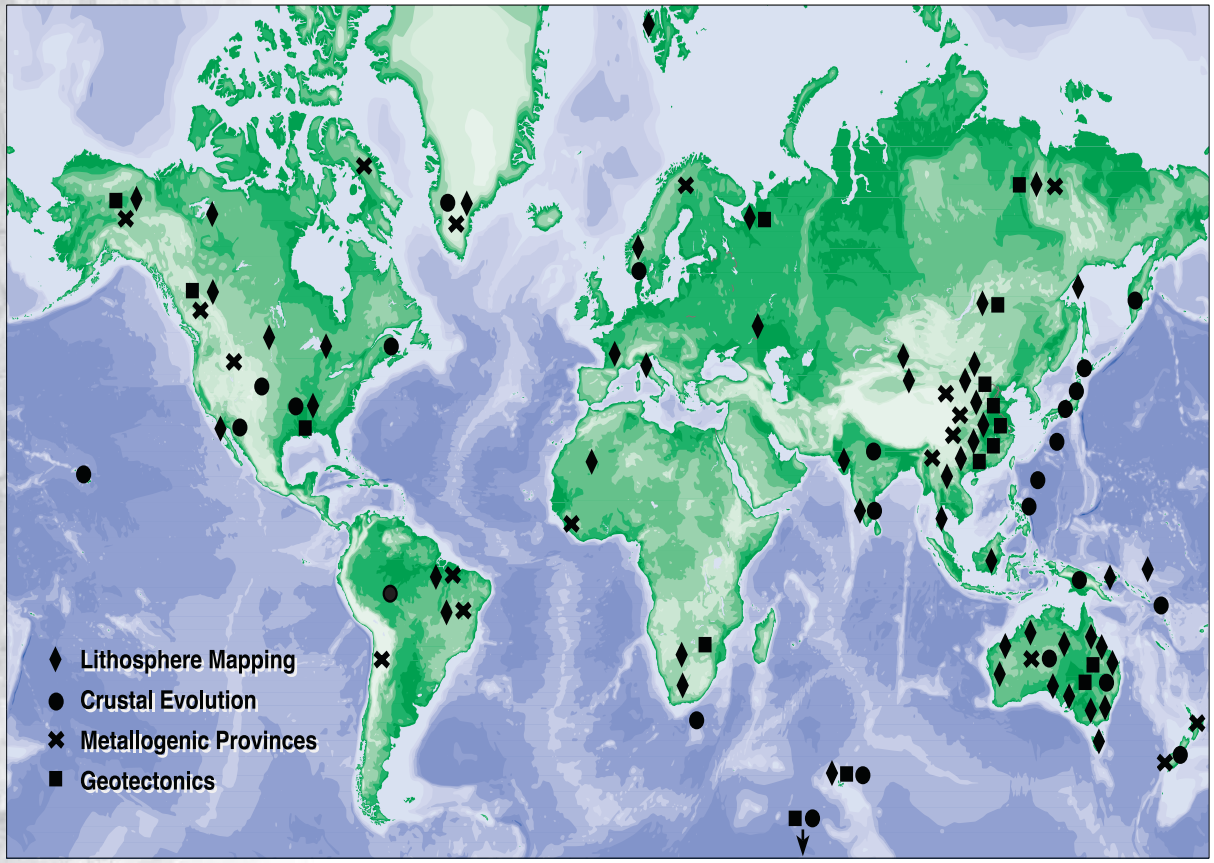
Deep crustal processes (New Zealand)

Plate margin processes (Papua New Guinea)

Geodynamic modelling of large-scale processes using constraints from 4-D Lithosphere Mapping results

Evolution of lithospheric composition and Earth geodynamics through time

WHERE IN THE WORLD IS GEMOC?



Funded basic research projects for 2005

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 2004 are given here.

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

Simon Jackson and B. Mountain: Supported by ARC Discovery (awarded in 2004 for 2005-7)

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.

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.**

Isotopic fractionation of the ore metals (Cu, Zn, Fe): Mechanisms and significance

Simon Jackson: Supported by Macquarie University Research Development Grant

Summary: **Utilising recent advances in laser and mass spectrometric technologies, it has been determined that the stable isotope ratios of important metals (eg Cu) exhibit significant variations in ore systems. However, little is known of the fractionating processes. The proposed project will determine the mechanisms that fractionate isotopes of Cu, Fe and Zn by: (a) building a data-base of isotopic signatures for rock types commonly associated with mineralisation, (b) study of selected active and ancient hydrothermal systems, (c) experimental studies. This information will allow metal isotopes to be applied to determining the genesis of, and, potentially, exploration for, ore deposits.**

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.**

Thallium isotopes: a novel geochemical tracer to map recycling in Earth's mantle

Sune Nielsen: Supported by a fellowship from the Danish Research Council

Summary: **The recycling of crustal material back into the mantle at subduction zones 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. The results will provide firm constraints on models of mantle convection, Earth evolution and the generation of continents**

Evolution of the upper mantle beneath the Siberian Craton and the southern margin of the Siberian Platform

Vladimir Malkovets: Supported by Macquarie University Research Fellowship

Summary: **This project will contribute new information and concepts about the formation of Earth's continents over the last 4 billion years. It will use geochemical techniques recently developed with state-of-the-art instrumentation in the GEMOC laboratories, and apply these techniques to unique suites of mantle-derived samples (xenoliths) from volcanic rocks across Siberia to investigate differences between mantle domains of different age and tectonic setting. The results will provide direct analogues for better understanding of mantle structure and mantle evolution beneath Australia, and will contribute to development of tectonic models relevant to the area selection process in mineral exploration.**

Lithosphere extension in East Asia: tectonic mechanisms and geochemical consequences

Kuo-Lung Wang: Supported by Macquarie University Research Development Grant

Summary: **This project seeks to better understand how continents pull apart (extend) and how the mantle part of the lithosphere (~200 km depth) responds. Novel Re-Os techniques will date mantle samples delivered to the surface in magmas; geochemical fingerprints of processes related to extension will be established. Integration of new geophysical data with geochemical results will constrain the lithosphere architecture. The East Asia region is an ideal natural laboratory and the results will be applicable to analogous tectonic scenarios globally and throughout geological time. The results will have particular relevance for unravelling the geological evolution of Phanerozoic eastern Australian lithosphere.**

Zircon analysis of Cretaceous and Eocene sediments of Lambert Graben - Prydz Bay, Antarctica

John Veevers: Supported by Macquarie University Research Development Grant

Summary: Five samples from Prydz Bay, East Antarctica, have become available recently. (a) Ocean Drilling Program (ODP) Leg 188, Site 1166, encountered an Upper Eocene (35 Ma) 100-m-thick coarse sand interpreted as deposited on an alluvial plain. 'Prydz Bay is at the downstream end of a drainage system that originates in the Gamburtsev Mountains of central East Antarctica' (ODP Initial Report 188) so that zircons from this sand may reflect the Gamburtsev provenance. Two samples have been supplied by the ODP. (b) ODP Leg 119 Sites 740 and 741 encountered an Early Cretaceous (middle to late Albian, 105-99 Ma) coal-bearing fluvial sediment 100 m thick. It is part of a subhorizontal sequence 2-3 km thick, that probably overlies Precambrian basement. Again, zircons from this sand are expected to reflect the Gamburtsev provenance. Three samples have been supplied by the ODP. Zircons from the five samples have been separated and mounted. Combined with those from Beaver Lake immediately upstream and the Mahanadi Basin (India) downstream, the Prydz Bay zircons will provide crucial data about the age and composition of the Gamburtsev provenance.

3D shape of the Mole Granite and the thickness of the Torrington Pendant

Mark Lackie and Dick Flood: Supported by Macquarie University Research Development Grant

Summary: The aim of this project is to undertake a gravity survey of the Mole Granite to quantify the 3D shape of the granite. As well, a seismic section utilising national seismic facility equipment will be undertaken across a contact of the granite to assist in the modelling of the shape of the granite. A secondary aim of this project will be to undertake a seismic survey across a roof pendant of the granite to delineate the pendant's thickness and shape. Understanding the shape of the Mole Granite is important in unravelling the geological history of the western New England region.

Timing and mechanisms of melt migration and interaction at mantle, lithospheric and crustal levels

Rhiannon George: Supported by Macquarie University Research Development Grant

Summary: A tantalising window into crust and mantle processes is opened up if we can link them to the key variable of time. A key initiative of this proposal is to provide a unique, quantitative way of constraining the physical mechanisms by which the Earth differentiates. It does so by strategically targeting two key areas: (1) Testing models of the movement of small melt fractions in the lithospheric mantle beneath island arcs, ocean islands and the continents; (2) The time scales of lower and upper crustal melting and the effect of such processes on the interpretation of Uranium-series isotope systematics.