

# GEMOC

## 2007 Annual Report

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

- GEMOC information is accessible on WWW at:  
<http://www.es.mq.edu.au/GEMOC/>
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*Front Cover: Analysis of trace elements in diamonds (see Research Highlights) is shedding new light on their origin and other features, such as the development of trigons (triangular etching features), and giving new understanding of fluid related processes deep in the Earth.*

**T**HIS REPORT SUMMARISES GEMOC'S 2007 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.

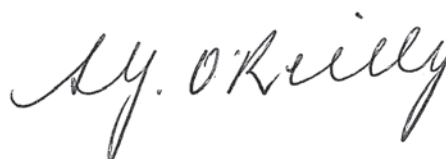
The GEMOC Annual Report is available from our website ([www.es.mq.edu.au/GEMOC/](http://www.es.mq.edu.au/GEMOC/)) as a downloadable pdf file or in html format, and by mail as a CD on request. Our previous Annual Reports are also available at that web address, as well as a consolidated version of all GEMOC's Research Highlights for 11 years.

Early in 2006, Macquarie's new Vice-Chancellor, Professor Steven Schwartz, designated GEMOC as one of Macquarie's CoREs (Concentrations of Research Excellence) and allocated 5 new academic positions (ranging from Level B to E) to extend and enhance our research profile. Advertisements were placed for applicants in the fields of rheology of rocks and minerals; geochemical analysis, lithosphere and Earth dynamics; geophysical imaging of Earth's interior; dynamic modelling of Earth's mantle; isotope and trace element geochemistry; cosmochemistry and meteoritics. These places have now been filled; Professor Bill Griffin, Dr Tracy Rushmer and Dr Craig O'Neill commenced in 2007 and are introduced on pages 7 and 8. Two more CoRE staff (Dr Bruce Schaefer and Dr Juan Carlos Afonso) will arrive shortly and will be profiled in the 2008 Report. A sixth position for a geophysicist is currently being advertised, and Professor Simon Turner has just been allocated a seventh CoRE position.

GEMOC was again successful with ARC Discovery and Linkage Projects commencing in 2007 (reported in *Appendix 5* and in the section on *Industry Interaction*). Collaborative research with industry continues to provide invaluable access to data, resources and samples for worldwide localities relevant to mantle and crust evolution projects. The combination of the new CoRE positions from Macquarie, funding from government competitive schemes, leverage of resources and expertise through collaborative projects with industry partners, strategic alliances with technology and instrument manufacturers, and international links and alliances provides a robust range of resources and income sources. Commercialisation ventures such as the marketing of GLITTER software expand this resource portfolio and enhance GEMOC's global recognition. GLITTER has now become the industry standard for reduction of laser-ablation ICPMS data, with systems operating in more than 110 laboratories worldwide and contributing to the development of uniform analytical protocols.

GEMOC has been highly visible in its research outputs throughout 2007 with 42 international refereed publications (see *Appendix 2*) including 35 in high impact journals (as recognised internationally by the Thomson Impact Scale) including *Nature*, *Geology*, *Earth and Planetary Science Letters*, *Journal of Petrology* and *Earth-Science Reviews*. GEMOC also had prominent representation at all peak relevant conferences with keynote, invited and presented lectures, and featured on the ABC "Catalyst" program (see "*Communications*" on pages 13-15 and *Appendix 4*). Our postgraduate students again had a high participation rate in international conferences, evidence of the vigorous postgraduate environment that continues to grow and attract students worldwide.

2008 will be another challenging year - the beginning of a new phase with new directions as the CoRE staff enhance our research expertise and widen our goals.



## Director's Preface



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



# GEMOC

in 2007



**“GEMOC’S research success and distinctiveness lie in its interdisciplinary approach to understanding the way the Earth works, integrating information across traditional discipline boundaries”**

*Bill Griffin and Sue O’Reilly examining unusual “outcrops” of eclogite on a field trip in Brittany.*

**G**EMOC’S RESEARCH SUCCESS AND DISTINCTIVENESS lie in its interdisciplinary approach to understanding the way the Earth works, integrating information across traditional discipline boundaries including geochemistry, geophysics, geodynamics and tectonics. This perspective has made GEMOC a world leader in understanding the complex evolution of the uppermost 200 km of the Earth (the lithosphere), its global geodynamic behaviour, the timing of important Earth episodes, and its origins. The addition of two Federation Fellows over the last 5 years has broadened GEMOC’s horizons and expertise, with the development of Australia’s first world-class facility to measure short-lived U-series isotopes for investigating processes with short timescales (such as volcanism and erosion), and the establishment of a state-of-the-art high pressure/high temperature experimental facility to simulate the physical conditions of the Earth’s interior. These experimental data can probe the early history and evolution of the Earth’s core, mantle and crust and illuminate planetary analogues.

The research foci on the different shells of the deep Earth and on planetary origins in GEMOC are complementary, and are totally dependent on the continuing effective functioning of its unique, internationally recognised Geochemical Analysis Unit to provide geochemical data that underpins their outcomes and outputs.

During 2007, GEMOC’s research expertise and capability have been enhanced by the implementation of Macquarie’s CoRE (Concentration of Research Excellence) strategy (see below), resulting in the expansion of our in-house expertise to include experimental rheology, geodynamic and geophysical modelling and computational Earth simulations.

Extensive international collaborations extend our expertise and enhance GEMOC’s resource base.

## **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 GEMOC became self-funded in 2002, to involve whole-mantle perspectives of geodynamics, far-field and feedback effects on the lithosphere that shape Earth’s crust on which we live, and planetary studies that relate to Earth’s formation, differentiation and geochemical/geodynamic evolution. New ways of measuring the timing of Earth processes are defining the fourth dimension (time) with increasing clarity for crust, mantle, core 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 and illuminating planetary analogues.



Industry collaboration has increased with funded large-scale collaborative projects related to lithosphere evolution, crustal generation and diamond formation and fingerprinting. The delivery of new tools and a new framework of terrane analysis to the mineral exploration industry has generated such collaboration. Funded projects dealing with magma-related Ni deposits, plume magmatism and PGE deposits, diamond exploration, and deep-lithosphere structure through time, 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 provide a leading interdisciplinary research environment for the development of the next generation of Australia's geoscientists
- to deliver new concepts about the spatial and temporal distribution of Earth resources to the mineral and energy industries

## GEMOC'S CONTEXT IN 2007

**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 succeeded and the evolved GEMOC started its new phase in 2002 and is continuing with an independent, well-funded base.

**GEMOC'S FUNDING BASE FROM 2002:** This funding, like a good investment portfolio, has a healthy, risk-minimising diversity ranging across traditional competitive 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*). Extensive international collaborations extend our expertise and enhance our resource base.

**GEMOC AND THE EARTH AND PLANETARY CoRE STRATEGY:** In 2006, Vice-Chancellor Professor Steven Schwartz, designated GEMOC as an existing Concentration of Research Excellence (CoRE) in Earth and Planetary Evolution at Macquarie. The CoRE is to be supported by new staff appointed from 2007 to enhance and expand research expertise and performance. GEMOC has built up an interdisciplinary approach to understanding the way the Earth works, integrating the traditional

This Mission Statement has evolved since GEMOC commenced in 1995, to reflect the evolution of GEMOC's activities to probe Earth geodynamics beyond the lithosphere. Current projects are extending our horizons further to planetary composition and dynamics. The postgraduate group is constantly expanding and has developed to reflect strong international research links.

“The research foci on the different shells of the deep Earth and on planetary origins in GEMOC are complementary.”



“ Strong new national and international collaborative research links and programs have emerged, and robust ongoing engagement with industry (mineral exploration and technology manufacturing) partners ”

disciplines of geochemistry, geophysics, geodynamics and tectonics. We have developed cutting-edge isotope, geochemical and experimental instrumentation and strong collaborations with national and international researchers and industry and international geoscientists. The Earth and Planetary Evolution CoRE seeks to build on these strengths to define the processes driving Earth’s global internal dynamics, and to understand how these have generated the present chemical and physical structure of our planet through time. New and reinforcing expertise from five CoRE recruits will now allow expansion into realistic geodynamic modelling and geologically significant modelling of geophysical datasets by combining new computational expertise with existing geochemical, petrological, tectonic and experimental knowledge bases and approaches. It will also enable continuing development of world-leading methodologies and applications in geochemistry (including isotopic) and especially for *in situ* (laser-ablation) analysis.

Advertisements sought applicants in the fields of rheology of rocks and minerals; geochemical analysis, lithosphere and Earth dynamics; geophysical imaging of Earth’s interior; dynamic modelling of Earth’s mantle; isotope and trace element geochemistry; cosmochemistry and meteoritics. Professor Bill Griffin, Dr Tracy Rushmer, and Dr Craig O’Neill commenced in 2007 and Dr Juan Carlos Afonso and Dr Bruce Schaefer will commence in 2008.

**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 continues to fulfil one of GEMOC’s original goals and extend our intellectual and funding base.

GEMOC had a high profile in both the organisation and scientific program at the 2007 European Mantle Workshop (EMAW), held in Ferrara in August 2007 (see *International Links and GEMOC Communications 2007*).





*Hoggar Region, Algeria  
(see International  
Links).*

## SCIENTIFIC PHILOSOPHY

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

This approach links...

*petrology and geochemistry*

*experimental petrology and petrophysics*

*geophysics*

*petrophysics*

*tectonics*

*numerical and dynamical modelling*

within the important contexts of...

*time and thermal state*

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

GEMOC is also distinctive in its aim to pursue parallel interlinked basic and strategic/applied research programs with targeted development of new geochemical analytical methodologies, geodynamic modelling protocols and experimental design.

## 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 on 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 compositions and to enhance interpretation of data using spatial contexts
- development of robust new geodynamic models of Earth's evolution using constraints provided by geochemical datasets
- strategic and collaborative alliances with technology manufacturers in design and application innovation

*This report documents achievement of these goals in 2007 and aims for 2008*



**G**EMOC IS BASED AT MACQUARIE UNIVERSITY (in the Department of Earth and Planetary Sciences).

There is active collaboration with state Geological Surveys, GA (Geoscience Australia), CSIRO, ANU/RSES and several major industry concerns, across a 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 (e.g. 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/](http://www.es.mq.edu.au/GEMOC/)***

## CHANGES IN 2007

### Appointments in the EAPE CoRE



**Professor William Griffin** was appointed to the EAPE CoRE in March 2007. His research deals primarily with the petrology and geochemistry of the lower crust and upper mantle in the context of integrating petrology with geophysics and tectonics to solve large-scale problems including the formation and modification of continents, and Earth evolution. His techniques for target evaluation in diamond exploration, using the trace-element chemistry of mantle-derived minerals, are now widely adopted by the industry and continue to provide a focus for interaction with the industry. This 4-D Lithosphere Mapping technique became the basis for mapping the composition, structure and

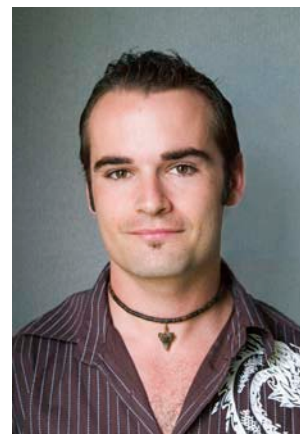
thermal state of the lithospheric mantle, and the recognition of its secular/episodic evolution. Previously seconded to GEMOC from CSIRO, he leads the Industry Interaction Program and the Technology Development Program, which has made breakthroughs including the Re-Os dating of sulfide minerals and the integrated U-Pb/Hf-isotope analysis of detrital zircons for analysis of crustal evolution. Since 2002 he has worked closely with WMCR (later BHPB) staff developing new interpretative techniques to integrate petrology, tectonics, geochemistry and geophysics.

## GEMOC participants



**Dr Tracy Rushmer** started her position at GEMOC in the Department of Earth and Planetary Sciences in mid June, 2007. Her background is in experimental rock deformation and experimental petrology. Her research interests include partial melting processes and the chemical and physical interplay between deformation and fluid flow. In particular, experimental studies, aided by fieldwork and numerical modelling, have focused on the production, extraction and migration of partial melt in continental arcs. Recent studies have extended to meteorites to investigate the interaction between metal and silicate. These investigations have placed emphasis on early differentiation processes in the growing planetary bodies and on possible core-mantle boundary interactions in the modern-day Earth.

**Dr Craig O'Neill** is an early-career researcher with an already established track record in innovative approaches to geodynamic modelling. He uses numerical models of mantle convection to understand the dynamics of plate tectonic systems, and the conditions under which plate tectonics breaks down. These models address the tectonic regime of the early Earth, and melt generation and crustal production in chaotic mantle convection regimes, with the view to understanding the formation and evolution of the continental lithosphere and its mantle environment.

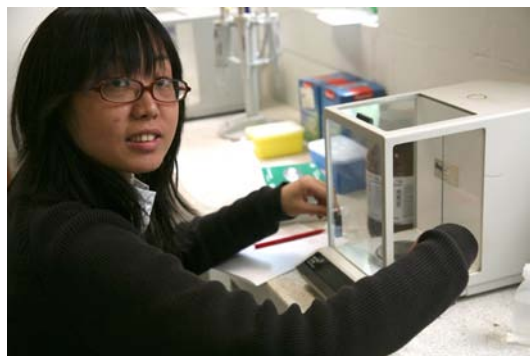


### Other new arrivals



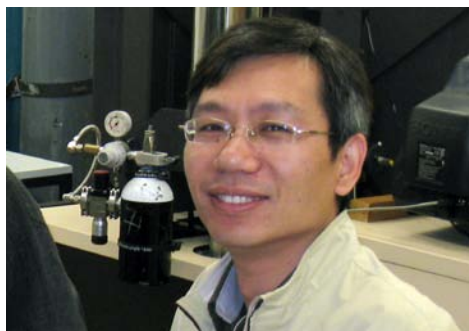
**Dr Christoph Beier** joined GEMOC in March 2007 as a 2-year Feodor-Lynen Research Fellow of the Alexander von Humboldt-Foundation. Christoph is primarily interested in understanding mantle heterogeneity and melting processes beneath ocean islands, mid-ocean ridges and subduction zones by means of major elements, trace elements, radiogenic isotopes and short-lived U-series isotopes. His specific research areas of recent interest are the short-lived U-series isotopes along the East Pacific Rise, in the Azores archipelago and in the Manus Basin. The goal of these studies is to establish a model of the impact of mantle heterogeneity on mantle melting.

**Dr Mei-Fei Chu** commenced at GEMOC in October 2007 as a Research Associate to develop the methodology for Li isotopic analysis in whole-rocks and apply this isotopic tool to understanding the genesis of crustal melts and the role of recycled components in mantle processes. Dr Chu was awarded her PhD at the National Taiwan University (NTU) in



2006. Her PhD research included setting up the first LA-ICPMS system in the Department of Geosciences, NTU and the application of LA-ICPMS geochemical results to the study of Trans-Himalayan petrogenesis by using trace-element abundances of apatite and isotopic compositions of zircon from different types of intrusive rocks in the Lhasa terrane, southern Tibet.

**Dr Jinhui Yang**, Professor of Geochemistry, from the State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, was awarded a Research Fellowship from the Chinese Academy of Sciences to undertake research for one year in GEMOC. During 2007 he worked



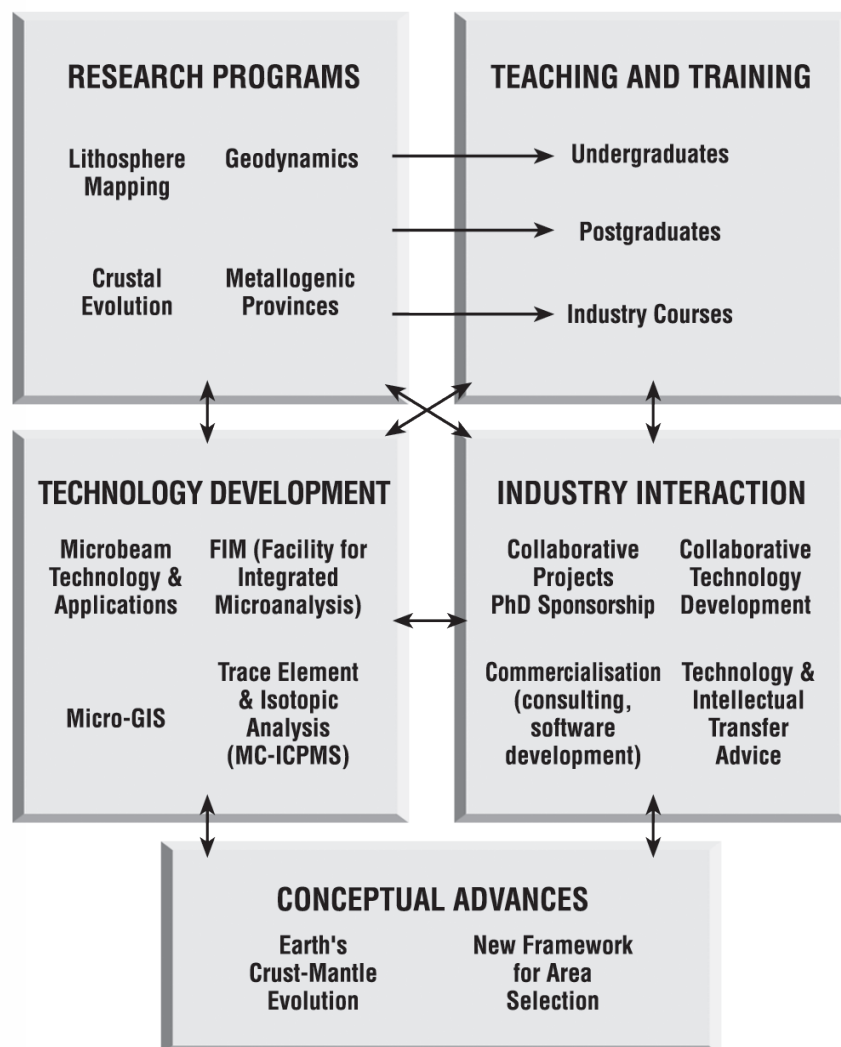
on the nature of the mantle beneath North Korea using mantle xenoliths from kimberlites, and on Mesozoic magmatism related to lithospheric thinning in the eastern North China Craton. He published, among others, an important paper in *Geology* re-emphasising that the “North China craton” is no longer a craton, and coined the term “decratonisation” to refer to this process. Planned future

collaborative research and joint PhD supervision will strengthen this link between GEMOC and the geochemical area of the Chinese Academy of Sciences.



# GEMOC programs

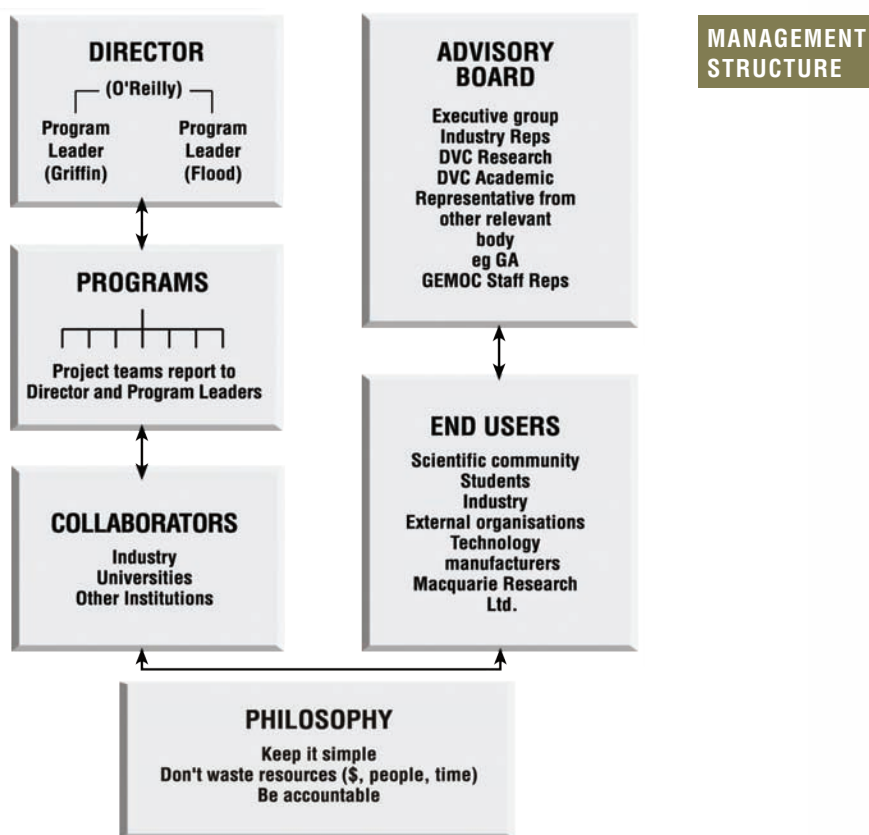
**G**EMOC'S PROGRAMS are set up to be interactive. Basic research strands are supported by parallel applied collaborative research with industry partners: these provide the impetus for technology development. This is, in turn, supported by strategic alliances with front-line instrument designers and manufacturers (e.g. 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, core formation and planetary origins in GEMOC.



# GEMOC structure

**T**HE 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, some strategic collaborative research projects and for any consulting. The Teaching Program stemming from GEMOC is fully 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.

GEMOC is recognised as a Concentration of Research Excellence within Macquarie University.



## 2007 MANAGEMENT ROLES

**Professor Suzanne O'Reilly:** Director of GEMOC.

**Mrs Nikki Bohan and Mrs Carol McMahon:** share the position of GEMOC Administrator.

**Professor William Griffin:** Professor at Macquarie University and GEMOC Program Leader responsible for Technology Development and Industry Interaction.

**Dr Kelsie Dadd:** Head of the Department of Earth and Planetary Sciences and coordinates the Teaching Programs.

**Dr Richard Flood:** represents Department Staff.

**Professor Bernard Wood:** leader of experimental petrology programs.

**Professor Simon Turner:** leader of the U-Series Geochemical Program.

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

**Ms Sally-Ann Hodgekiss:** GEMOC graphics and design consultant at Macquarie.

**ADVISORY BOARD MEMBERS (2007)**

**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*

**Dr Kelsie Dadd** – *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** – *Company Director*

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

**Dr Paul Heitherseay** – *representative of PIRSA*

**Dr Jon Hronsky** – *industry member from Western Mining Services (Australia) Pty Ltd*

**Dr Simon Shee** – *industry member (formerly De Beers)*

**“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.”**





# GEMOC communications 2007

**G**EMOC 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. Strong industry interaction in 2007 ranged from presentations to specific industry groups in their offices to numerous formal and informal workshops at GEMOC, and invited presentations at peak industry symposia, workshops and conferences nationally and internationally.

## AWARDS

Dr Craig O'Neill received a NSW Young Tall Poppy Award for excellence in research and was awarded an ARC Postdoctoral Fellowship.

Professor Sue O'Reilly was made a Fellow of the Geological Society of Australia.

## STARS IN ABC CATALYST PROGRAM

Craig O'Neill and Bill Griffin were the major focus of an ABC Catalyst segment in 2007 on Diamond Exploration in Australia.

## GEMOC PUBLICATIONS FOR 2007 ARE GIVEN IN APPENDIX 2

The 57 GEMOC Publications that were published or in press for 2007 are mainly in high-impact international journals as listed by the internationally recognised Thomson ISI Citation data.

## PARTICIPATION IN WORKSHOPS, CONFERENCES AND INTERNATIONAL MEETINGS IN 2007 (AND BEYOND)

GEMOC staff, postdoctoral researchers and postgraduates again increased their profile at peak metallogenic, geodynamic and geochemical conferences as convenors, invited speakers, or presenters, with more than 70 presentations. International presentations included:

- State of the Arc 2007 (Termas Puyehue, Chile)
- 7<sup>th</sup> Biennial Exploration Managers Conference of AMIRA (Australian Minerals Industry Research Association) "Making Collaborative R&D an Integral Part of the Exploration Business" (Barossa, Australia)
- the 17<sup>th</sup> V.M. Goldschmidt Conference (Cologne, Germany)
- the American Geophysical Union Fall Meeting (San Francisco, USA)



*Craig O'Neill and Bill Griffin on ABC's Catalyst, discussing Diamond exploration in Australia with the host Dr Paul Willis.*

*Bill Griffin and the attendees of the International Eclogite Field Symposium (Skye and Brittany).*



- Geological Society of America Cordilleran Section 103 Annual Meeting (Bellingham, Washington, USA)
- 6<sup>th</sup> International Hutton Symposium on the Origin of Granites and Related Rocks (Stellenbosch, South Africa)
- American Geophysical Union May Joint Assembly (Acapulco, Mexico)
- Geological Society of America/Geological Society of London Meeting: “Continental tectonics and mountain building – the Peach and Horne Meeting” (Ullapool, Scotland)
- International Eclogite Field Symposium (Skye and Brittany)
- 7<sup>th</sup> International Symposium on Applied Isotope Geochemistry (Stellenbosch, South Africa)
- European Mantle Workshop (EMAW): Petrological Evolution of the European Lithospheric Mantle: From Archean to Present Day, Ferrara University (Ferrara, Italy)
- 2007 Geological Society of America Annual Meeting (Denver, USA)
- Exploration 07 Conference, the peak Exploration Industry Decennial Conference (Toronto, Canada)



- Ores and Ore Genesis Conference (Arizona, USA)
- XVIII Symposium on Isotope Geochemistry (Moscow, Russia)

*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 many of the abstracts can also be found.*

Professor Sue O’Reilly was a co-convenor (with GEMOC international collaborators Professors Massimo Coltorti and Michel Grégoire) of the 2007 European Mantle Workshop

(EMAW) on the Petrological Evolution of the European Lithospheric Mantle from Archean to Present Day in Ferrara, August 2007. This was an international high-profile event with a strong GEMOC presence (including postgraduates), and has resulted in the formation of an international group to coordinate research on this topic with an annual workshop. Almost 100 researchers from Europe, China, Japan and Australia participated in the meeting. Many of the presentations are downloadable from [www.unife.it/dipartimento/scienze-terra/emaw-2007](http://www.unife.it/dipartimento/scienze-terra/emaw-2007).

Keynote talks in 2007 included (see *Appendix 4* for titles): VI Hutton – Belousova, Rushmer, Vernon; 2007 European Mantle Workshop (EMAW) – O’Reilly; 7<sup>th</sup> Biennial Exploration Managers Conference of AMIRA – O’Reilly. GEMOC research was represented by 21 talks at the 17<sup>th</sup> V.M. Goldschmidt Conference in Cologne

*Simon Turner and Tracy Rushmer at the 6<sup>th</sup> International Hutton Symposium on the Origin of Granites and Related Rocks, Stellenbosch, South Africa.*





and Bill Griffin gave an invited Workshop session on *TerraneChron*<sup>®</sup> at the Exploration 07 Conference in Toronto.

Professor Bernie Wood and Dr Alex Corgne wrote an invited contribution published in section 2.04 (Mineralogy of the Earth) in the Mineral Physics Volume (2) of the Elsevier Treatise on Geophysics titled “Trace elements and hydrogen in the Earth’s transition zone and lower mantle”.

Dr Tracy Rushmer was appointed to the Geological Society of America Penrose Committee as a “Member at Large” for 2007-2010.

Sue O’Reilly was appointed a panel member for the DEST RQF exercise.

Bill Griffin was appointed to the Australian Research Council (ARC) Expert Advisory Committee.

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 32<sup>nd</sup> IGC in Florence (by the Australian Bid Committee, of which she was a member).

Professors Bill Griffin and Sue O’Reilly are co-convenor and convenor for sessions at the 33<sup>rd</sup> IGC in Oslo (August, 2008) on “The continental lithosphere from geophysical and geochemical data” and “The lithosphere-asthenosphere boundary: nature, formation and evolution from Hadean to now” respectively.

Sue O’Reilly continued as a member of the Steering Committee for the DEST NCRIS process and the GEMOC Geochemical Analytical Unit (see the *Technology Development* section) at Macquarie was designated as one of three National Nodes in Geochemistry that will receive funding for five years under the Earth Composition and Evolution Project in the NCRIS AuScope Program (awarded \$42.8 m over the next 5 years ([www.auscope.org.au/](http://www.auscope.org.au/))).

## 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*



*GEMOC participants with Marco Scambelluri, Costanza Bonadiman and Massimo Coltorti at the 2007 European Mantle Workshop (EMAW) on the Petrological Evolution of the European Lithospheric Mantle from Archean to Present Day, Ferrara.*



*Elena Belousova getting the feel of granites at the 6<sup>th</sup> International Hutton Symposium on the Origin of Granites and Related Rocks, Stellenbosch, South Africa.*



# GEMOC's research program

GEMOC aims to achieve an integrated understanding of the evolution of the Earth and other planets to better understand the surface environment.

## 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 understand the processes responsible for the evolution of Earth's chemical reservoirs
- to use quantitative modelling to simulate Earth's geodynamic evolution
- to define the systematics of element redistribution in the mantle and crust
- to define timescales of magmatic and erosional cycles
- to understand mantle melting dynamics, the influence of recycled components and their ultimate contribution to plumes and the subcontinental lithosphere
- to constrain models of the crust and lithospheric mantle from geophysical datasets, through integration of geophysical, petrological and geochemical information
- to define the tectonic and geochemical processes that have created distinct 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 provide a new framework for area selection for a wide spectrum of economic deposits, by linking deep Earth 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

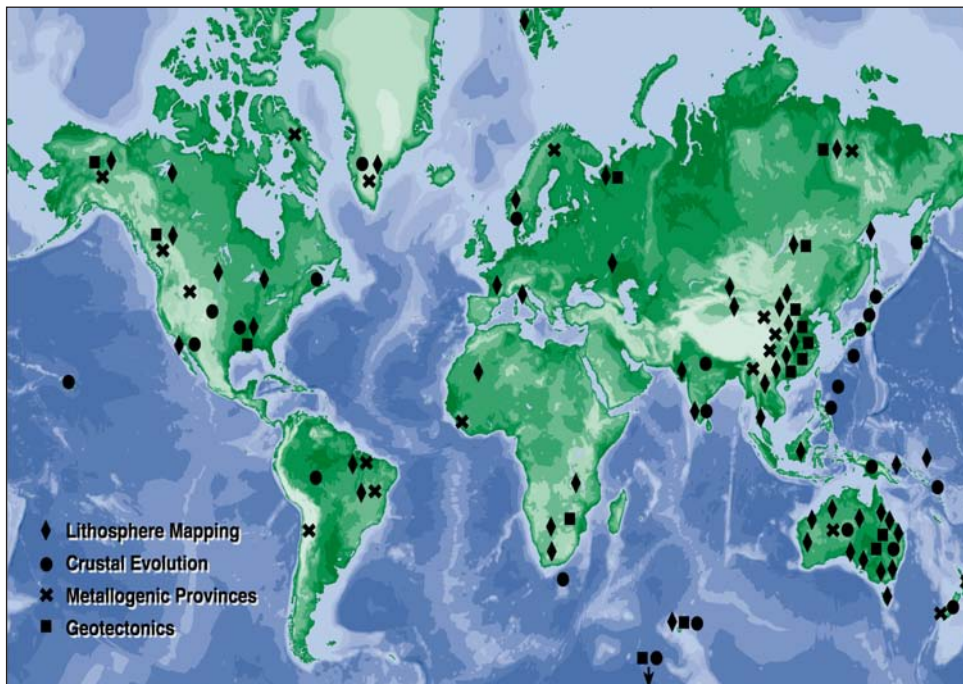
**T**HERMAL ENERGY TRANSMITTED FROM THE DEEP EARTH (core and convecting mantle) provides the energy to drive lithosphere-scale processes. Mantle-derived fluids and the tectonic environment control element transfer across the crust-mantle boundary and control commodity distribution in the accessible crust. The nature of mantle heat transmission reveals information on fundamental deep Earth processes from the core-mantle boundary to the surface. The lithology of the Earth's lithosphere can be mapped 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

#### WHERE IN THE WORLD IS GEMOC?



#### RESEARCH PROGRAM

The *Research Highlights* section gives an overview of major progress in 2007.

The Research Program for 2007 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 and new expertise in the Earth and Planetary Evolution CoRE.

Modelling of GEMOC's increasing knowledge base about Earth's thermal history and mantle composition through time is yielding new conceptual models for Earth's internal dynamics through time.

### • Mantle Dynamics and Composition

forms 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 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

Experimental studies of mantle minerals: high pressure partition coefficients; water in mantle minerals; role of accessory minerals in controlling mantle fluid compositions [Research Highlights](#)

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

Origin of mantle eclogites

The composition of Earth's core and timing of core formation; core-mantle interaction [Research Highlights](#)

Interpretation of deep seismic tomography

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

Diamonds: origin and clues to deep mantle and lithosphere evolution and structure [Research Highlights and cover](#)

Basalts as lithosphere/asthenosphere probes

Plume compositions, sources and origins [Research Highlights](#)

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

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

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)

U-series analysis of weathering and erosion processes

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

## GEMOC's research program

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*<sup>®</sup>, eastern China, South America, Canada, South Africa, Australia, India, Norway [Research Highlights](#)

Studies of detrital zircons in Paleozoic sediments: origins of terranes in Lachlan Fold Belt  
Formation of Earth's first silicic crust

### **Metallogenesis**

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

Diamond trace elements as clues to diamond formation [Research Highlights](#)

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

Re-Os dating of mantle sulfides *in situ* and timing of mantle processes  
[Research Highlights](#)

Highly siderophile element (including PGE) concentrations in sulfides  
(LAM-ICPMS) [Research Highlights](#)

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

Trace elements in diamonds - source fingerprinting and genetic indicators  
[Research Highlights](#)

### **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

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 [Research Highlights](#)

Evolution of lithospheric composition and Earth geodynamics through time  
[Research Highlights](#)

**F**UNDED RESEARCH PROJECTS WITHIN GEMOC are formulated to contribute to the long-term, large-scale strategic goals and determine the short-term Research Plan. Research goals for each year are linked to the aims of funded projects. Summaries of these projects are given here.

**Funded  
basic  
research  
projects  
for  
2007-2008**

## **Episodicity in mantle convection: effects on continent formation and metallogenesis**

*Craig O'Neill: Supported by ARC Discovery (commences 2008)*

**Summary:** The formation and destruction of supercontinents has far-reaching consequences for the evolution of life, the distribution of Earth's resources, and the shaping of the Earth's crust and surface that support human society. Tools to investigate these supercontinent processes have only recently been developed to the stage where they can be used to investigate the complex interactions of the continent-mantle system. Mantle convection simulations will be used to assess the thermal and dynamic impact the aggregation and dispersal of supercontinents has on the mantle, with a view to understanding the origin of anomalous volcanism often associated with supercontinent breakup.

## **Global lithospheric architecture mapping II**

*Sue O'Reilly, Bill Griffin and Craig O'Neill: Supported by ARC Linkage and BHP Billiton (awarded June 2007, commences 2008)*

**Summary:** Domains of different composition in the deep part of Earth's rigid outer shell (the lithosphere) reflect processes of continent formation and breakup through Earth's history. The boundaries of domains focus the fluid flows from the deeper convecting mantle that may produce giant ore deposits. We will integrate mantle petrology, tectonic syntheses, and geophysics to image the 3-D architecture of the continental lithosphere, and provide a basis for realistic dynamic modelling of the behaviour of these deep continental roots and their response to geodynamic forces through time. This will provide a new approach to identifying predictive relationships between different types of lithosphere domains and structures, and large-scale mineralisation.

## **Tomorrow's *TerraneChron*<sup>®</sup>: new developments, new deliverables and new destinations**

*Elena Belousova: Supported by Macquarie University Innovation Fellowship Program (commenced 2007)*

**Summary:** *TerraneChron*<sup>®</sup> is a unique methodology for studying the evolution of Earth's crust on which we live, and evaluating the metallogenic potential of target terranes. It capitalises on the erosion-resistant properties of zircon, a common mineral in most crustal rocks and easily collected from surface drainages. Zircon is a robust time-capsule; high-technology analytical procedures can yield its crystallisation age, the nature of its source region deep in the Earth's crust or mantle, and the nature of the actual rock it was eroded from. *TerraneChron*<sup>®</sup> is thus a cost-effective tool for mineral exploration in remote, inaccessible or complex terranes, and can be extended to sophisticated basin analysis applications relevant to petroleum reserves. This project will carry *TerraneChron*<sup>®</sup> methodology and delivery to a significantly higher level, and will develop a robust predictive framework for recognising prospective mineralised terranes using data-mining and advanced statistical analysis.



### **Forming Earth's first silicic crust**

*Tracy Rushmer: Supported by Macquarie University MQNS program (Awarded September 2007)*

**Summary:** Earth's earliest history (the Hadean eon) was a different world, yet we have recently discovered that in this unusual environment Earth's first silicic crust, the portion that forms the continents, began to grow and set the stage for the planet we know today. This experimental project aims to address fundamental issues concerning planetary evolution, early Earth and origin of the Hadean magmatism. The approach combines melting experiments performed on rocks with numerical modelling. The results will help allow us to assess the nature of earliest Earth and conditions necessary to produce crust during the Hadean eon.

### **Earth's internal system: deep processes and crustal consequences**

*Sue O'Reilly, Bill Griffin, Norman Pearson, Olivier Alard and Klaus Regenauer-Lieb (with 8 partner investigators): Supported by ARC Discovery (commenced 2007)*

**Summary:** New ways of imaging Earth's interior are providing remarkable insights into its structure and opening the way to a new synthesis linking tectonics, mantle structure and the internal transport of material and energy. We will harness the resources of an interdisciplinary, international team with leading expertise in geochemistry, seismic imagery and numerical modelling, and capitalise on new developments in these fields, to explore the internal dynamics of the Earth to understand how these produced the present structure of our planet. The resulting new conceptual framework for the evolution of the continents and their deep roots will be directly translatable into predictive exploration methodologies for Australia's mineral and energy sector. Outcomes will include significant new information about the structure and formation of the Earth's crust and the underlying mantle. An improved framework for interpreting the architecture of Australia and other continents will be directly relevant to exploration for world-class economic deposits, the Earth resources on which society depends.

### **Trace element analysis of diamond: new applications to diamond fingerprinting and genesis**

*Sue O'Reilly, Bill Griffin and Norman Pearson: Supported by ARC Linkage and Rio Tinto (commenced 2007)*

**Summary:** As diamond crystals grow, deep in the Earth's mantle, they trap minute inclusions of the fluids from which they crystallise. We will use recently developed laser-ablation microprobe techniques to analyse the trace-element patterns of diamond crystals from the Argyle, Diavik and Murowa mines (Australia, Canada and Zimbabwe). The results will define the nature and evolution of the parental fluids of the diamonds, and thus shed new light on the processes of diamond formation and the nature of fluids in the deep Earth. A better understanding of these processes can lead to improved models and techniques for diamond exploration, enhancing the prospect of finding new deposits in Australia and abroad. The project will test the potential of trace-element microanalysis to fingerprint diamonds by source. If successful, this technology will provide economic benefits by reducing theft and illegal mining, which represent significant losses to legitimate companies. Application of this Australian development could reduce the circulation of "conflict diamonds", which would have real social benefits worldwide, especially in some developing countries.

## **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 (ends 2008)*

**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. This research will examine the south eastern tectonic plate boundary of Australia, providing analogues for seafloor-spreading-related crustal processes at present plate boundaries and ancient examples now joined to the Australian continent. The scientific innovation represented by this project will help Australian scientists to better understand an important part of the plate tectonic cycle. This project will be of direct relevance to the Australian minerals exploration industry and will provide better constraints on rift-related metallogenesis.

## **Toward the use of metal stable isotopes in geosciences**

*Olivier Alard: Supported by ARC Discovery (ended 2007)*

**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.

## **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 (ended 2007)*

**Summary:** Stable isotopes of common ore metals (e.g. 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; e.g. 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.

## **Episodicity in mantle convection: effects on continent formation and metallogenesis**

*Craig O'Neill: Supported by Macquarie University Research Fellowship (ended 2007)*

**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.

## **Mantle melting dynamics and the influence of recycled components**

*Simon Turner: Supported by ARC Discovery (ends 2008)*

**Summary:** Precise information on 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. This proposal aims to use U-series isotopes to constrain the rates of mantle melting and residual porosity beneath the Manus basin, Papua New Guinea and the East Pacific Rise. By contrasting normal and enriched basalts we aim to constrain the effect of heterogeneities, including volatiles, on mantle melting. This will radically improve our understanding of mantle melting, which powers the Earth's dynamics. This proposal is directly concerned with the continuing aim of building a sustainable Australia through knowledge of deep earth resources. The more we know about the processes of melting and melt and fluid migration the better we will be able to inform models for resource exploration and volcanic hazard mitigation. Uranium series isotopes are relevant to the very recent history of the planet (< 350 000 years) - time scales which are often overlooked. Application to mantle melting may also have direct application to gold exploration in the Manus basin and elsewhere. It is to these techniques we must look if we are to understand the immediate past as a clue to the immediate future of our planet.

## **The behaviour of geochemical tracers during differentiation of the Earth**

*Bernard Wood: Supported by ARC Discovery (ends 2008)*

**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.



## Discovering the deep mantle: experimental petrology at very high pressures

*Bernard Wood (CI on project based at ANU with H.S. O'Neill and T. Irifune): Supported by ARC Discovery (ends 2008)*

**Summary:** A novel super-hard diamond composite material will be used to double the pressures accessible to experimental investigation under carefully controlled conditions in the 'multi-anvil' apparatus, in order to study the Earth's lower mantle (below 670 km depth). Anticipated results include a better understanding of how the Earth's core formed, how the mineralogy of the lower mantle changes with depth and with redox state, and what controls the strength of the lower mantle, and thus how the mantle convects and how long-lived geochemical heterogeneities might be preserved. The great processes that shape the Earth at its surface, including plate tectonics and continental drift, can only be understood by appreciating how the interior of the Earth works. However, studying the deep Earth is difficult because of the enormous pressures and temperatures involved. This research proposes to simulate conditions in the Earth's lower mantle (that is, below 670 km in depth) by making use of an Australian invented diamond-based ceramic, to double the pressure at which experiments can be performed.

# Research highlights 2007



**T**ERRANECHRON<sup>®</sup> is GEMOC's unique methodology for terrane evaluation. During 2007 collaborative research projects with industry using *TerraneChron*<sup>®</sup> yielded a wealth of information to map crustal history on different scales.

## *TerraneChron*<sup>®</sup> A new tool for regional exploration for minerals and petroleum



- ✓ Based on zircon analyses
- ✓ Efficient and cost-effective
- ✓ Identifies regional tectonic events
- ✓ Dates magmatic episodes
- ✓ Fingerprints crust reworking and mantle input (fertility)

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### What is *TerraneChron*<sup>®</sup>?

The methodology was developed by GEMOC to provide rapid, cost-effective characterisation of crustal history on regional (10-1000 km<sup>2</sup>) scales. It is based on U-Pb, Hf-isotope and trace-element analysis of single zircon grains by laser-ablation ICPMS (single- and multi-collector) methods.

- U-Pb ages, with precision equivalent to SHRIMP
- Hf isotopes trace magma sources (crustal vs juvenile mantle input)
- Trace elements identify parental rock types of detrital zircons

### What kind of samples?

- Regional heavy-mineral sampling (modern drainages: terrane analysis)
- Sedimentary rocks (basin analysis)
- Igneous rocks (dating, specialised genetic studies)

### Applications to mineral exploration

- Rapid assessment of the geology in difficult or poorly mapped terrains
- "Event Signatures" for comparison of crustal histories from different areas
- Identify presence/absence of key rock types (eg Cu/Au porphyries, A-type granites....)
- Prioritisation of target areas

### Applications to oil and gas exploration

In provenance studies, the information from Hf isotopes and trace elements provides a more detailed source signature than U-Pb ages alone.

- *TerraneChron*<sup>®</sup> defines the crustal history of the source region of the sediment
- Changes in direction of basin filling track regional tilting, subsidence
- Stratigraphic markers in thick non-fossiliferous sediment packages
- Proven applications in the North Sea

Visit the  
*TerraneChron*<sup>®</sup>  
web page at  
[www.es.mq.edu.au/GEMOC/TerraneChron.html](http://www.es.mq.edu.au/GEMOC/TerraneChron.html)



**Where  
on/in Earth are  
Diamonds?  
(Diamond,  
subcalcic  
garnet and  
mantle  
metasomatism)**

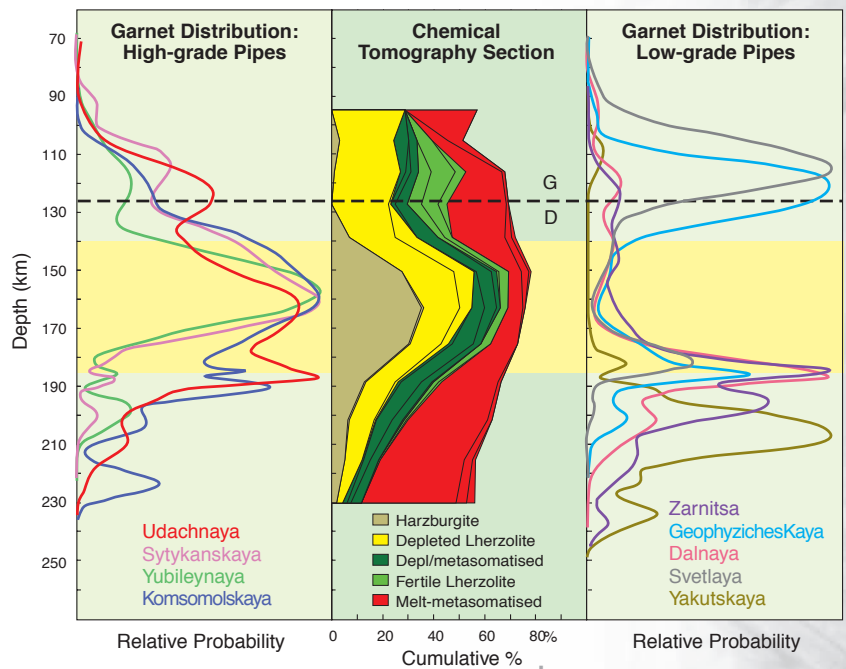
**K**IMBERLITES ARE THE MAJOR SOURCE OF NATURAL DIAMONDS, but fewer than 1% of kimberlites contain economic quantities of diamond. Even within a single kimberlite field, economic and barren kimberlites may occur within very short distance of one another, and it is rarely obvious what has controlled the small-scale distribution of diamond in the mantle volumes sampled by different kimberlites. However, a spinoff observation arising from GEMOC's ongoing 4-D Lithosphere Mapping project may have provided an important clue (*GEMOC Publication #449*).

The heavy mineral concentrates of

kimberlites typically contain xenocrysts of both peridotitic garnet and chromite, derived by disaggregation of the mantle wall rocks sampled by the kimberlite. The Ni content of the garnets, and the Zn content of the chromites, can be used to measure their temperature of equilibration, and these temperatures can be translated to depth estimates for each grain, by reference to a local geotherm derived either from the garnet populations or from peridotite xenoliths. With this information, we can draw curves showing where the kimberlite picked up its load of garnet and chromite during ascent to the surface.

In the Daldyn and Alakit kimberlite fields of Siberia, strongly depleted harzburgitic rocks are largely confined to a narrow depth range of 140-190 km, whereas less depleted lherzolites dominate the mantle section above and below the harzburgitic band. Numerous studies of diamond-bearing xenoliths and mineral inclusions in diamonds from these two fields show that the vast majority of the diamonds in the pipes come from the harzburgitic band. Depth-distribution curves of garnet from these two fields (Fig. 1) show that most of the garnets in the pipes with high diamond grade come from the harzburgite-rich level, whereas the low-grade pipes contain lherzolitic garnets from deeper and shallower depth, but few grains from 140-190 km depth. Similar patterns have been found in the Archangelsk kimberlite province of NW Russia.

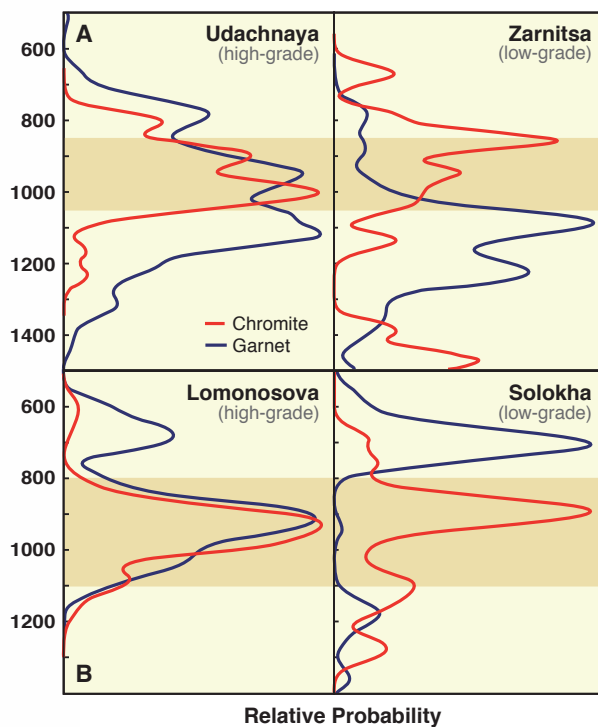
The distribution of chromite is quite different – it peaks in the harzburgitic layer in both the high-grade and the low-grade pipes (Fig. 2). It appears that (1) all of the kimberlites have sampled the harzburgite-rich layer; (2) chromite is ubiquitous through the layer; (3) diamond and garnet occur together, but only locally, within the layer. This suggests a genetic relationship, in which the metasomatic processes that deposit diamond also are responsible for depositing garnet. Another key observation is that chromite xenocrysts in barren kimberlites typically are more oxidised (with higher mean  $Fe^{3+}/Fe^{2+}$ ) than those from high-grade pipes, and chromites included in diamond generally have very low  $Fe^{3+}/Fe^{2+}$  (Fig. 3).



*Figure 1. Chemical tomography section for Daldyn kimberlite field (9 kimberlites, 858 garnets), showing relative abundance at each depth of garnets from harzburgites, depleted lherzolites, depleted but metasomatised lherzolites, fertile lherzolites (also interpreted as metasomatic products) and lherzolites metasomatised by silicate melts. The strong concentration of harzburgitic garnets in 140–180 km depth range is marked by a shaded horizontal band. Curves show distribution of sampling depths of garnet grains entrained in high-grade (left) and low-grade (right) kimberlites from Daldyn field and adjacent Alakit field. Horizontal dashed line is graphite (G)-diamond (D) phase transition.*



Figure 2. Temperature (depth) distribution of garnets and chromites in high- and low-grade kimberlites. A: Daldyn field, high-grade Udachnaya pipe and low-grade Zarnitsa pipe. B: Arkhangelsk field, high-grade Lomonosovskaya pipe and low-grade Solokha pipe. Shaded band shows temperature range of the depleted harzburgite-rich layer beneath each field (cf. Fig. 1).



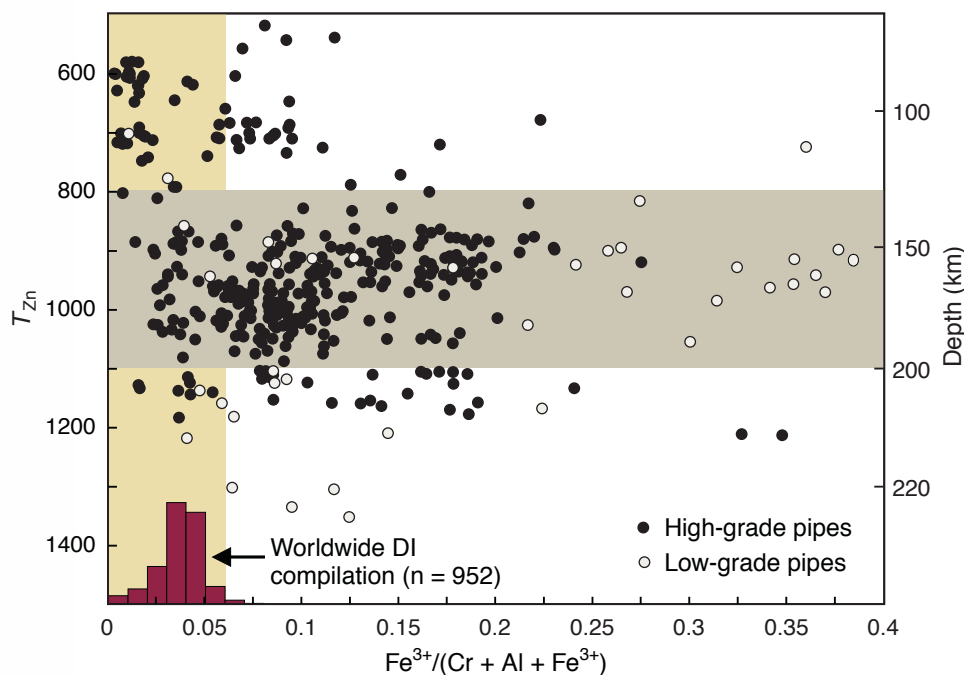
These observations suggest that diamond and harzburgitic garnet are linked to the same metasomatic process, through generalised reactions of the type:  $\text{CH}_4$  (in fluid) +  $\text{Fe}^{3+}$  (in chromite) + Si, Ca, Mg (in opx, fluid)  $\rightarrow$  diamond + garnet +  $\text{H}_2\text{O}$  +  $\text{Fe}^{2+}$  (in chromite).

We suggest that where melts or fluids derived from below the depleted lithospheric mantle first penetrate the harzburgitic layer along fractures,  $\text{CH}_4$ -rich fluids derived from them react with

the wall rocks, producing subcalcic garnet, diamond and a reduced diamond-bearing harzburgite. As the melts themselves penetrate into the lithosphere, metasomatism adds more Ca, Al and Fe, refertilising the harzburgite to produce lherzolites. Oxidation during this metasomatism would tend to destroy diamonds, producing a positive correlation between harzburgitic minerals and diamond, and a negative correlation between lherzolitic minerals and diamond, as observed in many kimberlite fields. Volumes of the harzburgitic layer that were never metasomatised would contain neither diamond nor garnet.

These processes could operate on the scale of individual melt conduits, producing very small-scale variations in diamond content within the lithosphere.

Figure 3.  $\text{Fe}^{3+}/(\text{Cr} + \text{Al} + \text{Fe}^{3+})$  of chromites vs depth in kimberlites from the Arkhangelsk field. Box shows range of values in diamond inclusions (DI) worldwide; horizontal band shows depth distribution of harzburgitic rocks.



The diamond grade of later kimberlites would be dependent on their path through this heterogeneous mantle (Fig. 4). Kimberlites following old conduits that experienced mainly the first stages of the metasomatism could have high grades; those that sampled unmetasomatised volumes would be barren; those that followed well-worn magma conduits, now lined by lherzolite, might contain diamonds, but at lower grades.

This picture of the mantle suggests that it might be possible to analyse the distribution of high-grade and low-grade pipes within a single kimberlite province to map out the positions of the best structures at depth, and to target detailed brown-field exploration efforts.

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Funded by: MURF, MUNS, ARC Discovery

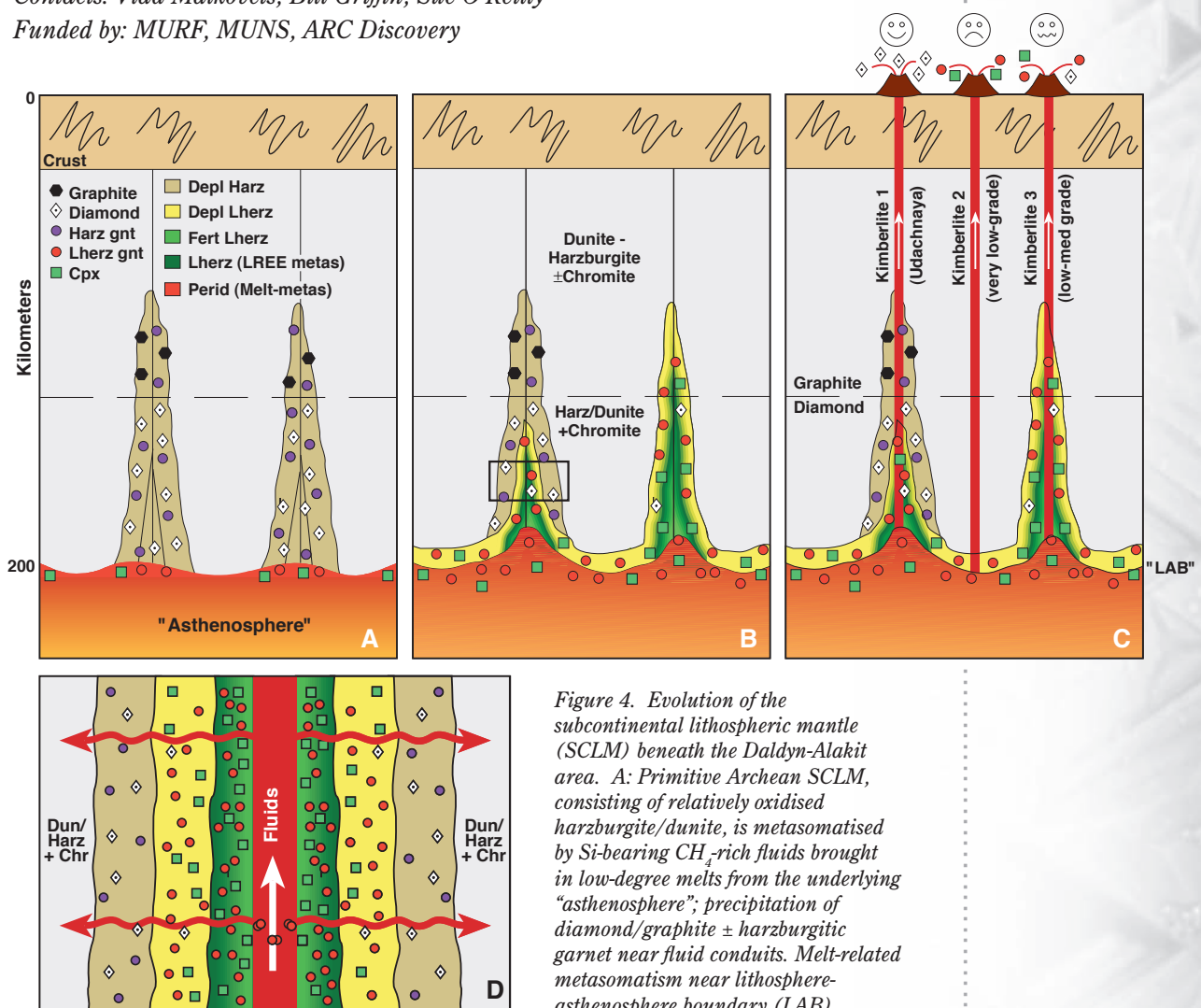


Figure 4. Evolution of the subcontinental lithospheric mantle (SCLM) beneath the Daldyn-Alakit area. A: Primitive Archean SCLM, consisting of relatively oxidised harzburgite/dunite, is metasomatised by Si-bearing  $CH_4$ -rich fluids brought in low-degree melts from the underlying "asthenosphere"; precipitation of diamond/graphite  $\pm$  harzburgitic garnet near fluid conduits. Melt-related metasomatism near lithosphere-asthenosphere boundary (LAB) converts some harzburgites to fertile

lherzolite by addition of Ca, Fe, Al. B: Continued input of melts/fluids; reduced harzburgite does not precipitate diamond/graphite; melt-related metasomatism refertilises harzburgite to lherzolite at base of lithosphere and along conduits (weakly in left conduit, more extensively in right conduit); relict harzburgitic diamonds in lherzolites. C: Kimberlite eruption (Devonian); high-grade pipes sample remnants of Stage-A modified mantle. Barren pipes sample least-metasomatised mantle and lack harzburgitic garnets and diamonds; some low-grade pipes sample highly metasomatised mantle with relict diamonds. D: Detail of melt conduit showing progressive metasomatism of wall rocks, first by  $CH_4$ -rich fluids expelled from melts, and then by the melts themselves. Abbreviations: Dun—dunite; Harz—harzburgite; Lherz—lherzolite

Chemical impurities in gem-quality diamonds

Figure 1. White octahedral diamond with smooth surface.



Figure 2. White octahedral diamond with rough surface covered with trigons, scale divisions = 1 mm.

Figure 3. Surface with trigons and micro-inclusions at 15 µm beneath the diamond surface.

THE STUDY OF DIAMONDS is a very attractive topic since they can reveal unique information from the Earth's mantle. A comprehensive study of diamonds includes both simple and advanced methods as morphologic description, cathodoluminescence imagery, vibrational spectroscopy and stable isotope analyses. Recently, a methodology developed at GEMOC using LA-ICPMS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry) has made it possible to investigate the very low levels of chemical impurities found in micro-inclusions within the diamonds. The technique consists of ablating the diamond surface with a laser beam, which drills a hole approximately 50 µm deep over about 2 minutes. The result is a time/space-resolved signal that reveals the chemical composition of the diamond across the depth analysed. These chemical impurities are interpreted as the composition of the fluids that once deposited that diamond in the mantle.

In our current research, the LA-ICPMS technique meets a simple and traditional method of studying diamonds: their morphology and surface textures. Diamonds are formed as octahedral and cubic crystals. Despite their well-known hardness, certain conditions (high oxygen fugacity) can corrode the surface of diamonds, forming a variety of corrosion figures, or etching pits. This dissolution can happen during the diamond's residence in the mantle and/or in the magma during its ascent to the Earth's surface. In octahedral diamonds, one of the most common corrosion figures is the trigon. These are triangular pits, either point- or flat-bottomed. The point-bottomed ones are formed at the end of crystal defects, where dislocation lines emerge from the centre of the diamond. The flat-bottomed trigons have been related to clusters of chemical impurities or crystal defects. For the first time we could test this hypothesis using LA-ICPMS.

In our investigation, we analysed gem-quality octahedral diamonds from Canada. Most of them have smooth surfaces (Fig. 1) but some have abundant flat-bottomed trigons (Fig. 2) covering some or all the surfaces. Using LA-ICPMS, we found that abundant flat-bottomed trigons occur only where a sub-surface layer is enriched with various trace elements, as Ca, Mg, Fe, K, Ba, Sr, LREE, among others. The surfaces with trigons were examined in the microscope (Fig. 3), and micro-inclusions were found distributed in a thin layer 15-20 microns beneath the surface, corresponding to depth of the flat bottoms of the trigons. The micro-inclusions are rounded and small single fractures, which can be both crystallographically [111] and randomly oriented, extend from them, producing a tadpole-like shape (Fig. 3). Such inclusions are absent beneath faces that lack trigons. The chemical composition of the micro-inclusions is similar those of carbonatitic fluids, suggesting that fluids of this composition were able to wet some surfaces of the growing diamonds, before becoming trapped beneath a new layer of "clean" diamond. The

role of such mantle fluids in the formation of diamonds is a key direction for further research.

Contacts: Debora Araujo, Bill Griffin, Sue O'Reilly, Norman Pearson

Funded by: ARC Linkage, Macquarie University and Rio Tinto



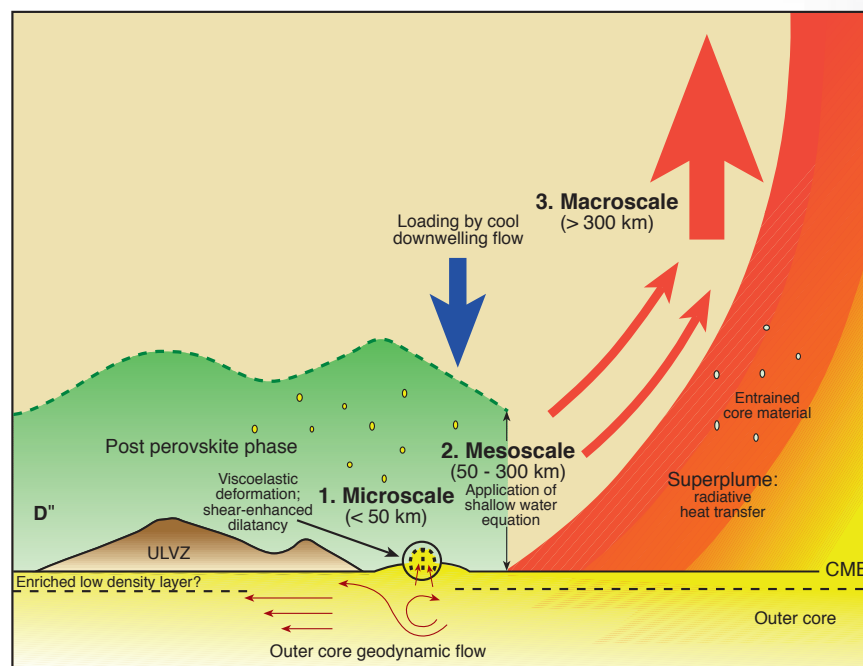


**Core-mantle boundary interactions: The deep mantle goes with the flow**

**O**UR UNDERSTANDING OF THE EARTH'S CORE-MANTLE BOUNDARY (CMB) region has improved significantly over the past several years, due in part to the discovery of the “post-perovskite phase”, a polymorphic transition in the deepest levels of the mantle. The post-perovskite mineral phase is known through experiment and theoretical calculations to be stable in the lowermost ~150 km of the mantle (the D'' layer). Seismic data suggest that the CMB region is highly heterogeneous; this heterogeneity may be partly due to the structure of the

post-perovskite phase, and may also reflect chemical and physical interaction between outer core liquid and the lowermost mantle. In 2007, we proposed a new mechanism of mass transfer across the CMB and suggested possible repercussions that include the initiation of deep, siderophile-element-enriched mantle plumes. We view the nature of core-mantle interaction, and the geodynamic and geochemical ramifications, as multiscale processes, both spatially and temporally (Fig. 1). On the microscale (1-50 km), the effect of loading and subsequent shearing of the CMB region where cold downwellings impinge on the outer core can drive local flow of the outer core fluid upwards into the D'' layer. This process can be linked to the larger-scale processes operating on the mesoscale (50-300 km) and macroscale regimes (> 300 km). As Fe-rich liquids from the outer core infiltrate into the D'' layer, they will interact with the silicates and enrich them in Fe. These processes may also impact on global mantle dynamics. Reacting Fe-rich post-perovskite material may be partially responsible for ultra-low-velocity zones (ULVZ: Fig. 1), which are zones in the D'' region where silicate melt is present, and will influence the nature of thermal conduction across the CMB. Infiltration of outer-core liquids into D'' also provides a mechanism for imparting a distinctive HSE chemical signature to the lowermost mantle, from where it can be transferred to plumes and the minerals enclosed in some lower-mantle diamonds (see *GEMOC publication #229*). Infiltration of core-derived fluids into the lower mantle requires shear-induced dilatancy to allow fluid movements; encouragingly, there is some new experimental evidence in support of the dilatant mechanism at elevated PT conditions.

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*Funded by: MQNS and NASA*

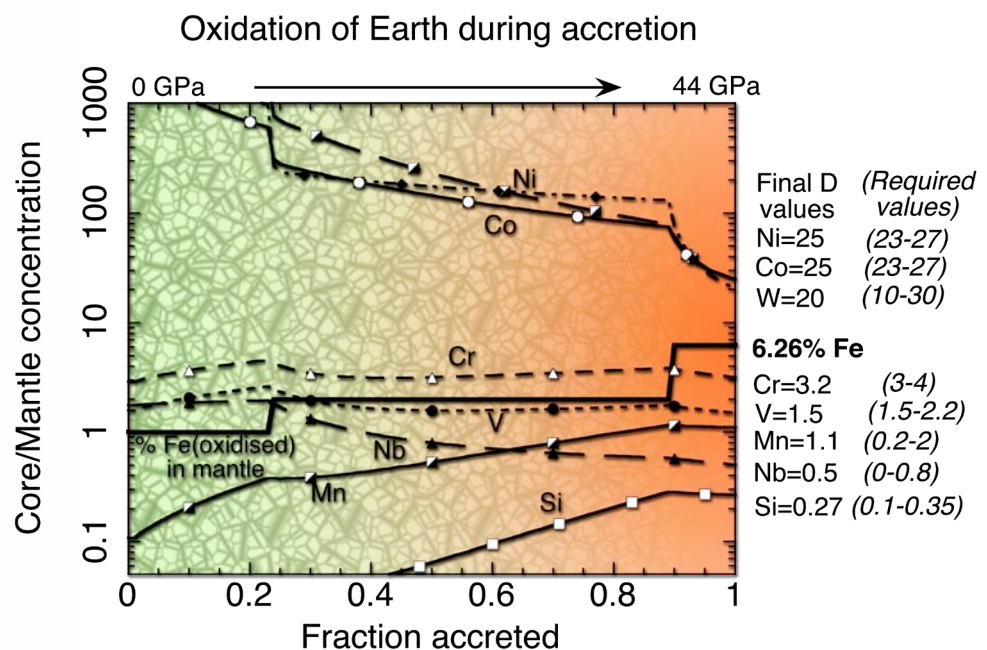


*Figure 1. Summary diagram showing the proposed relationship between each of the three key length scales described above.*

Core formation, crystallisation of the mantle and oxidation of the Earth

THE EARTH APPEARS TO HAVE GROWN FROM SMALLER ASTEROIDAL BODIES over a period of about 40 million years after the beginning of the solar system, 4567 million years ago (see *Research Highlight 2006*). Research at Macquarie is concentrating on understanding the timing and processes by which the Earth segregated its metallic core and the crust began to form from the silicate mantle. The way in which the research is done is by experimentally simulating the high pressure, high temperature conditions of, for example, metal separation and determining the partitioning of suites of important chemical elements between the metal and silicate liquids. Then, by comparing the compositions of the silicate parts of the experiment to that of the silicate part of the Earth, we can start to place constraints on how core formation occurred.

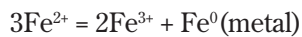
Figure 1. Changes in partition coefficients for different elements, as the Earth grew. Note the apparent increase in the oxidised-iron content of the mantle during this process.



An important requirement is a reference point for the composition of the bulk Earth. This is provided by the primitive meteorites which are chemically similar to the Sun and which have striking affinities with the Earth, Mars and the Moon (see *Research Highlight 2006*). Taking these meteorites as representatives of protoplanetary material we find that the silicate part of Earth is depleted in refractory “siderophile” elements (Fe, Ni, W, etc) because of extraction to the core but undepleted in refractory “lithophile” elements which remain in the mantle. By mass-balance we can calculate the partitioning of the siderophile elements between the core and the silicate mantle and compare the results to our experiments. The results indicate that the Earth must have started out very reduced and then become more oxidised as it grew. This is the only way we can match the core-mantle partitioning of all the well-studied elements. Figure 1 shows a typical oxidation path which correctly reproduces the core-mantle partitioning of a large number of elements. Progressive oxidation, as represented by the weight % of oxidised iron in the mantle is modeled, for simplicity in 2 steps, but in reality was probably continuous.

If the Earth became oxidised as it grew, the important questions are: (a) how did it happen? and (b) what are the implications? The answer to the first question

is that there are several possible mechanisms which call on outside influences (accretion of oxidised material, for example) and are hence unconstrained. Recent discoveries demonstrate, however, that there is a mechanism by which the Earth self-oxidised. This arises from the observation that silicate perovskite, the mineral which is stable throughout the Earth's lower mantle, has a very strong affinity for ferric iron,  $\text{Fe}^{3+}$ . We now know that this affinity is so strong that it forces  $\text{Fe}^{2+}$  to disproportionate to form  $\text{Fe}^{3+}$  and metallic iron:



Perovskite started to become stable in the Earth's interior when the planet reached 10% of its current size (about the size of Mars). Thereafter, segregation of metal to the core combined with continuous impact of accreting bodies "pumped-up" the  $\text{Fe}^{3+}$  content of the mantle. This occurred by continuous dissolution and reprecipitation of perovskite in the lower mantle (see Fig. 2).

The important point about Earth's self-oxidation is that it was caused internally rather than by, for example, subduction of oxidised material after the rise of atmospheric oxygen. This explains why all measurements of the oxidation states of materials from the mantle indicate no change since the Archean and no effect of the rise of atmospheric oxygen. The process took place earlier and was internal (see *GEMOC Publication #513*).

Contact: Bernard Wood

Funded by: Federation Fellowship, ARC Discovery, Macquarie University

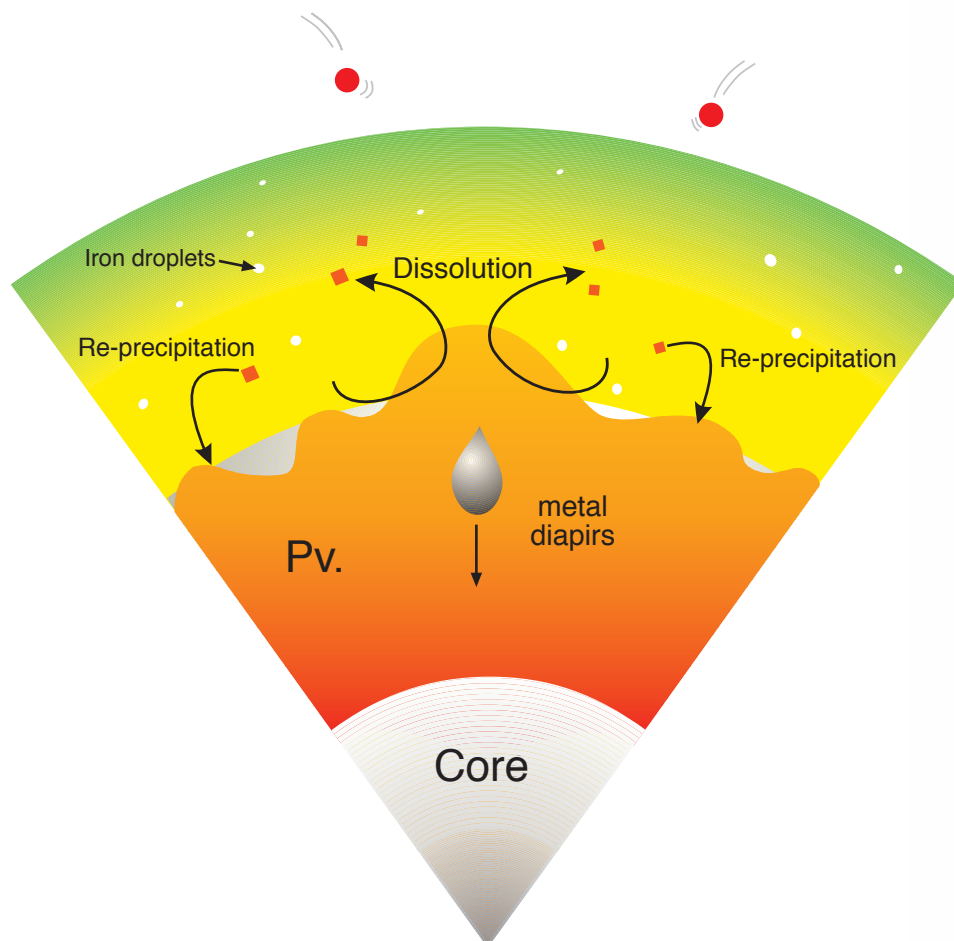


Figure 2. Cartoon illustrating the convective dissolution and reprecipitation of the high-pressure perovskite phase. As the Pv sequesters  $\text{Fe}^{3+}$  native iron (melt) is formed and sinks into the core.

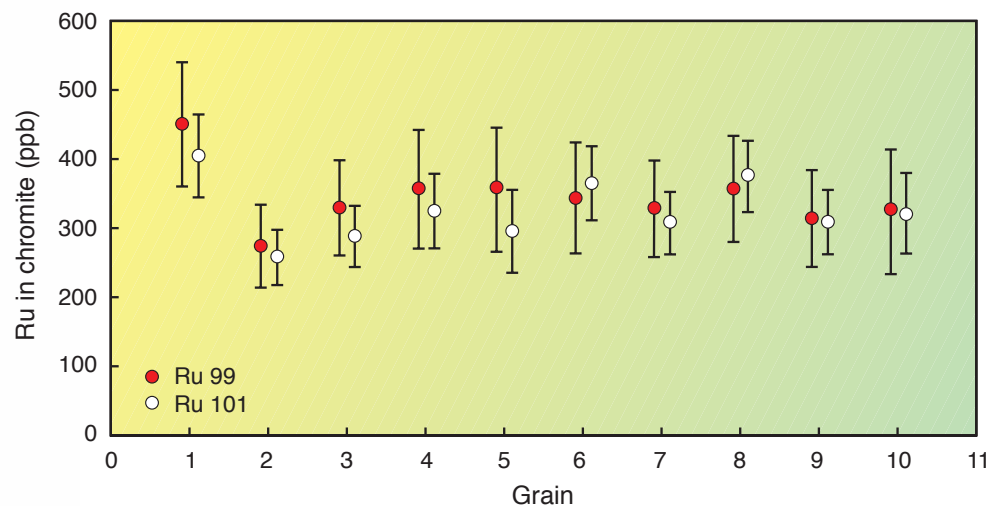


Nickel Sulfide Deposits – Developing New Exploration Tools

A LARGE PROPORTION OF THE WORLD'S NICKEL PRODUCTION comes from deposits of Fe-Ni-Cu sulphides within mafic/ultramafic intrusions and flows, e.g. komatiites and komatiitic dunite bodies. The Norseman-Wiluna Greenstone Belt (NWGB), Yilgarn craton (Western Australia), is one of the world's major nickel provinces, containing over ten million tons of nickel metal, and hosts two of the world's largest komatiite/komatiitic dunite-hosted Ni-Cu-(platinum-group element: PGE) deposits. Since the first nickel boom in the 1970s exploration for more world-class deposits has continued – but the complex deformation and metamorphism of the NWGB make it difficult to understand the stratigraphic relationships and the processes responsible for Ni-Cu-(PGE) ore localisation.

A long-standing goal of research on komatiite-associated nickel-sulfide (NiS) deposits has been the development of lithogeochemical indicators that can guide exploration. Such indicators have two purposes: 1) to discriminate mineralised from barren komatiite belts, and 2) to identify vectors towards sulphide ores within mineralised sequences. Lithogeochemistry of komatiites is currently applied in NiS exploration in two distinct ways: indirectly, through identification of favourable geological environments, and more directly, through identification of signatures that record sulphide liquid segregation.

Figure 1. Ruthenium concentration in komatiitic chromite, calculated from the isotopes <sup>99</sup>Ru and <sup>101</sup>Ru. Each number represents one analysed grain. Constant Ru concentrations on the sample scale indicate that Ru occurs in solid solution, as micro-inclusions would cause scattered patterns.



The AMIRA P710A project was established to find out if the PGE distribution in mafic and ultramafic systems is related to NiS mineralisation, and to test the applicability and usefulness of PGE lithogeochemistry in the discrimination of barren and mineralised units. The project is a co-operation between GEMOC, the Centre for Exploration Targeting (CET) of the University of Western Australia and CSIRO Exploration and Mining, and is funded by BHP Billiton, Norilsk Nickel, Independence, and Meriwa.

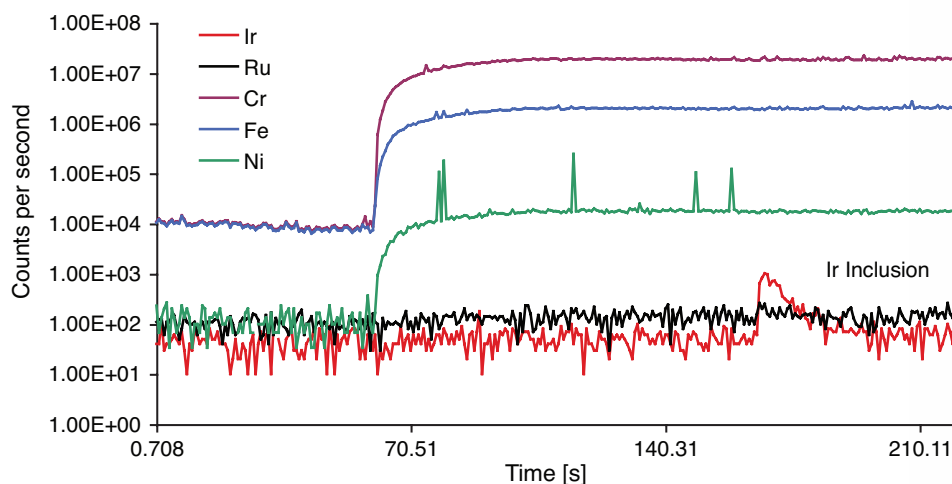
GEMOC's contribution to this project builds on its expertise in understanding the behaviour of PGE in the mantle and its world-class micro-analytical facilities. We are investigating mechanisms of PGE fractionation in mafic and ultramafic melts, to identify PGE signatures in oxides and silicates from S-undersaturated systems and develop vectors towards the sulphur-saturated part of a system, where NiS mineralisation might occur. The study started with komatiites, representing the most primitive magmas, and will move to more fractionated magma types, such as komatiitic basalts, ferropicrites and dolerites.

The generally accepted model for NiS ore-formation in komatiitic systems requires the interaction of a sulphide liquid with a silicate melt. As PGE (Os, Ir, Ru, Rh, Pt, Pd) partition very strongly into sulphides, the remaining silicate melt will be depleted in PGE. A depleted whole-rock PGE signature might reflect interaction with a sulphide liquid, and the degree of depletion might increase towards NiS mineralisation. However, the PGE contents of melts reflect many factors, including parental magma composition, initial sulphur content, oxygen fugacity and wall-rock contamination, so a PGE-depleted signature may not necessarily reflect segregation of sulphides. Therefore, all lithochemical vectors currently used in exploration for komatiite-hosted NiS deposits provide inconclusive and contradictory results. Rather than using absolute levels of PGE, sulphide segregation might be recognised by using correlations of the PGE with elements that record the evolution of the magmatic system. Instead of interpreting whole-rock signatures, this study will directly use PGE signatures in primary magmatic phases (e.g. chromite and olivine) to determine if a system equilibrated with sulphides and formed a NiS deposit.

For this purpose, a method for the *in situ* analysis of Ru in chromite by Laser Ablation ICP-MS is being developed to provide the industry with a fast but precise analytical technique in the exploration for NiS deposits. The initial results show the first convincing evidence that Ru exists as solid solution in komatiitic chromite (Figs. 1 and 2) – and suggest we can recognise chromites from barren and mineralised sequences using the Ru concentrations in chromite.



*Komatiitic flow field in the Norseman-Wiluna Greenstone Belt near Kambalda (Yilgarn Craton, Western Australia).*



*Figure 2. Time-resolved signals for several elements in a chromite from a komatiitic basalt, during a LAM-ICPMS analysis. An easily detectable Ir micro-inclusion less than 1 µm in diameter (black line) does not affect Ru abundance (red line), indicating that Ru is in solid solution in the chromite.*

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Funded by: Macquarie University iMURS, ARC Linkage, Industry*



Crust-mantle evolution in NW Spitsbergen: Re-Os, U-Pb and Hf isotope data

**S**PITSBERGEN, THE LARGEST ISLAND OF THE SVALBARD ARCHIPELAGO, is located in the northern Arctic Ocean. The Svalbard archipelago lies near the north-west margin of the Eurasian plate and represents an uplifted part of the submerged Barents Shelf. The NW tip of Spitsbergen is fertile ground for studying the evolution of the uppermost mantle and continental crust during continental breakup. The exposed crustal rocks are metamorphosed igneous rocks of the NeoProterozoic to Caledonian Hekla Hoek Group. Xenoliths derived from the mantle and lower crustal are abundant in Holocene basaltic flows and pyroclastics that make up the Bockfjord Volcanic Complex. *In situ* isotopic techniques have been used to date thermal events in the upper crust (zircons from glacial streams), lower crust (zircons in granulite xenoliths) and upper mantle (sulfide inclusions in mantle xenoliths).

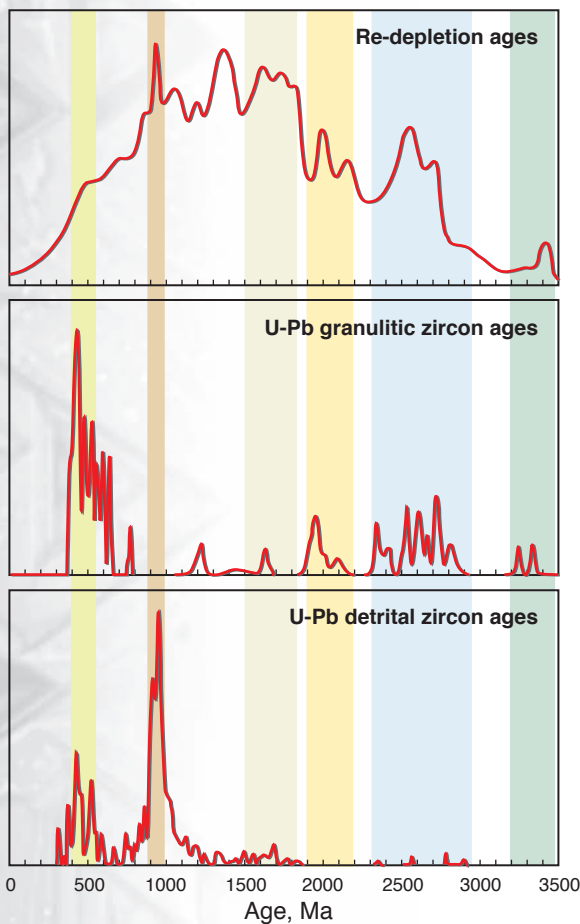


Figure 1. Thermal events recorded in sub-continental lithospheric mantle, lower upper continental crust under NW Spitsbergen, revealed from *in situ* Re-Os, U-Pb and Hf isotope data.

*In situ* U-Pb and Hf-isotope analysis have been performed on detrital zircon grains collected from outwash streams of the Adolfbreen Glacier, which drain a large area of outcropping Hekla Hoek formation. The most significant age population is Grenvillian (*ca* 0.94 Ga), and the Paleozoic component is surprisingly small, considering that Svalbard was affected by the Caledonian Orogeny (*ca* 0.41-0.32 Ga) with a climax in Silurian time. There are some scattered mid-Proterozoic ages, and a few grains with Archean ages (*ca* 2.9-2.3 Ga). On the age data alone, we could suppose that the crust is relatively young. However, the Hf isotope compositions of the zircons (Fig. 2) show that the Grenville and Caledonian zircons crystallised from magmas that were derived largely from much older crust – ranging from Mid-Proterozoic to Archean.

Zircon grains separated from the lower-crustal granulite xenoliths give an even more surprising story. There is a large Paleozoic population, but the Grenvillian population that is so prominent in the upper crust is absent. Instead, there are important populations in the Paleo-Proterozoic (2.0-2.5 Ga) and Archean (most 2.5-3.0 Ga, extending back to *ca* 3.3 Ga). The Hf isotopes indicate that juvenile crust was formed mainly in Archean time, whereas the Paleozoic magmatic event involved mixing between juvenile mantle-derived magmas and the ancient lower crust. The prominence of mafic lithologies suggests that basaltic magmas underplated the crust before and during the Caledonian orogeny.

*In situ* Re-Os analyses of sulfides in mantle-derived peridotite xenoliths give model ages ranging Early- Mid-Archean (*ca* 3.4 Ga) to Paleozoic (*ca* 0.4 Ga) (Fig. 1). The oldest sulfide populations (*ca* 3.4-3.3 Ga and 2.8-2.4 Ga) are preserved in the most depleted peridotites and are interpreted as minimum ages for the oldest melt-depletion events. They match the prominent older population of zircon ages in the lower-crustal xenoliths. Another sulfide population between *ca* 1.8-2.3 Ga has some equivalents in the zircon data from the lower crust, but upper-crustal ages in this range are rare. The sulfide populations between *ca* 1.8-1.3 Ga have few matches in the crustal ages from zircons, and may represent mixing between younger and



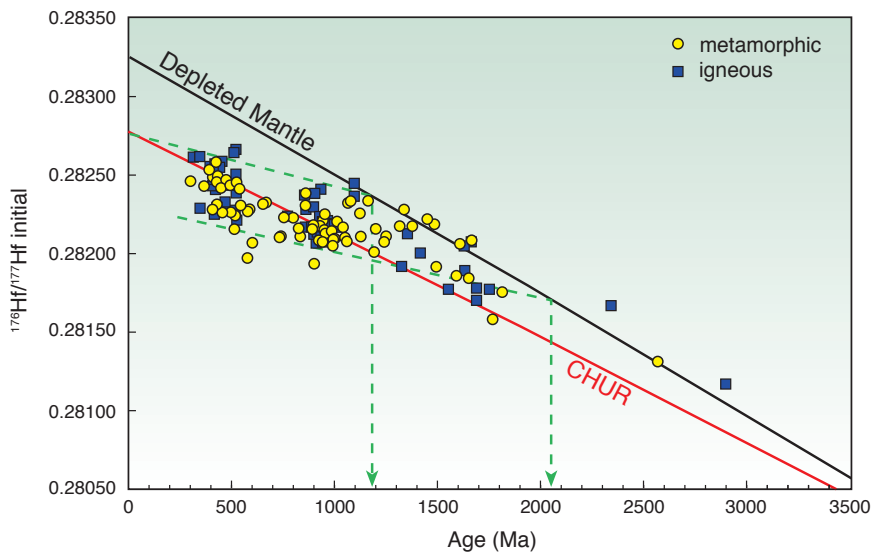


Figure 2. Hf-isotope data plotted against age, for zircons from Bockford. Sample taken in the outwash from Adolfbreen Glacier.

older sulfide generations. One significant age population ( $T_{MA}$  model age *ca* 0.94 Ga) correlates with the major Grenvillian crustal tectonic event seen in the zircon data (Fig. 1). The youngest sulfide population ( $T_{RD}$  model age *ca* 0.52 Ga) may represent refertilisation of the lithospheric mantle by metasomatic fluids introduced in pre-Caledonian time.

The correlation between major mantle events recorded in the sulfide populations, and thermal events recorded by magmatic zircons, suggest that several of these tectonic events, involving magmatism and reworking of older crust, affected the whole lithospheric column in this region from at least the Early/Mid-Archean to the Caledonian time (Fig. 1). While the Grenvillian and Caledonian events have effectively reworked the upper crust, the Hf-isotope data, and the ages from the lower crust and mantle, show that the older lower crust and its underlying mantle lithosphere were preserved through these major orogenies.

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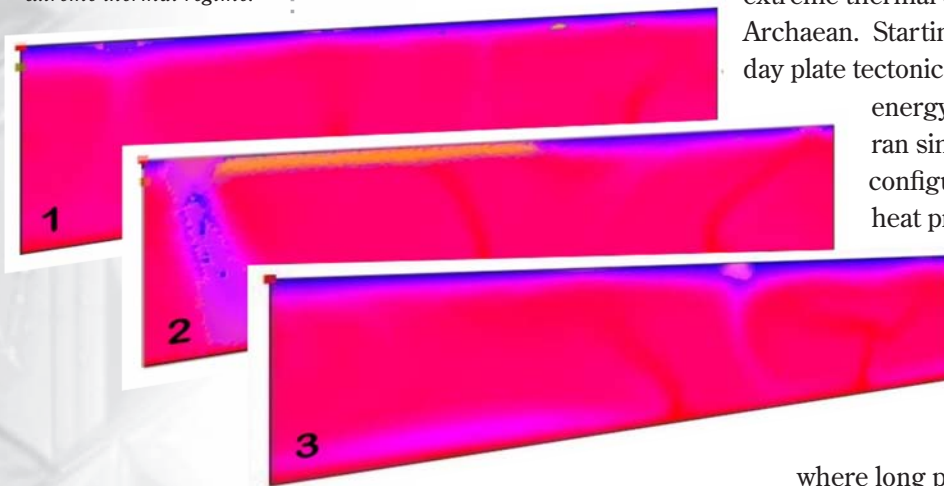
*Funded by: iMURS, ARC Discovery (O'Reilly, Griffin et al.), EPS and MQ postgraduate grants*



The view from Bockford: Sverrefjell volcano to the left, the crags of the Hekla Hoek gneisses in the distance, and Adolfbreen Glacier pushing down to the sea.

Extreme plate tectonics

Figure 1. Simulations show that when pushed to extremes - either through heat, size or lithospheric strength - plate tectonics can break down and mantle convection enters a regime known as episodic overturn, where long periods of quiescence are interspersed with rapid subduction events, accompanied by large pulses of mantle melting and plate velocity. 1-3 shows snapshots of such an event (sowing temperature field and mantle melting). Earth may have been in such a regime in its early history due to the extreme thermal regime.



**W**HY DOES PLATE TECTONICS OCCUR ON EARTH and not on other terrestrial planets? How long has Earth had plate tectonics? Would exosolar super-sized Earths around other stars have plate tectonics?

These questions were the impetus for work completed at GEMOC this year exploring the conditions for plate tectonics through numerical simulations (see *GEMOC publication #497*). To understand plate tectonics, we must understand the coupling between the convecting mantle and rheologically complex tectonic plates. If the driving stresses generated by the engine powering plate tectonics - mantle convection - are larger than the resistive strength of the plate, then the tectonic plate can fail, a crucial requirement for functional plate tectonics. If not, then the planet's lid will remain stagnant, much like the surface of Mars or Venus today.

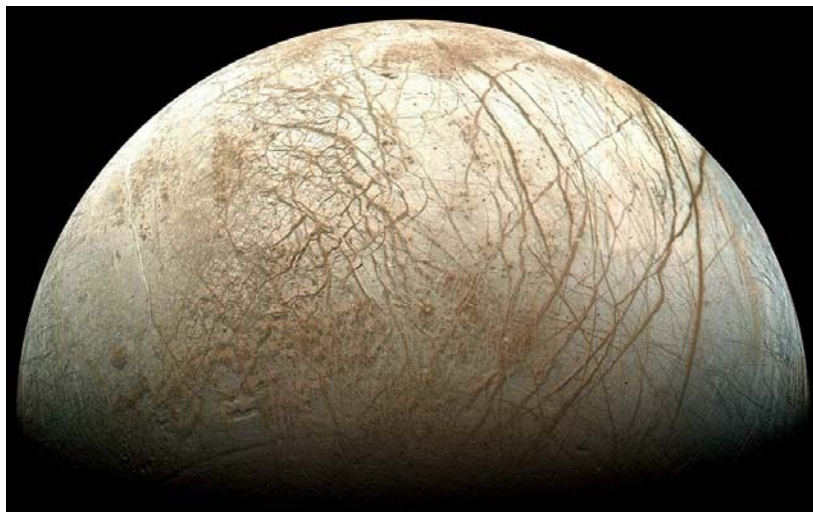
The studies used a combination of scaling arguments and numerical models to explore the transition of systems from stagnant-lid into active-lid (ie. plate tectonic) modes. We found that a critical factor is the depth to the brittle-ductile transition (BDT); along with the frictional strength of the lid, this determines the resistance of the lid to convection. The BDT is related to the thickness of the elastic lithospheric, which is a known quantity on most terrestrial planets and moons. This allowed a test of the theory against a spectrum of observed bodies in the solar system. Earth itself plots clearly on the plate tectonic side of the transition - a function of its powerful internal engine and water-weakened plates. Mercury, the Moon and Mars all have lithospheres that are too thick for their feeble mantles to budge. Mars may have been active in the distant past, but only if the surface was altered by liquid water. Venus lies close to the transition, consistent with suggestions it is in an episodic mode - oscillating between active and stagnant lid tectonics. Interestingly, Io and Europa also lie close to the transition. Rugged, tilted mountain ranges on Io and non-tidal ice cracking and evidence of a lithosphere on Europa both hint that these moons of Jupiter may experience more surface tectonism than previously thought.

How different might plate tectonics have been on the early Earth? Numerical modelling also allows us to explore the behaviour of tectonic plates under the extreme thermal conditions expected for the Archaean. Starting with a model for present-day plate tectonics, with the current mantle energy budget, we systematically ran simulations for similar mantle configurations, but with increasing heat production, simulating conditions in the past. Surprisingly, plate tectonics itself breaks down in the Archaean. Instead the planet goes through a transition into an episodic subduction regime, where long periods of quiescence are interspersed with periods of rapid and violent subduction.

The reason is that greater mantle heat production results in higher mantle temperatures. This makes the mantle convect faster, as expected. But the viscosity of the mantle is also a strong function of temperature, and the hotter mantle becomes "runny", so it cannot effectively transmit stress to the plates.

Could the Earth have operated this way? The Precambrian paleomagnetic record was reanalysed for evidence of this type of behaviour. Despite problems with the incomplete dataset, we found that Precambrian plate motions are in fact consistent with this sort of convection - which may explain many episodic features of the Precambrian geological record.

Finally, what happens if you take a planet in a plate-tectonic regime, and simply scale it to larger sizes? The problem is not trivial, and required a large suite of simulations. For larger planetary radii, and thus mass, mantle convection increases in vigour - a widely accepted result. What's more, the thickness of the lithosphere relative to the depth of the convecting mantle also decreases, and this would favour plate tectonics on giant terrestrial planets. However, there is an additional crucial factor in such systems. The brittle strength of rocks is pressure-dependent - as you go deeper into the Earth, the brittle strength of rocks increases substantially. On planets with masses larger than Earth's, and thus greater gravity and internal pressures, this effect will be even more dramatic, to the point where the surface plates will simply lock up. This regime change - from plate tectonics to stagnant lid - was dominant for the parameter range explored in our models. On Earth, plate



*Figure 2. The study predicts that a number of smaller worlds, such as Europa (shown here), may in fact be in an episodic overturn regime, and provide evidence for active tectonism on other planetary bodies. The gradual thickening of Europa's lithosphere over the last 80 Myr, and the distribution of non-tidal surface fracture systems, support this idea. Credit: JPL.*

tectonics acts as a regulatory mechanism for many atmospheric and hydrological systems, and thus the evolution of life on Earth is probably intimately tied to its tectonic regime. On super-sized versions of Earth without plate tectonics, the chances of life would be quite a bit slimmer.

Plate tectonics is a fundamental feature of the dynamic Earth system, but taken to extremes - either deep in the past, or for larger sized planets - it can break down, and the stability of such systems should not be taken for granted.

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*Funded by: MQRF*



Laser  
Microprobe  
-ICPMS U-Pb  
dating of  
groundmass  
perovskite  
from  
kimberlites

**K**IMBERLITES FORM A CLAN OF VOLATILE-RICH POTASSIC ULTRAMAFIC ROCKS that exhibit an inequigranular texture resulting from the presence of phenocrysts, xenocrysts and xenoliths set in a fine-grained matrix formed mainly of olivine, perovskite, spinels, diopside, monticellite, apatite, calcite, serpentine and/or phlogopite. The common methods of dating of kimberlites use U-Pb analysis of zircon and Rb/Sr on mica (phlogopite). Zircon ages may be older than the emplacement age of the kimberlite as zircon is not a groundmass mineral but occurs as xenocryst in kimberlite. Mica can occur as both xenocryst and groundmass phase in kimberlite. The dating of mica therefore may result in mixed ages (from combining different types of mica) or a cooling/resetting age due to the alteration of mica by late fluids.

This research focussed on development of a rapid and robust method of dating kimberlites using groundmass perovskites in thin sections (*GEMOC Publication #505*). Perovskite is one of the late-stage minerals to crystallise from the kimberlitic magma. It is found as individual crystals or overgrowths on minerals such as ilmenite. Since it is a main carrier of U and Th in the kimberlite, it offers the possibility of U-Pb dating, and because it is not an inherited mineral it is more likely to yield the emplacement age of the kimberlite.

The analytical techniques used are identical to those used for LAM-ICPMS U-Pb dating of zircon. The ablation is done in He which permits efficient sample transport, signal stability and reproducibility of U/Pb fractionation. Because there is no well-established perovskite standard, we used the zircon standard (GEMOC GJ-1, age 609 Ma) commonly used for zircon U-Pb dating.

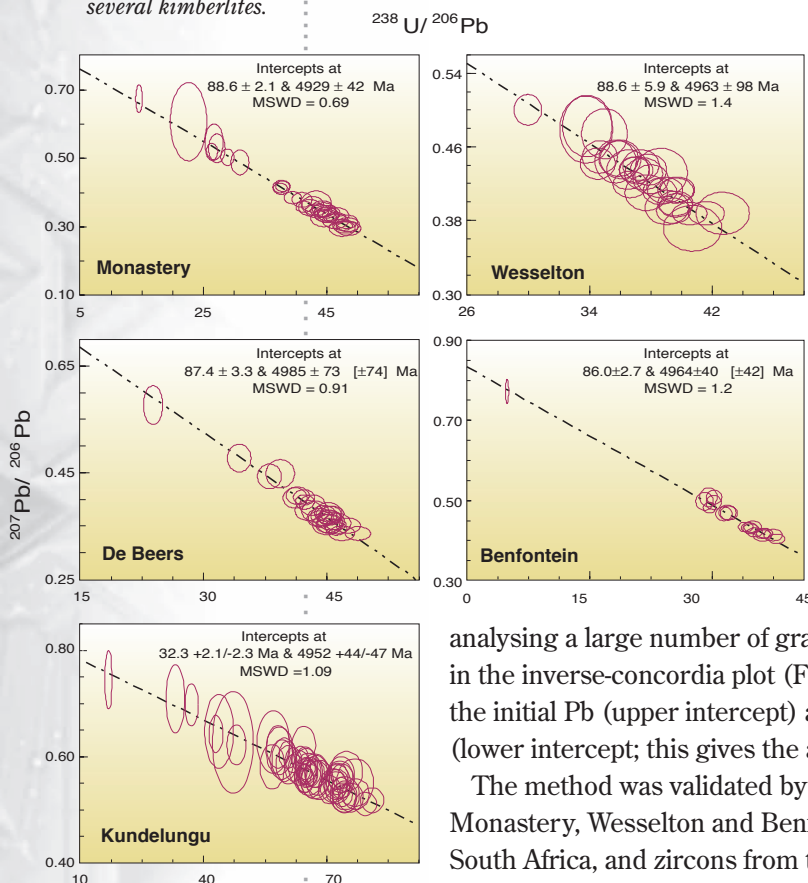
Perovskite, unlike zircon, takes up significant amounts of Pb in its lattice during crystallisation, and the measured Pb-isotope composition is a mixture of this “initial Pb” and the radiogenic Pb produced by decay of U and Th. We have corrected for the initial Pb content by

analysing a large number of grains, and carrying out a regression analysis in the inverse-concordia plot (Fig. 1) to determine both the composition of the initial Pb (upper intercept) and the composition of the radiogenic Pb (lower intercept; this gives the age).

The method was validated by analysis of perovskites from the De Beers, Monastery, Wesselton and Benfontein mines in the Kimberley District, South Africa, and zircons from the Monastery mine. The De Beers, Monastery and Wesselton kimberlites were previously dated respectively at  $86 \pm 3$  Ma (K-Ar on micas),  $90 \pm 4$  Ma (zircon U-Pb and Rb-Sr on whole-rock samples) and  $90 \pm 3$  Ma (zircon U-Pb).

Perovskite ages for the De Beers, Monastery, Wesselton and Benfontein kimberlites are respectively  $87.3 \pm 3.3$  Ma ( $n = 22$ ; MSWD = 0.91),  $88.6 \pm 2.1$  Ma ( $n = 32$ ; MSWD = 0.69),  $88.6 \pm 5.9$  Ma ( $n = 31$ ; MSWD = 1.4) and  $86.0 \pm 2.7$  Ma ( $n = 19$ ; MSWD = 1.2) (Fig. 1). Zircons from the Monastery kimberlite give an age of  $88.4 \pm 0.9$  Ma age ( $n = 18$ ; MSWD = 0.76). These ages compared to those determined by different

Figure 1.  
Inverse-concordia  
(Tera-Wasserburg)  
plots showing perovskite  
U-Pb analyses for  
several kimberlites.



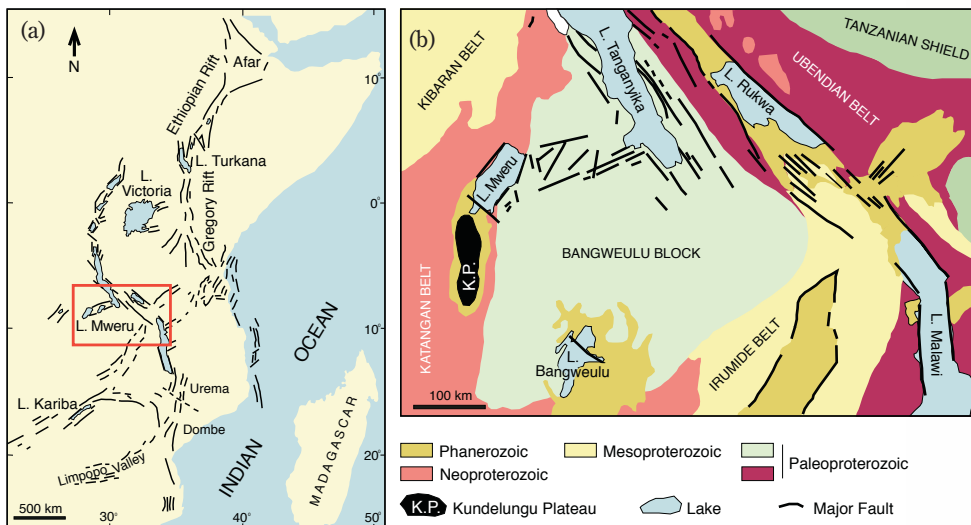


Figure 2. (a) Regional rift system in eastern Africa. Box shows area of Figure 2b. (b) Geological sketch map showing setting of the Kundelungu Plateau (KP), which is intruded by the Kundelungu kimberlites.

methods clearly support the robustness and accuracy of the method. This also indicates that the use of a zircon standard for U-Pb dating of perovskite gives robust results. The Kundelungu kimberlites (SE Congo) were dated at  $32.3 \pm 2.2$  Ma (lower Oligocene), making them perhaps the world's youngest true kimberlites.

The  $^{207}\text{Pb}/^{206}\text{Pb}$  of the initial-Pb component derived from the upper intercepts of the regression lines (see Fig. 1),  $0.831 \pm 0.022$  for Kimberley and  $0.813 \pm 0.022$  for Kundelungu, are similar to the values estimated for the bulk silicate Earth at around 80 Ma ( $0.851 \pm 0.019$ ) and 30 Ma (0.844). The value found for Group I kimberlites from Kimberley District is consistent with the average ( $0.80 \pm 0.1$ ) whole-rock Pb isotope composition of other Group I kimberlites in South Africa. This suggests that these kimberlites have entrained much of their lead content from the lithospheric mantle prior to crystallisation.

Kimberlites may also provide information on the regional tectonics at the time of their emplacement, as kimberlite magmatism is triggered by relatively weak extensional stresses affecting the lithosphere. The age distribution of the kimberlite intrusions may thus shed light on the tectonic evolution of the region. The age of the Kundelungu kimberlites corresponds to the initiation of the East African Rift, which has been dated at 43 Ma in Ethiopia, at 33-25 Ma in Kenya and Yemen and at 36 Ma in the Lake Turkana region (Fig. 2). The Kundelungu kimberlites are the youngest known in the continent. This implies the southward extension of the initial phase of the opening of the East Africa Rift. The Mweru Lake graben in the northern part of the Kundelungu Plateau (Fig. 2) is correlated with this early stage of the rift.

Contacts: Jacques Batumike,  
Sue O'Reilly, Bill Griffin, Elena  
Belousova  
Funded by: iMURS, ARC-DP,  
MQ International Grant, EPS  
Postgraduate Fund



Figure 3. Jacques Batumike selecting kimberlite samples in SE Congo.

Sino-Australian connections 1 billion years ago?

THE CONTEMPORARY CLOSE RELATIONSHIP between Australia and China can be confidently traced back to Paleozoic times with overwhelming evidence from fossil flora and fauna and paleomagnetic data. The evidence demonstrates that several major terranes of China, including the Yangtze and Cathaysian blocks in South China and the North China Craton, were connected to Australia as a part of Gondwanaland, a super-continent that broke up about 250 million years ago. However, the location of China, and especially the South China Block (SCB), relative to the other micro-continents within the Rodinia super-continent during Neoproterozoic times remains a contentious issue; several models have placed the SCB as a “missing link” between Australia and Laurentia but in different ways (see *Li et al., Precambrian Research, 160, p. 179-210, 2008* for a summary). The paleomagnetic data do not provide unique information on the paleolongitude, nor are stratigraphic comparisons between relevant terranes definitive. Further independent evidence is required to constrain the models.

Comprehensive studies of U-Pb geochronology and Lu-Hf isotopic systematics on detrital zircons from latest-Neoproterozoic (Sinian) sedimentary rocks of the Cathaysia block in South China have been carried out using GEMOC’s laser ablation technology (*GEMOC publication #518*). The detrital zircons show a range of ages and compositions, with a significant Grenvillian (ca 1 Ga) population. This suggests that there was once a Grenvillian orogenic belt, probably developed on a Neoproterozoic basement, along or close to the southern part of the Cathaysia block.

Minor Eo- to Meso-archean (~3.8 Ga, 3.3-3.0 Ga, ~2.5 Ga) and Mesoproterozoic (1.7 - 1.4 Ga) detrital zircon populations contained in the Sinian sediments may represent exotic input, probably derived from other continents previously linked with the South China block. U-Pb age spectra and Hf isotope compositions of the zircons indicate that they most likely came from India and East Antarctica. Comparisons with the tectono-magmatic history and compositions of crustal rocks in western Laurentia - eastern Australia and Eastern India - East Antarctica also suggest that these Chinese late Neoproterozoic sediments may have originated mainly from Eastern India and/or East Antarctica. This indicates that the South China Block was linked with the Eastern India - East Antarctica continents in the late Neoproterozoic rather than being located between the western Laurentia and eastern Australia continental blocks.

Therefore, U-Pb and Hf-isotope studies on detrital zircons provide an important

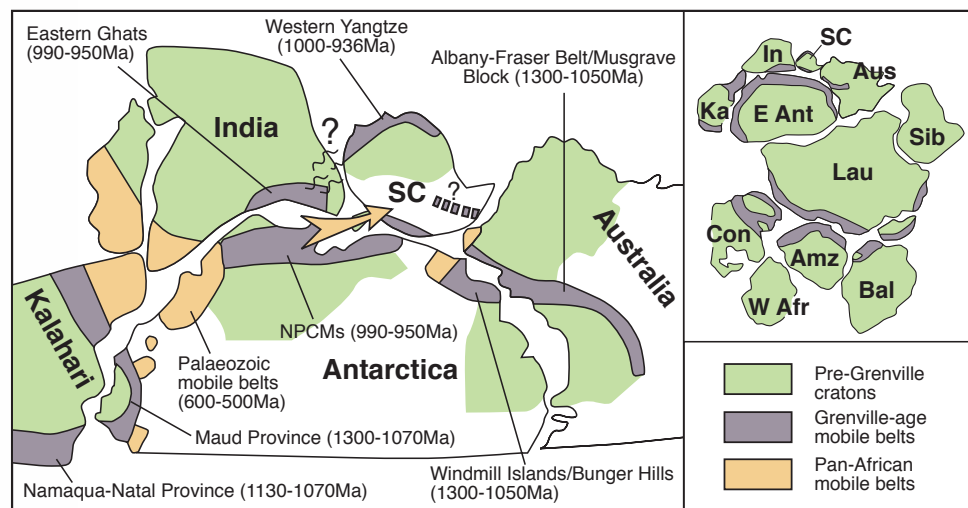
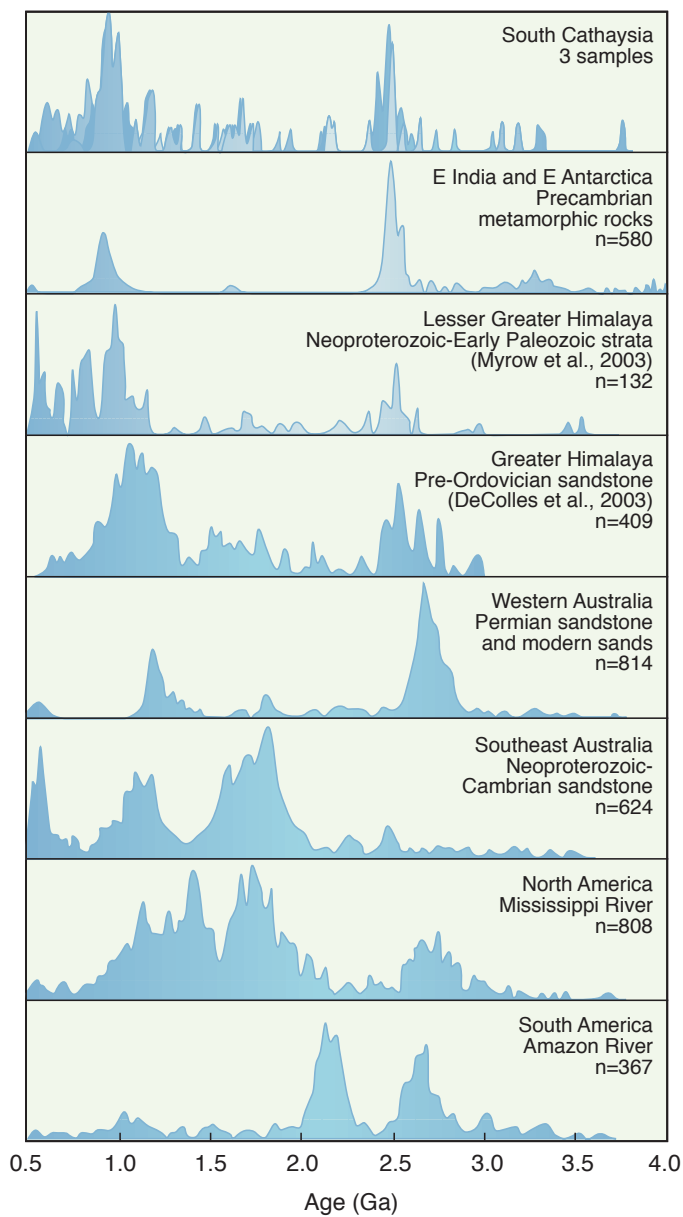


Figure 1. Reconstruction of Rodinia, with focus on the relationship between South China Block and other Rodinian terranes.





independent constraint on the palaeogeography of the South China Block in the context of the breakup of Rodinia and the subsequent assembly of Gondwana in late Neoproterozoic time, and also give insights into the historical links between the South China Block and various Australian terranes.

Figure 2. Zircon  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for the South China Block and other relevant locations.

Contacts: Sue O'Reilly, Bill Griffin, Ming Zhang, J-H. Yu (Nanjing)

Funded by: ARC Discovery, ARC International, NSF China, Nanjing University funds

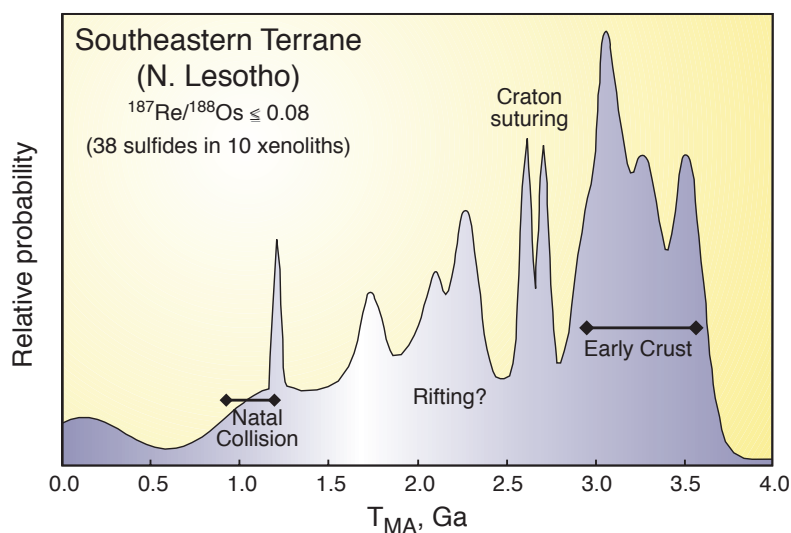
10 years of MC-ICPMS: linking the crust and mantle

Modern geochronology has moved beyond the acquisition of dates; the goal is to understand the significance of these numbers for the geodynamic evolution of Earth at all scales. The coupling of the laser-ablation microprobe (LAM) to inductively-coupled plasma mass spectrometers (ICPMS, multicollector (MC)-ICPMS) has revolutionised geochronology and geochemistry over the last decade. These systems enable the rapid and precise *in situ* analysis of trace-element patterns and isotopic systems, while adding information related to microstructural context and major-element composition. The integration of these multiple sources of data is crucial in constraining the origin of the sample and the processes leading to its formation, so that we can understand the meaning of a date in terms of geological events.

GEMOC INTRODUCED THE MULTI-COLLECTOR ICPMS TO AUSTRALIA IN 1998, adding a second instrument in 2003. As the operation of the MC-ICPMS laboratory at GEMOC enters its tenth year it is an appropriate time to review the advances this technology has brought to isotope geochemistry and geochronology. The most significant impact has been the development of high precision *in situ* isotope ratio measurements for a range of geologically important isotopic systems (e.g. Rb-Sr, Nd-Sm, Lu-Hf, Re-Os). The way had been paved by the coupling of the laser ablation microprobe (LAM) to the single-collector quadrupole ICPMS to provide *in situ* analysis of trace element patterns and isotope ratios (e.g. U-Pb dating of zircon).

The introduction of the second generation sector-field MC-ICPMS instruments brought a number of advantages over the quadrupole ICPMS, including simultaneous detection, flat-topped peaks and greater sensitivity. All of these factors contributed to the more precise measurement of isotope ratios and made the results from the MC-ICPMS directly comparable with those obtained on the more conventional thermal ionisation mass spectrometers (TIMS). The MC-ICPMS has two great advantages over TIMS: (1) due to the high efficiency of the ICP source to ionise refractory elements, the MC-ICPMS has become the instrument of choice to investigate mass-dependent isotopic fractionation of stable isotopes of light and heavy metals (e.g. Li, Mg, Fe, Cu, Mo, Tl); (2) a LAM system can be coupled to the MC-ICPMS for *in situ* high-precision microanalysis of isotopic ratios.

Figure 1. Re-Os model ages of sulfide grains in xenoliths from Northern Lesotho kimberlites, showing correlations with known tectonic events.



The impact of *in situ* isotope ratio analysis has advanced modern geochronology beyond the acquisition of dates. Not only does the method provide rapid and precise data, but it puts these data in a microstructural framework and allows integration with datasets produced by other microanalytical techniques. The integration of these multiple sources of data gives better constraints on the origin of the sample and the processes that produced it, so that we can understand the meaning of a date in terms of geological events.

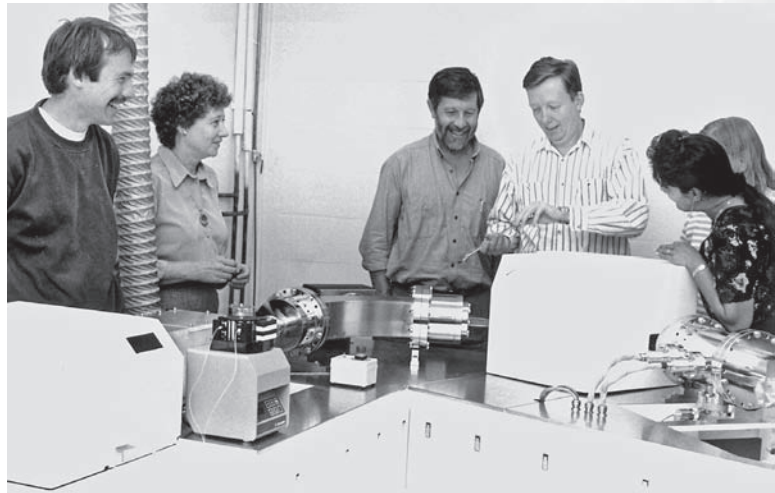
The two most significant developments in LAM-MC-ICPMS in the past decade have been the analysis of Lu-Hf isotopes in zircon and Re-Os isotopes in sulfides and PGE alloys. Zircon and the sulfide minerals are microscopic time capsules for the crust and mantle respectively, and the isotopic studies provide information about the evolution of each layer. By determining the timing of events in the

crust and the underlying lithospheric mantle, linkages between crustal and mantle processes can be assessed and used to address key problems in geodynamics.

The analysis of Hf isotopes in igneous zircon by LAM-MC-ICPMS provides information on the sources of the parent magmas. The analytical method was first demonstrated by Thirlwall and Walder in 1995 but was not taken up again until GEMOC developed high-precision *in situ* analysis in 1999 (see *GEMOC publication #179*). The integration of the *in situ* Hf-isotope data on zircons with data on their morphology and internal structure (imaged by BSE/CL), U-Pb age and trace element composition rapidly led to the establishment of *TerraneChron*<sup>®</sup>. *TerraneChron*<sup>®</sup> is GEMOC's unique methodology for terrane evaluation and studies of crustal genesis. The combination of age, composition and sources of magma for a large number of grains is used to construct an "Event Signature" that gives a fingerprint of crustal evolution in the terrane. The *TerraneChron*<sup>®</sup> methodology typically is applied to zircons in drainage samples collected from a defined catchment. The use of drainage samples has many advantages for regional studies: nature has separated and concentrated a statistically more meaningful sample than is achievable by conventional single-rock sampling, thus giving a more comprehensive coverage of the rock types in the drainage region. This enables this type of remote-sensing mapping on a range of scales (10-1000 km<sup>2</sup>) and in terrains ranging from mountainous (e.g. Himalayas, Andes) to alluvial plains (e.g. Yilgarn, WA; see *GEMOC publications #300, 385*).

On the global scale the combination of Hf-isotope data and age distributions can be used to distinguish between juvenile additions to the crust and upper-crustal rocks derived by reworking of older rocks. A compilation of results shows that since the late Archean, additions of juvenile crust have been small in comparison to the volume of reworked material. These types of data clearly are going to have a large impact on ideas about the rates of growth of the continental crust through time.

A major advance in the application of Re-Os to the mantle came with the



*Simon Jackson, Sue O'Reilly, Bill Griffin, Norman Pearson, Ashwini Sharma and Carol Lawson at the inauguration of Australia's first MC-ICPMS (1998); Nu-05 is still in operation (photo from archives).*



## Research highlights 2007

recognition that the Os budget of mantle-derived peridotites is controlled by trace sulfide phases, and that these rocks typically contain several generations of sulfide with widely differing Os contents and Re/Os. GEMOC pioneered the development of LAM-MC-ICPMS techniques for the *in situ* analysis of Os isotopes in individual sulfide grains and showed that different sulfide generations also have widely varying Re/Os and  $^{187}\text{Os}/^{188}\text{Os}$  (see *GEMOC publications* #267, 290; *Fig. 1*). The



*Sue O'Reilly, PhD students and overseas visitors surround Nu-05 in 2005 (photo from archives).*

implication is that whole-rock Os-isotope analyses of sulfide-bearing peridotites must represent mixtures of components with different ages and isotopic compositions. In such cases, the model ages of these rocks can only be regarded as minimum estimates of melt-depletion ages, and are unlikely to date any particular event (see *GEMOC publication* #326).

The development of these analytical techniques over recent years has made it possible to compare the large scale evolution of the crust and the history of its underlying mantle, where xenolith-bearing volcanic rocks

are available. Studies linking crustal and mantle evolution in cratonic settings, young fold belts and rift zones (see *Spitsbergen Research Highlight*) demonstrate the potential of this approach to shed light on continental generation, modification and destruction.

Deep-seated events are commonly mirrored in the crust; Os model-age spectra from xenolith suites show age “peaks” that correspond to the ages of thermal/tectonic events in the overlying crust, suggesting strong linkages between crust and mantle (*Fig. 1*). Integrated studies of the timing and nature of crustal and mantle events, using these techniques, will be important for understanding the large-scale dynamics of the Earth.

*Contacts: Norman Pearson, Bill Griffin, Sue O'Reilly*

*Funded by: ARC, DEST SII, Macquarie University and Industry*

**How much potassium is in the Earth's core?**

**T**HE PRESENCE OF POTASSIUM IN THE CORE is a vexing issue in Earth Science. The inner dynamics of our planet depend largely on how much energy is stored in its core. Crystallisation of the inner core, generation of the magnetic field and convection in the outer core and mantle are intimately linked to the amount of heat present in the core. Accurately describing the heat budget of the core depends on an accurate determination of the concentration of heat-producing elements. A significant amount of

these elements would permit much slower rates of cooling and inner-core growth.

The presence of potassium (K) as a significant radioactive element in the core was suggested over three decades ago. However, despite numerous theoretical and experimental studies, it is still not clear whether K actually is present in the core. In particular, previous experimental studies on K partitioning between metallic and silicate liquids have yielded contradictory results concerning the fate of K during the favoured scenario of core formation in a deep silicate-magma ocean. Experimental and analytical artefacts, large extrapolation to appropriate conditions of high pressure and high temperature and the use of oversimplified chemical compositions in these studies have cast doubt on previous experimental results.

Research at Macquarie University and the Carnegie Institution of Washington (see *GEMOC publication #455*) has provided new experimental data for the partitioning of potassium in a chemical composition relevant to models of Earth's differentiation. Experiments were carried out at 2200 °C and 7.7 GPa to equilibrate a silicate melt of primitive mantle composition (fertile peridotite) with a variety of Fe–Ni–S–C–O molten alloys. As shown in Figure 1, these new data reveal a negligible effect of pressure and temperature on the partition coefficient ( $D_K$ , the weight ratio of K content in the alloy over K content in the silicate), at least over the P-T conditions of the study. These observations contrast with recent predictions based on published data, which suggest a systematic increase of K solubility in the alloy with temperature (Fig. 1). Our experimental work also indicates that the K solubility is not directly affected by the S and C contents of the alloy. However, there may be an increase in the K partition coefficient with increasing O content in the molten alloy (Fig. 2). Overall, these new results, which are appropriate for modelling core formation in a shallow magma ocean, suggest that appreciable amounts of K are unlikely to be sequestered into Earth's core during a magma-ocean event unless oxygen is a major component in the light element budget of the core.

Contact: Alexandre Corgne  
 Funded by: ARC, Carnegie Institution of Washington, NASA and NSF

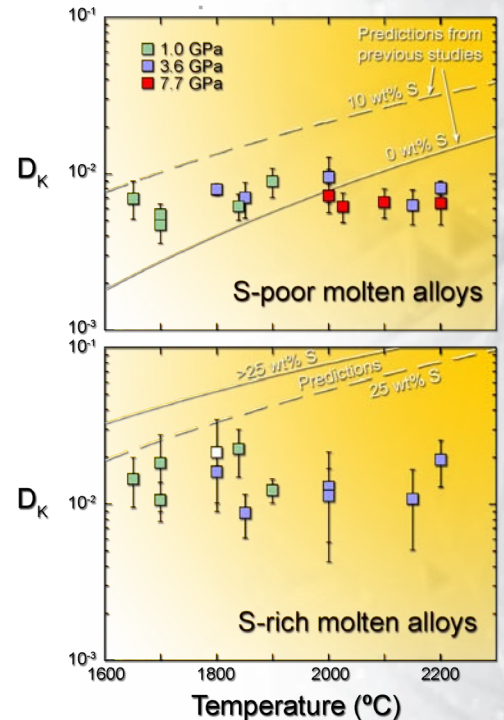


Figure 1. Partition coefficients for potassium ( $D_K$ ) shown as a function of temperature. In white, data and predictions from the literature. Our new data indicate that there are no significant pressure and temperature effects on K partitioning contrary to recent predictions.

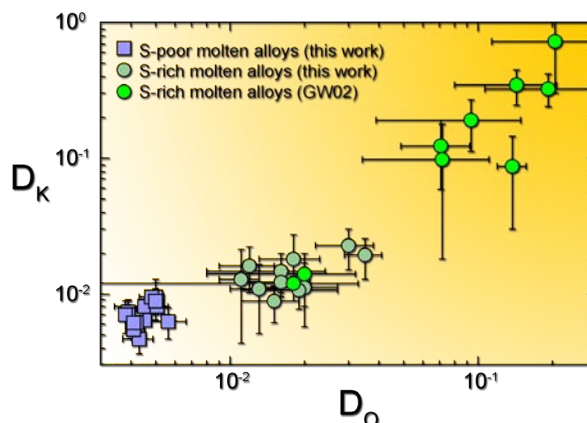


Figure 2. Potassium partition coefficient plotted as a function of oxygen partition coefficient. The observed correlation suggests that O may have a significant effect on K solubility in molten alloy.

Heat sources in mantle plumes

MELTING ANOMALIES IN THE EARTH'S UPPER MANTLE have often been attributed to the presence of mantle plumes that may originate in the lower mantle, possibly from the core-mantle boundary. Globally, mantle plumes exhibit a large range in buoyancy flux that is proportional to their temperature and volume. Plumes with higher buoyancy fluxes should have higher temperatures and experience higher degrees of partial melting. Excess heat in mantle plumes could reflect either a) an enrichment of the heat producing elements (HPE: U, Th, K) in their mantle source leading to an increase of heat production by radioactive decay or b) advective or conductive heat transport across the core-mantle boundary. The advective transport of heat may result in a physical contribution of material from the core to the lower mantle. A contribution of material from the core should result in higher Fe concentrations and coupled enrichments in  $^{186}\text{Os}/^{188}\text{Os}$  and  $^{187}\text{Os}/^{188}\text{Os}$  relative to the upper mantle (Fig. 1). If plumes are generated purely by differences in their chemistry (e.g. by varying HPE content), then increased abundances of U, Th, and K would lead to increased temperatures and, in turn, to higher buoyancy fluxes (Fig. 1).

Geophysical and dynamic modelling indicate that at least the Afar, Easter, Hawaii, Louisville and Samoa plumes may all originate at the core-mantle boundary. These plumes encompass the whole range of known buoyancy fluxes from  $0.9 \text{ Mgs}^{-1}$  (Afar) to  $6.5 \text{ Mgs}^{-1}$

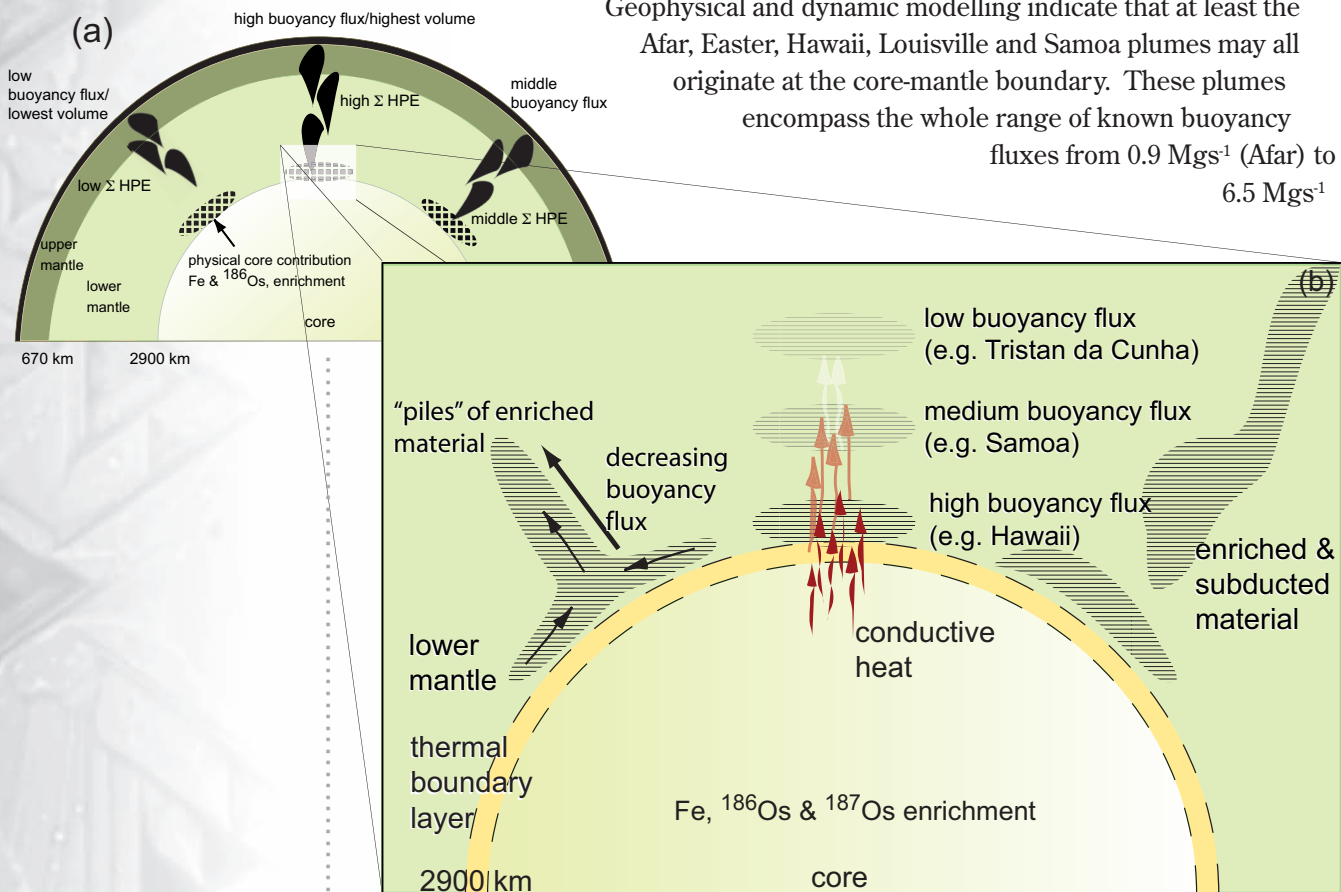


Figure 1. Model of possible effects leading to the formation and rise of mantle plumes. A physical, i.e. material, and hence, heat contribution from the core would be reflected in increased Fe,  $^{186}\text{Os}$  and  $^{187}\text{Os}$ , whereas a formation of mantle plumes as a result of increased concentrations of U, Th and K has been ruled out by a lack of correlation between HPE and buoyancy flux. It is most likely conductive heat transport from the core towards the mantle leads to the rise of enriched material. It has to be taken into consideration that the core-mantle boundary topography is irregular (Garcia and Souriau, *Physics of The Earth and Planetary Interiors*, 2000), but we suggest that the relative distance to the outermost core is the main factor of the conductive heat contribution to triggering plume generation. The formation of "piles" of enriched material may be consistent with our model, i.e. the relative distance to the core-mantle boundary may control the plume's excess heat largely independently of the shape of the enriched material along the core-mantle boundary. Not to scale.



(Hawaii) providing evidence that the buoyancy flux is largely independent of other geophysical parameters.

Major element, trace element and radiogenic isotope data for all available intraplate volcanic settings with published buoyancy fluxes (Sleep, JGR, 1990) were used in our analyses. We used the compiled GEOROC database (<http://georoc.mpch-mainz.gwdg.de/georoc/>) for all of our geochemical data except from the Azores. Data from the Azores were taken from a separate existing dataset. Only alkaline samples (>2 wt.%  $K_2O+Na_2O$  at 45 wt.%  $SiO_2$  with >5 wt.% and <20 wt.% MgO) were taken into consideration to avoid extended assimilation and fractional crystallisation effects. To minimise possible effects of mixing between depleted and enriched compositions, we focused on alkaline basalts rather than tholeiites. All alkaline data were fractionation-corrected to 10 wt.% MgO using a logarithmic fit.

We find that the fractionation-corrected heat producing elements (U, Th and K) and Fe are not correlated with buoyancy flux/upwelling rate (Fig. 2). This provides evidence that the excess temperatures in plumes require additional heat contribution rather than a chemical source heterogeneity. The lack of correlation between buoyancy flux and the possible core contributing tracer Fe tentatively suggests that the heat contributed may not be related to advective heat flow from the core, but may be a result of conductive heat transport from the core into the lower mantle.

The formation of thermochemical piles (Fig. 1) as proposed by geodynamic models is consistent with a heterogeneous distribution of enriched material along the core-mantle boundary and would also help to explain differences in buoyancy fluxes, where smaller piles (e.g. Azores, Canary islands) will have less internal heat, slightly higher viscosity, and hence less conductive heat transport, leading to a lower buoyancy flux than larger piles with more internal heat production, lower viscosity and higher heat contribution from the core (e.g. Hawaii).

Contact: Christoph Beier

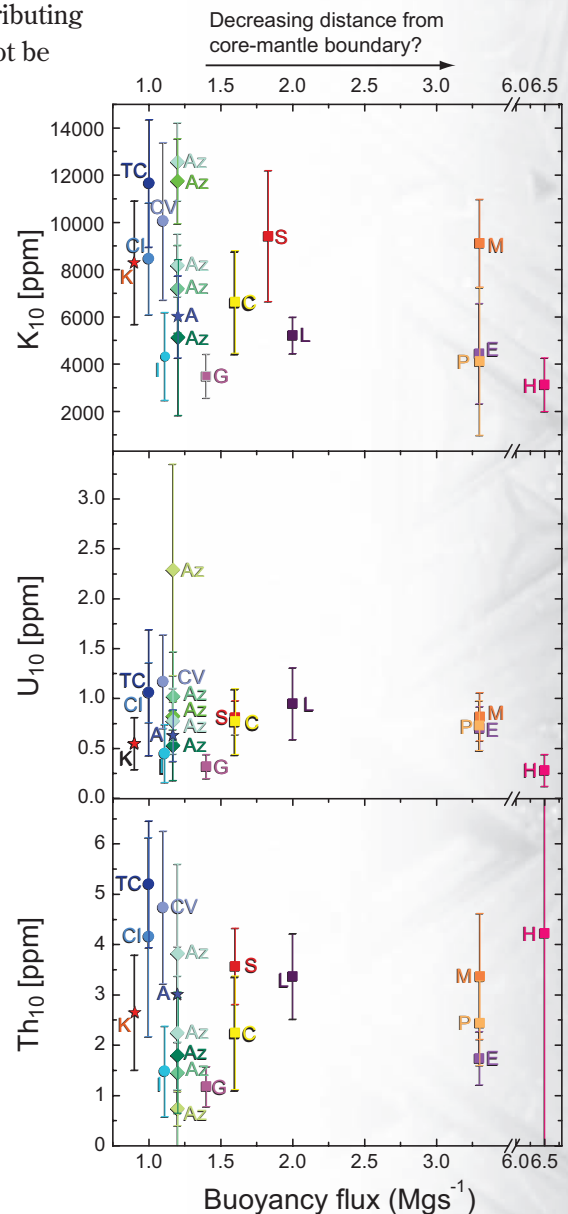
Funded by: Humboldt

Foundation, Macquarie

University

Figure 2. Average fractionation corrected (to 10 wt.% MgO) K, Th and U concentrations [ppm] versus buoyancy flux in  $Mgs^{-1}$  of Atlantic, Pacific and Indian plumes and from the Afar plume. Error bars represent compositional range of each plume. Buoyancy flux as given in Sleep (JGR, 1990).

- Atlantic plumes
  - Iceland (I)
  - ◆ Faial (Azores; Az)
  - ◆ Graciosa (Azores; Az)
  - ◆ Pico (Azores; Az)
  - ◆ Sao Miguel (Azores; Az)
  - ◆ Terceira (Azores; Az)
  - Canary islands (CI)
  - Cap Verde Islands (CV)
  - Tristan da Cunha (TC)
- Pacific Plumes
  - Hawaii (H)
  - Galapagos islands (G)
  - Easter islands (E)
  - Louisville Seamounts (L)
  - Samoa (S)
  - Marquesas (M)
  - Pitcairn Islands (P)
  - Caroline seamounts (C)
- Indian Ocean/Arabia
  - ★ Afar (A)
  - ★ Kerguelen (K)



Flawed crystals control Earth's properties

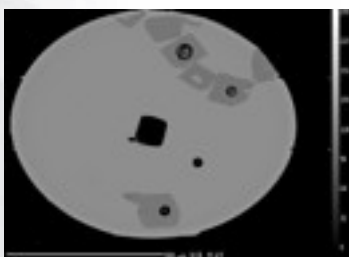
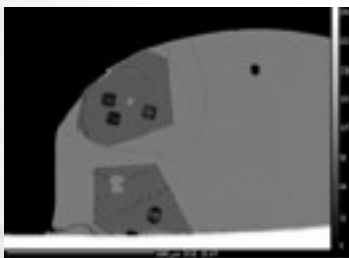
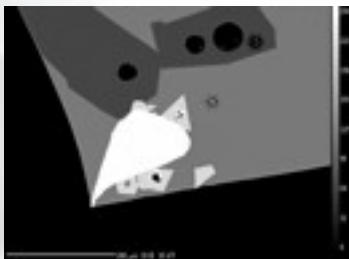


Figure 1. Scanning electron microscope images of synthetic spinel (light grey), forsterite (dark grey) and glass from experiments conducted in the High-Pressure laboratory.

**N**O MATTER HOW FLAWLESS THEY APPEAR TO THE NAKED EYE, natural crystals are never composed of atoms located in their perfect atomic arrangement. Without exception, crystals contain foreign atoms, or positions within the lattice that deviate from perfect crystal chemistry. Such imperfections are called 'defects', and there are several different types. Point defects exist when an atom normally present in the regular geometric atomic arrangement of a crystal is missing, or is present in an irregular place. Lattice vacancies, interstitial atoms and substitutional impurities are all types of point defect. The particular defect species present in a crystal is dependant on different thermodynamic parameters. Although these microscopic imperfections occur on a tremendously minute scale, their influence on the chemical, physical properties of the entire Earth is profound.

Adding impurity elements – a process ubiquitous in natural systems – is a common way of introducing point defects into natural crystals. Amongst other things defects control atomic diffusion – a process by which individual atoms move through media via vacancies, interstitial impurity atoms or different interstitial positions. Understanding point defects in natural samples helps understand the accretion and subsequent evolution of our planet, and represents a fundamental area of research in the experimental petrology laboratories at Macquarie University.

Through the synthesis of Earth-forming materials (Fig. 1), studies conducted in our labs have shown that, at concentrations relevant to many natural samples,  $\text{Sc}^{3+}$  and most other trivalent cations substitute into olivine by replacing  $\text{Mg}^{2+}$ , and charge balance is maintained by the creation of metal vacancies. At slightly higher concentrations, trivalent cations are incorporated via the development of  $\text{Sc}^{3+}\text{-Li}^{1+}$  centres replacing  $\text{Mg}^{2+}\text{-Mg}^{2+}$ . Experiments aimed at understanding the defect chemistry of Li in natural samples show that Li concentrations are in excess of those which can be accounted for through the development of trivalent-Li centres. Furthermore, the results of experiments conducted at variable oxygen fugacity ( $f\text{O}_2$ ) indicate that the dominant charge compensation mechanism in this regime is most likely via contemporaneous incorporation of Li on tetrahedral sites ( $\text{Li}'_{\text{Mg}}$ ) and interstitially. Since olivine is the dominant host for Li in the upper mantle and isotopic fractionation is strongly dependent on crystal chemistry, these results have important implications for understanding the isotopic composition of Li in natural rocks.

Additional experiments have shown that the concentration of water in mantle olivine is strongly influenced by  $f\text{O}_2$  and silica activity ( $a\text{SiO}_2$ ). Our results led us to propose a reaction for the formation of protonated  $\text{Fe}^{3+}$  centres in olivine and allowed us to interpret and reconcile the

results of several previous and apparently contradictory experimental studies. From a consideration of point defect equilibria we arrived at a mechanism for the incorporation of hydroxyl in olivine in a way that is appropriate for the actual range of conditions expected in the upper mantle of the Earth (see *GEMOC publications* #474, 478, 480, 510).

Contact: Kevin Grant

Funded by: Macquarie University and ARC Discovery





## Teaching and training program undergraduate

### GEMOC's teaching program aims to:

- provide undergraduate and postgraduate students with a broad, integrative understanding of Earth architecture and processes, bridging the discipline boundaries of geology and geophysics
- train undergraduate and postgraduate students in new conceptual approaches and the applications of advanced technology, including geochemical analysis techniques and the integrated field and laboratory use of geographic information systems (GIS)
- develop international links in teaching programs (especially postgraduate) relevant to GEMOC's goals
- develop formal tailored course work components at postgraduate level which also can be packaged for distance education delivery and as short courses available to the mining industry
- enhance the pool of high quality geoscience graduates by restructuring academic programs to attract a new clientele

### HIGHLIGHTS 2007

- Dr Craig O'Neill won a Young Tall Poppy Award. Craig pioneered sophisticated computer modelling tools to simulate planet formation and better understand the differences between earth and non-inhabitable planets.
- EPS successfully ran a field trip to Broken Hill with The University of Sydney. In 2008 we plan to include The University of Newcastle. All students enjoy the interaction with those that share their academic interests from other universities and find the whole experience a very stimulating learning environment.
- The new organic geochemistry research lab in E7B was completed in mid 2007 and is now fully operational. The new instruments for the lab have been purchased and are steadily being commissioned. Simon George has several new postgraduate students who will work in the lab.
- GEMOC was successful in recruiting 3 postgraduates funded in the first issue of the new China Government Scholarship Scheme.

*Students on Myrtle Beach, NSW south coast on an excursion in GEOS260 Marine Depositional Environments.*





## Teaching and training program: undergraduate



*Student participants with Kelsie Dadd on the RV Tangaroa.*

*John Caulfield and Simon Jackson on GEOS373 Volcanic Geology.*



- Kelsie Dadd participated in the UNESCO-funded University of the Sea program by supervising students during a 3-week Geoscience Australia research cruise on the RV Tangaroa in the Tasman Sea. The first leg of the cruise sailed from Wellington in New Zealand to Lord Howe Island. There were six final year undergraduate and postgraduate students from the Asia Pacific region who participated.
- The Pilbara Project was launched as a DVD called 'LifeLab' on the front cover of Cosmos Magazine (subscribed to by 60% of all Australian high schools) in April. The project was in collaboration with NASA, under a NASA Space Act Agreement, the University of Glamorgan in the UK and with the Macquarie ICT Innovations Centre. It won a grant of \$119,500 from ASISTM (Australian Schools Innovation in Science, Technology and Maths) fund.

The project has been adopted by the Victorian Space Science Education Centre in Victoria. The wiki website is at <http://pilbara.mq.edu.au> and NASA has it at <http://quest.nasa.gov/vft/> and between those two sites there is an ongoing close association with NASA plus frequent visits into Macquarie by Australian high school students. The DVD was also distributed via Cosmos to New Zealand, the USA and the UK. The site is very popular.

- In February 2007, we ran a very successful field unit to New Zealand – GEOS373 Volcanic Geology. This is always a highlight of the year for students who enjoy the amazing volcanic landscapes while learning skills in the identification of volcanic rocks, deposits and landforms. The students visit a range of deposits from the basaltic scoria cones of the Auckland region, to the andesitic cones of Ruapehu and Ngauruhoe to rhyolitic lavas and ignimbrites around Rotorua and Taupo. The unit will run again in 2009.
- As in previous years, we continue to develop our “tailored problem-based learning” modules and add new problems based on real industry problems or recent research. These prepare the students for employment by ensuring they acquire a range of generic skills such as problem-solving, team work and critical thinking as well as technical content. Where possible we integrate computers into the coursework using a combination of our portable computer laboratory and more traditional computer labs. Students are introduced to a number of computer packages used in industry.

### Geophysics teaching progress 2007

- Use of an extensive pool of GPS units for undergraduate (and postgraduate) fieldwork continued.
- Extended implementation of seismic, gravity, GPS and resistivity and the new GPR equipment for student field projects in exploration, groundwater, environmental and engineering geophysics.
- Equipment upgrades funded by Macquarie University over the last five years have resulted in an excellent array of new instrumentation. Acquisitions include:
  - GEOSOFT, MODELVISION, EMVISION, ERMAPPER, SeisImager, Maxwell, Profile Analyst, Discover and Reflexw software was either purchased or upgraded
  - ASHTECH Z-Xtreme Differential GPS system
  - DUALEM Frequency Domain EM System
  - MALA Ground Penetrating Radar (GPR)



*Mark Lackie on the Gunnamatta in Port Hacking, south of Sydney, during field work for GEOS116 Marine Geoscience.*

Teaching  
and  
training  
program  
GEMOC  
honours

The following honours projects in GEMOC were completed in 2007:

**Cara Danis:** The Wongwibinda Complex, New England Fold Belt: A tilted Low-P High-T terrane?

The following honours projects are relevant to GEMOC in 2008:

**Ben Wilkins:** An investigation of the structure of the Budawang Synclinorium

**Shelley Allchurch:** Petrographic and geochemical characterisation of charnockitic and cumulate gabbro xenoliths from Coliban Dam, central Victoria, with implications for the evolution of the Lachlan Orogen

**Peter Caffi:** Evolution of an active metamorphic core complex, Suckling-Dayman Massif, eastern PNG.

**Sharlin Emami:** Ultramafic hornblende-olivine complex within western Fiordland orthogneiss: origin and role of cumulates in subduction systems

**Melissa Murphy:** Petrography and geochemistry of oceanic crust: Provenance of sedimentary detritus, Macquarie Island

**Belinda Paton:** Exploration Geochemistry





## Teaching and training

### program

### GEMOC postgraduate

**G**EMOC'S ACTIVE INTERNATIONAL EXCHANGE PROGRAM continued, with three recipients of the new China Government (CSC) scholarships commencing in 2008. Yoann Gréau and Véronique le Roux commenced PhD co-tutelle programs jointly with the University of Montpellier (France) and Anne Fonfrege will commence a co-tutelle with University of Jean Monnet (St Etienne, France) in 2008.

#### completed

**Olivier Alard (PhD):** Chalcophile and siderophile elements in the mantle: Geochemical characteristics and distribution; *IPRS with MUIPRA stipend* (graduated 2001)

**Kari Anderson (PhD):** Palaeozoic Eastern Gondwana: palaeomagnetic investigations of Queensland; *IPRS with MUIPRA stipend* (graduated 2003)

**Sonja Aulbach (PhD):** Evolution of the lithospheric mantle beneath the Slave Craton and Alberta Canada; *IPRS with MUIPRA stipend* (graduated 2004)

**Elena Belousova (PhD):** Zircon and apatite geochemistry: applications to petrology and mineral exploration; *APA and sponsorship by Rio Tinto* (graduated 2000)

**Eloise Beyer (PhD):** Evolution of the lithosphere beneath Tasmania and Western Norway; *Field assistance from Ashton Mining* (graduated 2003)

**Rondi Davies (PhD):** East Australian Diamonds: Characterisation and origin; *Sponsored by Rio Tinto, Kennecott Canada* (graduated 1999)

**Guillaume Delpéch (PhD):** Trace-element and isotopic fingerprints in ultramafic xenoliths from the Kerguelen Archipelago (South Indian Ocean); *Co-tutelle with University of Jean Monnet, IPRS with GEMOC stipend and EURODOC scholarship* (graduated 2005)

**Oliver Gaul (PhD):** Composition of the lithospheric mantle beneath Australia; *APAI collaborative with Stockdale Prospecting, CSIRO EM* (graduated 2000)

**Bin Guo (PhD):** An integrated geophysical investigation of the Tamworth belt and its bounding faults; *IPRS with MUIPRA stipend* (graduated 2005)

**Joanne McCarron (MSc):** Mantle xenoliths from Queensland and South Australia (graduated 1997)

See advertisement  
for GEMOC  
postgraduate  
opportunities,  
*Appendix 7.*

## Teaching and training program: postgraduate

**Bertrand Moine (PhD):** The role of fluids in the genesis, segregation and crystallisation of intraplate oceanic mantle magmas: implications for crustal accretion; *Co-tutelle with University of Jean Monnet* (graduated 2000)



*Valeria Murgulov with supervisors Bill Griffin and Sue O'Reilly after the graduation ceremony held in April 2007.*

**Valeria Murgulov (PhD):** Lithosphere evolution and metallogeny in the Georgetown Inlier and adjacent Tasman Fold Belt, North Queensland, Australia; *APA* (graduated 2007)

**Mark Pirlo (PhD):** Australian groundwater geochemistry; applications to heat flow and exploration; *APA and Queen's Trust for Young Australians Award* (graduated 2003)

**Will Powell (PhD):** Geochemically diverse domains in lithospheric mantle, eastern Australia; *APA* (graduated 2006)

**Sonal Rege (PhD):** Trace-element geochemistry of diamond; *IPRS with iMURS scholarship* (graduated 2006)

**Stéphanie Touron (PhD):** Geochemical fingerprints of mantle metasomatism beneath the Massif Central, France; *IPRS with MURAACE scholarship* (graduated 2006)

**Esmé van Achterbergh (PhD):** Geochemical fingerprints of mantle metasomatism (graduated 2005)

**Shixin Yao (PhD):** Chromite as a petrogenetic indicator in ultramafic rocks; *Collaborative with Rio Tinto* (graduated 2000)

**Xu Xisheng (PhD):** The lithospheric mantle beneath eastern China; *Formal exchange PhD, Nanjing and Macquarie* (graduated 2000)

### current

**Brad Bailey (PhD):** Law Dome: Ice and crust mass balance studies (commenced 2004)

**Jacques Batumike (PhD):** The origin of kimberlites from the Kundelungu region (D.R. Congo) and the nature of the underlying lithospheric mantle; *IPRS, iMURS* (commenced 2005) (see *Research Highlights*)

**Stephanie Carroll (PhD):** The mechanisms and deep-crustal controls on continental rifting; *RAACE* (commenced 2005)

**John Caulfield (PhD):** Tofua volcano- Tonga Arc: Eruption history and timescales of magma chamber processes; *iMURS* (commenced 2006)

**June Chevet (PhD):** Gabbroic rocks from the Kerguelen Islands (Indian Ocean): a petrologic, geochemical and isotopic investigation of their origin; *iMURS* (commenced 2005)

**David Child (PhD):** Characterisation of Actinide particles in the environment for nuclear safeguards using mass spectrometric techniques (commenced part time 2007)

**David Clark (PhD):** Contributions to integrated magnetics - applications to the Earth Sciences (commenced 2006)

**Steven Cooper (PhD):** Diamonds and mantle-derived minerals, NW Australia and South Australia (commenced part time 2003)

**Stephen Craven (PhD):** The structural and metamorphic evolution of the Wongwibinda Complex, NSW, Australia (commenced 2006)

**Heather Cunningham (PhD):** A U-series isotope study of magma residence times, degassing and petrogenesis of Rabaul Caldera, Papua New Guinea; *iMURS* (commenced 2005)

**Cara Donnelly (PhD):** Mantle xenoliths, kimberlites and related rocks of the Kuruman Kimberlite Province, Kaapvaal Craton, South Africa; *iMURS* (commenced 2007)

**Yoann Gréau (PhD):** Elemental and isotopic fractionation of siderophile and chalcophile elements: A new perspective on eclogite origin; *iMURS and Co-tutelle with Montpellier University, France* (commenced 2007)

**Alan Kobussen (PhD):** Composition, structure, and evolution of the lithospheric mantle beneath Southern Africa; *iMURS* (commenced 2006)

**Véronique Le Roux (PhD):** Refertilisation and isotopic variations (Sr, Nd, Hf) in the Lherz Massif (France); *Eurodoc and Co-tutelle with Montpellier University, France* (commenced 2007)

**Weiqiang Li (PhD):** Stable metal isotope geochemistry of the Cadia and Northparkes porphyry Cu-Au deposits; *iMURS* (commenced 2006)

**Marek Locmelis (PhD):** Understanding nickel deposits using platinum group element geochemistry (commenced 2006) (see *Research Highlights*)

**Kathleen McMahon (PhD):** Fracturing and deformation along the Amery Ice Shelf: A seismic study (commenced 2004)



*GEMOC PhD student Yoann Gréau and fellow participants enjoying the International Eclogite Field Symposium excursion to the scenic Glenelg-Attadale Inlier, Scotland, July 2007.*



## Teaching and training program: postgraduate



**Luke Milan (PhD):** The emplacement, pressure-temperature-time path and structural evolution of lower crustal gneisses in Fiordland, New Zealand (commenced 2004)

**Nenad Nikolic (PhD):** Evolution of crust-mantle systems near a young rift: NW Spitsbergen, Norway; *iMURS* (commenced 2004) (see *Research Highlights*)

**Ryan Portner (PhD):** Spreading ridge sedimentation processes: a novel approach using Macquarie Island as a natural laboratory; *iMURS* (commenced 2006)

### commencing 2008

**James Cowlyn (PhD):** Growth of evolved continental crust in the primitive Tonga Arc: A study of the island of Fonualei; *MQRES (EAPE CoRE)*

**Cara Danis (PhD):** Geothermal structure of Eastern Australian Basins; *APA*

**Anne Fonfrege (PhD):** Geochemical and isotopic characterisation of magma mixing: comparative studies in volcanic and plutonic settings; *Co-tutelle with Jean-Monnet University, France*

**Jinxiang Huang (PhD):** Origin of eclogite and pyroxenite xenoliths in kimberlites and basalts; *China Government Scholarship and co-tutelle with China University of Geosciences, Beijing*

**Lijuan Wang (PhD):** Crustal evolution of the Yangtze Block using zircons in sediments; *China Government Scholarship*

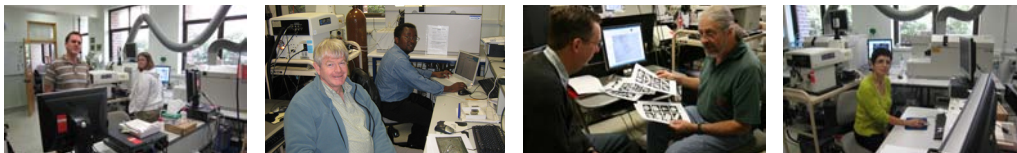
**Yamei Wang (PhD):** Evolution of the subcontinental lithospheric mantle beneath the Western Block of the North China Craton: a mantle xenolith approach; *China Government Scholarship*



*Some of GEMOC's 2007 postgraduate students.*

*Above: Weiqiang Li, Jacques Batumike, Cara Donnelly, Marek Locmelis and Alan Kobussen.*

*Below: Yoann Gréau, June Chevet, Ryan Portner and John Caulfield.*



## Technology development program

### Background

GEMOC's research, training and Industry Interaction programs require a high level of geochemical analytical technology, which is provided by the state-of-the-art facilities available to the Key Centre. Continual development of both technology and innovative analytical and microanalytical approaches is required to meet our research aims and the needs of our industry collaborators. GEMOC develops new analytical strategies as required, to determine the chemical and isotopic composition of geological materials (both solid and fluid) in solution and *in situ*. Special emphasis is placed on the development of advanced *in situ* microbeam methods. These developments are transmitted to industry via open and collaborative research, through technology exchange visits and workshops, and as an integral part of the training program.

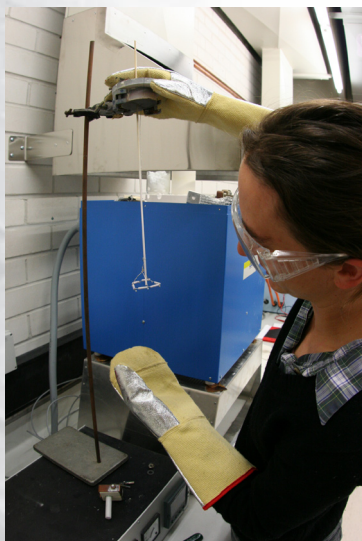
**T**HE ANALYTICAL INSTRUMENTATION and support facilities of the Macquarie University Geochemical Analysis Unit (GAU) represent a state-of-the-art geochemical facility.

- The GAU *contains*:
  - a Cameca SX-50 electron microprobe
  - a Cameca SX-100 electron microprobe (installed January 2003)
  - three Agilent 7500 ICPMS (industry collaboration; two installed October 2004)
  - a custom-built UV laser microprobe, usable on the Agilent ICPMS
  - five New Wave/Merchantek laser microprobes (two 266 nm, three 213 nm) for the MC-ICPMS and ICPMS laboratories (industry collaboration)
  - a New Wave/Merchantek excimer (193 nm) laser microprobe, based on a Lambda Physik OPTex laser
  - a Nu Plasma multi-collector ICPMS
  - a Nu Plasma high resolution multi-collector ICPMS (installed November 2003)
  - a Thermo Finnigan Triton TIMS (installed March 2005)
  - a Spectro XLAB2000 energy-dispersive XRF with rocker-furnace sample preparation equipment
  - a LECO RC412 H<sub>2</sub>O-CO<sub>2</sub> analyser (delivered September 2003)
  - an Ortec Alpha Particle counter
  - a New Wave MicroMill micro-sampling apparatus
  - clean labs and sampling facilities provide infrastructure for ICPMS, XRF and isotopic analyses of small and/or low-level samples

“The analytical instrumentation and support facilities of the Macquarie University Geochemical Analysis Unit (GAU) represent a state-of-the-art geochemical facility.”



## Technology development program



Laure Martin in the Experimental Petrology Lab.

- Experimental petrology laboratories include 4 piston-cylinder presses (pressure to 4 GPa), hydrothermal apparatus, controlled atmosphere furnaces and a multi-anvil apparatus for pressures to 27 GPa.
- The Centre for Isotope Studies has provided access to extraction lines and gas-source mass-spectrometers for stable-isotope analysis of fluids and minerals; it is planned that these facilities will be moved to GEMOC at Macquarie.

### THE GEMOC FACILITY FOR INTEGRATED MICROANALYSIS (FIM) AND MICRO GIS DEVELOPMENT

GEMOC is continuing to develop a unique, world-class geochemical facility, based on *in situ* imaging and microanalysis of trace elements and isotopic ratios in minerals, rocks and fluids. The Facility for Integrated Microanalysis now consists of four different types of analytical instrument, linked by a single sample positioning and referencing system to combine spot analysis with images of spatial variations in composition ("micro-GIS"). All instruments in the FIM have been operating since mid-1999. Major instruments were replaced or upgraded in 2002-2004 through the \$5.125 million DEST Infrastructure grant awarded to Macquarie University with the Universities of Newcastle, Sydney, Western Sydney and Wollongong as partners.

#### the facility provides:

- The capability to image both major- and trace-element distribution in a sample, as an interpretive tool and as the basis for higher precision spot analysis of trace-element concentrations and isotopic ratios
- Co-registration of images and spot data from different instruments, and use of digitised images to locate spots with a precision of better than 5  $\mu\text{m}$
- Analytical capability for most elements of the periodic table at ppm to sub-ppb levels
- *In situ* isotopic-ratio measurement for a range of elements, at the precision required for geologically useful results
- New approaches to data interpretation through application of micro-GIS principles

Peter Wieland and Cara Donnelly at the LAM-ICPMS.



**Electron Microprobe:** for imaging and point analysis of major and minor elements

**Scanning Nuclear Microprobe:** for imaging and point analysis of trace elements at ppm levels

**Laser-ablation ICPMS Microprobes:** for point analysis of a wide range of trace elements at low ppb levels

**Multi-collector Sector ICPMS with laser microprobe:** for high-precision *in situ* analysis of isotopic ratios

**Micro-GIS system:** A key aspect of the Facility is the co-registration of images and point analyses collected on all instruments. All data for a sample, from any of the instruments or from a bench microscope, are in the same coordinate system and can be overlaid in the computer to enhance interpretation.



When fully developed, images from one instrument will be read into the computer of another instrument and used to guide the analysis. Major-element maps from EMP, or trace-element maps from the nuclear microprobe, can be linked directly to images from petrographic or cathodoluminescence microscopes, BSE or SEM, or to spot analyses.

## CURRENT STATUS

**Electron microprobe (EMP):** The original GEMOC EMP is a CAMECA SX50, installed in 1993; it routinely produces high-precision analyses of major and minor elements with a spatial resolution of one micron, as well as high-quality images of major-element (> 0.1 wt%) distribution over areas up to 45 x 45 mm, by stage-scanning with five fixed wavelength-dispersive spectrometers. In early 1999 the EMP was upgraded with an energy-dispersive X-ray detector to allow rapid and simultaneous mapping of all major elements. A further upgrade in 2004 involved the replacement of the Sun-based operating system with the PC-based SAMx software. In early 2003 a new CAMECA SX100, with a similar configuration of spectrometers, was installed and the SX50 is now used mainly for the imaging and analysis of zircons, in connection with *TerraneChron*<sup>®</sup> applications and basic research. The CAMECA SX100 carries the workload of the routine major and minor element analyses for the majority of GEMOC's research projects. It is fitted with large-area diffracting crystals for improved sensitivity and lower limits of detection.

**Scanning nuclear microprobe (SNMP):** This instrument was built by Dr C.G. Ryan (with GEMOC funding contribution) as a separate beam line on the HIAF particle accelerator at CSIRO, North Ryde. The design incorporates several complementary types of detector, a new high-resolution probe-forming system and an innovative optical system, and provides both images of trace-element distribution and spot analyses, with a lateral resolution of 1-3  $\mu\text{m}$ . Current capabilities cover micro-PIXE, micro-PIGE and quantitative element imaging. Due to the closure of CSIRO's North Ryde site during 2004, the SNMP beam line has been relocated to the accelerator facility at the University of Melbourne.

**Laser Ablation ICPMS microprobe (LAM-ICPMS):** The original GEMOC LAM was installed in December 1994 using a Perkin-Elmer ELAN 5100 ICPMS (later replaced by an ELAN 6000), attached to a UV laser ablation microprobe built for GEMOC by Memorial University, Newfoundland. In 1999 the ELAN 5100 ICPMS was replaced by a Hewlett Packard 4500, and in 2000 an Agilent 7500S ICPMS was added. In 2004 two new Agilent 7500CS instruments were purchased (one primarily for solution work), and the 7500S replaced the HP4500 for zircon analysis at the end of the year. The 7500S and one 7500CS now routinely provide quantitative analyses of > 30 elements at sub-ppm levels in minerals, glasses and metals, as well as precise U-Pb dating of zircons. The laboratory currently uses three Nd:YAG LAM systems: a Quantel Brilliant laser that can deliver beams of either 266 nm or 213 nm light, a New Wave UP-266 nm system, and a New Wave UP-213 nm system. In November 2005 the New Wave UP-193 nm system (based on a Lambda Physik OPTex excimer laser) was moved from the Nu Plasma to provide an additional option for *in situ*

*Jacques Batumike demonstrating U-Pb dating of kimberlite petrography for Simon Shee (member of the GEMOC Advisory Board and kimberlite guru).*



## Technology development program

analysis of transparent minerals on the 7500CS. Spatial resolution varies with the application, but typically is on the order of 30-40  $\mu\text{m}$ . Each LAM is fitted with a computer-driven sample stage to provide co-registration of X-Y coordinates with the other instruments. On-line data reduction with the GEMOC-developed "GLITTER" software enhances laboratory productivity and data interpretation; the software is marketed internationally through AccessMQ.

### **Laser Ablation Multi-collector ICPMS microprobe (LAM-MC-ICPMS):**

The Facility has two Nu Plasma MC-ICPMS. The first was installed in November 1998 and the other in November 2003. The second Nu Plasma instrument has high-resolution capabilities and a retardation filter to enable U-series work. The instruments combine a laser ablation micro-sampler, an Ar-plasma ionisation source, and a multi-collector magnetic-sector mass spectrometer, to provide high-precision *in situ* analysis of isotope ratios in geological materials. The instruments use either a New Wave 193 nm system based on an Lambda Physik OPTex excimer laser, a New Wave UP-266 nm Nd:YAG laser, or a New Wave UP-213 nm Nd:YAG laser depending on the application. The MC-ICPMS also can be used in solution mode, with either a standard nebuliser or a desolvating nebuliser, to provide high-precision isotopic analysis of a wide range of elements, including many not accessible by standard thermal ionisation mass spectrometry.

**A Triton thermal ionisation mass spectrometer (TIMS):** The Triton was purchased in 2004 following a successful ARC LIEF application led by Professor Simon Turner and Dr Bruce Schaefer (Monash University), and was installed in March 2005. Following an intensive period of testing the Triton quickly became the primary source of Sr, Nd and Os isotope analyses in the Facility, relieving the MC-ICPMS of this aspect of the analytical workload. The instrument represents the state-of-the-art in thermal ionisation mass spectrometry and its capabilities have contributed to the developments in Ra isotope analysis.

### **Applications in use and under development include:**

#### **Laser Analysis (*in situ* point analysis)**

- U-Pb geochronology of zircons from igneous and metamorphic rocks
- U-Pb dating of groundmass perovskite and xenocrystal rutile in kimberlites
- Hf isotope analysis in zircon and rutile for studies of crustal generation, mantle evolution and crust-mantle interaction
- Re-Os dating of sulfides in mantle-derived xenoliths
- Nd isotope analysis in apatites, titanites and other REE-rich minerals, including kimberlitic perovskite
- Sr isotope analysis of carbonates, feldspars, apatites, pyroxenes and kimberlitic perovskite
- Pb isotope analysis of sulfides, silicates and perovskite
- Stable isotope ratios of Fe, Mg, Zn, Cu and other cations in appropriate minerals from ore systems and mantle rocks
- Multi-element trace element analysis of silicates, sulfides, oxides and diamond

*Elena Belousova  
slaving over Hf-isotope  
analyses of zircon, on  
the Nu-05.*





## Solution Analysis

- Re-Os – determination of mantle depletion ages and isochron ages in whole rocks, ilmenites and chromites; dating of sulfide assemblages in ore bodies
- Lu-Hf – crustal genesis, mantle metasomatism; Lu-Hf dating of garnet peridotites, eclogites, granulites; basalt genesis
- Rb-Sr, Sm-Nd, U-Pb, Pb-Pb – MC-ICPMS and TIMS
- U, Th-series analysis – for dating of young processes, ranging from magma genesis to weathering and erosion
- Multi-element analysis of trace elements in whole-rock samples

## PROGRESS IN 2007

### 1. Facility for Integrated Microanalysis

**a. Electron Microprobe:** During 2007 the SX50 continued to meet the imaging and analytical demands of the *TerraneChron*<sup>®</sup> projects and other zircon-related applications. The SX100 serviced all other projects including several new applications: CL-imaging and trace element analysis of hydrothermal quartz; analysis of platinum group minerals; minor and trace element analysis of metals.

**b. Laser-ablation ICPMS microprobe (LAM):** During 2007, the LAM laboratory produced large volumes of data for thirteen Macquarie PhD thesis projects, several projects carried out by international visitors and Honours students, in-house funded research projects and industry collaboration. These projects included the analysis of trace elements in the minerals of mantle-derived rocks, in sulfide minerals and in a range of unusual matrices. Methods were also developed to measure the trace element contents of fused glasses for whole-rock geochemistry. As in the recent years *more than 7000 U-Pb analyses of zircons were carried out*, related to projects (including *TerraneChron*<sup>®</sup> applications) in Antarctica, Brazil, Korea, New Zealand, Chile, Oman, India, Tibet, China, Mongolia, Russia, Tajikistan, North America, Africa, Uruguay and Australia. The LAM laboratory also routinely provides data for projects related to mineral exploration (diamonds, base metals, Au) as a value-added service to the industry (see *Research Highlights*).

U-Pb dating of zircons was carried out on the Agilent 7500S, while one of the two Agilent 7500CS instruments was dedicated to laser-probe applications, and the other set up for solution analysis. The addition of a third ICP-MS allowed uninterrupted periods of time for method development without disrupting the productivity of the laboratory.

**c. MC-ICPMS:** The rapid growth in the use of the *TerraneChron*<sup>®</sup> application (see *Research Highlights*), coupled with the demand for *in situ* Re-Os analysis and stable isotope analysis, continued to produce severe competition for instrument time on the MC-ICPMS.

In 2005 significant advances were made in the analysis of 'non-traditional' stable isotopes (see *Research Highlights*) and included the development of separation techniques and analytical protocols for Tl, Fe and Ni

*Norman Pearson and Steve Craven deciding which zircons need to be dated.*





## Technology development program

“ During 2007 a further 20 copies of GLITTER were sold bringing the total number in use to more than 130 worldwide, in forensics and materials science, as well as earth science applications ”

*Farida Ait-Hamou (Algeria) used the LAM-ICPMS to analyse trace elements in xenoliths from the Hoggar Massif (see p. 75).*

isotopes. These activities continued through 2007 along with a successful effort to improve separation techniques for Cu and Zn isotopes in a wide range of rock compositions from ultramafic to granitic. Preliminary steps were taken to establish separation and analytical methods for the measurement of Li isotopes. Major applications during 2007 using *in situ* techniques continued to centre on the high-precision analysis of Hf in zircons to trace lithosphere evolution and magma-mixing histories in granitic rocks and Re-Os dating of single grains of Fe-Ni sulfides in mantle-derived rocks. *In situ* Hf isotopes were measured in zircons from Antarctica, Korea, New Zealand, Chile, Tibet, China, Mongolia, Russia, North America, Africa and Australia. We carried out Re-Os studies on xenoliths from the USA, South Africa, eastern China, and Siberia. Sr and Nd isotopes were measured *in situ* in kimberlitic perovskites from South Africa.

**d. Laboratory development:** The new clean-room facility, which is being used primarily for isotope separations, opened in April 2004. It provides an ultra-clean environment within a 3-stage pressurised volume; it contains 6 Class 3500 work areas, three for radioactive isotopes and three for other activities.

**e. Software:** GLITTER (GEMOC Laser ICPMS Total Trace Element Reduction) software is our on-line interactive program for quantitative trace element and isotopic analysis and features dynamically linked graphics and analysis tables. This package provides the first real-time interactive data reduction for LAM-ICPMS analysis, allowing inspection and evaluation of each result before the next analysis spot is chosen. Its capabilities include the on-line reduction of U-Pb data. The use of GLITTER has greatly increased both the flexibility of analysis and the productivity of the laboratory. An arrangement by which New Wave Research marketed the software together with their laser microprobe equipment was terminated late in 2007. Sales are now handled by AccessMQ (formerly Macquarie Research Limited) and GEMOC provides customer service and backup. During 2007 a further 20 copies of GLITTER were sold bringing the total number in use to 130 worldwide, in forensics and materials science, as well as earth science applications. During 2005, Will Powell, Norm Pearson and Chris Ryan began updating GLITTER to version 4.4. Will Powell continued in his role in GLITTER technical support and software development through 2007, producing a new version (4.4.2) that was provided without charge to existing customers and accompanies all new orders.

## 2. Laser development

GEMOC continues to benefit from an industry partnership with New Wave Research (formerly Merchantek EO), a major US manufacturer of laser ablation systems. The mobility of the probes has allowed them to be used on the quadrupole ICPMS instruments as well, in a range of applications. A Merchantek/ New Wave Research 193 nm excimer system based on a Lambda Physik OPTex laser, delivered in March 2002 was repaired and realigned late in 2005 for use in diamond analysis. Three more New Wave laser systems, acquired during 2004 (a UP-266 nm and two UP-213 nm),



represented a major upgrading of the instrument park and giving redundancy to limit downtime. The 213 nm lasers are now used for most of the zircon analytical work including both U-Pb and Hf isotope analyses, especially where small grains are being analysed. The 266 nm systems have proven most useful for analysis of sulfides, and for other stable-isotope applications.

### 3. Energy dispersive XRF

A Spectro XLAB2000 energy-dispersive X-ray spectrometer, installed in November 2000 in a joint venture with Tasman Resources, produces high-quality major- and trace-element data. However, during 2007 productivity was severely reduced by recurring problems with the detector.

A LECO RC412 H<sub>2</sub>O-CO<sub>2</sub> analyser, installed in September 2003 to replace an outdated unit, is providing high-quality analyses to complete whole-rock analyses by XRF and solution-ICPMS.

### 4. Solution analysis

An Agilent 7500CS ICPMS is regularly used to provide trace-element analyses of dissolved rock samples for the projects of GEMOC researchers and students, and external users, supplementing the data from the XRF.

The *in situ* analysis of the Rb-Sr, Lu-Hf, Sm-Nd and Re-Os systems by laser ablation microprobe has required the development of corrections for isobaric overlaps (e.g. <sup>87</sup>Rb on <sup>87</sup>Sr), and has demonstrated that these corrections can be done with very high precision in the Nu Plasma MC-ICPMS. This has allowed us to simplify the ion-exchange chemistry traditionally used to obtain clean element separations for standard mass-spectrometry analysis. A new scheme was developed for the dissolution of rocks and mineral separates, to enable the separation of Sr, Nd and Hf from the same sample digestion. Prior to the installation of the Triton TIMS the isotopic analyses were performed using the MC-ICPMS in solution mode. Subsequently the analysis of Sr and Nd has been moved on to the Triton but Hf continues to be run on the MC-ICPMS. An additional clean-up column has been also added to the Nd separation method to remove Ba and LREE from samples with LREE-enriched compositions. This step has been found to be necessary in order to run these samples on either the MC-ICPMS or TIMS.

During 2007 further developments were made in the separation of 'non-traditional' isotopes, with significant improvements in the separation of Cu from silicate rocks and sulfide minerals. The permanent availability of one of the Agilent 7500CS for solution analysis greatly benefited the development of the separation techniques. Advances were also made in the U-series chemistry with the development of separation methods for Ra and <sup>210</sup>Pb.



*Oliver Gaul  
contemplates another  
batch of garnet data  
from the LAM-ICPMS.*

## Industry interaction



### INDUSTRY INTERACTION, TECHNOLOGY TRANSFER AND COMMERCIALISATION PROGRAM

**G**EMOC RELIES on a vigorous interaction with the mineral exploration industry at both the research and the teaching/training levels. The research results of the Centre's work are transferred to the industry and to the scientific community by:

- collaborative industry-supported Honours, MSc and PhD projects
- short courses relevant to the industry and government sector users, designed to communicate and transfer new technologies, techniques and knowledge in the discipline areas covered by the Key Centre
- one-on-one research collaborations and shorter-term collaborative research on industry problems involving national and international partners
- provision of high quality geochemical analyses with value-added interpretations in collaboration with industry and government organisations, extending our industry interface
- use of AccessMQ consultancies and collaborative industry projects, which employ and disseminate the technological developments carried out by the Centre
- GLITTER, an on-line data-reduction program for Laser Ablation ICPMS analysis, developed by GEMOC and CSIRO GEMOC participants, has been successfully commercialised and is available from GEMOC through AccessMQ (<http://www.es.mq.edu.au/GEMOC/>)
- collaborative relationships with technology manufacturers (more detail in the section on *Technology Development*)
  - GEMOC (Macquarie) is the Australian demonstration site for Agilent Technologies LAM-ICPMS applications
  - GEMOC (Macquarie) is an international test site for New Wave Research Lasers

### SUPPORT SOURCES

GEMOC industry support includes:

- direct funding of research programs
- "in kind" funding including field support (Australia and overseas), access to proprietary databases, sample collections, digital datasets and support for GIS platforms
- logistic support for fieldwork for postgraduate projects
- collaborative research programs through ARC Linkage Projects and the Macquarie University External Collaborative Grants (MUECRG) and PhD program support



- assistance in the implementation of GIS technology in postgraduate programs
- participation of industry colleagues as guest lecturers in undergraduate units
- extended visits to Macquarie by industry personnel for interaction and research
- ongoing informal provision of advice and formal input as members of the Advisory Board



## ACTIVITIES IN 2007

10 Industry Reports were completed for collaborative industry projects.

*TerraneChron*<sup>®</sup> studies (see *Research Highlights*) have enjoyed continued uptake by a significant segment of the global mineral exploration industry. This methodology, currently unique to GEMOC, requires the integration of data from three instruments (electron microprobe, LAM-ICPMS and LAM-MC-ICPMS) and delivers fast, cost-effective information on the tectonic history (with ages) of regional terranes ([www.es.mq.edu.au/GEMOC/TerraneChron.html](http://www.es.mq.edu.au/GEMOC/TerraneChron.html)).

The ARC Linkage Project titled “Global Lithosphere Architecture Mapping” (GLAM) continued with full industry partner support following the takeover of WMC Resources by BHP Billiton. Planning and workshop sessions at Macquarie with participants from BHP Billiton and GEMOC, and visits by Macquarie researchers to Perth, were key activities in 2007, leading to a successful application for a new 3-year Linkage Project. Dr Graham Begg spent significant research time at GEMOC through 2007 as part of the close collaborative working pattern for this project.

GEMOC’s development of a method to analyse trace elements in diamond has opened up potential further developments and applications relevant to industry, ranging from diamond fingerprinting for a range of purposes to improving the knowledge framework for diamond exploration. Rio Tinto supported a successful ARC Linkage Project application on Diamond Fingerprinting. Dr Debora Araujo has been employed as a Research Associate on the project and has carried out an extensive program of method development and diamond analysis.

A continuing collaborative research relationship with New South Wales Geological Survey is applying *TerraneChron*<sup>®</sup> to investigations of the provenance of targeted sequences in Paleozoic sedimentary terranes of eastern Australia.

BHP Billiton continued to support a project exploring a novel framework for the origin of magmatic Ni-deposits in 2007, following the previous successful project with WMC on Continental Flood Basalts related to Ni and PGE deposits (see *GEMOC publication #473*).

The alliance with PIRSA (Primary Industries and Resources, South Australia) applying *TerraneChron*<sup>®</sup> to collaborative projects has expanded with funding of a new collaborative research proposal for 2008.

*De Beers staff visited for several days to discuss ongoing and future collaborative research. Back row (L-R): Dave Apter, Rob Preston, Bruce Wyatt, Norm Pearson, Alan Kobussen. Front row: Bill Griffin, Sue O'Reilly, Cara Donnelly, Simon Shee.*

## Industry interaction

Industry visitors spent varying periods at GEMOC in 2007 to discuss our research and technology development (see visitor list, *Appendix 3*). This face-to-face interaction has proved highly effective both for GEMOC researchers and industry colleagues.

DIATREEM continued to provide LAM-ICPMS analyses of garnets and chromites to the diamond-exploration industry on a collaborative basis.

GEMOC publications, preprints and non-proprietary reports are available on request for industry libraries.

GEMOC was prominent in delivering keynote and invited talks and workshop modules at national and international industry peak conferences in 2007 including the 7<sup>th</sup> Biennial Exploration Managers Conference of AMIRA (Australian Minerals Industry Research Association), the Exploration 07 Conference in Toronto, and the Ores and Ore Genesis Conference (Tucson, Arizona, USA). See *Appendix 4* for abstract titles and *GEMOC Publication #491*.



### CURRENT INDUSTRY-FUNDED COLLABORATIVE RESEARCH PROJECTS

THESE ARE BRIEF DESCRIPTIONS OF CURRENT GEMOC PROJECTS that have direct cash support from industry with either formal ARC or Macquarie University Grant status, and timeframes of at least one year. Projects are both national and global. In addition to these formal projects, many shorter projects are directly funded by industry alone, and the results of these feed into our basic research database (with varied confidentiality considerations). Such projects are administered by AccessMQ, Macquarie's commercial entity.

GEMOC's industry collaborative projects are designed to develop the strategic and applied aspects of the basic research programs based on understanding the architecture of the lithosphere and the nature of Earth's geodynamic processes that have controlled the evolution of the lithosphere and its important discontinuities. Most of the industry collaborative projects rely on geochemical information from the Geochemical Analysis Unit in GEMOC and especially on novel methodologies developed by (and some unique to) GEMOC.

Geochemical data on crustal and mantle rocks are being integrated with tectonic analyses and large-scale datasets (including geophysical data) to understand the relationship between lithosphere domains and large-scale mineralisation.

The new methodologies of using mantle sulfides to date mantle events, and of characterising crustal terrane development using U-Pb dating and Hf isotopic compositions of zircons provide more information for integration with geophysical modelling (see *Research Highlight p. 44-46*). *TerraneChron*<sup>®</sup> (see *Research Highlights*) is proving an important new approach to characterising the tectonic history and crustal evolution of terranes on the scale of 10 – 100 km as well as delivering a cost-effective exploration tool to the mineral (and potentially petroleum) exploration industry.

The recent breakthrough in developing a robust methodology to analyse the trace elements in diamonds quantitatively is another world-first for GEMOC. In addition to providing a unique knowledge base about the nature and compositions of deep mantle fluids that has led to a new hypothesis for how diamonds form in the Earth's mantle (see *Research Highlights* p. 27, 30), it has potential practical applications to diamond fingerprinting for forensic applications and to better predicting global targets for diamond exploration.

#### **Formal projects known to be funded for 2008:**

##### **Basin development in Proterozoic South Australia: developing a time-integrated, compositional framework to assist mineral exploration**

*Supported by a matching Macquarie University External Collaborative grant*

*Industry Collaborator: PIRSA (Primary Industries and Resources, South Australia)*

**Summary:** This project will generate significant new geochemical and age information to improve the existing geochronological framework for geologically ancient regions of South Australia. These chemical "fingerprints" and age data will be obtained for the mineral zircon (collected from river sands and rocks), that acts as a time capsule allowing us to determine the nature and sources of individual magmatic rocks and also sedimentary sequences. This will provide an integrated understanding of the geological history of the region to aid mineral exploration, and will also add to knowledge of the composition, metallogeny and assembly of this region of the Australian continent.

#### **Formal projects commencing 2007:**

##### **Global Lithosphere Architecture Mapping II**

*Supported by ARC Linkage*

*Industry Collaborator: BHP Billiton*

**Summary:** Domains of different composition in the deep part of Earth's rigid outer shell (the lithosphere) reflect processes of continent formation and breakup through Earth's history. These boundaries focus the fluid flows from the deeper convecting mantle that may produce giant ore deposits. We will integrate mantle petrology, tectonic syntheses, and geophysics to image the 3-D architecture of the continental lithosphere, and provide a basis for realistic dynamic modelling of the behaviour of these deep continental roots and their response to geodynamic forces through time. This will provide a new approach to identifying predictive relationships between different types of lithosphere domains and structures, and large-scale mineralisation. The continents have been broken up and re-assembled along major zones of weakness many times through Earth's history. Boundaries between such continental domains focus large-scale movements of fluids that can produce giant ore deposits. This study will provide new perspectives on the localisation of world-class economic deposits, the Earth resources on which society depends.



## Trace element analysis of diamond: new applications to diamond fingerprinting and genesis

*Supported by ARC Linkage*

*Industry Collaborator: Rio Tinto*

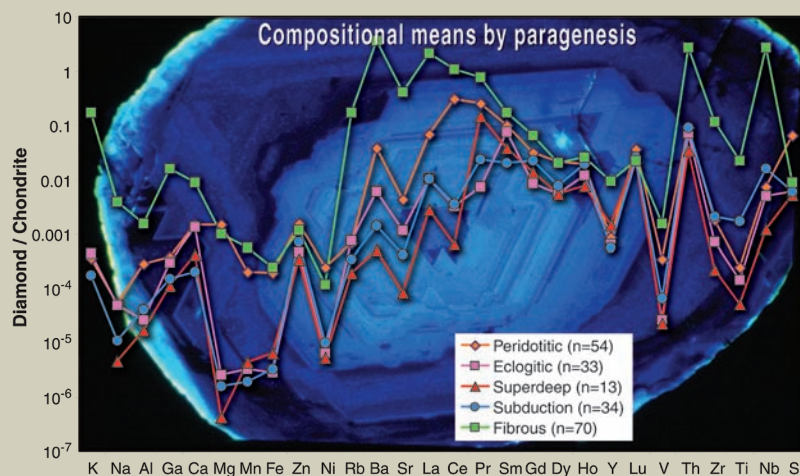
**Summary:** As diamond crystals grow deep in the Earth's mantle, they trap minute inclusions of the fluids from which they crystallise. We will use recently developed laser-ablation microprobe techniques to analyse the trace-element patterns of diamond crystals from the Argyle, Diavik and Murowa mines (Australia, Canada and Zimbabwe).



The results will define the nature and evolution of the parental fluids of the diamonds, and thus shed new light on the processes of diamond formation and the nature of fluids in the deep Earth. The data will be used to test the potential for fingerprinting diamonds by source; such fingerprinting can be used as a tool in controlling the flow of stolen and illegally mined diamonds. The project will provide new insights into the processes by which diamond crystallises in the Earth's mantle. A better understanding of these processes can lead to improved models and techniques for diamond exploration, enhancing the prospect of finding new deposits in Australia and abroad. The project will test the potential of trace-element microanalysis to fingerprint diamonds by source. If successful, this technology will provide economic benefits by reducing theft and illegal mining, which represent significant losses to legitimate companies. Application of this Australian development could reduce the circulation of "conflict diamonds", which would have real social benefits worldwide, especially in some developing countries.



*Bill Griffin and Sue O'Reilly with Dave Ballantyne (L) and Claude Dalpé (R) during a visit to the Canadian Mounties lab in Ottawa.*



## Formal projects active in 2007:

### Lithosphere evolution across a craton margin, southern Africa

*Supported by Industry and a matching Macquarie University Collaborative Grant*

*Industry Collaborator: De Beers*

**Summary:** The margins of cratonic blocks extend to 150-300 km depth, and exert a strong control on crustal tectonics. Kimberlite magmas intruded across the southern margin of the Kaapvaal Craton (S. Africa) provide detailed sampling of the lithospheric mantle.

We will use these samples to map the composition and structure of the mantle in two time slices (120 Ma, 90 Ma), providing new information on how the craton margins channel fluids. Linkages between crustal tectonics and mantle events are being constrained by comparing *TerraneChron*<sup>®</sup> analysis of zircons from modern streams, and the kimberlites themselves, with existing Re-Os ages for mantle rocks.



*Bill Griffin and Alan Kobussen picking over a concentrate pile during a trip to South Africa.*

### Trace-element analysis of diamonds

*Supported by Industry and a matching Macquarie University Collaborative Grant*

*Industry Collaborator: Rio Tinto*

**Summary:** Diamonds contain minute amounts of trapped fluids, representing the medium from which the diamonds grew; these fluids are a unique source of information on processes in Earth's mantle. New techniques for the trace-element analysis of these fluids, developed recently in GEMOC were further developed, and applied to the analysis of selected populations of diamonds from the Argyle mine (WA). The data will provide

new insights into the genesis of diamond, with applications both to exploration models and to test the feasibility of "fingerprinting" of diamonds for exploration and forensic purposes (tracing illegal diamond sources). This project led to the ARC Linkage Grant for 2007.



*Rio Tinto came to GEMOC for a project review meeting L-R: John Takos, Esmé van Achterbergh (GEMOC PhD 2005), Paul Agnew, Sue O'Reilly, Bill Griffin, Phil Plaisted, John Chapman, Debora Araujo, Norm Pearson.*



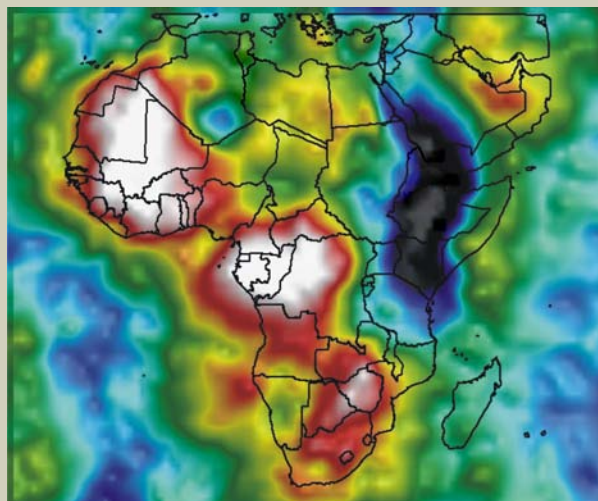
## Global Lithosphere Architecture Mapping

*Supported by ARC Linkage*

*Industry Collaborator: BHP Billiton*

**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 in this first-stage project is providing fundamental insights into Earth processes and a basis for the targeting of mineral exploration. We are integrating 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 (e.g. *GEMOC Publication #423*). These maps will provide a unique perspective on global dynamics and continental evolution, and on the relationships between lithosphere domains and large-scale mineralisation.

*Seismic tomography (Vs) image of Africa at 100-175 km depth: cratons (high-Vs) stand out in "hot" colours while low-Vs East Africa Rift is in blue-black.*



## Links between plume-mantle interaction, mantle sulfides and Ni-PGE endowment in Large Igneous Provinces

*Supported by industry and a matching Macquarie University Collaborative grant*

*Industry Collaborator: BHP Billiton*

**Summary:** Most large Ni-PGE (Platinum Group Elements) deposits are associated with some, but not all, Large Igneous Provinces (LIP = plume-related flood basalts). Isotopic and trace-element data suggests that the magmas of "fertile" LIPs have interacted with the deep mantle roots of ancient continents. We are testing the hypothesis that the Ni-PGE enrichment in some LIP magmas reflects the mobilisation of pre-existing Ni, PGE-rich sulfide phases as the magmas pass through these old, highly modified mantle roots. This model, if confirmed, will be a major advance on traditional models for Ni-PGE concentration, and will have a significant impact on exploration models. See *GEMOC Publication #473*.



## **Mechanisms of PGE fractionation and concentration in mafic and ultramafic melts**

*Supported by AMIRA and MERIWA and an international postgraduate scholarship from Macquarie University*

*Industry Collaborators: BHP Billiton, Independence, LionOre*

*In collaboration with Dr Marco Fiorentini from UWA with shared PhD student Marek Locmelis*

**Summary:** A long-standing goal of research on nickel-sulfide (NiS) deposits has been the development of reliable lithogeochemical indicators that can act as guides for exploration. In order to better constrain how platinum-group element (PGE) signatures may be utilised as pathfinders for those NiS deposits, this project focuses on the processes that control the fractionation and concentration of PGE in mafic and ultramafic magma types. The study looks into a range of variables controlling the PGE geochemistry, including the role of sulfides (i.e. pentlandite, millerite), oxides (i.e. chromite), silicate phases (i.e. olivine, pyroxene) and platinum-group minerals (i.e. alloys, antimonides, arsenides, tellurides) in the concentration and fractionation of PGE in mineralised and barren sequences. Furthermore, the study investigates the spatial relationship between the PGE signature of mafic and ultramafic rocks and the occurrence of various types of NiS mineralisation, thus optimising the use of the PGEs as vectors towards mineralised environments.

See *Research highlight p. 34*.

## GEMOC's international links



### BACKGROUND

**G**EMOC'S INTERNATIONAL LINKS provide leverage of intellectual and financial resources on a global scale, and an international network for postgraduate experience. International activity includes funded projects and substantial collaborative programs with exchange visiting programs in France, Norway, Germany, United Kingdom, Canada, USA, Taiwan, Italy, Spain, South Africa, China, Brazil, Japan, Thailand and the former USSR.

### FUNDED COLLABORATIVE PROJECTS COMMENCED OR ONGOING IN 2007 INCLUDE:



- Collaboration in the CERCAMS project ([www.nhm.ac.uk/research-curation/projects/cercams/gallery.html](http://www.nhm.ac.uk/research-curation/projects/cercams/gallery.html)) as part of the ARC Discovery project "Earth's internal system: deep processes and crustal consequences" (see section on *Funded Research Projects*). The CERCAMS project is a major study of crustal evolution across the Altaiides, led by the Centre for Russian and Central EurAsian Mineral Studies at the Natural History Museum, London (Dr Richard Herrington, PI on the Discovery Project, and Dr Reimar Seltman, left) and involving Russian research groups, a number of industry sponsors and GEMOC.
- Trace elements and fluids in diamonds and relevance to mantle fluids and processes with Professor Oded Navon (Hebrew University, Israel).
- Shear-induced segregation in ordinary chondrites, a collaborative project with Professor N. Petford (Bournemouth University, UK).
- Core formation and degassing of the Earth, a collaborative project with Dr S. Nielsen and Professor A. Halliday (University of Oxford) and Dr M. Rehkamper (Imperial College, London).
- Partitioning of chalcophile elements between metal, sulphide and silicate, a collaborative project with Dr D. Frost and Professor D. Rubie (Bayreuth University, Germany).
- Detailed 2-D and 3-D structure of the Kaapvaal Craton in several time slices, using mantle-derived xenocrysts: a collaborative project with De Beers.
- Global Lithosphere Architecture Mapping, involving analysis of crustal evolution, the composition of the lithospheric mantle and the interpretation of seismic tomography: a collaborative project with BHP Billiton and Steve Grand (University of Texas at Austin).
- Collaboration with Professor Massimo Coltorti and Dr Costanza Bonadiman from the University of Ferrara on the geochemistry of amphiboles, mantle metasomatism, and the age and origin of the lithospheric mantle beneath the Cape Verde Islands and Antarctica.

- *TerraneChron*<sup>®</sup> study to unravel the timing and tectonic history of regions in Tibet was initiated as a collaborative program with the National University of Taiwan (led by Professor Sun-Lin Chung), and has expanded to include collaboration with Nanjing University.
- The nature of the lithosphere in Mongolia, and lithosphere extension in the Taiwan region, with Dr Kuo-Lung Wang (Institute of Earth Sciences, Academia Sinica, Taiwan).
- Collaboration with colleagues at the University of Jean Monnet, St Etienne, including Professor Jean-Yves Cottin, Dr Bertrand Moine and Dr Marie-Christine Gerbe (with reciprocal funding from both sides) expanded. A formal agreement between the two universities includes PhD exchange, academic exchange and research collaboration relevant to the nature of the lithosphere in the Kerguelen Archipelago, Crozet Islands and the Hoggar region of Algeria. In addition, studies on magma mixing in granites commenced with a new co-tutelle agreement (Anne Fonfrege).
- Trace elements in mineral inclusions in lower mantle diamonds from Juina, Brazil with Dr Felix Kaminsky (KM Diamond Exploration, Vancouver, Canada).

- Dr Farida Ait-Hamou from the Université des Sciences et de la Technologie Houari Boumediene (USTHB), Algeria, undertook fieldwork in Algeria to collect mantle xenoliths from the Hoggar region as part of the Hoggar strand of the Discovery Project “Earth’s Internal System: deep processes and crustal consequences”. These xenoliths were analysed during her visit to GEMOC for the lithosphere mapping of this part of Algeria to integrate with geophysical datasets.



*Dr Farida Ait-Hamou needed a camel caravan to sample the remote volcanoes of the Hoggar region, Algeria.*

- Igneous rocks, mineral deposits, lithosphere structure and tectonic setting: southeastern China and eastern Australia. This collaboration with Nanjing University has expanded from an AusAID grant under the ACILP scheme with Professor Xisheng Xu (Nanjing University).
- Studies with Professor Jianping Zheng (China University of Geosciences, Wuhan) on the evolution of the lithosphere beneath several parts of China, crustal evolution in the North China Block the Yangtze Block and southeastern China, and the UHP metamorphism of Dabie-Sulu peridotites.
- Studies on Cathaysia’s place in Rodinia, crustal evolution of southeast China, and crustal evolution of the Yangtze Block with Professor Jinhai Yu and Ms Lijuan Wang from Nanjing University.
- Studies continued with Dr Rendeng Shi (University of Science and Technology, Hefei, China) on the age and origin of platinum group alloy phases in podiform chromitites in ophiolites from Tibet.



## GEMOC's international links

Refer to the Research Program and Postgraduate sections of this Report for details of other projects.

*Massimo Coltorti and Costanza Bonadiman (University of Ferrara) formulate collaborative research with GEMOC.*

- Analysis of off-craton lithospheric mantle in the East Central Asia Orogenic Belt and fundamental studies on the origin of diamonds, with Dr V. Malkovets, Novosibirsk.
- *TerraneChron*<sup>®</sup> analysis of Proterozoic terrains in Africa, North America and Europe, with BHP Billiton and several other mineral-exploration companies.
- Tectonic domains in southern Norway and Mozambique using *TerraneChron*<sup>®</sup> with Professor T. Andersen (University of Oslo) and Dr B. Bingen (Norwegian Geological Survey).
- Age and magma sources of Chilean Cu-porphyrries, with Codelco (Chile) and the CSIRO Division of Exploration and Mining (Perth)
- Several collaborative projects were initiated with Dr Kreshimir N. Malitch (Department of Geochemistry All-Russia Geological Research Institute (VSEGEI), St Petersburg) including: (1) the nature and origin of zircons from the intra-continental paleorift-related ultramafic-mafic intrusions of the Noril'sk area (northern Siberia, Russia). The latter include world-class PGE (platinum-group element)-Cu-Ni sulfide deposits related to Noril'sk-1, Talnakh and Kharaelakh ultramafic-mafic intrusions, subeconomic PGE-Cu-Ni deposits related to Chrnogorsk, Zub-Marksheider and Vologochan intrusions, prospective Mikchanga intrusion and non-economic Nizhny Talnakh, Zelyonaya Griva and Kruglogorsk intrusions; (2) analysis of Os-(Ir-Ru) alloy grains derived from two world-class Au-PGE placer deposits associated with the Guli clinopyroxenite-dunite massif (northern Siberia, Russia) and the Evander Goldfield within the Witwatersrand Basin (South Africa). The main aim of this study is to place further constraints on osmium-isotope signatures of the mantle sources for Os-rich alloy grains at Guli and Evander, which (along with Witwatersrand grains) represent the oldest terrestrial platinum-group minerals known so far.



### European Mantle Workshop in Ferrara

GEMOC had a high profile in both the organisation and scientific program at the 2007 European Mantle Workshop (EMAW) on the "Petrological Evolution of the European Lithospheric Mantle from Archean to Present Day", held in Ferrara in August 2007. The event was organised by M. Coltorti (University of Ferrara), H. Downes (London University), M. Grégoire (Toulouse) and S.Y. O'Reilly (GEMOC) and was sponsored by the University of Ferrara, the Istituto Universitario di Studi Superiori (IUSS) of the same university, the Gruppo Nazionale di Petrografia (GNP) and the Federazione Italiana di Scienze della Terra (FIST). This was a high-profile international event with nearly 100 participants and has resulted in the formation of an international group to coordinate research on this topic with an annual workshop. Abstracts, photographs and some presentations in pdf format are available at: <http://www.unife.it/dipartimento/scienze-terra/emaw-2007>.

**G**EMOC'S BUSINESS PLAN HAS PROVED TO BE A SUCCESSFUL blueprint, resulting in viable funding to continue and evolve GEMOC's activities beyond the Commonwealth funding period that ended in 2001.

**Key elements of funding continuation include:**

- Recognition as Centre of Concentration of Research Excellence at Macquarie by the new Vice-Chancellor in 2006 and award of six new funded academic positions
- Macquarie University provides Postgraduate Scholarships for Australian and international students
- ARC Discovery and Linkage successes
- Award of two Federation Fellowships (Professors Simon Turner and Bernard Wood)
- Industry funding has increased through substantial collaborative ventures supporting basic research
- Commercialisation of GLITTER software through AccessMQ
- Independent Research Fellowships to support Postdoctoral Fellows (Australian and International sources)
- LIEF successes for infrastructure with co-investment by industry and other universities
- DEST Systemic Infrastructure Initiative Grant (\$5.125 million) for 2002-2004
- Success in Macquarie University competitive funding schemes for research, postgraduate studies, and teaching development for undergraduate studies
- 3 academic staff members (Drs Kelsie Dadd, Simon Jackson and Nathan Daczko) appointed to GEMOC in 1995, 1996 and 2003 have continuing appointments

**Strategy for ongoing Geochemical Analysis Unit funding**

GEMOC's outstanding analytical facilities are vital to our innovative research programs and to attracting research and industry income. This technology concentration also represents a high-budget item in terms of maintenance, running costs, replacement and especially for new purchases to maintain frontline developments. Funding strategies in place include:

- User-pays system for running, maintenance and development costs
- University annual contributions through competitive schemes and capital equipment allocations
- Annual contribution from the Department of Earth and Planetary Sciences
- Macquarie University was designated as one of the National Geochemistry Nodes in the AuScope ([www.auscope.org.au](http://www.auscope.org.au)) award in the NCRIS round in 2007 and will receive a funding contribution to staff and small equipment items for five years from 2007
- Macquarie University's guarantee of a strategic plan to ensure the integrity, maintenance and appropriate staffing of the Geochemical Analysis Unit
- Collaborative project building with industry partners

## GEMOC Funding

- Delivery of new exploration tools to industry through novel analytical methodologies
- Research and Development ventures with manufacturers leading to equipment replacement
- Applications to funding schemes for matching funds for new purchases and with partner co-investment
- Industry capital investment in return for access equity, negotiated intellectual property and collaborative rates

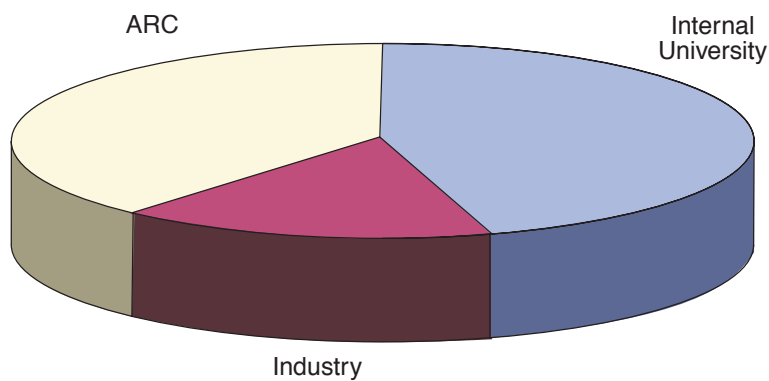
## GEMOC INCOME 2007

This is a summary of 2007 income. A full, audited statement of detailed expenditure and income is prepared by Macquarie University. *No in-kind support is included here.*

	<b>\$K</b>
<b>ARC</b>	
<i>Discovery (including Fellowships), Linkage (Project and International), Federation Fellowships</i>	1,029.6
<b>INDUSTRY</b>	
Collaborative Research grants (MUECRG industry components and direct industry)	203.0
External collaborative research projects and GLITTER through AccessMQ	238.7
<b>INTERNAL UNIVERSITY</b>	
<i>GAU maintenance (Department)</i>	30.0
<i>Internal competitive schemes</i>	
Macquarie Fellowships	172.3
Matching to ARC schemes	307.2
Research grants	102.4
Postgraduate awards	490.8
Postgraduate research grants	45.0
Infrastructure (RIBG)	60.0
Capital Equipment	52.5
<b>TOTAL</b>	<b>2,731.5</b>



**PIE-CHART OF  
INCOME SOURCES  
2007**



**BENEFITS TO AUSTRALIA**

- **Scientific innovation relevant to National Priority Areas**
  - Research Priority 1: An Environmentally Sustainable Australia (Goal 1: Water – a Critical Resource and Goal 3: Developing Deep Earth Resources) and*
  - Research Priority 3: Frontier Technologies for Building and Transforming Australian Industries (Goal 1: Breakthrough Sciences and Goal 2: Frontier Technologies)*
- **Enhanced international links**
- **Excellence in training of our future generation of geoscientists**
- **Enhanced industry links nationally and internationally**
- **Improved exploration tools and strategies for Australian mineral exploration companies both on- and off-shore**
- **Technological innovation (scientific advances, intellectual property, commercialisation, value-added consulting services)**

## Appendix 1: Participants

### GEMOC PARTICIPANTS 2007/2008

#### MACQUARIE UNIVERSITY

#### Department of Earth and Planetary Sciences

#### *Academic and GEMOC Managerial Staff*

##### *(Teaching and Research)*

Dr Nathan Daczko (Structural and metamorphic geology, tectonics, geodynamics)

Dr Kelsie Dadd (Physical volcanology, geochemistry, tectonics)

Dr Richard Flood (Volcanic geology, application of magnetic fabrics to reconstruction of volcanic terrains)

Professor W.L. Griffin, Program Leader (Technology development and industry liaison)

Dr Simon Jackson (Trace element geochemistry, metallogeny)

Dr Mark Lackie (Rock magnetism, paleomagnetic reconstructions)

Dr Craig O'Neill (Geodynamic modelling)

Professor Suzanne Y. O'Reilly, Director (Crust and mantle evolution, lithosphere modelling)

Dr Norman Pearson (Manager, GAU)

Dr Tracy Rushmer (Experimental rock deformation and experimental petrology)

Professor Simon Turner (Isotopic geochemistry)

Professor Bernard Wood (Experimental petrology)

#### *Research Staff*

Dr Olivier Alard

Dr Debora Araujo

Dr Christoph Beier

Dr Elena Belousova

Dr Mei-Fei Chu

Dr Alex Corgne

Dr Anthony Dosseto

Dr Kevin Grant

Emeritus Professor Trevor Green

Dr Heather Handley

Dr Kierran Maher

Dr Laure Martin

Dr Lev Natapov

Emeritus Professor John Veevers

Emeritus Professor Ron Vernon

Dr Ming Zhang

#### *Professional Staff*

Miss Shelley Allchurch (Technical Assistant)

Ms Manal Bebbington (Rock preparation)

Mr James Bevis (Technical Assistant)

Dr Eloise Beyer (Geochemist)

Mrs Nikki Bohan (Administrator)

Mr Steven Craven (Rock preparation)

Ms Suzy Elhlou (Geochemist)

Dr Oliver Gaul (Research Officer)

Ms Sally-Ann Hodgekiss (Research Officer, Design consultant)

Ms Carol Lawson (Technical Officer)

Mrs Carol McMahan (Administrator)

Dr William Powell (Research Officer)

Dr Ayesha Saeed (Geochemist)

Mr Peter Wieland (Geochemist)

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Professor Bruce Chappell (Granite petrogenesis, geochemistry)

Professor Mike Etheridge

Dr Richard Glen

Dr Jingfeng Guo

Dr Jon Hronsky (BHP Billiton)

Professor Else-Ragnhild Neumann

Professor Xisheng Xu

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Dr Bin Guo

Dr Xiumian Hu

Dr Bram Janse

Dr Mel Jones

Dr Felix Kaminsky

Dr Oliver Kreuzer  
Dr Hans-Rudolf Kuhn  
Dr Vladimir Malkovets  
Dr Bertrand Moine  
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Dr Geoff Nichols  
Dr Mark C. Pirlo  
Dr Yvette Poudjom Djomani  
Dr Sonal Rege  
Dr Peter Robinson  
Dr Chris Ryan  
Dr Bruce Schaefer  
Dr Stirling Shaw  
Dr Simon Shee  
Dr Zdislav Spetsius  
Dr Nancy van Wagoner  
Dr Kuo-Lung Wang  
Professor Xiang Wang  
Dr Xiao-Lei Wang  
Mr Bruce Wyatt  
Ms Chunmei Yu  
Professor Jin-Hai Yu  
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Professor Allan Chivas (DEST  
Systemic Infrastructure partner)

##### ***Monash University***

Dr Bruce Schaefer (LIEF and  
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##### ***University of Newcastle and James Cook University***

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##### ***University of Sydney***

Dr G. Clarke (DEST Systemic  
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##### ***University of Western Sydney***

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Professor Geoff Davies  
Professor Brian Kennett  
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Professor Steve Grand (University of  
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Professor Oded Navon (The Hebrew  
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Dr Patrice Rey (University of  
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Professor Marco Scambelluri  
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Dr Reimar Seltmann (Natural  
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Professor Thomas Stachel  
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##### ***Technology Partners***

Agilent Technologies (Hewlett  
Packard)

New Wave Research

Spectro Instruments

Nu Instruments



## Appendix 2: Publications 2007/2008

A full list of GEMOC Publications is available at

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

337. Reid, A., Wilson, C.J.L., Shun, L., Pearson, N.J. and Belousova, E. 2007. Mesozoic plutons of the Yidun Arc, SW China: U/Pb geochronology and Hf isotopic signature. *Ore Geology Reviews*, 31, 88-106.
419. Powell, W. and O'Reilly, S.Y. 2007. Metasomatism and sulfide mobility in lithospheric mantle beneath eastern Australia: implications for mantle Re-Os chronology. *Lithos*, 94, 132-147.
427. Downes, P.J., Griffin, B.J. and Griffin, W.L. 2007. Mineral chemistry and zircon geochronology of xenocrysts and altered mantle and crustal xenoliths from the Aries micaceous kimberlite: Constraints on the composition and age of the central Kimberley Craton, Western Australia. *Lithos*, 93, 175-198.
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441. Yu, J., O'Reilly, S.Y., Wang, L., Griffin, W.L., Jiang S., Wang, R. and Xu, X. 2007. Finding of ancient materials in Cathaysia and implication for the formation of Precambrian crust. *Chinese Science Bulletin*, 52, 13-22.
442. Murgulov, V., Beyer, E., Griffin, W.L., O'Reilly, S.Y., Walters, S.G. and Stephens, D. 2007. Crustal evolution in the Georgetown Inlier, North Queensland, Australia: a detrital zircon grain study. *Chemical Geology*, 245, 198-218.
445. Bomparola, R.M., Ghezzi, C., Belousova, E., Griffin, W.L. and O'Reilly, S.Y. 2007. Resetting of the U-Pb zircon system in Cambro-Ordovician intrusives of the Deep Freeze Range, Northern Victoria Land, Antarctica. *Journal of Petrology*, 48, 327-364.
446. Clarke, G.L., White, R.W., Lui, S., Fitzherbert, J.A. and Pearson, N.J. 2007. Contrasting behaviour of rare earth and major elements during partial melting in granulite facies migmatites, Wuluma Hills, Arunta Block, central Australia. *Journal of Metamorphic Geology*, 25, 1-18.
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449. Malkovets, V.G., Griffin, W.L., O'Reilly, S.Y. and Wood, B.J. 2007. Diamond, subcalcic garnet and mantle metasomatism: Kimberlite sampling patterns define the link. *Geology*, 35, 339-342.
450. Guo, B., Lackie, M.A. and Flood, R.H. 2007. Upper crustal structure of the Tamworth Belt, New South Wales: constraints from new gravity data. *Australian Journal of Earth Sciences*, 54, 1073-1087.
451. Griffin, W.L., Pearson, N.J., Belousova, E.A. and Saeed, A. 2007. Reply to "Comment to short-communication 'Comment: Hf-isotope heterogeneity in zircon 91500' by W.L. Griffin, N.J. Pearson, E.A. Belousova and A. Saeed (Chemical Geology 233 (2006) 358-363)" by F. Corfu. *Chemical Geology*, 244, 354-356.
452. Sapienza, G.T., Griffin, W.L., O'Reilly, S.Y. and Morten, L. 2007. Crustal zircons and mantle sulfides: Archean to Triassic events in the lithosphere beneath south-eastern Sicily. *Lithos*, 96, 503-523.
454. Zedgenizov, D.A., Rege, S., Griffin, W.L., Kagi, H. and Shatsky, V.S. 2007. Composition of trapped fluids in cuboid fibrous diamonds from the Udachnaya kimberlite pipe: LAM-ICPMS analysis. *Chemical Geology*, 240, 151-162.
455. Corgne, A., Keshav, S., Fei, F. and McDonough, W.F. 2007. How much potassium is in the Earth's core? New insights from partitioning experiments. *Earth and Planetary Science Letters*, 256, 567-576.
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463. O'Neill, C., Lenardic, A., Jellinek, A.M. and Kiefer, W.S. 2007. Melt propagation and volcanism in mantle convection simulations, with applications for Martian volcanic and atmospheric evolution. *Journal of Geophysical Research - Planets*, 112 E07003, doi:10.1029/2006JE002799.
464. Batumike, J.M., O'Reilly, S.Y., Griffin, W.L. and Belousova, E.A. 2007. U-Pb and Hf-isotope analyses of zircon from the Kundelungu Kimberlites, D.R. Congo: Implications for crustal evolution. *Precambrian Research*, 156, 195-225.
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466. **Turner, S., Tonarini, S., Bindeman, I., Leeman, W.P. and Schaefer, B.F.** 2007. Boron and oxygen isotope evidence for recycling of components over the past 2.5 Gyr. *Nature*, 447, 702-705.
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468. **Heyworth, Z., Turner, S., Schaefer, B., Wood, B., George, R., Berlo, K., Cunningham, H., Price, R., Cook, C. and Gamble, J.** 2007.  $^{238}\text{U}$ - $^{230}\text{Th}$ - $^{226}\text{Ra}$ - $^{210}\text{Pb}$  constraints on the genesis of high-Mg andesites at White Island, New Zealand. *Chemical Geology*, 243, 105-121.
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470. **Veevers, J.J. and Saeed, A.** 2007. Central Antarctic provenance of Permian sandstones in Dronning Maud Land and the Karoo Basin: Integration of U-Pb and TDM ages and host-rock affinity from detrital zircons. *Sedimentary Geology*, 202, 653-676.
471. **Coltorti, M., Bonadiman, C., Faccini, B., Grégoire, M., O'Reilly, S.Y. and Powell, W.** 2007. Amphiboles from suprasubduction and intraplate lithospheric mantle. *Lithos*, 99, 68-84.
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473. **Zhang, M., O'Reilly, S.Y., Wang, K.L., Hronsky, J. and Griffin, W.L.** 2008. Flood basalts and metallogeny: The lithospheric mantle connection. *Earth-Science Reviews*, 86, 145-174.
474. **Grant, K.J., Kohn, S.C. and Brooker, R.A.** 2007. The partitioning of water between olivine, orthopyroxene and melt synthesised in the system albite-forsterite- $\text{H}_2\text{O}$ . *Earth and Planetary Science Letters*, 260, 227-241.
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478. **Grant, K.J., Brooker, R.A., Kohn, S.C. and Wood, B.J.** 2007. The effect of oxygen fugacity on hydroxyl concentrations and speciation in olivine: implications for water solubility in the upper mantle. *Earth and Planetary Science Letters*, 261, 217-229.
479. **O'Neill, C.J., Lenardic, A., Griffin, W.L. and O'Reilly, S.Y.** 2008. Dynamics of cratons in an evolving mantle. *Lithos*, 102, 12-24.
480. **Grant, K., Ingrin, J., Lorand, J.P. and Dumas, P.** 2007. Water partitioning between mantle minerals from peridotite xenoliths. *Contributions to Mineralogy and Petrology*, 154, 15-34.
481. **Aulbach, S., Pearson, N.J., O'Reilly, S.Y. and Doyle, B.J.** 2007. Origins of xenolithic eclogites and pyroxenites from the central Slave Craton, Canada. *Journal of Petrology*, 48, 1843-1873.
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483. **Wyman, D.A., O'Neill, C. and Ayer, J.A.** 2008. Evidence for modern-style subduction to 3.1Ga: A plateau - adakite - gold (diamond) association. *Precambrian Research Special Penrose Volume*. (in press)
484. **O'Neill, C., Jellinek, A.M. and Lenardic, A.** 2007. Conditions for the onset of plate tectonics on terrestrial planets and moons. *Earth and Planetary Science Letters*, 261, 20-32.
485. **Griffin, W.L. and O'Reilly, S.Y.** 2007. The earliest subcontinental lithospheric mantle. In *M. Van Kranendonk, Smithies, H. and Bennett, V. (eds.) Earth's Oldest Rocks*, (Developments in Precambrian Geology, Volume 15) Elsevier, Amsterdam, p1013-1035. ISBN: 978-0-444-52810-0.
486. **Wang, X.L., Zhou, J.C., Griffin, W.L., Wang, R.C., Qiua, J.S., O'Reilly, S.Y., Xua, X., Liuc, X.M. and Zhang, G.L.** 2007. Detrital zircon geochronology of Precambrian basement sequences in the Jiangnan orogen: Dating the assembly of the Yangtze and Cathaysia Blocks. *Precambrian Research*, 159, 117-131.
487. **Veevers, J.J., Saeed, A., Pearson, N., Belousova, E. and Kinny, P.** 2008. Zircons and clay from morainal Permian siltstone at Mt Rymill (73°S, 66°E), Prince Charles Mountains, Antarctica, reflect the ancestral Gamburtsev Subglacial Mountains-Vostok Subglacial Highlands complex. *Gondwana Research*. (in press, online)
488. **Turner, S., Sims, K.W.W., Reagan, M. and Cook, C.** 2007. A  $^{210}\text{Pb}$ - $^{226}\text{Ra}$ - $^{230}\text{Th}$ - $^{238}\text{U}$  study of Klyuchevskoy and Bezymianny volcanoes, Kamchatka. *Geochimica et Cosmochimica Acta*, 71, 4771-4785.



## Appendix 2: Publications

489. **Murgulov, V., O'Reilly, S.Y., Griffin, W.L. and Blevin, P.L.** 2008. Magma sources and gold mineralisation in the Mount Leyshon and Tuckers Igneous Complexes, Queensland, Australia: U-Pb and Hf isotope evidence. *Lithos*, 101, 281-307.
490. **Xu, X., Griffin, W.L., O'Reilly, S.Y., Pearson, N.J., Geng, H. and Zheng, J.** 2008. Re-Os isotopes of sulfides in mantle xenoliths from eastern China: progressive modification of lithospheric mantle. *Lithos*, 102, 43-64.
491. **Griffin, W.L., Belousova, E.A. and O'Reilly, S.Y.** 2007. Crustal history and metallogenic fertility: Terrane-scale assessment with detrital zircons. *Proceedings of Exploration 07: 5<sup>th</sup> Decennial International Conference on Mineral Exploration, Toronto, September 2007*, 311-315.
492. **Condie, K.C., Belousova, E.A. and Griffin, W.L.** 2008. Granitic events in space and time: Constraints from igneous and detrital zircon age spectra. *Gondwana Research*. (in press).
493. **Zheng, J.P., Griffin, W.L., O'Reilly, S.Y., Yu, C.M., Zhang, H.F., Pearson, N. and Zhang, M.** 2007. Mechanism and timing of lithospheric modification and replacement beneath the eastern North China Craton: Peridotitic xenoliths from the 100 Ma Fuxin basalts and a regional synthesis. *Geochimica et Cosmochimica Acta*, 71, 5203-5225.
494. **Klimm, K., Blundy, J.D. and Green, T.H.** 2008. Trace element partitioning and accessory phase saturation during H<sub>2</sub>O saturated melting of basalt with implications for subduction zone chemical fluxes. *Journal of Petrology*, 49, 523-553.
495. **Corgne, A., Keshav, S., Wood, B.J., McDonough, W.F. and Fei, Y.** 2008. Metal-silicate partition coefficients and constraints on core composition and oxygen fugacity during Earth accretion. *Geochimica et Cosmochimica Acta*, 72, 574-589.
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498. **Adam, J., Oberti, R., Camara, F. and Green T.H.** 2007. An electron microprobe, LAM-ICP-MS and single-crystal X-Ray structure refinement study of the effects of pressure, melt-H<sub>2</sub>O concentration and fO<sub>2</sub> on experimentally produced basaltic amphiboles. *European Journal of Mineralogy*, 19, 641-655.
499. **O'Neill, C., Lenardic, A., Moresi, L., Torsvik, T. and Lee, C.-T.** 2008. Episodic Precambrian subduction. *Earth and Planetary Science Letters*, 262, 552-562.
500. **Dosseto, A., Bourdon, B. and Turner, S.P.** 2008. Uranium-series isotopes in river materials: insights into the timescales of erosion and sediment transport. *Earth and Planetary Science Letters*, 265, 1-17.
501. **Veevers, J.J., Saeed, A. and O'Brien, P.E.** 2008. Gamburtsev Subglacial Mountains provenance from U-Pb and Hf-isotope analysis of detrital zircons in Cretaceous, Eocene, and Quaternary sediment in Prydz Bay and beneath the Amery Ice Shelf. *Sedimentary Geology*. (in press)
502. **Zheng, J.P., Sun, M., Griffin, W.L., Zhou, M.F., Zhao, G.C., Robinson, P., Tang, H.Y. and Zhang, Z.H.** 2008. Age and geochemistry of contrasting peridotite types in the Dabie UHP belt, eastern China: Petrogenetic and geodynamic implications. *Chemical Geology*, 247, 282-304.
503. **Turner, S., Regelous, M., Falloon, T., Taylor, P., Gamble, J. and Green, T.** 2008. Mantle dynamics and mantle melting beneath Niufo'ou Island and the northern Lau back-arc basin. *Contributions to Mineralogy and Petrology*. (in press, online)
504. **Nielsen, S.G., Rehkämper, M., Brandon, A.D., Norman, M.D., Turner, S. and O'Reilly, S.Y.** 2008. Thallium isotopes in Iceland and Azores lavas – Implications for the role of altered crust and mantle geochemistry. *Nature*. (in press)
505. **Batumike, J.M., Griffin, W.L., Belousova, E.A., Pearson, N.J., O'Reilly, S.Y. and Shee, S.R.** 2008. LAM-ICPMS U-Pb dating of kimberlitic perovskite: Eocene-Oligocene kimberlites from the Kundelungu Plateau, D.R. Congo. *Earth and Planetary Science Letters*, 267, 609-619.
506. **Griffin, W.L.** 2008. Major transformations reveal Earth's deep secrets. (*Invited Research Focus note*) *Geology*, 36, 95-96.
507. **Dosseto, A., Turner, S.P., Sandiford, M. and Davidson, J.** 2008. Uranium-series isotope and thermal constraints on the rate and depth of silicic magma genesis. *Geological Society of London*. (in press)
508. **Wyman, D.A., O'Neill, C. and Ayer, J.A.** 2008. Evidence for modern-style subduction to 3.1 Ga: A plateau-adakite-gold (diamond) association. In *Condie, K.C. and Pease, V. (eds.). When Did Plate Tectonics Begin on Planet Earth?* Geological Society of America Special Paper 440, doi: 10.1130/2008.2440(06).
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510. **Grant, K.J., Kohn, S.C., Brooker, R.A. and Wood, B.J.** 2008. Hydroxyl in natural and experimentally re-equilibrated olivine and orthopyroxene from Ichinomegata, N.E. Japan. *Contributions to Mineralogy and Petrology*. (in press)
511. **Wang, L., Yu, J., O'Reilly, S.Y., Griffin, W.L., Sun, T., Wei, Z., Jiang, S. and Shu, L.** 2008. Are there Grenvillian orogenies in the Southern Cathaysia Block? *Chinese Science Bulletin*. (in press)
512. **Yang, J.-H., Wu, F.-Y., Wilde S.A., Belousova, E. and Griffin, W.L.** 2008. Mesozoic Decratonization of the North China Block. *Geology*. (in press)
513. **Wood, B.J., Wade, J. and Kilburn, M.R.** 2008. Core formation and the oxidation state of the Earth: additional constraints from Nb, V and Cr partitioning. *Geochimica et Cosmochimica Acta*, 72, 1415-1426.
514. **Weiss, Y., Griffin, W.L., Elhlou, S.E. and Navon, O.** 2008. Comparison between LA-ICP-MS and EPMA analysis of trace elements in diamonds. *Chemical Geology*. (in press, online)
515. **Wood, B.J., Nielsen, S.G., Rehkämper, M. and Halliday, A.N.** 2008. The effects of core formation on the Pb- and Tl-isotopic composition of the silicate Earth. *Earth and Planetary Science Letters*. (in press, online)
516. **Pedersen, S., Andersen, T., Konnerup-Madsen, J. and Griffin, W.L.** 2008. Recurrent Mesoproterozoic continental magmatism in south-central Norway. *International Journal of Earth Sciences*. (in press)
517. **Corgne, A., Wood, B.J. and Fei, Y.** 2008. C- and S-rich molten alloy immiscibility and core formation of planetesimals. *Geochimica et Cosmochimica Acta*, 72, 2409-2416.
518. **Yu, J.H., O'Reilly, S.Y., Wang, L., Griffin, W.L., Zhang, M., Wang, R., Jiang, S. and Shu, L.** 2008. Where was South China in the Rodinia supercontinent? Evidence from U-Pb geochronology and Hf isotopes of detrital zircons. *Precambrian Research*. (in press, online)
519. **Zheng, J.P., Griffin, W.L., Hu, B.Q., Zhang, M., Pearson, N., Wang, F.Z. and Lu, F.X.** 2008. Continental collision and accretion recorded in the deep lithosphere of central China. *Earth and Planetary Science Letters*. (in press)
520. **Burton, G.R., Dadd, K.A. and Vickery, N.M.** 2008. Volcanic arc-type rocks beneath cover 35 km to the northeast of Bourke. *Quarterly Notes, Geological Survey of New South Wales*. (in press)
521. **Afonso, J.C., Fernández, M., Ranalli, G., Griffin, W.L. and Connolly, J.A.D.** 2008. Integrated geophysical-petrological modelling of the lithosphere and sublithospheric upper mantle: methodology and applications. *Geochemistry, Geophysics, Geosystems*, 9, Q05008, doi:10.1029/2007GC001834.
522. **Kobussen, A.F., Griffin W.L., O'Reilly, S.Y. and Shee, S.R.** 2008. The ghosts of lithospheres past: Imaging an evolving lithospheric mantle in southern Africa. *Geology*. (in press)
523. **Beier, C., Rushmer, T., Turner, S.P.** 2008. Heat sources for mantle plumes. *Geochemistry, Geophysics, Geosystems*. (in press)
524. **Wang, Q., Wyman, D.A., Xu, J., Dong, Y., Vasconcelos, P.M., Pearson, N., Wan, Y., Dong, H., Li, C., Yu, Y., Zhu, T., Feng, X., Zhang, Q., Zi, F. and Chu, Z.** 2008. Eocene melting of subducting continental crust and early uplifting of central Tibet: evidence from central-western Qiangtang high-K calc-alkaline andesites, dacites and rhyolites. *Earth and Planetary Science Letters*. (in press)
525. **Aulbach, S., O'Reilly, S.Y., Griffin, W.L. and Pearson, N.J.** 2008. Subcontinental lithospheric mantle origin of high Nb/Ta in eclogite xenoliths. *Nature Geoscience*. (in press)
526. **Griffin, W.L., Belousova, E.A. and O'Reilly, S.Y.** 2007. TerraneChron analysis of zircons from Western Australian samples. *Western Australia Geological Survey, Record 2007/4*, 51pp.
527. **Li, W., Jackson, S.E., Pearson, N.J., Alard, O. and Chappell, B.W.** 2008. Cu isotopic signature of granites from the Lachlan Fold Belt, SE Australia. *Chemical Geology*. (in press)
528. **Veevers, J.J.** 2008. Antarctic-Indian connexions in Rodinia and Gondwanaland. *Gondwana Research*. (in press)
529. **Veevers, J.J.** 2008. Antarctic-Indian rift system: Permian-Triassic analog of the Neogene East African rift system. *Geology*. (in press)
530. **Fei, Y., Zhang, L., Corgne, A., Watson, H., Ricolleau, A., Meng, Y. and Prakapenka, V.** 2007. Spin transition and equations of state of (Mg, Fe)O solid solutions. *Geophysical Research Letters*, 34, L17307, doi:10.1029/2007GL030712.
531. **Wood, B.J. and Corgne, A.** 2007. 2.04 Mineralogy of the Earth – Trace elements and hydrogen in the Earth's transition zone and lower mantle. In *G.D. Price. (ed.) Treatise on Geophysics*, 2, 63-89. ISBN: 978-0-444-519283.
532. **Price, R.C., George, R., Gamble, J.A., Turner, S., Smith, I.E.M., Cook, C., Hobden, B. and Dosseto, A.** 2007. U-Th-Ra fractionation during crustal-level andesite formation at Ruapehu volcano, New Zealand. *Chemical Geology*, 244, 437-451.
533. **Davidson, J., Turner, S., Handley, H., Macpherson, C. and Dosseto, A.** 2007. Amphibole "sponge" in arc crust? *Geology*, 35, 787-790.

## Appendix 3: Visitors/GAU users

### GEMOC VISITORS 2007 (Excluding Participants in Conferences and Workshops) Macquarie

- Dr Juan Carlos Afonso (Institute of Earth Sciences “Juame Almera”, Spain)
- Paul Agnew (Rio Tinto Exploration Pty Limited)
- Dr Farida Ait-Hamou (Universit e des Sciences et de la Technologie Houari Boumediene, Algeria)
- Dr David Apter (De Beers Group Exploration, South Africa)
- Dr Graham Begg (BHP Billiton, Perth, WA)
- Dr Graham Begg (Minerals Targeting International Pty Ltd)
- John Chapman (Rio Tinto Diamonds)
- Dr Claude Dalpe (Royal Canadian Mounted Police, Canada)
- Dr David Foster (University of Florida, USA)
- Dr Galen Halvorson (University of Adelaide, Department of Geology and Geophysics)
- Dr Hielke Jelsma (De Beers Group Exploration, South Africa)
- Dr Felix Kaminsky (KM Diamond Exploration Ltd, Canada)
- Dr Jason Kirby (CSIRO Land and Water Adelaide Laboratory, Glen Osmond, SA)
- Prof Yuri Kostitsyn (GEOKHI RAS, Moscow, Russia)
- Prof Paul Munroe (UNSW Electron Microscopy Centre)
- Prof Oded Navon (Hebrew University, Israel)
- Phil Plaisted (Rio Tinto Exploration Pty Limited)
- Mr Robin Preston (De Beers Group Exploration, South Africa)
- Dr Simon Shee (Glen Iris, Victoria)
- Prof Ian Smith (University of Auckland, New Zealand)
- Mr Roberto Souza (BHP Billiton, Rio de Janeiro Brazil)
- Prof Marion Stevens-Kalceff (UNSW Electron Microscopy Centre)
- Dr Kenneth Tainton (De Beers Group Exploration, South Africa)
- John Takos (Rio Tinto Operational and Technical Excellence (OTX), Victoria)
- Esme van Achterbergh (Rio Tinto Operational and Technical Excellence (OTX), Victoria)
- Dr Kuo-Lung Wang (Institute of Earth Sciences, Taiwan)
- Ms Lijuan Wang (Nanjing University, China)
- Mr Bruce Wyatt (Wyatt Geology Consulting Ltd, Victoria)
- Dr Jin-Hui Yang (Chinese Academy of Sciences, China)
- Prof Jinhai Yu (Nanjing University, China)
- Mr Bernie Zarcinas (CSIRO Land and Water Adelaide Laboratory, Glen Osmond, SA)
- Prof Jianping Zheng (China University of Geosciences, China)

**EXTERNAL USERS OF THE  
GEOCHEMICAL ANALYSIS UNIT  
FACILITIES IN 2007**

**(Note: this does not include  
contract work through  
AccessMQ)**

Dr Jin-hui Yang (Chinese Academy  
of Sciences, Beijing, China)

Prof Jinhai Yu (Nanjing University,  
China)

Dr Jianping Zheng (China  
University of Geosciences,  
China)

Dr Chris Adams (Institute of  
Geological and Nuclear Science,  
New Zealand)

Ms Katie Howard (Adelaide  
University, SA)

Dr Xiumian Hu (Nanjing  
University, China)

Dr Felix Kaminsky (KM Diamond  
Exploration, Vancouver,  
Canada)

Dr Kreshimir Malitch (Department  
of Geochemistry, All-Russia  
Geological Research Institute  
(VSEGEI), St Petersburg)

Ms Kylie Mationi (University of  
Adelaide, SA)

Prof Oded Navon (Hebrew  
University of Jerusalem,  
Jerusalem, Israel)

Prof Kye-Hun Park (Pukyong  
National University, Korea)

Dr Glen Phillips (University of  
Newcastle, NSW)

Dr Bruce Schaefer (School  
of Geosciences, Monash  
University, Vic)

Ms Ailsa Shwarz (Adelaide  
University, SA)

Mr Mike Szpurner (PIRSA/  
University of Adelaide, SA)

Dr Ken Tainton (De Beers)

Dr Kuo-Lung Wang (Institute of  
Earth Sciences, Academia  
Sinica, Taiwan)

Ms Lujiang Wang (Nanjing  
University, China)



## Appendix 4: Abstract titles

### TITLES OF ABSTRACTS FOR CONFERENCE PRESENTATIONS IN 2007

Full abstracts available at  
<http://www.es.mq.edu.au/GEMOC/>

#### SOTA - STATE OF THE ARC 2007, TERMAS PUYEHUE, CHILE, JANUARY 28-FEBRUARY 2, 2007

**Where radioactive isotopes meet  
diffusion: time scales of igneous  
processes from plutonic or volcanic  
crystals**

F. Costa<sup>1</sup> and S. Turner<sup>2</sup>

1. Spanish Research Council (CSIC)  
Institute of Earth Sciences 'Jaume  
Almera', Pedralbes, Spain, 2. GEMOC,  
Macquarie

**An important role for amphibole in  
arc magmas – a crustal sponge?**

J. Davidson<sup>1</sup>, C. Macpherson<sup>1</sup>,  
H. Handley<sup>1</sup> and S. Turner<sup>2</sup>

1. Department of Earth Sciences,  
University of Durham, Durham, UK,  
2. GEMOC, Macquarie

#### 7<sup>TH</sup> BIENNIAL EXPLORATION MANAGERS CONFERENCE "MAKING COLLABORATIVE R&D AN INTEGRAL PART OF THE EXPLORATION BUSINESS", BAROSSA VALLEY, SOUTH AUSTRALIA, MARCH 26-29, 2007

**Global lithospheric domains:  
A multidimensional framework  
to enhance mineral exploration  
targeting**

S.Y. O'Reilly and W.L. Griffin **Invited**  
GEMOC, Macquarie

#### GEOLOGICAL SOCIETY OF AMERICA CORDILLERAN SECTION 103 ANNUAL MEETING: BELLINGHAM, WASHINGTON, USA, MAY 4-6, 2007

**Inverted regional metamorphism  
in the coaxially refolded Tonga  
Formation: Evidence for  
Cretaceous accretional tectonics in  
the Cascades crystalline core**

L.A. Jensen<sup>1</sup>, H. Lebit<sup>2</sup>, S.R. Paterson<sup>1</sup>,  
R.B. Miller<sup>3</sup> and R.H. Vernon<sup>4</sup>

1. Department of Earth Sciences,  
University of Southern California,  
Los Angeles, USA, 2. Department of  
Earth and Environmental Sciences,  
University of New Orleans, New  
Orleans, LA, USA, 3. Department of  
Geology, San Jose State University, San  
Jose, USA, 4. GEMOC, Macquarie

#### GEOLOGICAL SOCIETY OF AMERICA/ GEOLOGICAL SOCIETY OF LONDON MEETING: "CONTINENTAL TECTONICS AND MOUNTAIN BUILDING - THE PEACH AND HORNE MEETING", ULLAPOOL, SCOTLAND, MAY 16, 2007

**Coaxial refolding and inverted  
regional metamorphism in the  
Tonga Formation: evidence for  
Cretaceous thrust tectonics in the  
Cascades crystalline core**

L. Jensen<sup>1</sup>, H. Lebit<sup>2</sup>, S.R. Paterson<sup>1</sup>,  
R.B. Miller<sup>3</sup> and R. Vernon<sup>4</sup>

1. Department of Earth Sciences, USC,  
Los Angeles, USA, 2. Department of  
Earth and Environmental Sciences,  
UNO, New Orleans, USA, 3. Geology  
Department, SJSU, San Jose, USA, 4.  
GEMOC, Macquarie

#### AMERICAN GEOPHYSICAL UNION JOINT ASSEMBLY, ACAPULCO, MEXICO, MAY 22-25, 2007

**Fragmentation processes,  
depositional mechanisms and  
lithification of glassy fragmental  
rocks, Macquarie Island**

N.R. Daczko, N. Harb, J.A. Dickinson  
and R. Portner  
GEMOC, Macquarie

#### Exhumation of the Sucking- Dayman Massif, Papua New Guinea

N.R. Daczko, P. Caffi and S.A. Carroll  
GEMOC, Macquarie

**Episodic Precambrian subduction**  
C.J. O'Neill<sup>1</sup>, A. Lenardic<sup>2</sup>, L. Moresi<sup>3</sup>,  
T. Torsvik<sup>4</sup> and C. Lee<sup>2</sup>

1. GEMOC, Macquarie, 2. Rice  
University, Department of Earth  
Science, Houston, USA, 3. Monash  
University, MC2, Department of  
Mathematics, Melbourne, Australia,  
4. Centre for Geodynamics, NGU,  
Trondheim

**New Constraints on the  
petrogenesis and time scales of  
high Mg andesite evolution, White  
Island, New Zealand**

B.F. Schaefer<sup>1</sup>, S.P. Turner<sup>2</sup>, B.J. Wood<sup>2</sup>  
and Z. Heyworth<sup>1</sup>

1. Monash University, School of  
Geosciences, Vic, Australia, 2.  
GEMOC, Macquarie

**Origin of high-Mg andesites at  
White Island**

S.P. Turner and B.J. Wood  
GEMOC, Macquarie University

**High-Mg Andesites, Slab Melts,  
and Wedge Melts: Significance for  
Crustal Genesis?**

S. Turner<sup>1</sup> and I. Smith<sup>2</sup>

1. GEMOC, Macquarie, 2. University  
of Auckland, NZ

#### INTERNATIONAL ECLOGITE FIELD SYMPOSIUM, LOCHALASH, SCOTLAND, JUNE 29-JULY 6, 2007

**Eclogites in the SCLM: Are any  
subducted?**

W.L. Griffin, S.Y. O'Reilly and  
N.J. Pearson **Invited**  
GEMOC, Macquarie

**6<sup>TH</sup> HUTTON SYMPOSIUM ON THE ORIGIN OF GRANITES AND RELATED ROCKS, INTERNATIONAL HUTTON 2007 CONFERENCE, STELLENBOSCH, SOUTH AFRICA, JULY 2-7, 2007**

**The assembly of magma chambers: Evidence from detailed zircon investigations**

E.A. Belousova, W.L. Griffin, S.Y. O'Reilly and V. Murgulov

**Keynote**

GEMOC, Macquarie

**Significance of magma fractionation in generation of rare-metal granites: geochronological and geochemical study of the Raucid multiphase granite (S. Pamir)**

Y.A. Kostitsyn<sup>1</sup>, E.A. Belousova<sup>2</sup> and V.N. Volkov<sup>3</sup>

1. V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow, Russia,
2. GEMOC, Macquarie,
3. Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry (IGEM) RAS, Moscow Russia

**New constraints on metamorphic processes in the eastern Lachlan Fold Belt, south-eastern Australia: relating I- and S- types granites in their type area**

C.D. Quinn<sup>1</sup> and R.A. Glen<sup>1,2</sup>

1. Geological Survey of NSW, Department of Primary Industries,
2. GEMOC, Macquarie

**Generating compositional diversity in TTG magmas during melt segregation in the lowermost crust**

T. Rushmer **Keynote**

GEMOC, Macquarie

**Similarities between A-type granites and low-Ti rhyolites from continental flood basalt provinces**

S.P. Turner and T. Rushmer

GEMOC, Macquarie

**Where do the big S-type granites come from? Problems of extraction and sources of felsic magma**

R.H. Vernon **Keynote**

GEMOC, Macquarie

**"DEFORMATION IN THE DESERT" CONFERENCE, GEOLOGICAL SOCIETY OF AUSTRALIA, SPECIALIST GROUP: TECTONICS AND STRUCTURAL GEOLOGY, ALICE SPRINGS, NT, JULY 9-13, 2007**

**The crustal evolution of the Musgrave Province**

A. Schwarz<sup>1,2</sup>, M. Hand<sup>2</sup>, K. Barovich<sup>2</sup>, B. Wade<sup>2</sup>, E. Belousova<sup>3</sup> and E. Jagodzinski<sup>1</sup>

1. Department of Primary Industries and Resources of South Australia, Adelaide, South Australia,
2. Continental Evolution Research Group, School of Earth and Environmental Sciences, University of Adelaide, South Australia,
3. GEMOC, Macquarie

**THIRD INTERNATIONAL WORKSHOP AND FIELD EXCURSION FOR IGCP 480, BEIJING SHRIMP CENTRE, BEIJING, AUGUST 6-15, 2007**

**The problem of continental margin turbidites: examples from the Lachlan Orogen, Tasmanides, SE Australia**

R.A. Glen<sup>1,2</sup>, A. Saeed<sup>2</sup> and W. Griffin<sup>2</sup>

1. Geological Survey of NSW, Department of Primary Industries,
2. GEMOC, Macquarie

**17<sup>th</sup> VM GOLDSCHMIDT CONFERENCE 2007, COLOGNE, GERMANY, AUGUST 19-24, 2007**

**Thallium isotope constraints on Earth's accretion**

R.G.A. Baker<sup>1,2</sup>, S.G. Nielsen<sup>3</sup>, M. Rehkämper<sup>1,2</sup>, M. Schönbächler<sup>1</sup>, B.J. Wood<sup>4</sup> and A.N. Halliday<sup>3</sup>

1. Impact and Astromaterials Research Centre (IARC), Imperial College, London, UK,
2. The Natural History Museum, London, UK,
3. Department of Earth Science, Oxford, UK,
4. GEMOC, Macquarie

**Experimental constraints on trace element fluxes from slab to wedge**

J. Blundy<sup>1</sup>, K. Klimm<sup>1</sup> and T. Green<sup>2</sup>

1. Earth Sciences, University of Bristol, UK,
2. GEMOC, Macquarie

**Water in the mantle: the effect of olivine and orthopyroxene composition and fO<sub>2</sub>**

R.A. Brooker<sup>1</sup>, K.J. Grant<sup>2</sup>, S.C. Kohn<sup>3</sup> and B.J. Wood<sup>2</sup>

1. Dept of Earth Sciences, University College London, UK,
2. GEMOC, Macquarie,
3. Department of Earth Sciences, University of Bristol, UK

**Source depletion versus extent of melting in the Tongan sub-arc mantle**

J.T. Caulfield, S. Turner, A. Dosseto and N.J. Pearson

GEMOC, Macquarie

**Zircon and whole-rock Hf isotope constraints on the petrogenesis of Transhimalayan plutonic rocks**

M.-F. Chu<sup>1,2</sup>, S.-L. Chung<sup>1</sup>,

S.Y. O'Reilly<sup>3</sup>, N.J. Pearson<sup>3</sup>, X.-H. Li<sup>4</sup> and F.-Y. Wu<sup>4</sup>

1. Department of Geosciences, National Taiwan University,
2. Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan,
3. GEMOC, Macquarie,
4. Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China

**New metal-silicate partition coefficients and constraints on core composition and oxygen fugacity during Earth accretion**

A. Corgne<sup>1,2</sup>, B.J. Wood<sup>1</sup>, W.F.

McDonough<sup>3</sup>, S. Keshav<sup>2</sup> and Y. Fei<sup>2</sup>

1. GEMOC, Macquarie,
2. Geophysical Laboratory, Carnegie Institution of Washington, USA,
3. Department of Geology, University of Maryland, USA

**Amphibole control in the differentiation of arc magmas**

J. Davidson<sup>1</sup>, C. Macpherson<sup>1</sup> and S. Turner<sup>2</sup>

1. Department of Earth Sciences, University of Durham,
2. GEMOC, Macquarie

**The timescale of sediment transport in a small tropical watershed**

A. Dosseto<sup>1</sup>, S.P. Turner<sup>1</sup>, H.L. Buss<sup>2</sup> and F. Chabaux<sup>3</sup>

1. GEMOC, Macquarie,
2. USGS, CA, USA,
3. CGS-EOST, Université de Strasbourg, Strasbourg, France



## Appendix 4: Abstract titles

### **Lithium incorporation in olivine**

K.J. Grant and B.J. Wood  
GEMOC, Macquarie

### **Processes and timescales of magma genesis and differentiation at Lopevi Volcano, Vanuatu, SW Pacific**

H.K. Handley<sup>1</sup>, S.P. Turner<sup>1</sup>,  
S.J. Cronin<sup>2</sup> and I.E.M. Smith<sup>3</sup>  
1. GEMOC, Macquarie, 2. Institute of Natural Resources, Massey University, New Zealand, 3. Department of Geology, University of Auckland, New Zealand

### **Insights into refertilization processes in lithospheric mantle from integrated isotopic studies in the Lherz Massif**

V. Le Roux<sup>1,2</sup>, J.-L. Bodinier<sup>1</sup>, O. Alard<sup>1,2</sup>,  
P. Wieland<sup>2</sup> and S.Y. O'Reilly<sup>2</sup>  
1. Géosciences Montpellier, Université Montpellier 2. Montpellier, France,  
2. GEMOC, Macquarie

### **Cu isotope signature of granites**

W. Li, S.E. Jackson, B.W. Chappell,  
O. Alard and N.J. Pearson  
GEMOC, Macquarie

### **Hf-in-zircon perspective on crustal growth and recycling in the Arabian-Nubian Shield**

N. Morag<sup>1</sup>, D. Avigad<sup>1</sup>, K. Kolodner<sup>1</sup>, E. Belousova<sup>2</sup>, T. Ireland<sup>3</sup> and Y. Harlavan<sup>4</sup>  
1. Institute of Earth Sciences, The Hebrew University of Jerusalem, Israel, 2. GEMOC, Macquarie, 3. Planetary Science Institute, The Australian National University, ACT, Australia, 4. The Geological Survey of Israel, Jerusalem, Israel

### **The first record of allochthonous kimberlite within the Batain Nappes, Eastern Oman**

S. Nasir<sup>1</sup>, S. Al-Khribash<sup>1</sup>, A. Al-Sayigh<sup>1</sup>, A. Alharthy<sup>1</sup>, A. Mubarek<sup>1</sup>,  
H. Rollinson<sup>1</sup>, A. Lazki<sup>1</sup>, E. Belousova<sup>2</sup>,  
W. Griffin<sup>2</sup> and F. Kaminsky<sup>3</sup>  
1. Department of Earth Sciences, Sultan Qaboos University, 2. GEMOC, Macquarie, 3. KM Diamond Exploration Ltd. Vancouver, Canada

### **Mass bias: a comparison of solution and laser ablation MC-ICPMS**

N.J. Pearson<sup>1</sup>, W.L. Griffin<sup>1</sup>, H.-R. Kuhn<sup>1</sup>, O. Alard<sup>1,2</sup>, K.J. Grant<sup>1</sup>, S.E. Jackson<sup>1</sup>, S.Y. O'Reilly<sup>1</sup>  
1. GEMOC, Macquarie, 2. CNRS, Université de Montpellier, France

### **<sup>238</sup>U- and <sup>232</sup>Th-decay series constraints on the timescales of generation and degassing for phonolite erupted in 2004 near Tristan da Cunha**

M.K. Reagan<sup>1</sup>, S. Turner<sup>2</sup>, M. Legg<sup>1</sup>,  
K.W.W. Sims<sup>3</sup> and V. L. Hards<sup>4</sup>  
1. University of Iowa, Iowa City, USA,  
2. GEMOC, Macquarie, 3. WHOI, Woods Hole, MA, USA, 4. British Geological Survey, UK

### **Trace elements in garnets of diamondiferous xenoliths from the Nurbinskaya pipe, Yakutia**

Z.V. Spetsius<sup>1</sup>, W.L. Griffin<sup>2</sup>,  
S.Y. O'Reilly<sup>2</sup> and V.I. Banzeruck<sup>1</sup>  
1. YANIGP CNIGRI, ALROSA Co. Ltd., Mirny, Yakutia, Russia, 2. GEMOC, Macquarie

### **Magma genesis and differentiation at Merapi volcano, Sunda arc, Indonesia**

V.R. Troll<sup>1</sup>, R. Gertisser<sup>2</sup>,  
J.P. Chadwick<sup>1</sup>, J. Keller<sup>3</sup> and  
H.K. Handley<sup>4</sup>  
1. Department of Geology, Trinity College, Dublin, Ireland, 2. Earth Sciences and Geography, Keele University, Keele, UK, 3. Institut für Mineralogie, Petrologie und Geochemie, Universität Freiburg, Germany, 4. GEMOC, Macquarie

### **Fractionation of Fe and O isotopes in the mantle: Implications for the origins of eclogites and the source regions of mantle plumes**

H.M. Williams<sup>1,2</sup>, S.G. Nielsen<sup>1,2</sup>,  
C. Renac<sup>3</sup>, C.A. McCammon<sup>4</sup>,  
W.L. Griffin<sup>1</sup> and S.Y. O'Reilly<sup>1</sup>  
1. GEMOC, Macquarie University, Australia, 2. Department of Earth Sciences, Oxford University, UK, 3. Dept de Géologie de l'Université Jean Monnet, France, 4. Bayerisches Geoinstitut, Universität Bayreuth, Germany

### **Fe-FeS-silicate partitioning of chalcophile and siderophile elements: implications for core formation**

B.J. Wood<sup>1</sup>, A. Corgne<sup>1</sup> and J. Wade<sup>2</sup>  
1. GEMOC, Macquarie, 2. Planetary and Space Sciences Research Institute, Open University, Milton Keynes, UK

### **The age and reworking of Cathaysia crustal basement**

X. Xu<sup>1,2</sup>, S.Y. O'Reilly<sup>2</sup>, W.L. Griffin<sup>2</sup>,  
X. Wang<sup>1,2</sup>, N.J. Pearson<sup>2</sup> and Z. He<sup>1</sup>  
1. State Key Laboratory for Mineral Deposits Research, Department of Earth Sciences, Nanjing University, Nanjing, China, 2. GEMOC, Macquarie

### **EUROPEAN MANTLE WORKSHOP (EMAW): PETROLOGICAL EVOLUTION OF THE EUROPEAN LITHOSPHERIC MANTLE: FROM ARCHEAN TO PRESENT DAY, FERRARA UNIVERSITY, FERRARA ITALY, AUGUST 29-31, 2007**

### **Mantle xenoliths evolution during Neogene post-collisional transition from calc-alkaline to alkaline volcanism in Oranie : A slab breakoff**

J.E. Cottin<sup>1</sup>, G. Delpech<sup>2</sup>, M. Zerkam<sup>3</sup>,  
S.Y. O'Reilly<sup>4</sup>, A. Louni<sup>5</sup>, M. Gregoire<sup>5</sup>  
and J.-P. Lorand<sup>6</sup>  
1. Department of Geology-UMR 6524 Magmas et Volcans, University of Jean Monnet, Saint-Etienne Cedex, France, 2. Interactions et Dynamique des Environnements de Surface, 3. IST, Université d'Oran Es Senia, Oran, Algérie, 4. GEMOC, Macquarie, 5. Dynamique Terrestre et Planétaire, Observatoire Midi-Pyrénées, Toulouse, France, 6. LAB. Minéralogie, Muséum Paris, France

### **Evidence of melt stage refertilization and metasomatism in abyssal peridotites from Hess Deep (ODP LEG 147)**

Y. Gréau<sup>1</sup>, M. Godard<sup>2</sup> and O. Alard<sup>1,2</sup>  
1. GEMOC, Macquarie, 2. Laboratoire de Tectonophysique, Université Montpellier II, Montpellier, France



**Insights into refertilization processes in lithospheric mantle from integrated isotopic studies in the Lherz Massif**

V. Le Roux<sup>1</sup>, J.-L. Bodinier<sup>1</sup>, O. Alard<sup>1,2</sup>, and S.Y. O'Reilly<sup>2</sup>

1. Géosciences Montpellier, France,  
2. GEMOC, Macquarie

**Trace-element patterns of diamond: clues to mantle processes**

W.L. Griffin, S. Rege, D. Araujo,  
S. Jackson and N. Pearson  
GEMOC, Macquarie

**Linking crustal and mantle events using in-situ U-Pb, Lu-Hf and Re-Os isotope analysis**

N. Pearson, S.Y. O'Reilly, W.L. Griffin,  
O. Alard and E. Belousova  
GEMOC, Macquarie

**Geochemical features of spinel peridotites in the Upper Miocene Valle Guffari Diatreme (Hyblean Plateau, Sicily): Implications on evolution of south-eastern Sicily lithosphere**

C. Perinelli<sup>1</sup>, G.T. Sapienza<sup>2</sup>, P. Armienti<sup>1</sup>, L. Morten<sup>\*3</sup>, W.L. Griffin<sup>4</sup> and S.Y. O'Reilly<sup>4</sup>

1. Dipartimento di Scienze della Terra, Università di Pisa, Italy, 2. Dipartimento di Scienze della Terra e Geologico-Ambientali, Università di Bologna, Italy, 3. Dipartimento di Scienze della Terra e Geologico-Ambientali, Università di Bologna, Italy; \* deceased, Nov 18 2006, 4. GEMOC, Macquarie

**Geochemical fingerprinting: variations in lithospheric mantle signatures within and between terranes**

W. Powell and S.Y. O'Reilly  
GEMOC, Macquarie

**Archean lithospheric mantle: the refertilised remains**

S.Y. O'Reilly, W.L. Griffin and G. Begg **Keynote**  
GEMOC, Macquarie

**Characterisation of the metasomatic agent in mantle xenoliths from Deves, massif central (France) using coupled in-situ trace element and O, Sr, Nd isotopic compositions**

C. Renac<sup>1</sup>, S. Touron<sup>1</sup>, J.-Y. Cottin<sup>1</sup>, S.Y. O'Reilly<sup>2</sup> and W.L. Griffin<sup>2</sup>

1. Département de Géologie, Faculté de Sciences et Techniques, Université Jean Monnet – France, 2. GEMOC, Macquarie

**EXPLORATION 07: FIFTH DECENTENNIAL INTERNATIONAL CONFERENCE ON MINERAL EXPLORATION, TORONTO CANADA, SEPTEMBER 9-12, 2007**

**Workshop 3: Indicator mineral methods in mineral exploration Mineral chemistry**

W.L. Griffin **Invited**  
GEMOC Macquarie

**Crustal history and metallogenic fertility: Terrane-scale assessment with detrital zircons**

W.L. Griffin, E. Belousova and S.Y. O'Reilly **Invited**  
GEMOC, Macquarie

**7<sup>TH</sup> INTERNATIONAL SYMPOSIUM ON APPLIED ISOTOPE GEOCHEMISTRY STELLENBOSCH, SOUTH AFRICA, SEPTEMBER 10-14, 2007**

**Crustal architecture in the Mozambique Belt, northeastern Mozambique: Perspective from U-Pb and Lu-Hf isotopes in zircon**

B. Bingen<sup>1</sup>, G. Viola<sup>1</sup>, W.L. Griffin<sup>2</sup>, J. Jacobs<sup>3</sup>, R. Boyd<sup>1</sup>, R. Thomas<sup>4</sup>, X. Daudi<sup>5</sup>, I. Henderson<sup>1</sup>, E. Beyer<sup>2</sup>, A. Engvik<sup>1</sup>, R. Key<sup>4</sup>, A. Solli<sup>1</sup>, J.S. Sandsad<sup>1</sup>, E. Tveten<sup>1</sup>, T. Bjerkgård<sup>1</sup> and D. Jamal<sup>6</sup>

1. Geological Survey of Norway, Trondheim, Norway, 2. GEMOC, Macquarie, 3. Department of Earth Science, University of Bergen, Norway, 4. British Geological Survey, UK, 5. National Directorate for Geology, Maputo, Mozambique, 6. Eduardo Mondlane University, Maputo, Mozambique

**AGS-2007 SYMPOSIUM: ORES AND OROGENESIS: CIRCUM-PACIFIC TECTONICS, GEOLOGIC EVOLUTION, AND ORE DEPOSITS, A SYMPOSIUM IN HONOR OF WILLIAM R. DICKINSON, TUCSON ARIZONA, USA, SEPTEMBER 24-30, 2007**

**Living with Archean lithosphere**  
G. Begg<sup>1</sup>, W.L. Griffin<sup>2</sup>, S.Y. O'Reilly<sup>2</sup> and L. Natapov<sup>2</sup> **Invited**

1. Carnarvon Crescent, Coolbinia, Australia, 2. GEMOC, Macquarie

**Archean, Proterozoic and Phanerozoic lithospheres: preservation, modification or delamination?**

W.L. Griffin<sup>1</sup>, S.Y. O'Reilly<sup>1</sup> and G. Begg<sup>1,2</sup> **Invited**

1. GEMOC, Macquarie, 2. BHP Billiton, Perth, Australia

**GEOLOGICAL SOCIETY OF AUSTRALIA, SPECIALIST GROUP IN GEOCHEMISTRY, MINERALOGY AND PETROLOGY (SGGMP), DUNEDIN, NZ, OCTOBER 14-19, 2007**

**Age constraints and new field relationships of high-pressure mafic granulites of Fiordland, New Zealand**

N.R. Daczko<sup>1</sup>, S.A. Carroll<sup>1</sup>, L.A. Milan<sup>1</sup> and G.L. Clarke<sup>2</sup>

1. GEMOC, Macquarie, 2. University of Sydney, Sydney, Australia

**A U-Pb and hafnium in-situ zircon investigation of orthogneiss and paragneiss units of Western Fiordland, New Zealand**

L.A. Milan<sup>1</sup>, N.R. Daczko<sup>1</sup>, I. Turnbull<sup>2</sup>, A. Allibone<sup>2</sup> and G.L. Clarke<sup>3</sup>

1. GEMOC, Macquarie, 2. GNS Science, Dunedin, New Zealand, 3. University of Sydney, Sydney, Australia

**Origin of compositional variations in TTG-like magmas: An integrated experimental and numerical study**

T. Rushmer<sup>1</sup>, A. Getsinger<sup>2</sup> and M.D. Jackson<sup>3</sup>

1. GEMOC, Macquarie, 2. Department of Geology, University of Vermont, Burlington, VT, USA, 3. Department of Earth Science and Engineering, Imperial College, London, UK

#### Appendix 4: Abstract titles

##### THE 2007 GSA (THE GEOLOGICAL SOCIETY OF AMERICA) ANNUAL MEETING, DENVER, USA, OCTOBER 28-31, 2007

###### Episodic granitic magmatism in space and time: constraints from igneous and detrital zircon age spectra

K.C. Condie, E.A. Belousova, and W.L. Griffin  
GEMOC, Macquarie

##### 7TH AUSTRALIAN SPACE SCIENCE CONVENTION, SYDNEY, SEPTEMBER 24-27, 2007

###### The tectonics of super-sized Earths

C. O'Neill  
GEMOC, Macquarie

##### WORKSHOP ON RELATIONSHIPS BETWEEN FRACTURING, DEFORMATION, RECRYSTALLIZATION AND METAMORPHIC REACTIONS, PERTH, WESTERN AUSTRALIA, SEPTEMBER, 2007

###### Metamorphism-deformation relationships — problems

R.H. Vernon **Invited**  
GEMOC, Macquarie

##### XVIII SYMPOSIUM ON ISOTOPE GEOCHEMISTRY, MOSCOW, RUSSIA, NOVEMBER 12 –16, 2007

###### *TerraneChron*@ methodology: detrital zircons as a new tool in crustal evolution studies

E.A. Belousova, W.L. Griffin, and S.Y. O'Reilly **Invited**  
GEMOC, Macquarie

###### Comparative studies of isotopic and trace-element composition of zircon and host granites of the Raamid Complex (in Russian)

Y.A. Kostitsyn<sup>1</sup>, E.A. Belousova<sup>2</sup>, V.N. Volkov<sup>3</sup> and K.N. Shatagin<sup>3</sup>  
1. V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow, Russia, 2. GEMOC, Macquarie, 3. Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry (IGEM) RAS, Moscow, Russia

##### AMERICAN GEOPHYSICAL UNION (AGU) FALL MEETING, SAN FRANCISCO, DECEMBER 10-14, 2007

###### A magmatic perspective and zircon Hf isotope constraints on Tibetan orogenesis

S. Chung<sup>1</sup>, M. Chu<sup>1,2,3</sup>, S. O'Reilly<sup>3</sup>, N. Pearson<sup>3</sup>, D. Liu<sup>4</sup>, B. Song<sup>4</sup>, J. Ji<sup>5</sup>, C. Lo<sup>1</sup> and T. Lee<sup>1</sup>

1. Dept Geosciences, National Taiwan University, Taipei, Taiwan, 2. Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, 3. GEMOC, Macquarie, 4. Institute of Geology, Chinese Academy of Geological Science, Beijing, China, 5. School of Earth and Space Sciences, Peking University, Beijing, China

###### U-series disequilibria from the East Pacific Rise (9°3N and 10°4N, 11°5N): evidence for off-axis magmatism along fast spreading ridges?

C. Beier<sup>1</sup>, S.P. Turner<sup>1</sup> and Y. Ni<sup>2</sup>  
1. GEMOC, Macquarie, 2. Department of Earth Sciences, Durham University, Durham, UK

###### Spin transition and equation of state of ferropericlase at high temperature: implications for density model of the lower mantle

Y. Fei<sup>1</sup>, A. Ricolleau<sup>1</sup>, E. Cottrell<sup>2</sup>, L. Zhang<sup>1</sup>, A. Corgne<sup>3</sup>, Y. Wang<sup>4</sup>, T. Komabayashi<sup>1</sup>, N. Sata<sup>5</sup>, V. Prakapenka<sup>6</sup> and Y. Meng<sup>7</sup>  
1. Geophysical Laboratory, Carnegie Institution of Washington, DC, USA, 2. National Museum of Natural History, Smithsonian Institution, Washington, DC, USA, 3. GEMOC, Macquarie, 4. Peking University, Department of Geology, Beijing, China, 5. Japan Agency for Marine-Earth Science and Technology, Institute for Research on Earth Evolution, Yokosuka, Kanagawa, Japan, 6. GSECARS, University of Chicago, IL, USA, 7. HPCAT, Carnegie Institution of Washington, IL, USA

###### The geodynamics of super-sized Earths

C. O'Neill<sup>1</sup> and A. Lenardic<sup>2</sup>  
1. GEMOC, Macquarie, 2. Rice University, Houston, TX, USA

###### Sediment gravity flows in a Mid-Ocean Ridge environment and their relationship to spreading related faults, Macquarie Island

R. Portner<sup>1</sup>, N.R. Daczko<sup>1</sup> and J.A. Dickinson<sup>2</sup>  
1. GEMOC, Macquarie, 2. RPS Energy, Surrey, UK

###### New insights into the heat sources of mantle plumes, or: where does all the heat come from, heat producing elements, advective or conductive heat flow?

T. Rushmer, C. Beier and S. Turner  
GEMOC, Macquarie

###### An inter-laboratory assessment of the Th isotopic composition of synthetic and rock standards

K.W. Sims<sup>1</sup>, J. Gill<sup>2</sup>, A. Dosseto<sup>3</sup>, D.L. Hoffmann<sup>4</sup>, C. Lundstrom<sup>5</sup>, R. Williams<sup>6</sup>, L. Ball<sup>1</sup>, D. Tollstrup<sup>2</sup>, S. Turner<sup>3</sup>, J. Prytulak<sup>4</sup>, J. Glessner<sup>5</sup>, J. Standish<sup>1</sup> and T.R. Elliott<sup>4</sup>  
1. Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, USA, 2. Earth and Planetary Sciences, University of California, Santa Cruz, USA, 3. GEMOC, Macquarie, 4. Bristol Isotope Group, University of Bristol, UK, 5. Dept of Geology, University of Illinois Urbana Champaign, Urbana, USA, 6. Chemical Biology and Nuclear Science Division, Lawrence Livermore National Laboratory, Livermore, USA

###### New constraints from Tonga-Kermadec on the origin of O-Hf-Os isotope signatures in oceanic arc lavas

S. Turner<sup>1</sup>, M. Handler<sup>2</sup> and I. Bindeman<sup>3</sup>  
1. GEMOC, Macquarie, 2. School of Geography, Environment and Earth Sciences, Victoria University of Wellington, New Zealand, 3. Department of Geological Sciences, University of Oregon, USA

**Proterozoic mantle lithosphere  
beneath the Tariat Depression and  
Dariganga Plateau, Mongolia: *in  
situ* Re-Os evidence**

K.-L. Wang<sup>1,2</sup>, S.Y. O'Reilly<sup>2</sup>, W.L.  
Griffin<sup>2</sup>, N. Pearson<sup>2</sup> and M. Zhang<sup>2</sup>

1. Institute of Earth Sciences,  
Academia Sinica, Taipei, Taiwan,

2. GEMOC, Macquarie

**Generation of high-silica melts  
from the mantle: effects of alkalis  
and water**

B.J. Wood and S. Turner **Invited**

GEMOC, Macquarie



## Appendix 5: Funded research projects

### GRANTS AND OTHER INCOME FOR 2007

2007 Funding Source	Investigators	Project Title	Amount
ARC Discovery	Alard	Toward the use of metal stable isotopes in geosciences	continuing
ARC Discovery	Daczko, Dickinson	Spreading ridge sedimentation processes: a novel approach using Macquarie Island as a natural laboratory	\$70,000
ARC Discovery	Jackson, Mountain	Isotopic fractionation of the ore minerals (Cu, Fe, Zn): A new window on ore-forming processes	\$60,000
ARC Discovery	O'Reilly, Griffin, Pearson, Alard, et al.	Earth's internal system: deep processes and crustal consequences	\$230,000
ARC Discovery	Turner	Mantle melting dynamics and the influence of recycled component	\$90,000
ARC Discovery	Wood	The behaviour of geochemical tracers during differentiation of the Earth	\$100,000
ARC Discovery	O'Neill, Wood, Irifune (Administered by ANU)	Discovering the deep mantle: experimental petrology at very high pressures	\$10,000
ARC Linkage Project with BHPB	O'Reilly, Griffin	Global lithosphere architecture mapping (Industry contribution)	\$30,000
ARC Linkage Project with BHPB	O'Reilly, Griffin, O'Neill	Global lithospheric architecture mapping II (including Industry contribution)	\$77,000
ARC Linkage Project with Rio Tinto	O'Reilly, Griffin, Pearson	Trace-element analysis of diamonds: new applications to diamond fingerprinting and genesis (including Industry contribution)	\$157,823
ARC Federation Fellowship	Wood	Origin and evolution of Earth's chemical reservoirs	\$322,625
ARC Federation Fellowship (MQ contribution)	Wood	Origin and evolution of Earth's chemical reservoirs	\$180,000
ARC Federation Fellowship	Turner	The time scales of geochemical cycles and Earth processes	\$22,129
ARC Federation Fellowship (MQ contribution)	Turner	The time scales of geochemical cycles and Earth processes	\$92,243

2007 Funding Source	Investigators	Project Title	Amount
DEST RIBG	O'Reilly	GEMOC-Geochemical Analyst	\$60,000
Aust. Antarctic Division	Daczko, Mosher	The environmental and tectonic implications of volcanoclastic deposits on Macquarie Island	\$70,000 (in kind)
MQVC Innovation Fellowship Research Grant	Belousova	Tomorrow's <i>TerraneChron</i> <sup>®</sup> : new developments, new deliverables and new destinations	\$19,684
MQVC Innovation Fellowship	Belousova	Tomorrow's <i>TerraneChron</i> <sup>®</sup> : new developments, new deliverables and new destinations	\$74,151
MUECRG Scheme with BHPB	Belousova et al.	How have the continents grown? Investigation of three key areas	\$50,000
MUECRG Scheme with BHPB	Belousova et al.	How have the continents grown? Investigation of three key areas (Industry contribution)	\$50,000
Safety Net	Belousova	The growth of the continental crust: a global approach	\$19,350
Department of EPS	O'Reilly	GAU maintenance contribution	\$30,000
MQRF Research Grant	O'Neill	Episodicity in mantle convection: effects on continent formation and metallogenesis	\$13,400
MQ Research Fellowship	O'Neill	Episodicity in mantle convection: effects on continent formation and metallogenesis	\$78,180
DVC (Research) Discretionary Fund	Beier	Support for Fellow in Feodor Lynen Project (Christoph Beier)	\$20,000
Capital equipment	Lackie	Time-Domain EM system	\$52,495
ARC LIEF	O'Reilly CI (Honda et al., administered by ANU)	A new generation noble gas mass spectrometer facility for advanced research in the Earth, Planetary and Environmental Sciences	\$700,000
ARCLIEF (MQ contribution)	O'Reilly CI (Honda et al., administered by ANU)	A new generation noble gas mass spectrometer facility for advanced research in the Earth, Planetary and Environmental Sciences	\$35,000
Santos Ltd	Rushmer	Petrological and thermal characteristics	\$12,950
RAACE	Bailey	An ice and crust mass balance study of the Law Dome ice cap, East Antarctica, using geophysical techniques	\$14,436
iMURS	Caulfield	Tofua Volcano, Tonga Arc, eruption history and timescales of magma chamber processes	\$43,116
iMURS	Chevet	Gabbroic rocks from the Kerguelen Island (Indian Ocean): a petrologic, geochemical and isotopic investigation of their origin	\$43,116

## Appendix 5: Funded research projects 2007

2007 Funding Source	Investigators	Project Title	Amount
iMURS	Cunningham	A U-series isotope study of magma residence times, degassing and petrogenesis of Rabaul Caldera, Papua New Guinea	\$43,116
iMQRES	Donnelly	Mantle xenoliths, kimberlites and related rocks of the Kuruman Kimberlite Province, Kaapvaal Craton, South Africa	\$43,116
iMURS	Gréau	Elemental and isotopic fractionation of siderophile and chalcophile elements: A new perspective on eclogite origin	\$43,116
iMURS	Kobussen	Composition, structure and evolution of the lithospheric mantle beneath Southern Africa	\$43,116
IPRS	Li	Stable metal isotope geochemistry of the Cadia and Northparkes porphyry Cu-Au deposits	\$43,116
iMURS	Locmelis	Understanding nickel deposits using platinum group element geochemistry	\$43,116
IPRS	Mwandulo Batumike	The origin of kimberlites from the Kundelungu region (D.R. Congo) and the nature of the underlying lithospheric mantle	\$43,116
iMURS	Nikolic	Evolution of crust-mantle systems near a young rift: NW Spitsbergen, Norway	\$13,684
iMURS	Portner	Spreading ridge sedimentation processes: a novel approach using Macquarie Island as a natural laboratory	\$43,116
RAACE	Carroll	The mechanisms and deep-crustal controls on continental rifting	\$19,616
RAACE	Milan	The emplacement, pressure-temperature-time path and structural evolution of lower crustal gneiss in Fiordland, New Zealand	\$11,880



## FUNDED RESEARCH PROJECTS FOR 2008

2008 Funding Source	Investigators	Project Title	Amount
ARC Discovery	Daczko/Dickinson	Spreading ridge sedimentation processes: a novel approach using Macquarie Island as a natural laboratory	\$65,000
ARC Discovery	O'Reilly, Griffin, Pearson, Alard, et al.	Earth's internal system: deep processes and crustal consequences	\$230,000
ARC Discovery	Turner	Mantle melting dynamics and the influence of recycled component	\$90,000
ARC Discovery	Wood	The behaviour of geochemical traces during differentiation of the Earth	\$100,000
ARC Discovery	O'Neill, Wood, Irifune (Administered by ANU)	Discovering the deep mantle: experimental petrology at very high pressures	\$10,000
ARC Discovery	O'Neill	The role of supercontinents in Earth's dynamic evolution (DP0880801)	\$114,955
ARC Linkage Project with BHPB	O'Reilly, Griffin, O'Neill	Global lithosphere architecture mapping II (including Industry contribution)	\$149,500
ARC Linkage Project with Rio Tinto	O'Reilly, Griffin, Pearson	Trace-element analysis of diamonds: new applications to diamond fingerprinting and genesis (including Industry contribution)	\$153,426
ARC Federation Fellowship	Wood	Origin and evolution of Earth's chemical reservoirs	\$329,078
ARC Federation Fellowship (MQ contribution)	Wood	Origin and evolution of Earth's chemical reservoirs	\$180,000
Department of Earth and Planetary Sciences	O'Reilly	GAU maintenance contribution	\$30,000
MQRF Research Grant	O'Neill	Episodicity in mantle convection: effects on continent formation and metallogenesis	\$13,000
MQ Research Fellowship	O'Neill	Episodicity in mantle convection: effects on continent formation and metallogenesis	\$78,181
DVC (Research) Discretionary Fund	Beier	Support for Fellow in Feodor Lynen Project (Christoph Beier)	\$20,000
MQRF Research Grant	Dosseto	Impact of European settlement on soil loss in the Murray-Darling Basin: a novel quantitative geochemical approach	\$14,340

## Appendix 5: Funded research projects 2008

2008 Funding Source	Investigators	Project Title	Amount
MQ Research Fellowship	Dosseto	Impact of European settlement on soil loss in the Murray-Darling Basin: a novel quantitative geochemical approach	\$78,181
MQNS	Rushmer	Formation of the Earth's first silicic crust	\$19,420
RIBG	GEMOC	Fourier Transform Infrared (FTIR) Microscope	\$80,000
ARC LIEF	O'Reilly CI (ANU Lead Institution)	IOPD	\$6,000,000
ARC LIEF (MQ contribution)	O'Reilly CI (ANU Lead Institution)	IOPD	\$40,000
NCRIS (MQ contribution)	O'Reilly	AuScope ( <a href="http://www.auscope.org.au">www.auscope.org.au</a> )	\$50,000
RAACE	Carroll	The mechanisms and deep-crustal controls on continental rifting	\$20,007
iMURS	Caulfield	Tofua Volcano, Tonga Arc, eruption history and timescales of magma chamber processes	\$45,007
iMURS	Chevet	Gabbroic rocks from the Kerguelen Island (Indian Ocean): a petrologic, geochemical and isotopic investigation of their origin	\$45,007
iMURS	Cunningham	A U-series isotope study of magma residence times, degassing and petrogenesis of Rabaul Caldera, Papua New Guinea	\$45,007
iMQRES	Donnelly	Mantle xenoliths, kimberlites and related rocks of the Kuruman Kimberlite Province, Kaapvaal Craton, South Africa	\$45,007
iMURS	Gréau	Elemental and isotopic fractionation of siderophile and chalcophile elements: A new perspective on eclogite origin	\$45,007
iMURS/IPRS	Kobussen	Composition, structure and evolution of the lithospheric mantle beneath Southern Africa	\$45,007
iMURS	Li	Stable metal isotope geochemistry of the Cadia and Northparkes porphyry Cu-Au deposits	\$45,007
iMURS	Locmelis	Understanding nickel deposits using platinum group element geochemistry	\$45,007
iMURS/IPRS	Mwandulo Batumike	The origin of kimberlites from the Kundelungu region (D.R. Congo) and the nature of the underlying lithospheric mantle	\$45,007

<b>2008 Funding Source</b>	<b>Investigators</b>	<b>Project Title</b>	<b>Amount</b>
iMURS	Nikolic	Evolution of crust-mantle systems near a young rift: NW Spitsbergen, Norway	\$12,500
iMQRES	Portner	Spreading ridge sedimentation processes: a novel approach using Macquarie Island as a natural laboratory	\$45,007

ARC Research Projects initiated prior to 2007 are available at our website: <http://www.es.mq.edu.au/GEMOC/>  
 Follow the Annual Report Link to Appendix 5 of the previous Annual Reports.



## Appendix 6: GEMOC postgraduate opportunities

Postgraduate scholarship information as well as a list of scholarships currently open for application is available at: [www.research.mq.edu.au/students/scholarships](http://www.research.mq.edu.au/students/scholarships)

### POSTGRADUATE OPPORTUNITIES

GEMOC has a flourishing postgraduate research environment with postgraduate students from many countries (including France, Germany, China, Russia, USA, Canada and Australia). Scholarships funding tuition fees and a living allowance are available for students with an excellent academic record or equivalent experience. These include:

- **Australian Postgraduate Awards (APA):** available for Commonwealth citizens to cover tuition fees and living allowance, with a closing date in late October annually
- **Macquarie University Research Excellence Scholarship (MQRES) scholarships:** available for Australian citizens and international students who wish to undertake a postgraduate program in a Centre of Excellence at Macquarie University (e.g. GEMOC)
- **International Postgraduate Research Scholarships (Endeavour Scholarships):** available to overseas students to cover tuition fees with a closing date in late August annually

Macquarie University also provides research funding through a competitive internal scheme and GEMOC's funded projects (see *Appendix 5*) provide further resources to support postgraduate research projects.

Postgraduate projects are tailored to your expertise and interests within the framework of GEMOC's research goals. GEMOC carries out interdisciplinary research across the boundaries of petrology, geochemistry, tectonics, metallogenesis, geodynamics and geophysics to explore the nature and evolution of the lithosphere and global geodynamics. Current funded projects are based in Australia, Antarctica, Canada, China, Taiwan, Italy, France, Siberia, Norway, North America, South America, Africa, Kerguelen Islands and other global locations (see the section on GEMOC's *Research Program*).

GEMOC postgraduate programs have opportunities through access to our outstanding analytical facility (see *Technology Development* section) with currently unique technologies and instrumentation configurations to tackle exciting large-scale problems in the Geosciences.

Examples of broad PhD project areas include:

- Lithosphere structure and geochemistry: mantle provinciality and tectonism
- Granitoid and mineralised provinces along western Pacific convergent margins
- Fluid-vapour transfer of elements in the crust and mantle
- Heat production and evolution of the crust: crust-mantle interaction
- Geophysical applications to lithosphere studies
- Isotopic and trace element geochemistry: mantle and crustal systems
- Metal isotopes: applications to ore formation
- Magma genesis and crustal evolution: includes trace elements of accessory minerals, isotopic fingerprints
- High-pressure experimental studies

Potential applicants should discuss possible projects with a potential supervisor and the Director of GEMOC before applying.

## Contact details

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## GLOSSARY

ACILP	Australia China Institutional Links Program
AMIRA	Australian Mineral Industry Research Association
ANU	Australian National University
APA (I)	Australian Postgraduate Award (Industry)
ARC	Australian Research Council
ARC LIEF	Australian Research Council Linkage Infrastructure Equipment and Facilities
BSE	Backscattered Electrons
CNRS	French National Research Foundation
CoRE	Concentrations of Research Excellence
CSIRO (EM)	Commonwealth Scientific Industrial Research Organisation (Exploration and Mining)
DEST (SII)	Department of Education, Science and Training (from 2002) (Systemic Infrastructure Initiative)
DIATREEM	Consulting company within AccessMQ
DP	Discovery Project
EAPE CoRE	Earth and Planetary Evolution Concentration of Research Excellence
EMP	Electron Microprobe
(D)EPS	(Department of) Earth and Planetary Sciences
EURODOC	The council for postgraduate students and junior researchers in Europe
FIM	Facility for Integrated Microanalysis
GA	Geoscience Australia (formerly AGSO)
GAU	Geochemical Analysis Unit (DEPS, Macquarie University)
GIS	Geographic Information System
GLITTER	GEMOC Laser ICPMS Total Trace Element Reduction software
GPS	Global Positioning System
HIAF	Heavy Ion Analytical Facility
ICPMS	Inductively Coupled Plasma Mass Spectrometer
iMURS	International Macquarie University Research Scheme
IPRS	International Postgraduate Research Scholarship
JCU	James Cook University
LAM-ICPMS	Laser Ablation Microprobe - ICPMS
LIEF	Linkage Infrastructure, Equipment and Facilities
MC-ICPMS	Multi-Collector ICPMS
MERIWA	The Minerals and Energy Research Institute of Western Australia
MQNS	Macquarie University New Staff Research Grants Scheme (formerly MUNS)
(i)MQRES	(International) Macquarie University Research Excellence Scholarships
MQRF	Macquarie University Research Fellowship (formerly MURF)
MQVC	Macquarie University Vice Chancellor
MUIPRA	Macquarie University International Postgraduate Research Award
MURAACE	Macquarie University Research Award for Areas and Centres of Excellence
NASA	National Aeronautics and Space Administration
NCRIS	National Collaborative Research Infrastructure Scheme
PGE	Platinum Group Element
PIRSA	Primary Industries and Resources, South Australia
RAACE	Research Areas and Centres of Excellence Postgraduate Scholarships
RIBG	Research Infrastructure Block Grant
RSES	Research School of Earth Sciences at ANU
SEM	Scanning Electron Microscope
UN'cstle	University of Newcastle
UNE	University of New England
USYD	University of Sydney
UWA	University of Western Australia
UW'gong	University of Wollongong
UWS	University of Western Sydney
XRF	X-Ray Fluorescence



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