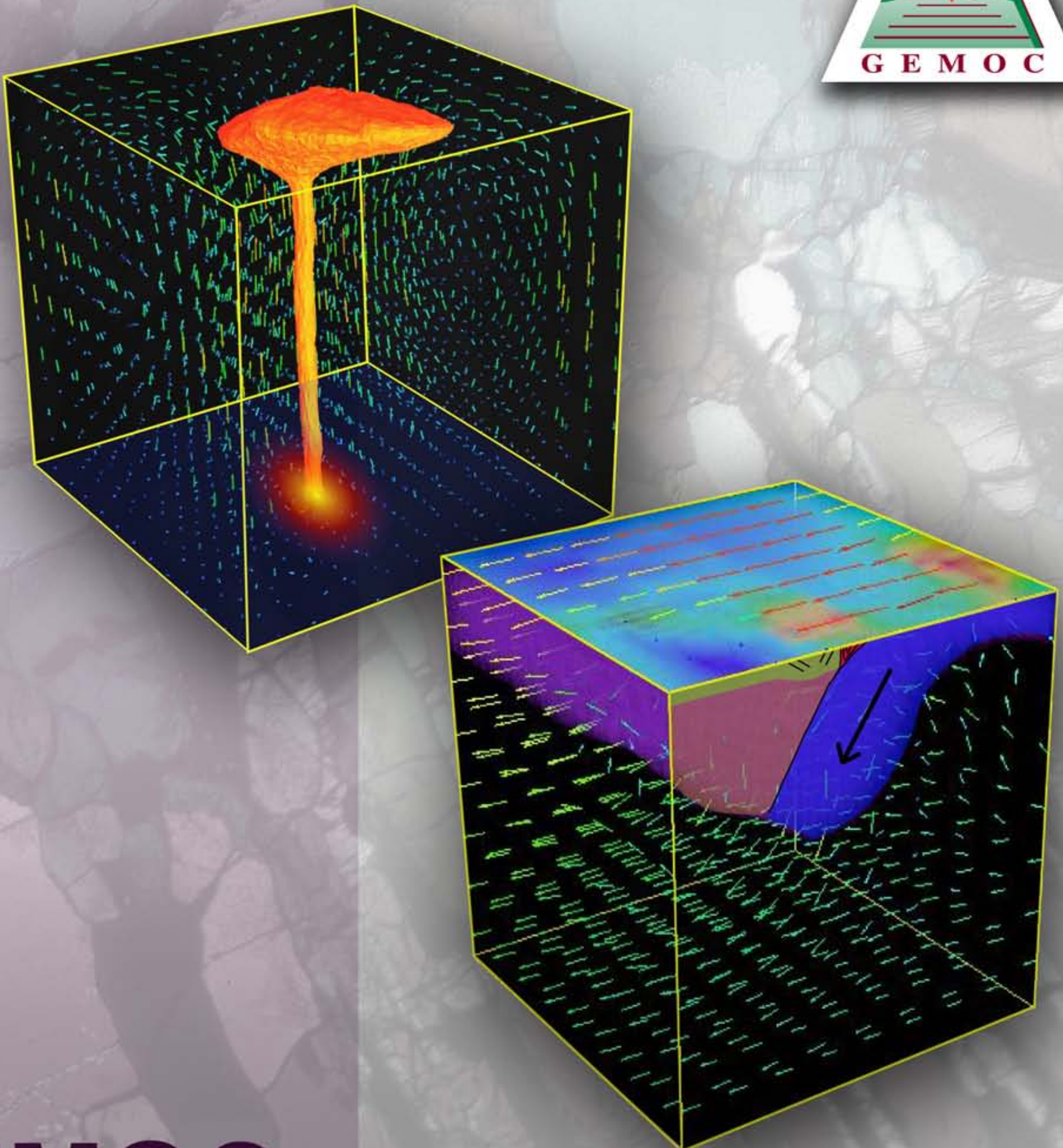


GEMOC

2006 Annual Report

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

MACQUARIE
UNIVERSITY~SYDNEY

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

Dynamic modelling of mantle plumes, subduction processes and the stability of continental lithosphere provides new insights into the internal workings of the Earth (see Research Highlights). At GEMOC, this type of modelling is being linked with the constraints provided by detailed studies of mantle samples. The inset shows a high-temperature clinopyroxenite exsolving lamellar garnet and orthopyroxene, and recrystallising to produce a websterite; such rocks define geotherms related to the upwelling of asthenosphere above subduction zones.

Contents

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

Director's Preface

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

THIS REPORT summarises GEMOC's 2006 activities including research, technology development, strategic applications and industry interaction, international links and teaching (at both undergraduate and postgraduate levels). The report is required as part of GEMOC's formal annual accounting to the Australian Research Council (ARC). The ARC acknowledges GEMOC as a continuing ARC National Key Centre while GEMOC attracts sufficient income to fund its activities and achieve its annual goals, and submits an Annual Report fulfilling ARC reporting requirements.

This is the third year of a fully electronic GEMOC Annual Report available from our website (www.es.mq.edu.au/GEMOC/) as a downloadable pdf file or in html format and by mail as a CD on request. A consolidated version of all GEMOC's Research Highlights over 10 years can be downloaded from our website.

Early in 2006, Macquarie's new Vice-Chancellor, Professor Steven Schwartz, announced that GEMOC was designated one of Macquarie's CoREs (Concentrations of Research Excellence) at Macquarie University and allocated 5.5 new academic positions (ranging from Level B to E) to extend and enhance our research profile. Advertisements were placed in late 2006 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; and cosmochemistry and meteoritics. Selection is taking place through 2007. As this report is being finalised, offers have been made to 5 outstanding candidates, and we anticipate reporting on the successful recruitment in the 2007 Report.

GEMOC was 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 partners is increasing and providing invaluable access to data on global localities relevant to mantle and crust evolution projects. The combination of funding from conventional government competitive schemes, collaborative projects with industry partners, strategic alliances with technology and instrument manufacturers, commercialisation ventures (such as the marketing of GLITTER software), and international links and alliances provides a diversified portfolio of income and resource sources.

GEMOC has been highly visible throughout 2006 in its representation at peak relevant conferences and specialist workshops with many Keynote and Invited lectures (see *Appendix 4* and "*Communications*" on page 11), convening many sessions and symposia and organising the 2006 Goldschmidt Conference in Melbourne. The high participation rate of postgraduate students in international conferences evidences the vigorous postgraduate environment that continues to grow and attract students worldwide.

Our interaction with industry significantly enhances our research capabilities: in addition to funding for our research, the interaction with industry project and research leaders provides access to an enormous fund of intellectual property and stimulating concepts. Advice from, and participation by, industry colleagues significantly augments our research resource base and broadens our international networking.

2007 will be a challenging year - the beginning of a new phase and new directions as the CoRE appointments are made.

Introducing GEMOC




THE SUCCESS OF GEMOC stems from an 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.

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

These three research foci 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.

GEMOC'S STRATEGIC FOCUS

The main targets of GEMOC's *original* activities addressed large-scale problems related to lithosphere evolution and understanding the relevance of different types of crust-mantle domains to area selection for mineral exploration. These have broadened since 2002 to involve whole-mantle perspectives of geodynamics; 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 and geodynamic evolution. New ways of measuring the timing of Earth processes are encapsulating 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.

A joint DeBeers - GEMOC field trip in October 2006 visited key kimberlite localities in South Africa. Here the group enjoys a pit-stop at the new open-air museum at the Kimberley 'Big-Hole' mine.

Industry collaboration has increased with funded large-scale 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. Projects dealing with magma-related Ni deposits, plume magmatism and PGE deposits, and diamond exploration, capitalise on our depth of intellectual property about deep Earth processes from the lithosphere to the core.

Mission

- **to define the processes driving Earth's internal dynamics, and understand how these have generated the present chemical and physical structure of our planet through time, integrating petrological, geochemical, tectonic 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**

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

GEMOC'S CONTEXT

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

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

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 extends our intellectual and funding base.

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
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.

NEW DEVELOPMENTS IN GEMOC IN 2006

The Earth and Planetary Evolution CoRE (Centre of Research Excellence)

Early in 2006, the new Vice-Chancellor, Professor Steven Schwartz, designated GEMOC as an existing Centre of Research Excellence (CoRE) and sought an expression of interest based on the appointment of about 5 new academic staff. As a result, positions for 1.5 Professors, 2 Senior lecturers and 2 Lecturers were advertised in October 2006.

The success of the National Key Centre for the Geochemical Evolution and Metallogeny of Continents stems from an interdisciplinary approach to understanding the way the Earth works, integrating the traditional disciplines of geochemistry, geophysics, geodynamics and tectonics. We have built up 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.

Advertisements were placed in late 2006 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; and cosmochemistry and meteoritics. Selection will take place through 2007.

STRATEGIC OUTCOMES

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

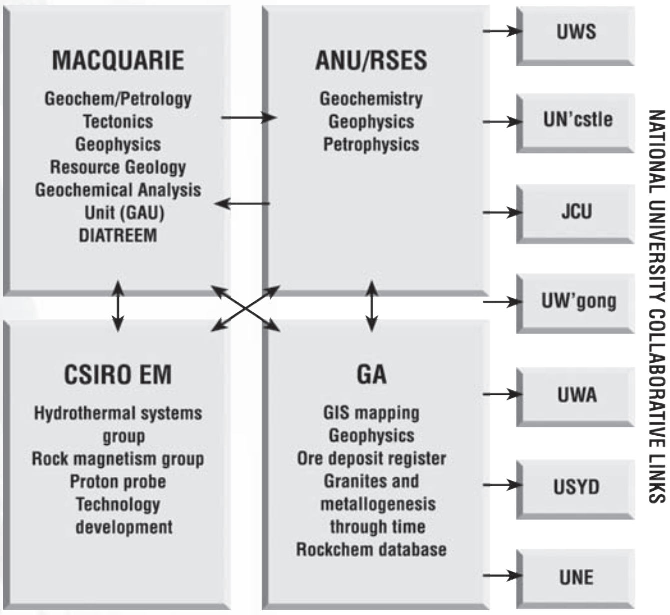
- **improved understanding of the composition and structure of the Earth from the mantle to the core and the dynamics of the Earth system**
- **insights to planetary formation, evolution, composition and dynamics from Earth-based analogues**
- **fundamental insights into the processes that create and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

This report documents achievement of these goals in 2006 and aims for 2007

GEMOC participants

GEMOC 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 (eg some Australian states, Canada, Norway).

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

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

CHANGES IN 2006

Dr Debora Araujo commenced in March 2006 as a Research Associate and is using laser-ablation microprobe techniques, recently developed in GEMOC, to analyse the trace-element patterns of diamond crystals from several localities worldwide. 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.

Dr Elena Belousova was awarded a Macquarie University Vice-Chancellor's Innovation Fellowship for a project titled "Tomorrow's *TerraneChron*®: new developments, new deliverables and new destinations". Her project will carry *TerraneChron*® methodology (see p. 25) 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.

Dr Alex Corgne joined GEMOC as a Research Associate in March 2006 to work with Professor Bernard Wood in the experimental geochemistry laboratory and to set up experimental equipment including the 800-ton multi-anvil press. His current scientific projects address the formation, internal structure and chemical composition of terrestrial planets. Using high-pressure and high-temperature experiments to recreate a variety of physicochemical conditions at depth, Alex is measuring the affinity of key chemical elements for the Earth's core. His experiments can tell us about the composition of the Earth's core as well as the conditions at the time of core formation. Alex is also investigating the effect of varying mantle composition on the sharpness of seismic discontinuities, with important implications for the mineralogy of the deep mantle.

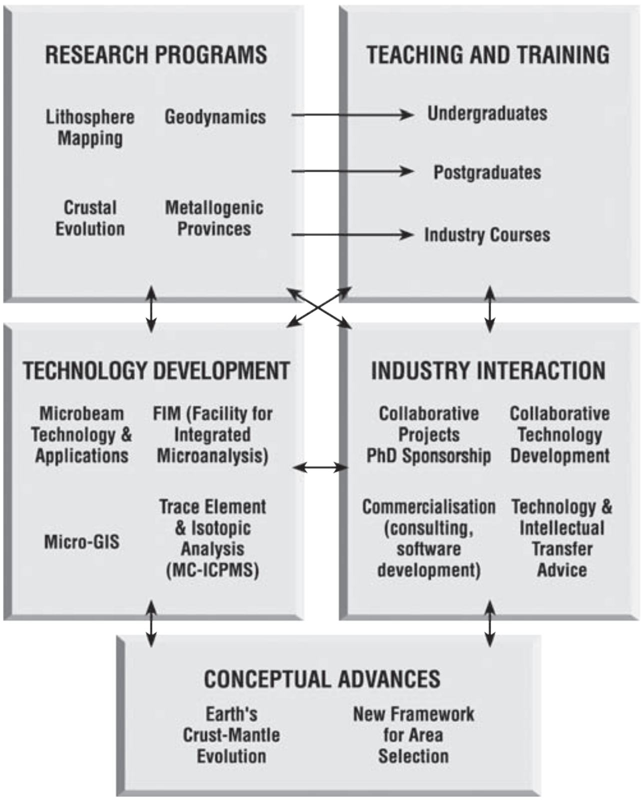
Dr Kevin Grant joined GEMOC in January 2006 as a 5-year Research Associate. Kevin is primarily interested in employing sample heterogeneities measured on an atomic scale to help understand the chemical composition of the Earth's lithosphere. His research takes the shape of an interdisciplinary approach that blends experimental petrology and themodynamic modelling with the analysis of natural samples. Specific areas of recent interest have centred upon the incorporation of trace elements into silicate minerals and melts. The goal of these studies is to characterise the chemistry of the dominant phases that comprise the lithospheric upper mantle and to understand the role of different processes in the long-term evolution of this part of the Earth.

Dr Laure Martin joined GEMOC as a Research Associate working on elemental exchange between the surface and interior of the Earth via subduction zones. In the course of its burial, the subducting plate is dehydrated, leading to the crystallisation of high-pressure (HP) minerals and the production of fluids. These fluids induce partial melting in the overlying mantle which, in turn, is responsible for arc volcanism. Fluids formed during slab dehydration are, therefore, vectors for the elemental transfer between the subducting slab and the mantle. Constraining their composition, and that of the associated HP minerals, is the key to understanding the role of subduction zones in the geochemical evolution of the mantle. An experimental program is aimed at simulating such processes at subduction zones and understanding the partitioning behaviour of elements between the fluids and the HP minerals.

Dr Craig O'Neill commenced a Macquarie University Research Fellowship for three years. His project will use quantitative numerical modelling to evaluate the links between episodes of intense mantle convection and the production of the continental crust. 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 and will also address the potential longevity of domains of lithospheric mantle. The research addresses a critical shortcoming in our understanding of the formation and evolution of continents, with important implications for the distribution of major mineral and energy resources.

GEMOC's program structure

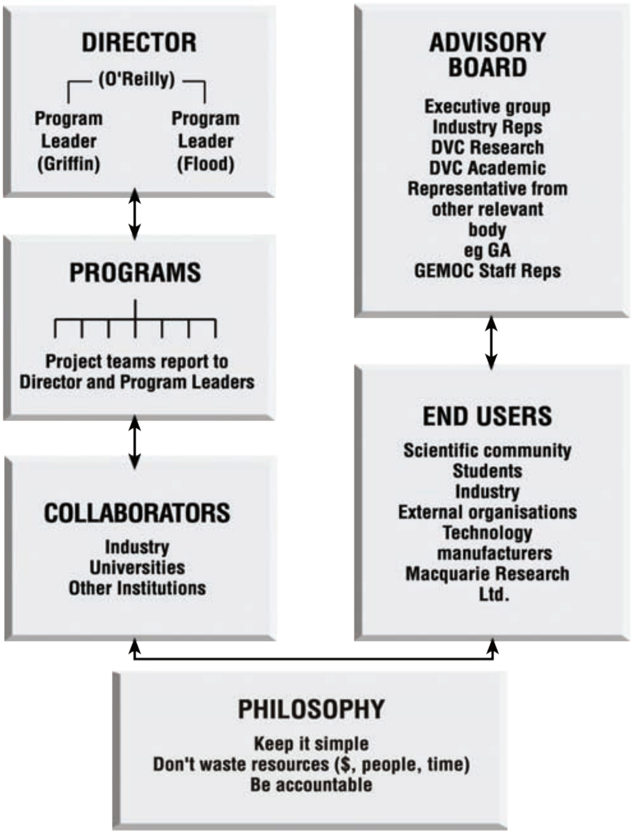
GEMOC'S PROGRAMS are set up to be interactive. Basic research strands are supported by parallel applied collaborative research with industry partners: these provide the impetus for technology development. This is, in turn, supported by strategic alliances with front-line instrument designers and manufacturers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



GEMOC structure

THE ORGANISATIONAL STRUCTURE of GEMOC is designed for efficiency, flexibility and interaction. The financial management operates within Macquarie University's Finance System and within AccessMQ for commercialised products, 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 Centre of Research Excellence and research concentration within Macquarie University.



MANAGEMENT STRUCTURE

2006 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: Adjunct Professor at Macquarie University and 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 (2006)

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 – *GEMOC, EPS Macquarie*

Federation Fellows Professors Bernard Wood and Simon Turner *and*

GAU Manager Dr Norman Pearson are ex officio members

External Board Members

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

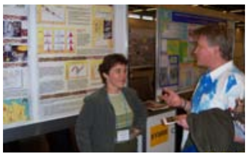
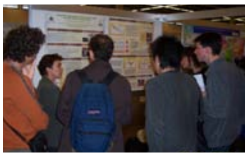
Dr Richard Glen – *representative of Geological Survey of New South Wales*

Dr Paul Heithersay – *representative of PIRSA*

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

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

GEMOC communications 2006

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

AWARDS

Craig O'Neill was a finalist in the 2006 national "Fresh Science" awards, aimed at publicising the work of up and coming young Australian Scientists. He was also chosen as the 2006 "Young Scientist of the Year" by the Australian Newspaper.

Elena Belousova was awarded one of the inaugural Macquarie University Vice-Chancellor's Innovation Fellowships and follows the success of *TerraneChron*® in winning the Macquarie Innovation in Research Award the previous year.

Nathan Daczko received a Macquarie University Citation for Outstanding Contribution to Student Learning and a NSW Young Tall Poppy Award for excellence in research.

PARTICIPATION IN WORKSHOPS, CONFERENCES AND INTERNATIONAL MEETINGS IN 2006 (AND BEYOND)

GEMOC staff and postgraduates again increased their profile at peak metallogenic, geodynamic and geochemical conferences as convenors, invited speakers, or presenters, with more than 55 presentations. International fora included: the European Geosciences Union General Assembly in Vienna, the 16th V. M. Goldschmidt Conference (Melbourne), the IAVCEI Conference on Continental Volcanism in Guangzhou, Asia Oceania Geosciences Society (AOGS) 3rd Annual Meeting (Singapore), the 11th International Conference on Experimental Mineralogy, Petrology and Geochemistry (Bristol), and the American Geophysical Union Fall Meeting (San Franscisco). A full list of abstract titles for Conferences and Workshops attended is given in *Appendix 4* and on the GEMOC website where full-text versions of most of the abstracts can also be found.

"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."

Some of the GEMOC contingent at the 16th Goldschmidt Conference in Melbourne. Dr Shi Rendeng (Hefei University) was visiting to work on the origin of Os-Ir alloys in Tibetan ophiolites.

Professor Simon Turner led the organisation of the very successful 2006 International Goldschmidt Conference held in Melbourne in August 2006. Dr Yvette Poudjom Djomani co-convened a session on "Geochemical and Geophysical Probing of Continental Dynamics".

Professor Bernie Wood was one of the organisers for the 11th International Conference on Experimental Mineralogy, Petrology and Geochemistry held in Bristol in September 2006.

Professor Bill Griffin convened a session at the IAVCEI Conference in May 2006 on "Ultradeep samples and the Earth's Interior".

Professors Bill Griffin and Sue O'Reilly and Dr Kuo-Lung Wang convened a session on "Asian Lithosphere: Evolution of the Asian continental mantle lithosphere - constraints from xenolith studies" at the AOGS Conference in Singapore in July 2006

Keynote talks in 2006 included (see *Appendix 4* for titles): EUG - Belousova, Pearson; IAVCEI - Griffin, Turner, O'Neill; AOGS - Griffin; Goldschmidt - Griffin. GEMOC research was very prominent at the IAVCEI Conference with 15 papers presented including 3 Keynote and 9 Invited as well as a session convened by Bill Griffin.

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

Professors Bill Griffin and Sue O'Reilly are co-convenors for sessions at the 33rd IGC in Oslo (2008) on "The continental lithosphere from geophysical and geochemical data" and "What is the LAB (Lithosphere to Asthenosphere Boundary)?" respectively.

GEMOC had a high profile in the DEST NCRIS (National Collaborative Research Infrastructure Scheme) process during 2006 with Adjunct Professor Mike Etheridge appointed as the Facilitator, Professor Sue O'Reilly appointed as a member of

Tin Tin Win, Sue O'Reilly, Bill Griffin, Kuo-Lung Wang and colleagues from Thailand and Germany (Alfred Krohner at rear), at the AOGS Conference in Singapore.

the National Steering Committee and Professor Turner and Dr Norman Pearson serving as members of Working Groups reporting to the Steering Committee. The resultant AuScope bid was successful, with the award of $42.8 m over the next 5 years (www.auscope.org.au/).

A GEMOC Workshop in 2006 on "Geochemical Fingerprinting of Lithosphere and Deep Earth Processes" was held before the Goldschmidt Conference in Melbourne in August. The Workshop attracted participants from national and international Universities and Research Institutions and industry (the limit of 30 participants was oversubscribed). The presentations by GEMOC researchers represented a mix of technical information about the analytical methods applications and relevance of analytical results to large-scale Earth problems.

GEMOC PhD graduate Stephanie Touron, Elena Belousova and GEMOC visiting scientist Giovanna Sapienza (Univ. Bologna) in front of Elena's popular poster at the EGU meeting, Vienna.

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

Is GEMOC making a difference?

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

RESEARCH EXAMPLES:

- Unique methodology for geochemical imaging of the lithosphere (4-D Lithosphere Mapping) developed to maturity and now being extended to whole-mantle perspectives. This has given a new understanding of the mechanisms by which the lithosphere is formed and modified through time, and has delivered new targeting concepts to the mineral exploration industry
- Unique methodologies developed for dating mantle events (melt extraction and metasomatic overprinting; Re-Os *in situ* dating of mantle sulfides) and studying crustal evolution (*TerraneChron*® using zircon geochemistry)
- Two Federation Fellows in Geoscience attracted to Australia
- Establishment of world-class U-series isotope facility
- Revitalisation of high-pressure experimental petrology in Australia and establishment of new world-class facility

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

HIGHLIGHTS OF TECHNOLOGY DEVELOPMENT OUTCOMES:

- Development of *in situ* analytical techniques for heavy stable isotopes: Fe, Cu, Zn, Mg
- Development of the techniques for quantitative *in situ* analysis of trace elements in diamond, opening new research perspectives on the origin of diamonds and industrial applications
- Development of techniques for the rapid and precise dating of kimberlites and related rocks, using *in situ* LAM-ICPMS analysis of groundmass perovskite
- Development of *in situ* Re-Os methods to date mantle events
- Development of an integrated methodology to track crustal evolution (U-Pb dating and Hf-isotope and trace-element fingerprinting of zircons, rutile, titanite): *TerraneChron*®
- Delivery of rapid, cost-effective and user-friendly software for on-line LAM-ICPMS analysis (GLITTER)
- Establishing the rates of geological processes both for the deep Earth and for surface processes using Uranium decay series dating

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

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

HIGHLIGHTS OF TEACHING OUTCOMES:

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

HIGHLIGHTS OF INDUSTRY INTERACTION OUTCOMES:

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

GEMOC's research program

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

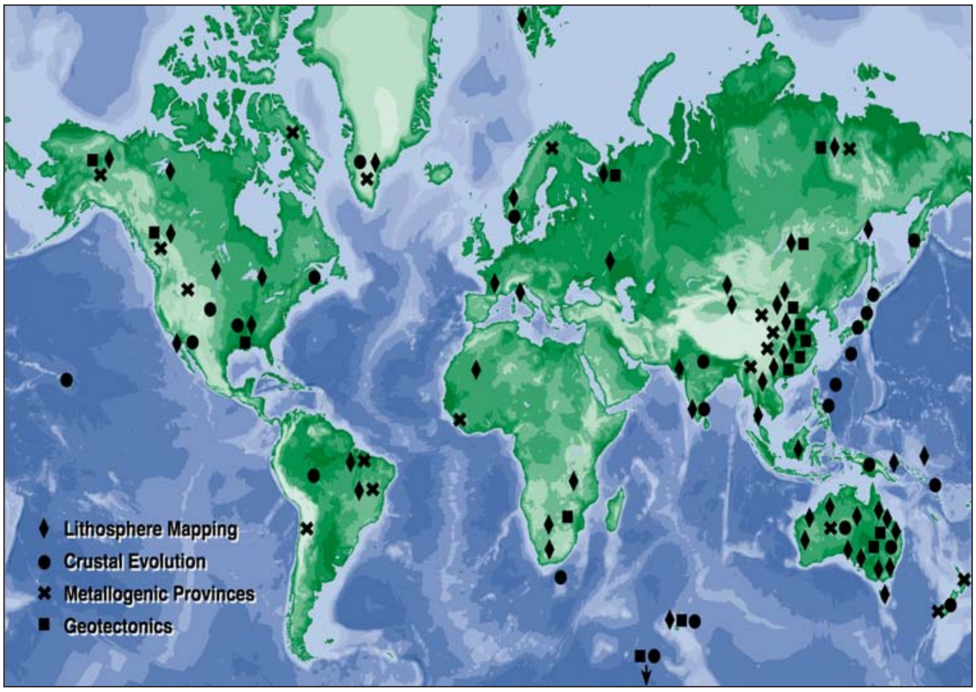
THERMAL ENERGY transmitted from the deep Earth (core and convecting mantle) provides the energy to drive lithosphere-scale processes. Mantle-derived fluids and the tectonic environment control element transfer across the crust-mantle boundary and control commodity distribution in the accessible crust. The nature of mantle heat transmission reveals information on fundamental deep Earth processes from the core-mantle boundary to the surface. The 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 2006.

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.

• Mantle Dynamics and Composition

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

"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."

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

U-series applications to timescales of lithosphere processes Research Highlights

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

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

Origin of mantle eclogites Research Highlights

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

Interpretation of deep seismic tomography Research Highlights

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

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

Basalts as lithosphere/asthenosphere probes

Plume compositions, sources and origins

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

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

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

Metal isotopes as tracers of lithosphere processes and Earth evolution

Crustal Evolution and Crustal Processes

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

U-series analysis of weathering and erosion processes

Dating lower crust domains and tracking extent of Archean crust

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

Tracers of magmatic processes: trace elements in accessory minerals

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

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

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

Metallogenesis

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

Lithosphere domains through time and location of ore deposits

Effect of deep mantle processes on lithosphere evolution and structure

Identification of plume types fertile for Ni and PGE mineralisation

Crust-mantle interaction, granites and metallogenesis through time

Sulfide and PGE budget of the mantle

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

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

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

Trace elements in diamonds - source fingerprinting and genetic indicators

Geodynamics

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

Tasman Fold Belt: terrane analysis

Paleomagnetic studies of the northern New England Orogen

Antarctic seismic studies

Deep crustal processes (New Zealand)

Plate margin processes (Papua New Guinea, Macquarie Island)

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

Evolution of lithospheric composition and Earth geodynamics through time

Funded basic research projects for 2007

Funded 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 for 2007 are given here.

Toward the use of metal stable isotopes in geosciences

Olivier Alard: Supported by ARC Discovery

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

Tomorrow's *TerraneChron*®: new developments, new deliverables and new destinations

Elena Belousova: Supported by Macquarie University

Summary: TerraneChron® 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*® 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*® 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. Through a multi-faceted outreach program, it will target the largely unexploited market of the petroleum industry, and engage with a greater proportion of the mineral exploration sector in Australia and globally. It aims to establish *TerraneChron*® as an industry-standard exploration reconnaissance tool, maintain GEMOC's leadership in this area, and enhance Macquarie's reputation for frontline research, industry interaction and innovation.

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

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

Summary: This project is the first that aims to understand the generation, deposition and lithification of sedimentary rocks at mid-ocean spreading ridges. It will improve our understanding of the construction of significant volumes of oceanic crust that commonly host important economic resources such as cupriferous sulfides. The project will examine spreading-related sedimentary rocks, including processes relating to their depositional system, utilising unique exposures on Macquarie Island, where *in situ* oceanic crust still lies within the basin in which it formed. This research will examine the south eastern tectonic plate boundary of Australia, providing analogues for seafloor spreading related crustal processes that relate to 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.

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

Simon Jackson and Bruce Mountain: Supported by ARC Discovery

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

Episodicity in mantle convection: effects on continent formation and metallogenesis

Craig O'Neill: Supported by Macquarie University Research Fellowship

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

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

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. Innovations in geochemical technology and in the integration of information from geochemistry, geophysics and geodynamics will maintain our high international profile in research relevant to National Priority 1.6 (Developing Deep Earth Resources). The project and its interaction with the minerals industry will provide advanced Postgraduate training in a field critical to Australia's future.

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

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.

Mantle melting dynamics and the influence of recycled components

Simon Turner: Supported by ARC Discovery

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 Earths 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

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

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. The information gained from this fundamental research will help predict how giant ore bodies form. The development of the high-pressure apparatus will also aid material scientists in their quest for novel materials.




Research highlights 2006

TERRANECHRON® is GEMOC's unique methodology for terrane evaluation. During 2006 industry continued extensive use of *TerraneChron*® as a cost-effective tool for mapping crustal history on different scales.

Reworking the Archean Gawler Craton, South Australia: U-Pb and Hf-isotopes in detrital zircon.

THE *TERRANECHRON*® METHODOLOGY (www.es.mq.edu.au/GEMOC/) was applied to zircons in drainage samples collected from 24 defined catchments across the Gawler Craton, South Australia. The results define the relative contribution of juvenile sources and recycled crust to the continental crust through time and constrain the role of the mantle during the Proterozoic rejuvenation of the Archean craton.

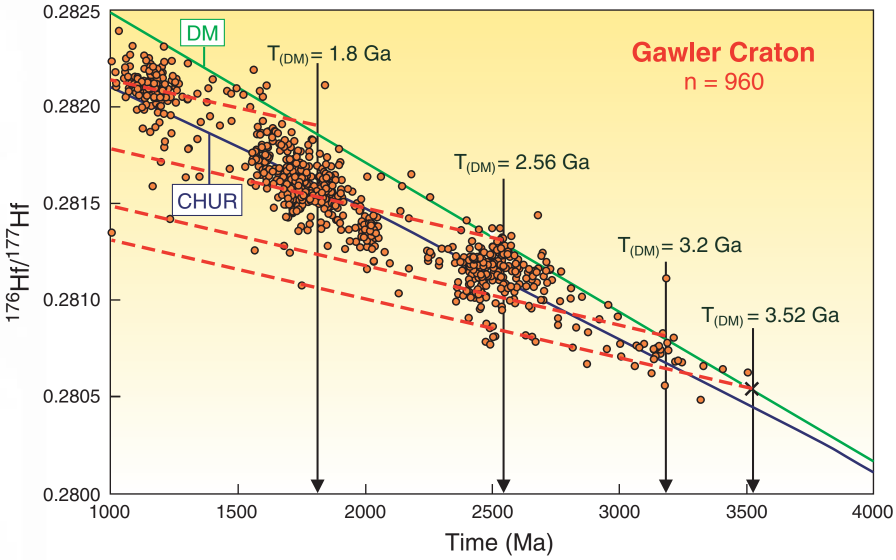


Figure 1. Hf-isotope composition vs age for detrital zircons from the Gawler Craton. Most grains in the 1500-2000 Ma range fall below the CHUR line, indicating derivation largely from older crust (2.5-3.2 Ga). Dashed lines show the evolution of average continental crust of different ages.

Widespread Hf model ages (measured by *in situ* LAM-MC-ICPMS) of about 3.5 Ga, and the presence of inherited zircon grains with comparable U-Pb ages (3.2 - 3.5 Ga), show that Archean crust as old as ca 3.5 Ga exists in the Gawler Craton. This component may now reside largely in the lower crust, where it has provided a source of crustal magmas throughout the Proterozoic rejuvenation of the craton (Fig. 1).

The Hf isotope data show that juvenile mantle-derived material represents a minor contribution to crustal generation relative to the reworking of older crust. Three periods of juvenile input can be recognised at ca 2540 Ma, 1850 Ma and 1595 Ma

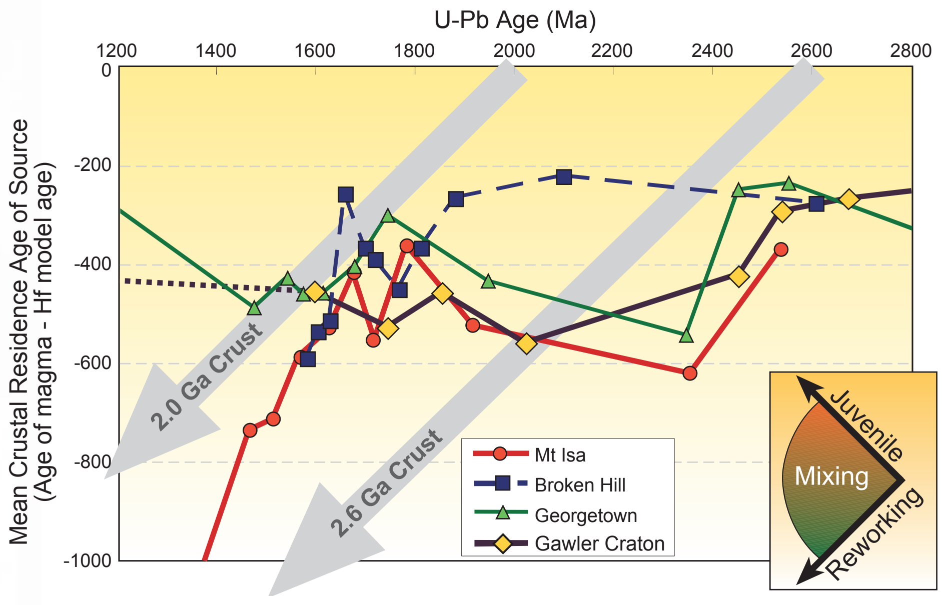


Figure 2. Event Signature curves for Australian tectonic blocks. The Gawler Craton evolved differently from the other three terrains after ca 1900 Ma; it lacks the large juvenile inputs associated with ca 1.7 Ga mineralisation events in the Broken Hill and Mt Isa blocks.

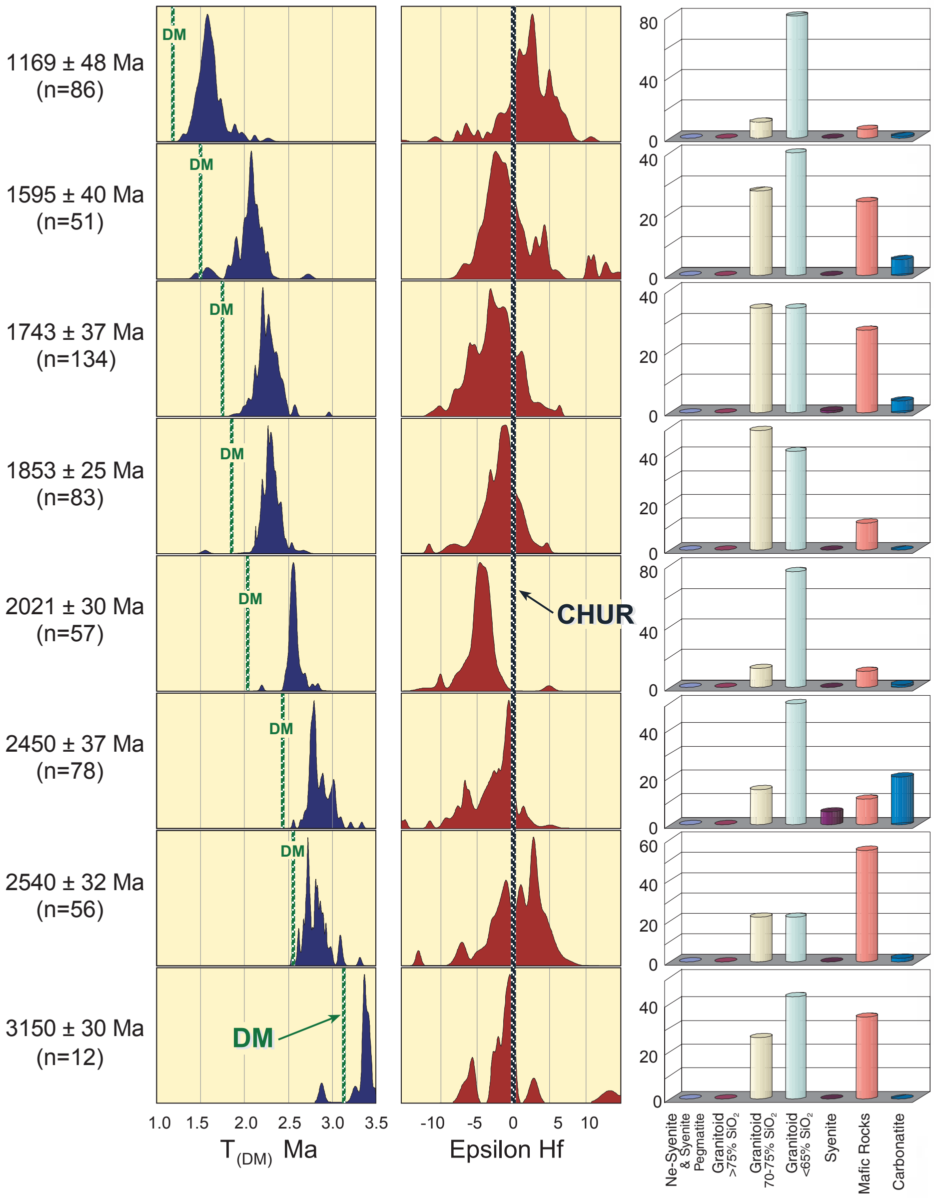


Figure 3. Model ages, epsilon Hf values and modelled rock types for the Gawler Craton in different time slices. Time slices with more mafic rocks show generally higher epsilon values, consistent with more mantle-derived magmatism.

(Fig. 2,3). However, only a minor proportion of the zircons formed during these time intervals have strongly juvenile signatures (εHf ≥ 4), and most magmatic rocks represent mixtures of remelted crustal material with mantle-derived material input.

"Event Signature" curves (Fig. 2) allow the visual synthesis of terrane evolution, and a useful way to compare the evolution of different crustal domains; they provide a new tool to advance existing plate tectonic models for the evolution of the Australian continent. Comparison of the Event Signature of the Gawler Craton with those from the Mount Isa Block and Georgetown Inlier shows some similarities in Late Archean-Early Proterozoic time, but makes it clear that the Gawler Craton evolved independently from these terrains, and from the Broken Hill Block, between ca 1800 and 1500 Ma.

Contacts: Elena Belousova, Bill Griffin
Funded by: ARC, PIRSA, Macquarie University

Heavy Rock(s) in Tamworth

Modelling of detailed gravity data can reveal the subsurface structure of fold belts and their associated faults. For much of the period 400 – 200 Ma, the southern New England Fold Belt (SNEFB) was a convergent plate margin at the eastern edge of the Gondwana continent with a west-dipping subduction zone. The SNEFB (Fig. 1) consists of the Tamworth Belt in the west and the Tablelands Complex in the east. The SNEFB has been thrust westward over the Permian-Triassic Sydney-Gunnedah Basin, along the Mooki Fault. The Peel Fault, which trends north-northwest, separates the less deformed rocks of the Tamworth Belt from the more deformed rocks of the Tablelands Complex.

The Bouguer anomaly map of the SNEFB (Fig. 2) has two meridional linear gravity highs: the Namoi Gravity High (NGH) on the east, and the Meandarra Gravity Ridge (MGR) on the west. The NGH lies over the Tamworth Belt along its entire length and lies east of the Mooki Fault in the south and the Kelvin Fault in the north. The eastern edge of the NGH coincides roughly with the Peel Fault. To the west, the MGR lies within the Gunnedah Basin, which otherwise generally shows a relative gravity low. These gravity highs are distinct features and understanding what is causing them should help us to understand the upper crustal structure of the SNEFB.

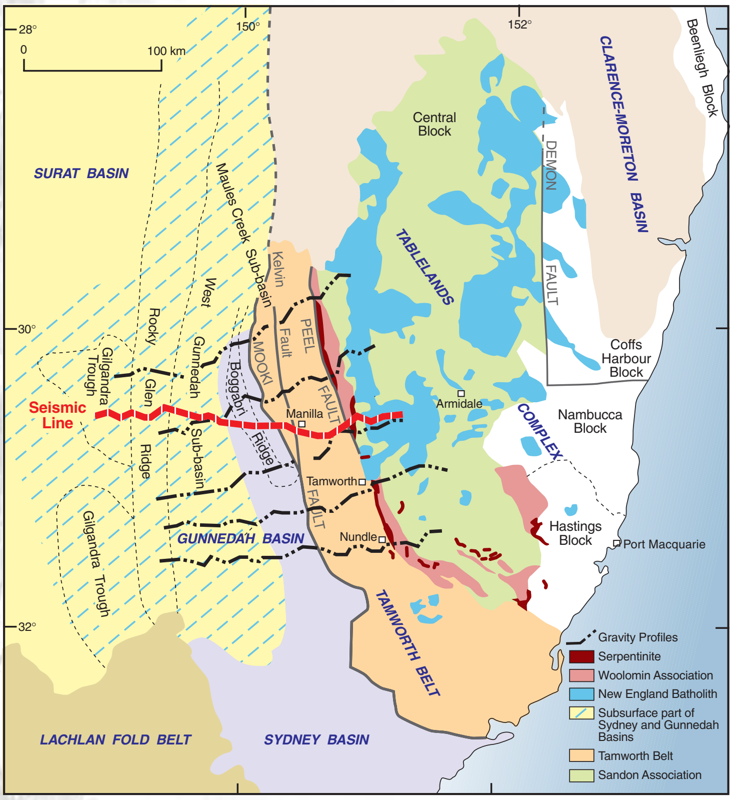


Figure 1. Generalised structural units of the southern New England Fold Belt and the Gunnedah Basin. Also shown are locations of the five gravity profiles acquired for this study and the GA seismic line BMR91-G01.

Five ENE-trending high-resolution gravity traverses (450 readings) were conducted across the belt, adjacent parts of the Gunnedah Basin and the Tablelands complex. These data were modelled together with density determinations of surface and drillcore samples. The data were first modeled using the geometry derived from the interpretation of GA's BMR91-G01 seismic line.

This modelling (Fig. 3) indicated that the gravity anomalies correlate with the densities of the exposed rock units. The Namoi Gravity High over the Tamworth Belt is produced by the high density of the rocks in this belt. These high densities reflect the mafic volcanic source of the older sedimentary rocks in the Tamworth Belt, the burial metamorphism of the pre-Permian units and the presence of some mafic volcanic units. Modelling shows that the Woolomin Association, present immediately east of the Peel Fault and constituting the most western part of the Tablelands Complex, also has a relatively high density, which also contributes to the NGH. The Tamworth Belt can be best modelled with a configuration in which the Tablelands Complex has been thrust over the Tamworth Belt along the Peel Fault, which dips steeply to the east to a depth of more than 10 km. Plutons near the Peel Fault (eg Moonbi) are also clearly delineated by the data. The Tamworth Belt is thrust westward over the Sydney-Gunnedah Basin for 15-30 km on the Mooki Fault that has a shallow dip (~25°) to the east and is consistent with the new gravity data.

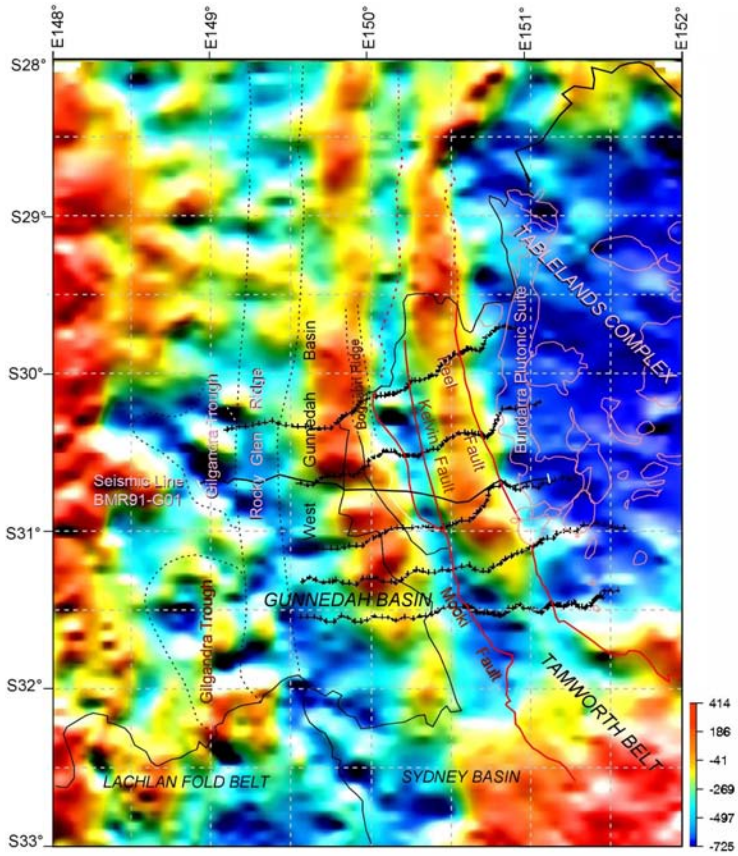


Figure 2. Bouguer gravity anomaly image covering the southern New England Fold Belt and the Gunnedah Basin, with location of the gravity profiles surveyed in this study. Unit: µm/s². Red lines indicate the Peel and Mooki Faults. Also shown is the seismic line BMR91-G01.

The Meandarra Gravity Ridge within the Gunnedah Basin was modelled as a high-density volcanic rock unit with a density contrast of 0.25 tm^{-3} relative to the underlying rocks of the Lachlan Fold Belt. The modelled unit has a steep western margin, a gently tapering eastern margin and a thickness ranging from 4.5 - 6 km. These volcanic rocks are assumed to be Early Permian in age; they may be the western extension of the Permian Werrie Basalts that outcrop on the western edge of the Tamworth Belt, and that may have formed within an extensional basin.

Contacts: Mark Lackie, Dick Flood, Bin Guo
Funded by: Macquarie University Postgraduate Research Fund

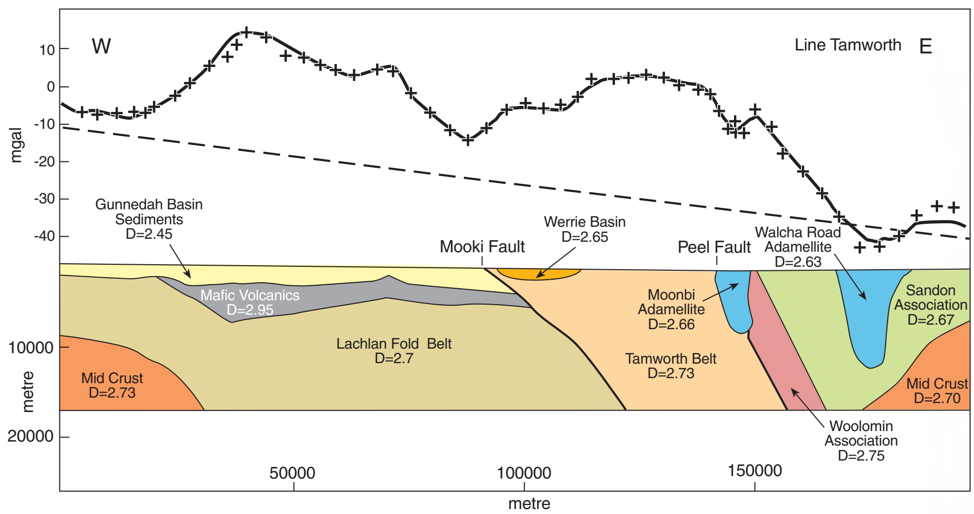


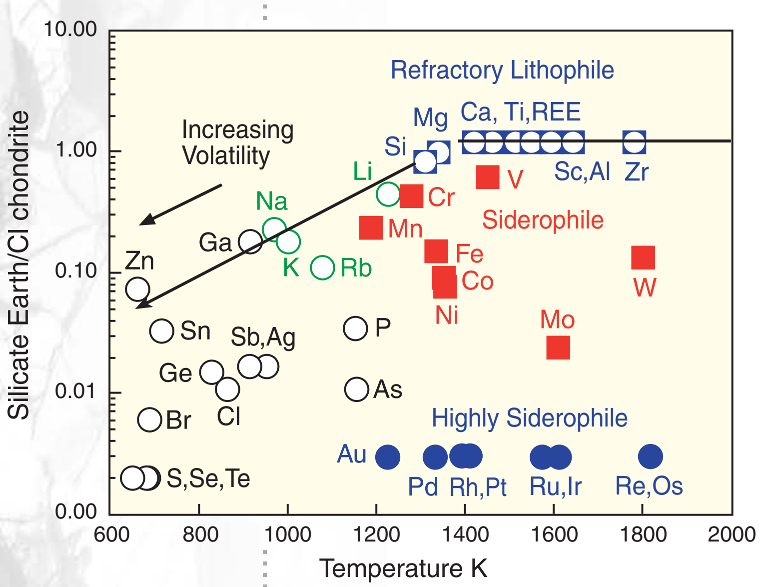
Figure 3. 2.5D gravity model along the Tamworth Profile (cross-section view) shows a good fit between the observed data and calculated profile. The Peel Fault was modelled as a steep east-dipping fault extending to mid crustal levels. Crosses represent observed data and solid line is the calculated anomaly, V/H=1.9. Density in tm^{-3}. Dashed straight line is the regional gradient.

How did the Earth form?

FROM OBSERVATIONS OF NEWLY-FORMING STARS it seems that our solar system developed from a flattened disk of dust and gas around the young sun 4567 million years ago. The mechanisms of growth of particles of dust into asteroidal (20 km diameter) bodies are not well understood, but once this size had been reached, gravitational attraction would have ensured growth to planetary-size bodies. Understanding of these processes of planetary growth and their timing can be obtained by studying the chemical compositions of the planets and asteroids and the characteristic isotopic signatures for some key elements.

Amongst the thousands of meteorites in museum collections there are about a dozen that appear to represent primitive protoplanetary material. These "carbonaceous chondrites" come from the asteroid belt between Mars and Jupiter and have compositions which closely mimic that of the Sun. They also have, for elements that condense at high temperatures from a gas of solar composition, striking affinities with the Earth, Mars and the Moon. Figure 1 shows ratios of element abundances in the silicate part of the Earth (mantle+crust) to those in carbonaceous chondrites, plotted against the temperature at which 50% of the element of interest would condense from a solar gas. Refractory elements, which condense at high temperatures, are divided into 3 groups, "lithophile", "siderophile" and "highly siderophile". Lithophile elements such as Ca, Ti, Hf, Al and the Rare Earths are those elements which did not enter the Earth's iron-rich metallic core. They are present in the same relative abundances in the silicate Earth as in the meteorites, Mars and the Moon. The siderophile elements (Fe, Ni, Mo, W etc) are all depleted in the silicate part of the Earth because they have partitioned into the core, while the highly siderophile elements (Au, Pt etc) are >99% partitioned into the core. The Earth is also depleted in volatile elements (those with low condensation temperatures) because of late volatile loss.

Figure 1. Abundance in silicate Earth versus temperature of 50% condensation.



Asteroids, many of which have metallic cores like the Earth, are known to have formed within a few million years (some as soon as 1 Ma) after the beginning of the solar system. This result was obtained using the radioactive decay of ^{182}Hf (a short-lived isotope present when the solar system formed) to ^{182}W. Hafnium is lithophile while tungsten (W) is siderophile (Fig. 1). Therefore as core formed on any body, most of the tungsten was extracted to the core, leaving the silicate part with a very high Hf/W ratio. The build-up of ^{182}W during the first 50 Ma of solar system history (by which time all ^{182}Hf had decayed) then dates the time at which Hf and W were separated by core formation. Application of this method to Mars gives a time about 10 Ma after the beginning of the solar system and the Earth about 30 Ma. This then enables us to estimate the timescales of formation of asteroids (1-4 Ma), a planet 10% of Earth-size (Mars) and Earth itself.

Research at Macquarie is concentrating on studying the conditions on Earth as the metal core formed. Earth grew by initially sweeping up lots of smaller bodies,

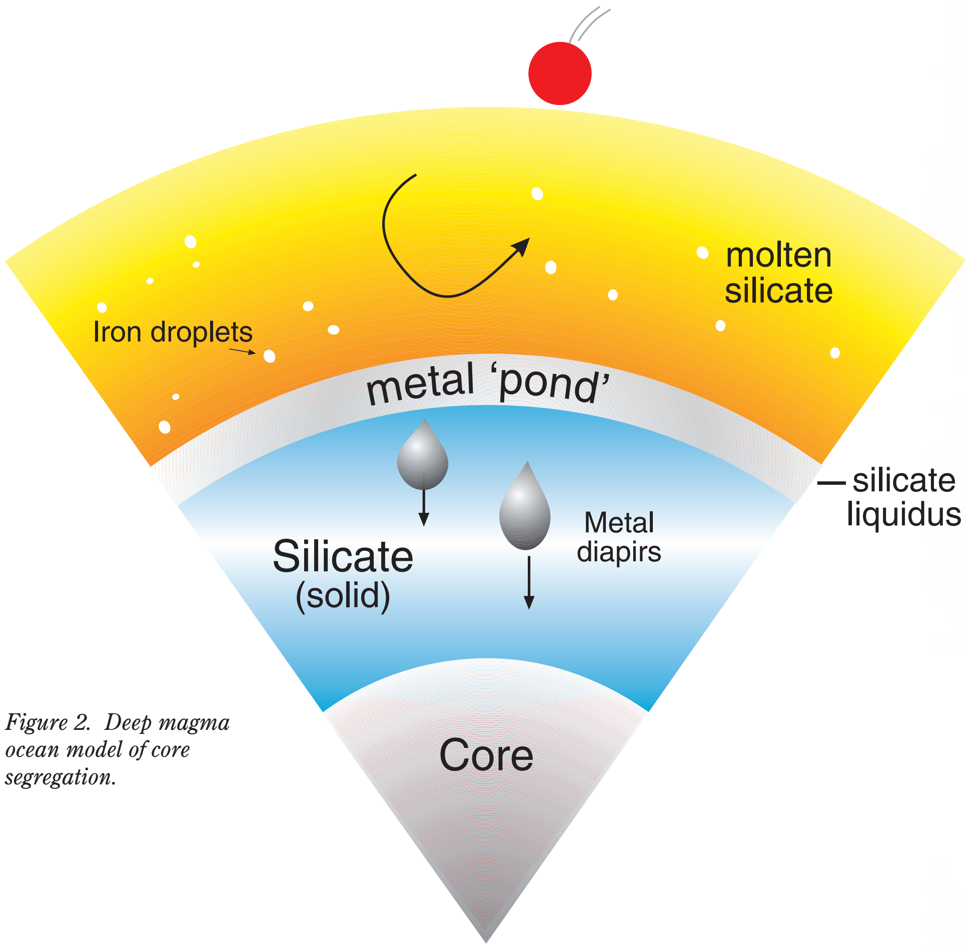


Figure 2. Deep magma ocean model of core segregation.

then progressively fewer larger and larger bodies, culminating in the impact of a Mars-sized body which generated the moon about 40 Ma after the beginning of the solar system. Our experimental work is aimed at finding the pressures and temperatures under which the siderophile element contents of the silicate Earth (Fig. 1) match those observed. We find that the metal was extracted at high pressures, probably at the base of a deep (>400 km) ocean of molten silicate (Fig. 2). This magma ocean was kept molten by the high energies of impacting bodies. We also find that the Earth appears to have become more oxidised as it grew. It is likely that the earliest atmosphere (during early growth of the Earth) was hydrogen-rich, solar-like in composition, and strongly reducing. However, this was blown away (together with many volatile elements; Fig. 1) by large impacts later in accretion, leaving the Earth to oxidise by a combination of internal and external processes.

Contact: Bernie Wood
Funded by: ARC (Federation Fellowship, Discovery Project)

Flushing the mantle: Harzburgite to lherzolite in the Lherz Massif (France)

DIFFERENTIATION OF THE EARTH'S MANTLE occurs mainly through partial melting and extraction of basaltic melts. Among the mantle rocks occurring at the Earth's surface, lherzolites are widely regarded as samples of the pristine mantle, from which no (or only small amounts of) melts have been extracted. In contrast, harzburgites are seen as refractory mantle residues left after extensive partial melting.

The Lherz Massif (Pyrenees, France; picture above) is the type locality of lherzolite. The massif is predominantly composed of layered spinel lherzolites; in the upper part of the massif the lherzolites enclose bodies of highly refractory spinel harzburgite metres to tens of metres in size (Fig. 1).

Detailed structural mapping shows that all harzburgites, even small bodies, have a constant foliation throughout the massif. In contrast, the foliation in the lherzolites is variable and generally oblique to the harzburgite foliation. This suggests that the lherzolites are secondary rocks, and that the harzburgites are remnants of a highly refractory mantle protolith, largely replaced by the lherzolites through a process of melt percolation.

Crystallographic orientations were measured by indexation of electron back scattered diffraction (EBSD) patterns at the Géosciences Montpellier laboratory. Analysis of microstructures and crystal-preferred orientations suggests that the harzburgites deformed by dislocation creep with activation of the high temperature, low stress (010) [100] slip system. Refertilised lherzolites display a much weaker alignment of the *a* axis of olivine (Fig. 2).

Figure 1. Harzburgite-lherzolite contacts are sharp and steep, and emphasised by a cm-scale websteritic layering.

These features suggest that melt percolation and melt-rock reaction started at static conditions, and produced changes in modal composition, grain growth and a weakening of the olivine fabric.

Variations of major, minor and trace elements across the harzburgite-lherzolite contacts indicate that the lherzolites were formed by a near-solidus refertilisation reaction involving crystallisation of pyroxene and spinel, and dissolution of olivine. These processes produce chemical trends in the relationships between mineral and whole-rock chemistry that are different in detail from partial-melting trends (Fig. 3).

The combination of detailed fieldwork, petrophysical analysis and geochemical

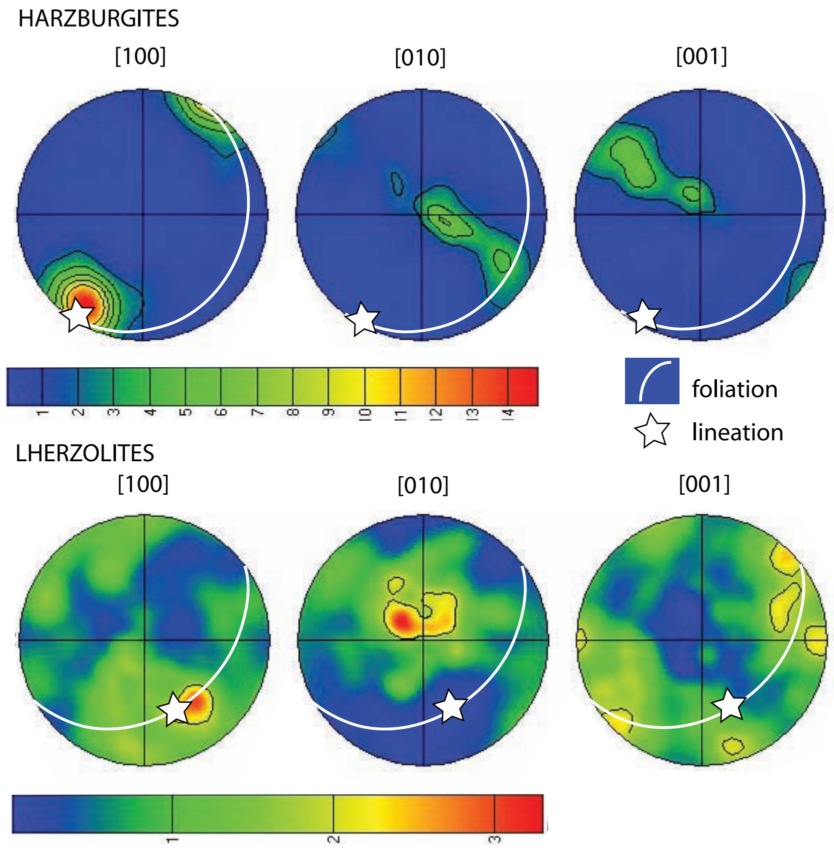


Figure 2. Illustration of the high temperature deformation in Lherz harzburgites and the weakening of crystallographic fabrics in refertilised lherzolites.

modelling reveals that the type lherzolites of the Lherz massif represent refertilised, rather than pristine, mantle. The refertilisation process has involved the interaction of refractory lithospheric mantle with upwelling asthenospheric partial melts. This study highlights the fact that melt transport and melt-rock reaction play a key role in modifying the composition of the lithospheric mantle, and that models of lithospheric mantle composition based on such lherzolites must be reconsidered.

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Funded by: Bourse MENRT, INSU

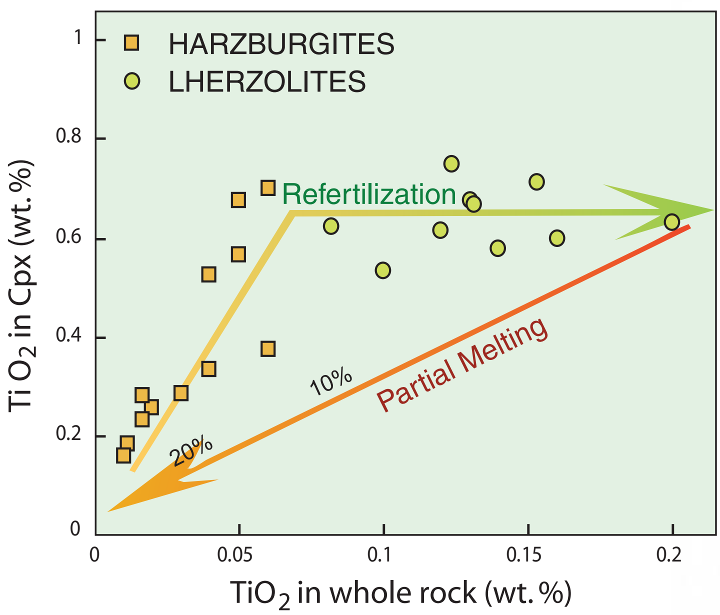

Figure 3. Modelling of partial melting versus refertilisation reaction. Orange squares, harzburgites; green circles, lherzolites.

Mantle "Botox" and the tale of the primitive upper mantle

ONE OF THE RECURRENT QUESTIONS IN PLANETARY SCIENCE is what the Earth is made of; what were the "building blocks" of our planet? Of special interest is the nature of the 'late veneer', a final meteoritic bombardment that may have been the main carrier of water and possibly life-seeds to Earth. However, the nature of this late component remains elusive, and constraints from various geochemical systems seem at first glance to be contradictory. In that respect, the siderophile elements may be one of the most promising sources of first-hand constraints on the nature of the late accreting material. The broadly chondritic relative abundances of highly siderophile elements (HSE) in the Earth's mantle are assumed to reflect the addition of chondritic material to the mantle after core formation. The HSE composition of the Primitive Upper Mantle (PUM) is thus an important goal of modern geochemistry. Current estimates of PUM for siderophile elements (PGE and Os isotopes) are based largely on two suites of mantle samples: peridotite xenoliths from Kilbourne Hole maar in Texas, and the Lherz orogenic peridotite massif in the Pyrenees (*Le Roux et al., Earth and Planetary Science Letters*, in press; see *pp. 32-33*). The Os isotopic composition of the Earth's Primitive Upper Mantle ($^{187}Os/^{188}Os$ =0.1296 ± 0.0008) is significantly higher than the ratio measured in carbonaceous chondrites (CC; $^{187}Os/^{188}Os$ = 0.1262 ± 0.0006). Taken at face value, this estimate thus rules out CC as the source of the 'late veneer' and suggests that ordinary chondrites (OC) formed the bulk of the 'late veneer'. However, carbonaceous chondrites are the only water-bearing chondrites and have a Deuterium to Hydrogen ratio (D/H) similar to the Earth's ocean (≈ 150 x10^{-6}).

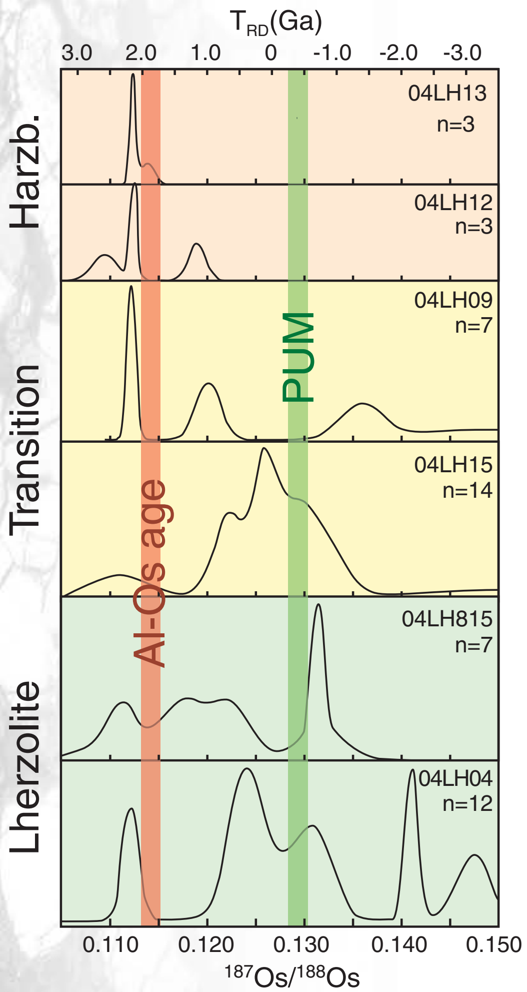

Figure 1. Os-isotope compositions of sulfide grains in samples of the primary harzburgite, the refertilised lherzolite and transitional rocks in the Lherz massif. Bars show the $^{187}Os/^{188}Os$ corresponding to the "aluminochron age" and the "PUM" estimate derived from these rocks; both are spurious.

These sorts of inconsistencies have led to proposals that the Earth was made of an unsampled type of material dubbed "Earth-chondrite" or "Earth achondrite". However, before calling upon the existence of a never-sampled material, we need to examine the robustness and significance of the PUM estimate. Indeed, the same mantle-sample suites also yield a Pd/Ir (≈ 2) much higher than any type of chondrite. Since Os, Ir, Pd and Re are all HSE and thus should behave similarly, this inconsistency raises suspicion about the nature of the data.

The Lherz Orogenic massif is the type area of lherzolite (usually assumed to represent the dominant rock type of the upper mantle) and has always been a key area for studying mantle composition and processes. However as demonstrated in the previous highlight (see *pp. 32-33*) structural, petrographic and geochemical features clearly indicate that the lherzolite suite was developed at the expense of the more refractory harzburgite via a refertilisation reaction involving precipitation of pyroxene (±spinel) and sulfide at the expense of olivine and infiltrated melt.

In situ measurement of the Os composition of rare sulfides in the harzburgites yields a constant unradiogenic Os composition indicating a T_{RD} age ≈ 2.4 Ga (Fig. 1). In contrast, the numerous sulfides in the lherzolite show a large spread of Os composition (0.11 ≤ $^{187}Os/^{188}Os$ ≤ 0.18). However, the unradiogenic sulfides characteristic of the harzburgite are common in the lherzolite, while extremely radiogenic Os is characteristic of Lherz's pyroxenite suite. The whole-rock composition of individual

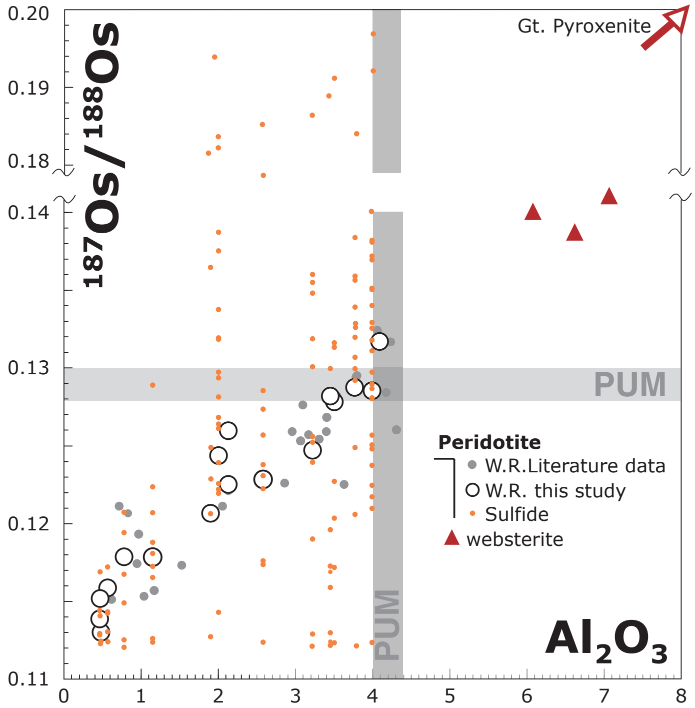

Figure 2. Al_2O_3 vs. $^{187}Os/^{188}Os$ for whole-rock samples as used to define the PUM Os composition and the Os isotopic variability of the sulfides in each sample, Red triangles are the websterite and other pyroxenites in Lherz.

lherzolite samples are intermediate between these two end members, depending on the proportion of each sulfide population (Fig. 2). This indicates that the lherzolites are in fact old, refractory harzburgites which were re-fertilised by fluids that carried radiogenic Os. This conclusion is consistent with the structural, petrographic, petrophysical and geochemical evidence presented by Le Roux et al. (in press).

Our previous work has demonstrated that the abundances of sulfides and HSE in several of the xenolith suites used to derive the Os-isotope composition of PUM have been heavily altered by metasomatic events. Together with the Lherz study, the results cast strong doubt on the robustness and significance of the currently accepted Os-isotope composition of the PUM, its bulk composition and the long-term evolution of the mantle. It appears that the "PUM" in fact represents refertilised/metasomatised, old, depleted upper mantle; it lost its "primitive" character a long time ago.

Recognition that the currently accepted model composition for the PUM is not meaningful can help to resolve some of the contradictions noted above. A better estimate of the PUM and the original bulk composition of the Earth will come through detailed studies of the budgets of siderophile and chalcophile elements in a dynamic Earth. This will need a better understanding of metasomatic processes, detailed studies of key terrestrial and meteoritic sample suites and integration with experimental studies (see *pp. 30-31*).

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Funded by: ARC-DP/APD

Building an oceanic plateau: The Kerguelen Archipelago

THE KERGUELEN ARCHIPELAGO, located in the southern Indian Ocean (49°S and 69°E), is the emergent part of the northern Kerguelen oceanic plateau (Fig. 1). The magmatic edifice of the Kerguelen Islands was produced over about the last 40 Ma. When the volcanic activity associated with the Kerguelen Plume started, the Kerguelen area was situated near or on the South East Indian Ridge (SEIR). The SEIR then moved away to the NE, leaving the Kerguelen Plateau in its present intraplate setting. The early magmatism was dominantly of tholeiitic-transitional affinity and became progressively alkaline to highly alkaline over time. Therefore the Kerguelen Archipelago has a complex history, superposing in time and space two types of hotspot activity. Between ~40 and ~26 Ma, the volcanism was similar to Iceland (interaction between a hotspot and a ridge); since 26 Ma, it was more similar to the Hawaiian (intraplate) hotspot type.

The Kerguelen Archipelago is made up mainly of flood basalt (80%), plutonic rocks (5%), and dykes with ultramafic and mafic xenoliths.

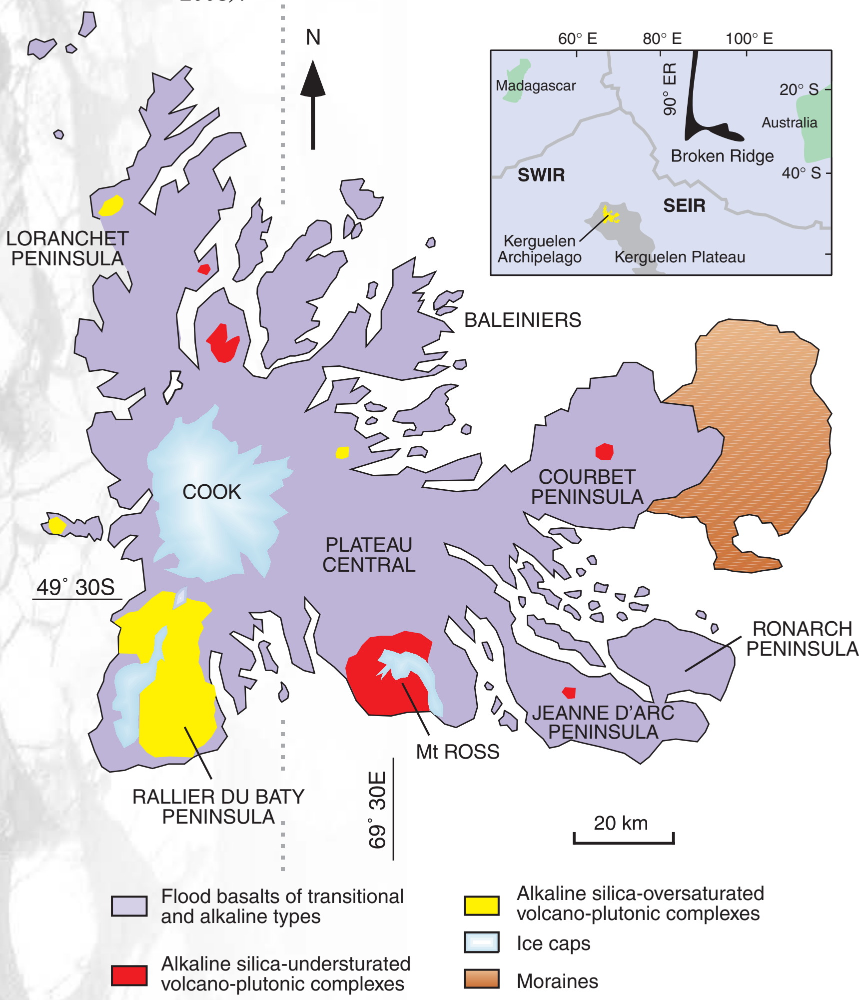

Figure 1. Simplified geological map of the Kerguelen Archipelago, after Delpech (GEMOC Research Highlights 2003).

Over the last fifteen years, petrologic, geochemical and isotopic studies have mainly focused on the flood basalts and ultramafic xenoliths brought up from the upper mantle by alkaline basalts. These studies have characterised (i) the petrologic and geochemical heterogeneity of the mantle, (ii) the nature of the magmas and fluids circulating through the lithosphere, (iii) the different mantle sources. Geochemical studies coupled with geophysical studies have shown that the oceanic lithosphere was thickened by underplating of mafic magmas under the Kerguelen archipelago.

Gabbroic rocks (gabbros and meta-gabbro) are found at different structural levels in the oceanic lithosphere (crust, mantle/crust boundary and upper mantle), but they have been studied very little. The characterisation of these intrusive rocks (gabbroic and hypovolcanic) and related cumulate ultramafic-mafic xenoliths will help to understand the different stages of lithospheric differentiation in the context of a thickened oceanic crust. These rocks are the key to understanding how magmas evolved from their source to the surface. In a more general context, this work will also help to better constrain the formation of Large Igneous Provinces (LIP).

The gabbros and xenoliths for the initial work came from the St-Etienne

University collection (France). Further sampling was done in December 2006 during the DyLioKer campaign supported by IPEV (Institut Paul Emile Victor). The gabbros and other plutonic rocks are exposed in massifs, sills (Fig. 2) and stratified or ring complexes. Some have also been found as xenoliths in alkali basalts.

Both *in situ* and whole-rock techniques have been used to characterise the gabbros in terms of major and trace elements (microprobe, XRF, LA-MC-ICPMS). The preliminary studies show that several types of gabbroic and intrusive rocks can be distinguished on the basis of their rare earth element (REE) composition. The REE patterns of the clinopyroxenes from different localities (Fig. 2) vary between two end-members. A tholeiitic-transitional pattern is characterised by low light REE contents (LREE, La to Sm) compared with the heavy REE contents (HREE, from Tb to Lu). A second highly alkaline pattern is characterised by high LREE/HREE. Compositions intermediate between these end-members are also observed.

Figure 2. Gabbroic sill, Val Travers, Kerguelen Island (DyLioKer campaign 2006). Photo: Damien Guillaume.

The preliminary results on the gabbroic rocks are consistent with previous studies that indicate two types of magmatic trends, from tholeiitic-transitional to alkaline, and interaction between them. Isotopic studies of the samples will help to better constrain the sources of the different gabbroic rocks, and U-Pb dating of zircon will also put better constraints on the evolution of the different sources with time.

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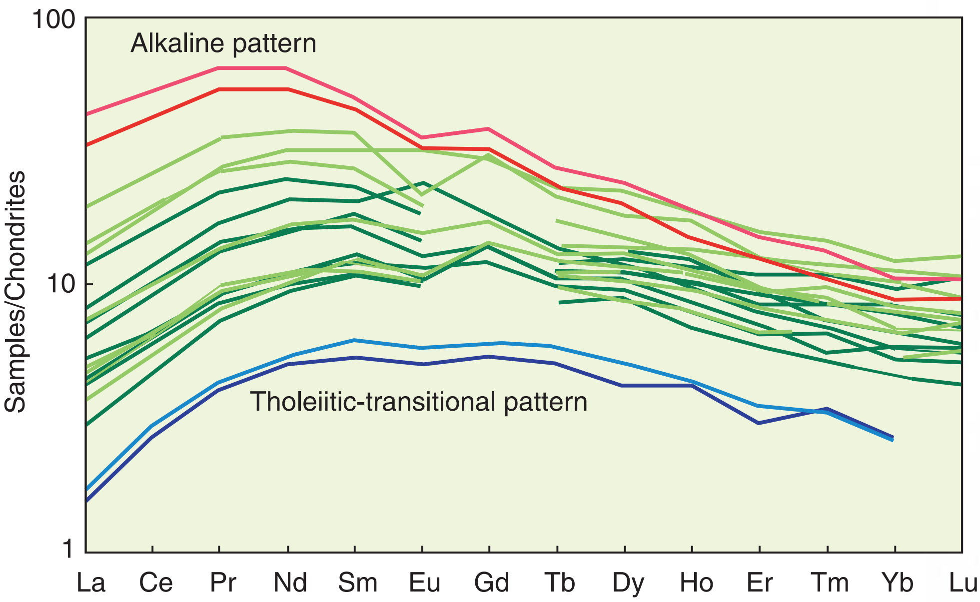

Figure 3. REE patterns measured in the cores and rims of clinopyroxenes in gabbro sampled in different localities on the Kerguelen Archipelago (red lines = alkaline composition, blue lines = tholeiitic-transitional composition, green lines = intermediate compositions).

Using kimberlites as drill holes: Crustal evolution beneath the Kundelungu Plateau (D.R. Congo)

THE KUNDELUNGU PLATEAU is located in the SE corner of the Democratic Republic of the Congo. Twenty-four kimberlitic pipes are known in the area; recent dating of perovskites at GEMOC shows that they intruded 33±3 Ma ago. The Plateau is formed of rocks belonging to the Neoproterozoic Katangan belt, which is surrounded by the Archean Congo Craton, the Paleoproterozoic Bangweulu Block, the Paleo- to Mesoproterozoic Irumide Belt, the Mesoproterozoic Kibaran Belt and Choma Kalomo Block. The Archean Zimbabwe Craton lies to the south (Fig. 1). The Gungwania and Talala kimberlitic pipes on this plateau have been used as drillholes, to obtain crustal zircons for a study of crustal evolution in the region and to constrain the age of the basement and the sedimentary provenance of the Katangan Supergroup. Zircons were separated from heavy mineral concentrates collected in streams that crosscut these pipes (Fig. 2).

229 zircons were analysed for U-Pb ages (LAM-ICPMS) and Hf isotope (LAM-MC-ICPMS) compositions. The analyses show that the oldest juvenile crust in the region is approximately 3.4 Ga old, and underwent varying degrees of recycling during Neoarchean and Paleoproterozoic times. The major Paleoproterozoic event is characterised by little production of juvenile crust; any juvenile input was essentially mafic in composition (Fig. 3). Important bimodal magmatism affected the region in the Mesoproterozoic (1 Ga) and Neoproterozoic (700-568 Ma). These events correspond to the continental extension and rifting related to the break-up of the Rodinia supercontinent (~1 Ga), the opening of the Mwashia basin (~700 Ma) and the Lufilian orogeny. The generation of Mesoproterozoic and Neoproterozoic crust involved recycling of Paleoproterozoic crust but these periods are also characterised by an important input of juvenile material (Fig. 3). The existence of a high-^{176}Lu/^{177}Hf (0.059) Archean crust (eg garnet-rich rocks) in the region is suggested by the presence of zircons that lie above the Depleted Mantle line, on a line that projects back to 3.4 Ga (Fig. 3).

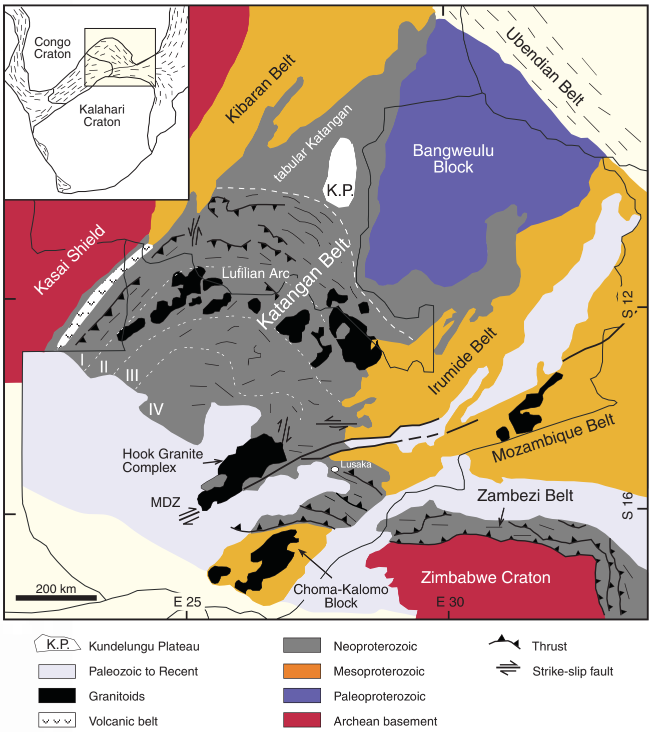

Figure 1. Simplified geological map of the Katangan belt and surrounding basements (modified after Binda and Porada, 1995), showing the location of the Kundelungu Plateau (K.P.).

The zircons in these samples may come both from the basement and from the Katangan Supergroup sediments. Morphological examination of the zircon grains in different age groups shows that the Paleoproterozoic population has the highest proportion of euhedral zircons, which implies that the basement rocks may be of this age. Most Archean zircons are rounded, indicating long transport. This does not support the presence of an Archean crust beneath the region. However, the Hf-isotope data may indicate that an Archean crust existed at depth at least during Paleoproterozoic time (Fig. 3).

The sediments constituting the Katangan Supergroup were derived from most of the older rocks in the region including the Archean Congo Craton, the Paleoproterozoic Ubendian Belt (Bangweulu Block), the Paleo- to Mesoproterozoic Irumide Belt, the Mesoproterozoic Kibaran Belt and the Choma-Kalomo Block, with a possible minor contribution from the Zimbabwe Craton far south of the Katangan Basin. The absence of any zircons with ages < 560 Ma suggests that the Biano Subgroup sediments were deposited during the Lufilian orogeny.

Figure 2. Jacques Batumike collecting heavy mineral concentrates on the Talala River (near Talala pipe, Kundelungu Plateau).

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Funded by: iMURS, IPRS, ARC-DP

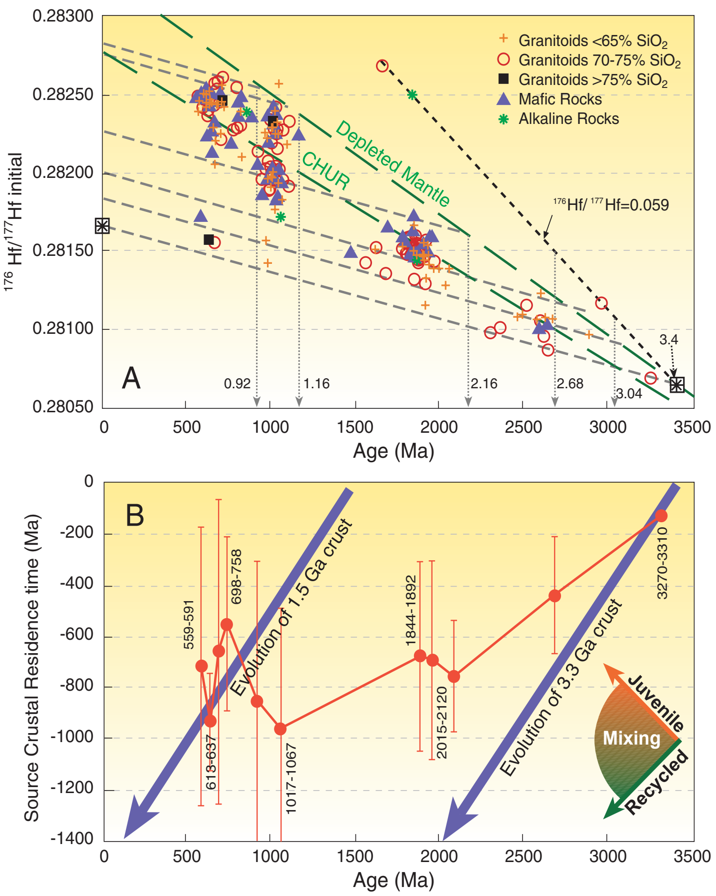

Figure 3.
A. Age, Hf-isotope and rock type data for each sample and calculated crustal ages. CHUR: Chondritic Uniform Reservoir. Dashed lines show evolution of crustal volumes with $^{176}Lu/^{177}Hf = 0.015$, corresponding to the average continental crust.
B. Event signature curve. Source crustal residence time is the time from the separation from the Depleted Mantle to the crystallisation of the zircon. In this plot, an upward trend with decreasing age indicates juvenile input, while a downward trend implies reworking of older crust. The most pronounced juvenile input occurred during the Neoproterozoic events.

The ghosts of lithospheres past: Imaging a changing mantle in southern Africa

Geologists and geophysicists view the subcontinental lithospheric mantle (SCLM) in different ways at vastly different scales. Geologists can characterise the chemistry and physical state of relatively small volumes of the lithosphere in detail, usually at the scale of an outcrop or the xenoliths sampled in a volcanic eruption. These parameters also contain a time component since the material being studied has been removed from the mantle at a specific point in time. Geophysicists must sample the SCLM in the present using methods that are sensitive to both chemical and physical properties, but at scales many orders of magnitude larger. They then must invert their data to extract information on thermal and chemical properties of the SCLM. Neither of these approaches can show detailed, large-scale maps of the properties of the lithosphere through time, due to the paucity of available material to study (geology) and limitations on sensitivity in time and space (geophysics).

Southern Africa presents a unique opportunity to rectify this; kimberlite intrusions are both spatially and temporally widespread, and provide an abundance of xenolithic material sampled in different time slices. In the southwest corner of the Kaapvaal Craton a cluster of kimberlites from two different intrusive events provides material from the same volume of mantle and allows direct comparison of SCLM composition and structure across the craton margin in two time slices (Group II kimberlites at 115-130 Ma, Group I kimberlites at 85-105 Ma) (Fig. 1). Using methods developed at GEMOC and newly available data from collaborative work with De Beers Exploration we have been able to make more detailed images of the lithosphere than was previously possible with either geologic or geophysical methods, using garnet xenocrysts extracted from the kimberlites.

Geotherms can be derived from the Ni and Cr content of the garnets. Combining these data with the distribution of garnets depleted in Y defines a “chemical” lithosphere-asthenosphere boundary. This coincides with the depth where thermobarometry on xenoliths from other localities indicates a kink in the geotherm, and there is strong enrichment in incompatible trace elements (Fig. 2). The garnet thermobarometry provides a framework on which we can overlay other garnet chemical information, such as Ti content, and also information about the calculated “whole-rock” Al content or the calculated Mg# (Mg/(Mg+Fe)) of coexisting olivine.

We have projected these data onto the cross-section indicated in Figure 1 and produced a continuous surface with a gridding algorithm. Figure 3 is the resulting image for the Mg# of coexisting olivine. This parameter is a sensitive indicator of melt depletion (high Mg#) and metasomatic refertilisation

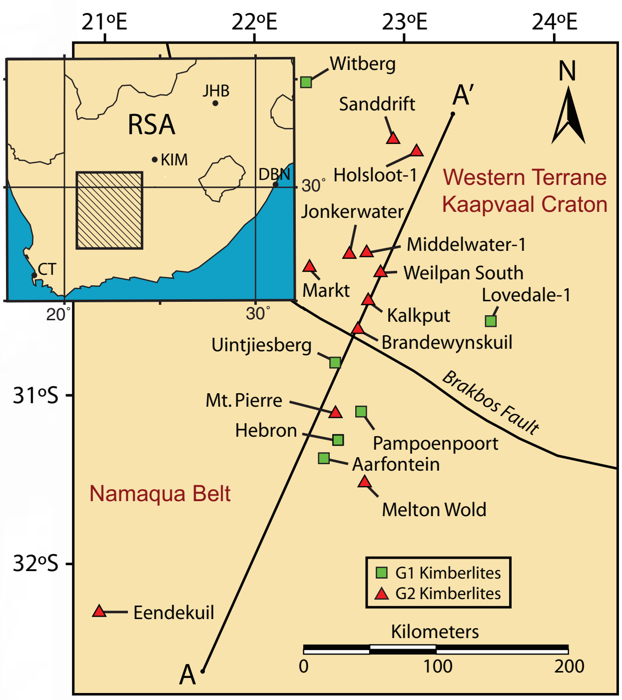

Figure 1. The study area: red triangles, older Group 2 kimberlites; green squares, younger Group 1 kimberlites. The Brakbos Fault is commonly taken as the boundary of the Kaapvaal Craton.

(low Mg#). There is marked change in the SCLM between the eruption of the Group 2 kimberlites (130-115 Ma) and the eruption of the Group 1 kimberlites (105-85 Ma), reflecting a thinning and overall re-enrichment of the depleted SCLM in this area. Both images indicate that the depleted cratonic SCLM extends at least 50 km SW of the Brakbos Fault, usually taken as the craton margin.

The Mg# of olivine has particular geophysical significance because seismic velocities are very sensitive to the Mg/Fe of olivine and other upper mantle minerals. By integration of all the chemical and physical data available through garnet chemistry and mineral elasticity data, it is possible to use data such as those in Fig. 3 to calculate models of seismic wave speeds. In areas with appropriate distribution of data both spatially and temporally, we can in essence make historical seismic images of the SCLM and its evolution through time. In some cases this can be done at higher resolutions than is currently possible with geophysical methods. Continuing collaboration with De Beers Exploration will further develop these methods and extend the models across the entire Kaapvaal Craton and its surrounding mobile belts.

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Funded by: iMURS, MUECRG (De Beers)

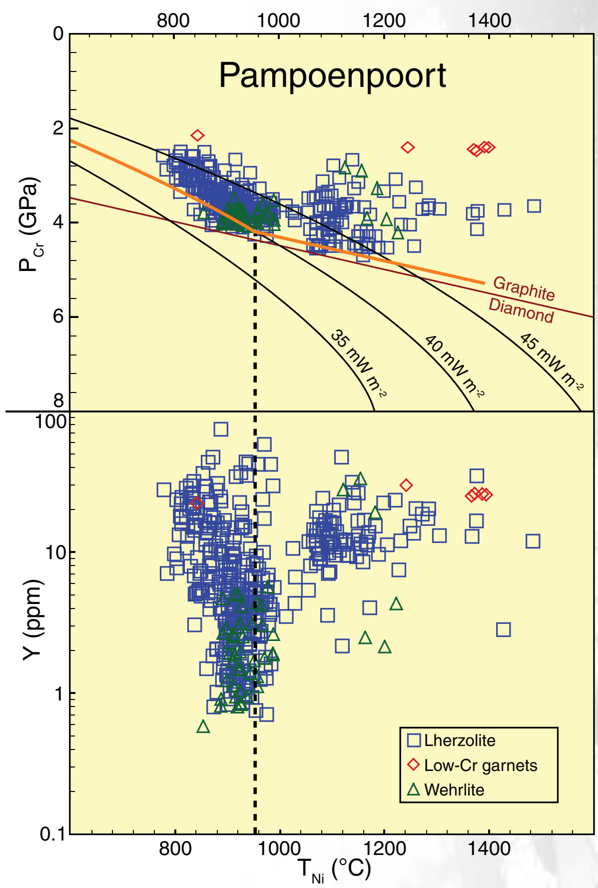

Figure 2. Derivation of the garnet geotherm for Group 1 kimberlite Pampoenpoort. A kink in the geotherm is placed at the lower limit of Y depletion, in line with observations on peridotite xenoliths.

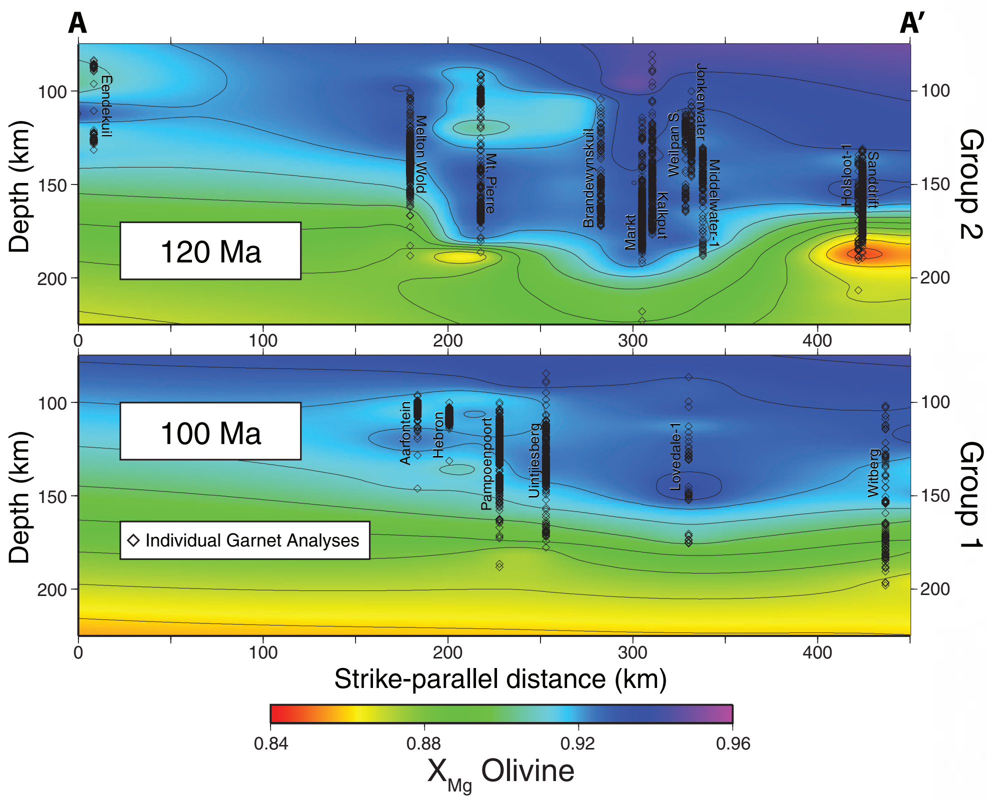

Figure 3. Vertical and lateral distribution of Mg# of olivine coexisting with Cr-garnets projected along section A-A' (Fig. 1) for two time slices.

Eclogites in the SCLM: The subduction myth

IT HAS BECOME CONVENTIONAL WISDOM that eclogite and garnet pyroxenite xenoliths derived from cratonic subcontinental lithospheric mantle (SCLM) represent fragments of subducted ocean floor, implying that the SCLM has grown by a lithosphere-stacking mechanism involving repeated shallow subduction beneath cratons. However, the implied behaviour of these ancient "slabs" is markedly different from what we observe in the modern Earth; seismic-tomography images clearly show slabs descending steeply to at least 660 km depth, rather than layering at shallow depths beneath the continents.

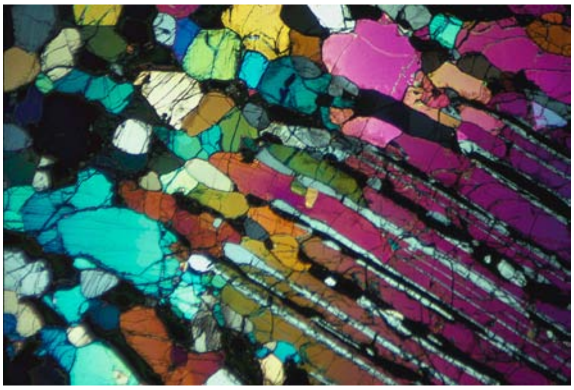

Figure 1. High-temperature clinopyroxenite (crystallised in the lithospheric mantle from mafic magma) exsolving lamellar garnet and orthopyroxene, and recrystallising to produce a websterite.

Xenolith suites in basalts from young terrains (Tectons: eg E. China, E. Australia, western USA, Hawaii) commonly contain garnet pyroxenites that display exsolution microstructures clearly reflecting their origin as high-T cumulates or crystallised melts (Fig. 1). Similar microstructures also occur in cratonic eclogites. The compositional field of Tecton garnet pyroxenites can be expressed by mixing of high-T, high-Al cpx ± opx ± gnt. This compositional field is coincident with that of nearly all cratonic eclogites (reconstructed from mineral compositions); both rock types are distinct in composition from clearly metabasaltic eclogites in HP/UHP metamorphic belts (Fig. 2). Many eclogites also have experienced episodes of metasomatism, making bulk compositions (especially trace element patterns) an unreliable guide to their origin.

Simultaneous solutions of cpx-gnt thermometers with the equations for xenolith-derived geotherms show that rather than being widely distributed in the SCLM as implied by lithosphere-stacking models, eclogites from many cratonic areas are concentrated in layers <20 km thick, co-spatial with a strong signature of metasomatism in the surrounding peridotites (Fig. 3). In many cases this combination of features defines a "lithosphere-asthenosphere boundary" marking the transition from depleted SCLM to more fertile underlying mantle. This pattern strongly

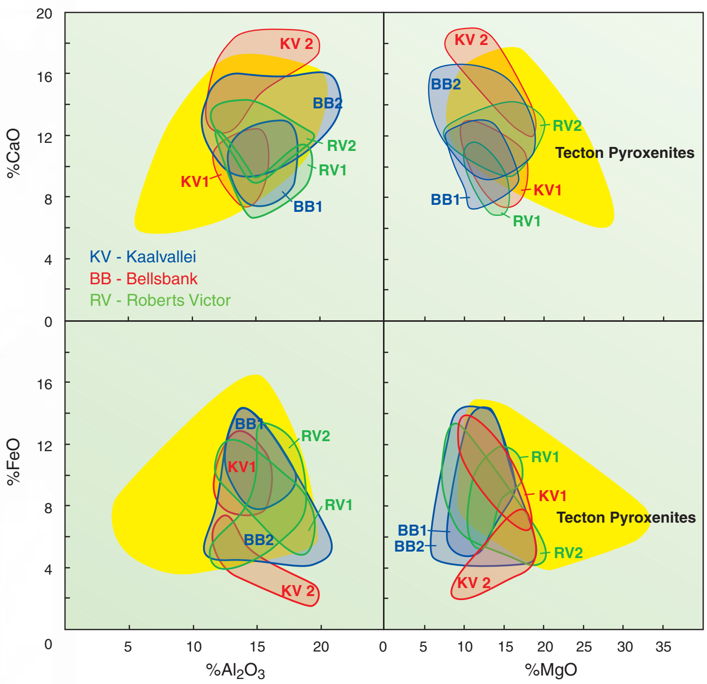

Figure 2. Compositions of cratonic eclogite suites, calculated from mineral chemistry assuming that gnt:cpx=1. Yellow shaded field encompasses data from whole-rock compositions for Phanerozoic garnet pyroxenite xenoliths in alkali basalts from SE Australia and Hawaii and pyroxenite dikes from European peridotite massifs.

suggests that the eclogites reflect the intrusion of asthenosphere-derived melts near compositional/rheological boundaries, causing metasomatism in their peridotite wall-rocks.

The strongest argument for a crustal origin for cratonic eclogites is the large spread in $\delta^{18}O$ observed in some suites; such fractionation is commonly thought to require a low-T origin. However, Mg isotopes in high-T peridotites show equally large fractionation even within single xenoliths (Pearson et al., 2006); significant isotopic fractionation clearly can take place at T >1000°C. SCLM eclogites commonly host diamonds with low-$\delta^{13}C$ carbon; this has been interpreted as biogenic in origin, but this model is not consistent with N-isotope data (Cartigny et al., 1998). The $\delta^{13}C$ variation can instead be explained by Rayleigh fractionation during redox reactions (Muroka et al., 2005). In framesites, the covariation of $\delta^{13}C$ in diamond and $\delta^{18}O$ in cogenetic silicates suggests that similar redox-related fractionation mechanisms are involved (Fig. 4); the O-isotopic signatures thus are not prima facie evidence of a shallow origin for SCLM eclogites. Eu anomalies in cratonic eclogites also have been presented as evidence of the previous presence, or fractionation, of plagioclase. However, similar anomalies are found in peridotitic phases, and may simply reflect redox processes during metasomatism.

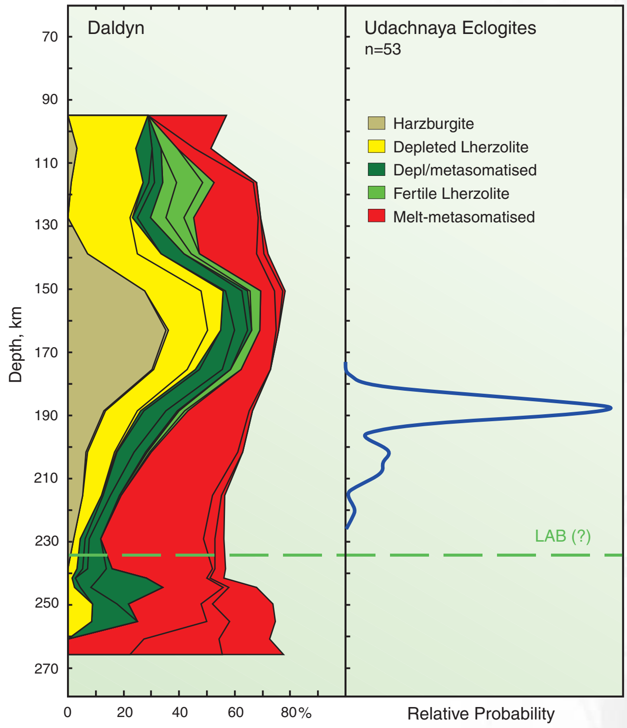

Figure 3. Distribution of eclogites in the SCLM beneath the Udachnaya kimberlite, Yakutia.

Some SCLM eclogites carry "crustal" radiogenic-isotope signatures – but so do many intraplate magmas. These signatures may reflect derivation of parental magmas from deeply subducted crust, rather than the direct emplacement of ocean floor into the SCLM. The cratonic eclogites, like the Tecton pyroxenites, may be telling us about the growth or erosion of the SCLM from below, through magmatic processes, rather than from the side, through shallow subduction.

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Funded by: ARC Discovery Project

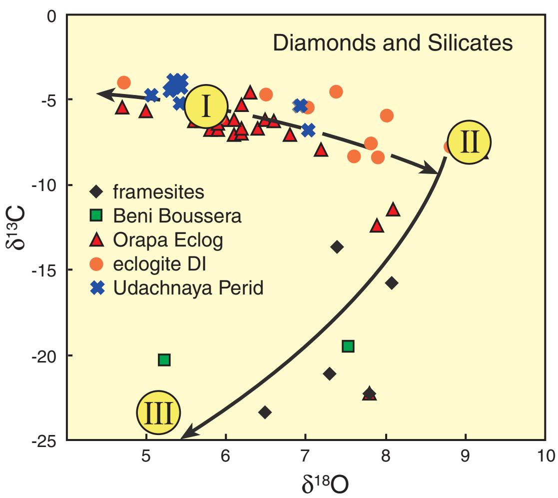


Figure 4. $\delta^{18}O$ of diamonds vs $\delta^{18}O$ in coexisting silicates.

Ancient mantle in modern plumes: B and Os in the Azores

THE DYNAMICS OF THE EARTH reflect its internal heat but the nature and time scales of mantle convection remain poorly constrained. Over the past decade tomography data have provided spectacular images of seismically fast material, associated with subducting plates. These are interpreted as the cool slabs descending through the warmer mantle, suggesting that the slabs can penetrate the 670 km discontinuity, continue into the deep mantle and pond at the core-mantle boundary. Conversely, a significant component of return flow is associated with mantle plumes; many of these, including the Azores, appear to rise from the core-mantle boundary (Fig. 1). These observations have generated a lot of interest in the possibility that subducted material is entrained in these plumes. These ideas can be independently tested by examining the composition of ocean island basalts (OIB) erupted above plumes. Radiogenic isotopes have long been employed in this search because of their potential to constrain the time scales of recycling. Many OIB have indeed been found to have signatures distinct from those of mid-ocean ridge basalts (MORB) that sample the uppermost mantle.

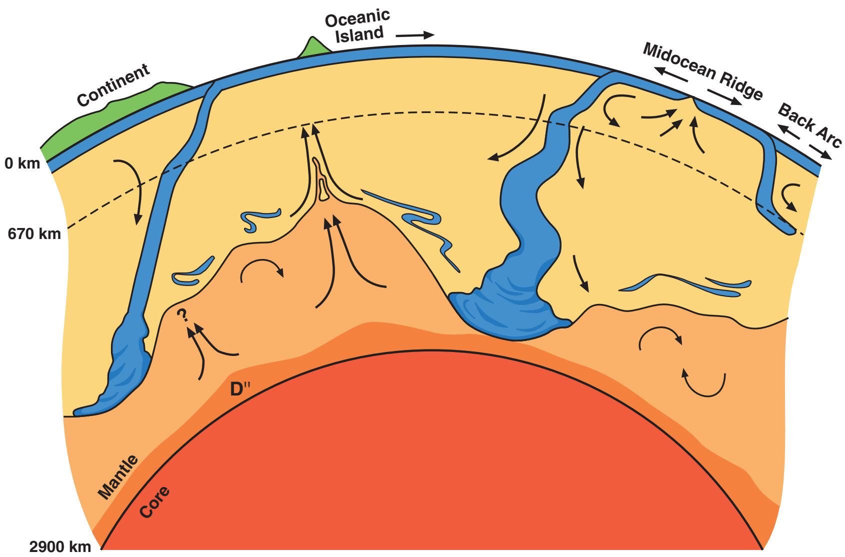


Figure 1. Cartoon of convecting mantle showing cold down-wellings (subducting slabs) in blue and hot upwellings from the core-mantle boundary (plumes) in orange. Kellogg et al., 1999.

However, although such signals undoubtedly reflect the time-integrated effects of fractionated parent-daughter element ratios, the age and extent of this fractionation can rarely be sorted out. Even if this is possible, the parent-daughter fractionation is not restricted to processes occurring near the Earth's surface and could instead reflect intra-mantle metasomatism. In contrast, the isotopes of light elements, such as O, B and Li, are commonly fractionated by low-temperature processes near the Earth's surface and significant variations in the stable isotope ratios of MORB and OIB could provide evidence for contributions from recycled material. However, the range of O and B isotope ratios observed in MORB and OIB is rather restricted and observed variations often are attributed to shallow assimilation of altered oceanic crust. Furthermore, stable isotopes cannot be used to constrain the time scales of recycling.

A recent study of basalts from the Azores islands (Fig. 2) has found high Nb/B ratios and a large range in $\delta^{11}B$ ratios, which provide compelling evidence for the recycling of materials that have undergone fractionation near the Earth's surface. Moreover, $\delta^{11}B$ is negatively correlated with $^{187}Os/^{188}Os$ ratios that extend to subchondritic values (Fig. 3). The low $^{187}Os/^{188}Os$ constrains the age of the high

Figure 2. Two of the Azores islands: (left) The Caldeira das Sete Cidades on São Miguel and (below) the Island of Pico, dominated by the stratovolcano, Pico Mountain.

Nb/B, ^{11}B-enriched end-member to be ≥ 2.5 Ga. This is inferred to be melt- and fluid-depleted lithospheric mantle from a subducted oceanic plate; other Azores basalts contain a contribution from ~ 3 Ga enriched basalts (Schaefer et al. 2002, *Nature 420, 304*). The simplest interpretation is that both components are derived from an Archean oceanic plate that was subducted into the deep mantle, where it was stored until thermal buoyancy caused it to rise beneath the Azores islands.

Contact: Simon Turner
Funded by: ARC Federation Fellowship

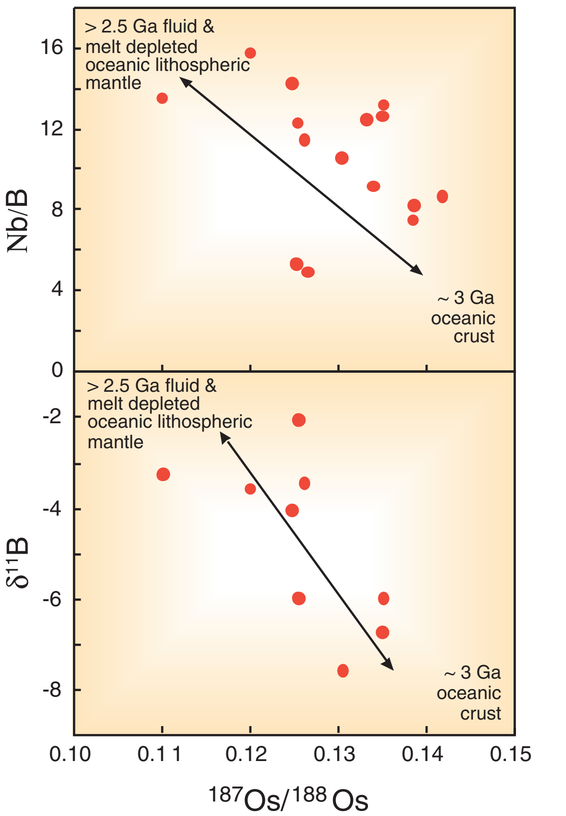


Figure 3. Variation of Os isotopes with other geochemical indices in the Azores (see text for discussion).

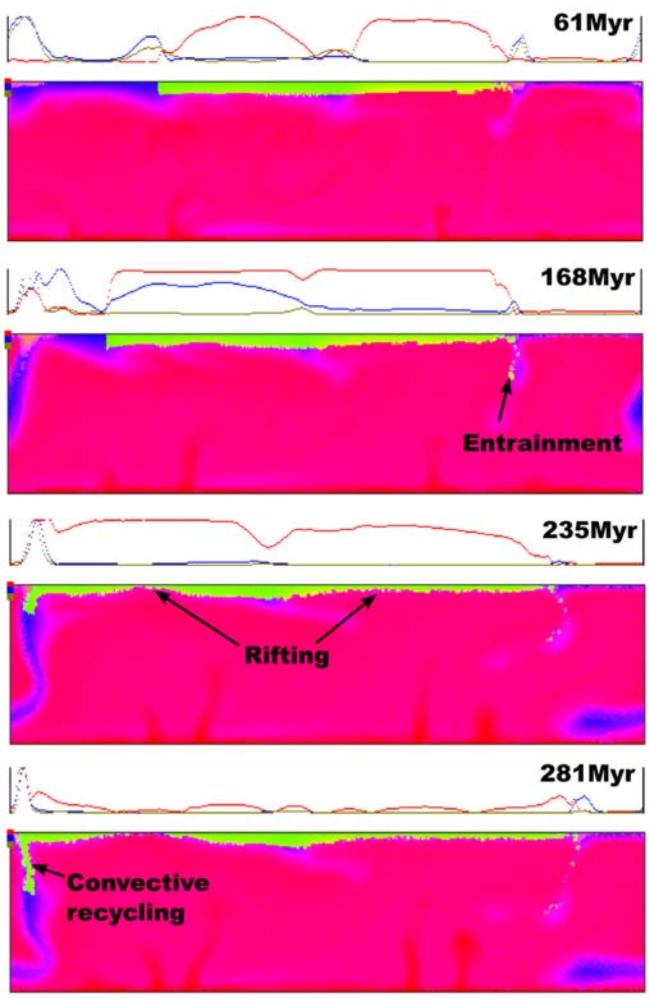
The tenacity of cratons: a low stress home environment?

THE CRATONIC REGIONS OF THE EARTH'S CONTINENTAL CRUST have avoided deformation for billions of years. This by itself is not remarkable – the surfaces of the Moon and Mars have avoided deformation for far longer. However, considering that the oceanic crust, representing nearly 70% of the Earth's surface, is recycled on a timescale of 100 Myr, and most continental regions are reworked over similar periods, then the survival of cratons becomes an enduring geophysical mystery.

Cratons themselves have a number of physical characteristics that may account for their strength. The crust of cratons overlies a thick, buoyant chemical lithosphere. Cratonic lithosphere exhibits extreme degrees of melt depletion, accounting for its buoyancy with respect to the mantle. The depletion also has led to very low water contents, imparting a potential 100-fold increase in viscosity compared to the asthenosphere. On top of that, cratons are cold, and their deep root regions are expected to be even more viscous and resilient as a result.

The problem arises when one tries to model cratons with these properties in a convecting mantle - they just aren't extreme enough. Buoyancy itself cannot impart strength and give rise to cratonic stability - buoyant continents either spread out under their own gravitational instability, get entrained bit-by-bit by downwelling mantle and subducting slabs, or at the least are grossly deformed by their dynamic environment. Previous mantle simulations have shown that viscosity *can* impart stability, but the high viscosities required are far beyond reasonable bounds for cratonic mantle. For plausible viscosity contrasts, the models tell us that cratons should have been heavily deformed, reworked, and even wholesale recycled under Archean mantle conditions.

Figure 1. The fate of buoyant lithosphere without any instrinsic strength in a strongly convecting Archean mantle. Despite its convective buoyancy, the lithosphere rifts in response to the regional stress regime and is partially recycled into the mantle (O'Neill et al. 2007).



And yet the cratons are still here. What factors give rise to their remarkable tenacity? Geodynamic simulations performed at GEMOC have explored these factors in detail, and have shed light on the survival of these economically important terranes. While most previous simulations have focused on the properties of cratons themselves, few have adequately addressed their dynamic environment - the convecting mantle.

Convection in the Earth differs from simple "box" convection simulations in some important ways. Firstly, strongly temperature-dependent viscosity, with brittle/plastic failure and strain-rate weakening, is needed to simulate plates - a condition met in some previous studies. Secondly, the Earth's mantle displays a strong variation in viscosity with depth, but this effect has not been incorporated in previous craton simulations. This strongly affects the dynamics of the mantle, and the surface stress regime. Thirdly, an endothermic phase change at 670 km hinders slab penetration into the lower mantle, strongly affecting mantle dynamics and its thermal evolution. It also gives rise to a curious phenomenon known as "mantle avalanches", where material piled up at 670 km periodically breaks through into the lower mantle, instigating a corresponding injection of hot material into the upper mantle. These violent episodes have been associated with crustal production in the past, but represent a highly destructive surface regime for existing cratons.

The main results of the new modelling show that realistic mantle viscosity structures cushion cratons from mantle dynamics; a low-viscosity asthenosphere partly decouples the surface plates from the mantle beneath, and a viscous lower mantle mitigates the stress extremes experienced by cratons during mantle avalanche events. Under the hotter mantle conditions of the past, however, two more effects conspire against the humble craton. Firstly, the velocity of mantle convection increases - this inevitably leads to a higher stress environment for cratons. Secondly, since the phase change at 670 km is endothermic, the layering is enhanced under hotter mantle conditions, and avalanches are more violent and spectacular. But a third mechanism, previously unrecognised, acts to save cratons from these destructive effects. Mantle viscosities are highly sensitive to temperature, and under hotter mantle conditions in the past, the drop in bulk mantle viscosities would be dramatic. This acts to minimise the stresses transferred to the surface plates, and thus to cratons. The modelling shows that the magnitude of this effect far outweighs the stress increase due to faster convection, and craton stability for billions of years is not paradoxical at all in these simulations, for reasonable cratonic properties (see *GEMOC Publication #479*).

Contacts: Craig O'Neill, Sue O'Reilly, Bill Griffin
Funded by: Macquarie University Research Fellowship

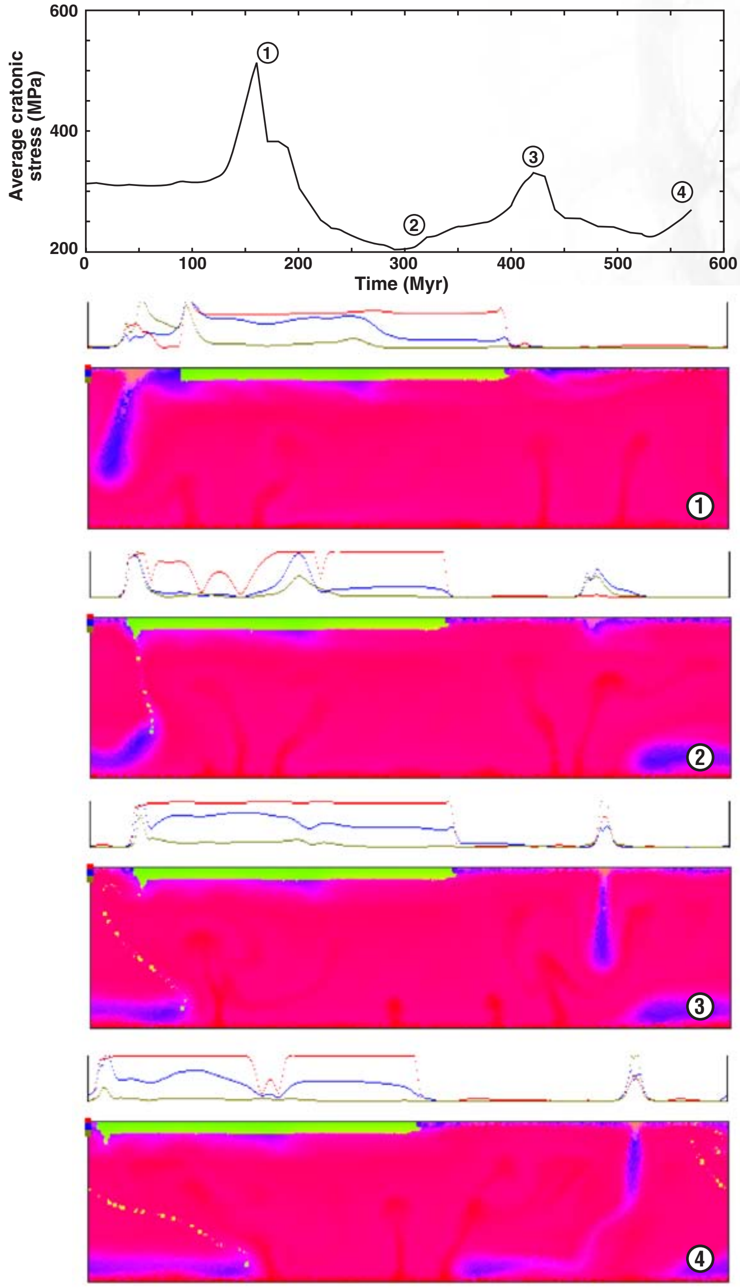


Figure 2. A stable craton with intrinsically strong roots resists tectonically violent mantle avalanches and wildly fluctuating regional stress, in part due to its physical properties, but also due to mild stresses of the 'warm bath' Archean mantle environment.

Teaching and training program

undergraduate




HIGHLIGHTS 2006

Curriculum Development

- The Department of Earth and Planetary Sciences continues to deliver units using our tailored problem-based learning (TPBL) model. GEOS116 Marine Geoscience and GEOS115 Earth Dynamics, Materials and the Environment have successfully used this innovative technique for a number of years and in 2006, this was extended to GEOS260 Marine Depositional Environments. This format is designed to encourage the students to become more active learners and to develop a range of generic skills. Workshops are completed as group work projects and the students are required to produce scientific reports based on the results of their investigations. Generic skills developed include teamwork, problem-solving, critical thinking and written and verbal communication. A series of lectures provide background to each problem. GEOS260 is now divided into 4 modules: Methods of Analysis,

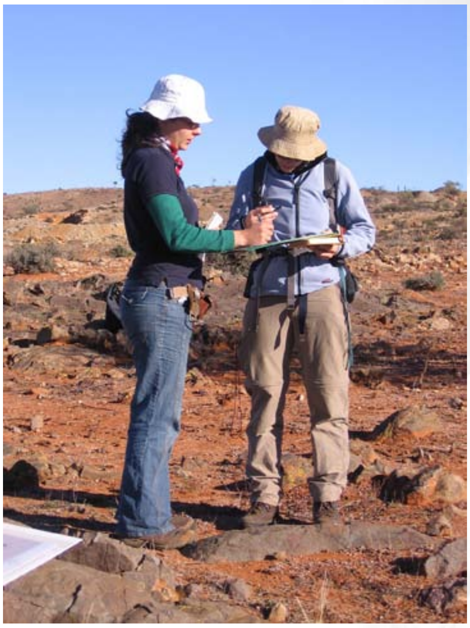
GEOS260 (Marine Depositional Environments) at the interface between old ones and recent ones.

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**

Ocean Island Volcanoes, Passive Margin Processes, and Deep Marine Processes. The last three modules each have an assessable research project that combines technical skills training and production of a report or poster. The students attend a field trip to gather data for the project within the Passive Margin Processes module.

- GEOS307 Field Geology and Mapping was run in Broken Hill in 2006 in conjunction with Sydney University. The combined field trip allowed the students from both departments to interact and having staff from both departments provided a broad range of expertise.
- Our units continue to use the portable computer facility, computer packages and web interfaces in Earth and Planetary Sciences for content and skills delivery. Both geology and geophysics units incorporate packages used by industry into classroom and field teaching. A large number of our units now utilise "i-lecture" recordings, which provide MP3 recordings of our live lectures through a secure web interface. These are teamed with Microsoft PowerPoint slides to provide immediate access to lectures for distance education students and a flexible learning option for internal students.



GEOS307 Field Geology and Mapping, Broken Hill.

Students in GEOS373: Volcanic Geology Fieldwork, exploring New Zealand's scenic volcanic environments.

Geophysics teaching progress 2006

- The advanced geophysics stream in the Bachelor of Science degree continued.
- The Bachelor of Technology in Exploration Geoscience has a Geophysics strand initiated in 1999, streamed from second year level (see flow sheet in *Appendix 6*).
- Use of an extensive pool of GPS units for undergraduate (and postgraduate) fieldwork continued.
- Extended implementation of new seismic, gravity, GPS and resistivity equipment for student field projects in exploration, groundwater, environmental and engineering geophysics.

GEOS316 Exploration Geophysics students undertaking a seismic survey using a sledge hammer as a seismic source.

- Equipment upgrades funded by Macquarie University over the last five years have resulted in an excellent array of new instrumentation. Acquisitions include:
- GEOMETRICS G856 Proton Precession Magnetometer
- GEOSOFT, MODELVISION, EMVISION, ERMAPPER, SeisImager, Maxwell and Reflexw software was either purchased or upgraded
- ABEM SAS4000 Resistivity System and an ABEM LUND system
- ASHTECH Z-Xtreme Differential GPS system
- DUALEM Frequency Domain EM System
- MALA Ground Penetrating Radar (GPR)

Unit Outcomes

Our units continue to attract new clientele to the geosciences, many of whom go on to further studies in this area. However, this is within an environment of a contracting pool of science undergraduates. Despite this, GEMOC core units at 100 level have maintained enrolment levels and our units at 200 and 300 level have seen increases in numbers. Reorganisation of course structures and acquisition of teaching infrastructure (computers, high-technology instruments, GIS units) have increased the visibility of geoscience and have resulted in the presentation of geoscience with an interdisciplinary and innovative approach using state-of-the-art technology and concepts.

Nicole Harb was awarded the University Medal for her 2006 honours work.

The following honours projects in GEMOC were completed 2006:

Nicole Harb: Fragmentation processes, depositional mechanisms and lithification of glassy fragmental rocks, Macquarie Island

The following honours projects are relevant to GEMOC in 2007:

Cara Danis: The 3D upper crustal structure of the Wongwibinda Complex, New England Fold Belt: a tilted block?

Peter Caffi: Fabric development and finite strain patterns in a metamorphic dome bounding shear zone, Dayman-Suckling Dome, Papuan Peninsula, Eastern PNG

Elizabeth Hoese: Investigation of Type 1 and Type 2 kimberlites from southern Africa

Teaching and training program

GEMOC honours

Sue O'Reilly and Nicole Harb at Nicole's graduation in April.

Teaching and training program

GEMOC postgraduate




June Chevet getting to know the locals on Kerguelen (see June's Research Highlight on p36-37).

GEMOC'S ACTIVE INTERNATIONAL EXCHANGE PROGRAM continued, with Weiqiang Li from Nanjing University (China) commencing in early 2006. June Chevet, as a part of a co-tutelle program with the University of Jean Monnet (St Etienne, France) undertook fieldwork in Kerguelen; Yoann Gréau and Véronique le Roux will commence PhD co-tutelle programs with the University of Montpellier (France).

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

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 Delpech (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)

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)

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)

Will Powell, Kelsie Dadd and Dick Flood at Will's graduation.

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) (see *Research Highlights*)

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)

Sue O'Reilly, Dave Apter (De Beers) and Alan Kobussen picking goodies from heavy-mineral concentrate at the Lace Mine, South Africa.

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

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)

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

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

Valeria Murgulov (PhD): Lithosphere evolution and metallogeny in the Georgetown Inlier and adjacent Tasman Fold Belt, North Queensland, Australia; *APA* (commenced 2003, submitted Nov. 2006)

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

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

Some of GEMOC's 2006/7 postgraduate students. Above: Jacques Batumike, John Caulfield, Alan Kobussen, Nenad Nikolic, Luke Milan, Stephen Craven and Weiqiang Li. Below: Véronique Le Roux, June Chevet, Cara Donnelly and Yoann Gréau.

commencing 2007

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

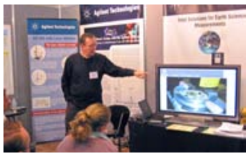
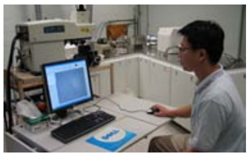
Cara Donnelly (PhD): Mantle xenoliths, kimberlites and related rocks of the Kuruman Kimberlite Province, Kaapvaal Craton, South Africa; *iMURS*

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*

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

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 being 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.

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

"The 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)

GEMOC's clean labs have separate areas for work with radioactive and (here) non-radioactive materials; both require special clothing to keep contamination down.

  - a Thermo Finnigan Triton TIMS (installed March 2005)
  - a Spectro XLAB2000 energy-dispersive XRF with rocker-furnace sample preparation equipment
  - a LECO RC412 H_2O-CO_2 analyser (delivered September 2003)
  - an Ortec Alpha Particle counter
  - a New Wave MicroMill
  - clean labs and sampling facilities provide infrastructure for ICPMS, XRF and isotopic analyses of small and/or low-level samples

- 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 Macquarie.

Alex Corgne and Laure Martin in the Experimental Petrology Lab.

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:

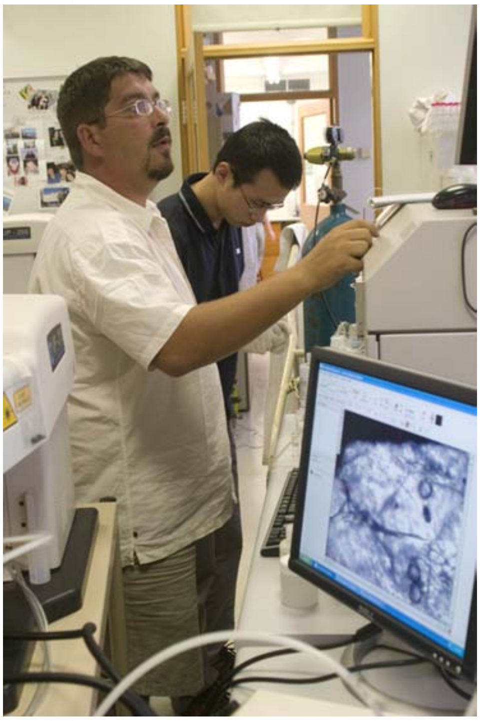
- The capability to image both major- and trace-element distribution in a sample, as an interpretive tool and as the basis for higher precision spot analysis of trace-element concentrations and isotopic ratios
- Co-registration of images and spot data from different instruments, and use of digitised images to locate spots with a precision of better than 5 µm
- 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

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



Olivier Alard and Weiqiang Li carrying out solution analysis on the Agilent ICPMS.

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.

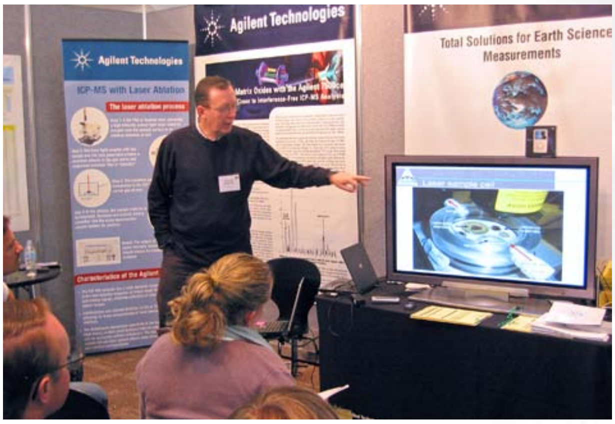
When fully developed, images from one instrument will be read into the computer of another instrument and used to guide the analysis. Major-element maps from EMP, or trace-element maps from the nuclear microprobe, can be linked directly to images from petrographic or cathodoluminescence microscopes,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

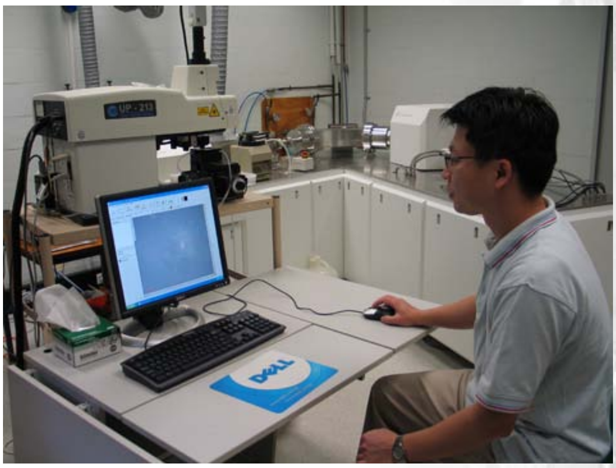
Laser Ablation ICPMS microprobe (LAM-ICPMS): The original GEMOC LAM was installed in December 1994 using a Perkin-Elmer ELAN 5100 ICPMS (later replaced by an ELAN 6000), attached to a UV laser ablation microprobe built for GEMOC by Memorial University, Newfoundland. In 1999 the ELAN 5100 ICPMS was replaced 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* analysis of transparent minerals on the 7500CS. Spatial resolution varies with the application, but typically is on the order of 30-40 µm. 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 by New Wave Research and AccessMQ.



Norm Pearson giving a workshop on laser-ablation ICPMS techniques at the Agilent product stand at the 16th Goldschmidt Conference, Melbourne.

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.

Kuo-Lung Wang measuring the Os-isotope composition of sulfides in xenoliths from Mongolia, using the LAM-MC-ICPMS.



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)

Dr Chuma Keswa visited to learn GEMOC's LAM-ICPMS techniques for use in the De Beers laboratories in Johannesburg.

- U-Pb geochronology of zircons from igneous and metamorphic rocks
- 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
- Sr isotope analysis of carbonates, feldspars, apatites and pyroxenes
- Pb isotope analysis of sulfides and silicates
- 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 diamonds

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 2006

1. Facility for Integrated Microanalysis

a. Electron Microprobe: During 2006 the SX50 continued to meet the imaging and analytical demands of the *TerraneChron*® 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 2006, the LAM laboratory produced large volumes of data for eight 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. *Over 7000 U-Pb analyses of zircons were carried out,* related to projects (including *TerraneChron*® applications) in Antarctica, New Zealand, Scandinavia, Chile, Tibet, China, Italy, southern Africa 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*® application (see *Research Highlights*), coupled with the demand for *in situ* Re-Os analysis and stable isotope analysis, led to severe competition for instrument time on the MC-ICPMS. An order was placed early in 2003 for a second instrument, funded by the DEST infrastructure grant, and this instrument (Nu034) was installed in November 2003. Nu034 is equipped with a retardation filter and high-resolution capability, specifically for U-series analysis. In 2004-2005 methods for the analysis of other isotopic systems (Re-Os, Sm-Nd, Lu-Hf, Pb) were transferred to Nu034, and considerable time was spent in doing comparisons of the performance of Nu005 and Nu034 with respect to these isotopic systems.

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 isotopes. These activities continued in 2006 along with a renewed 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. A major project continued on the isotopic composition of Cu and Ni in sulfides and whole rocks from major ore bodies, in a collaboration with Anglo American. Major applications during 2006 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, New Zealand, Scandinavia, Chile, Tibet, China, Italy, southern Africa and Australia. We carried out Re-Os studies on xenoliths from western USA, South Africa, Vietnam, eastern China and Taiwan, Ethiopia, Siberia and Sicily.

d. Scanning Nuclear Microprobe: The closure of the CSIRO North Ryde site forced the shutdown of the SNMP in late 2003. The beam line was dismantled, and re-installed on the University of Melbourne accelerator during 2004. It is in operation for 2-3 days/week.

Yakov Weiss (Hebrew University of Jerusalem, Israel) and Bill Griffin using the LAM-ICPMS to analyse the trace-element composition of diamonds for Yakov's PhD project.

e. 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.

Valeria Murgulov using the Agilent 7500 for U/Pb dating of zircons with the help of the GLITTER software.

f. Software: GLITTER (GEMOC Laser ICPMS Total Trace Element Reduction) software is our on-line interactive program for quantitative trace element 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. New Wave Research market the software together with their laser microprobe equipment; GEMOC provides customer service and backup through AccessMQ (formerly Macquarie Research Limited). During 2006 a further 12 copies of GLITTER were sold bringing the total number in use to more than 100 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, and this version is now provided to all new Glitter purchases and is available as an upgrade to existing installations. Will Powell continued in his role in GLITTER technical support and software development through 2006.

"During 2006 a further 12 copies of GLITTER were sold bringing the total number in use to more than 100 worldwide, in forensics and materials science, as well as earth science applications"

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, continued to produce high-quality major- and trace-element data. During 2006 over 1200 samples were analysed for major and trace elements, providing data to student theses, in-house research projects, and industry collaborators. The number of samples analysed in 2006 was lower than in previous years due to a 3-month downtime while the detector was refurbished.

A LECO RC412 H_2O-CO_2 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 (eg ^{87}Rb on ^{87}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 for the dissolution of rocks, separation of Sr, Nd, Hf and Pb, and isotopic analysis using the MC-ICPMS in solution mode provides precise whole-rock isotopic analyses that are faster, simpler and ultimately cheaper than those obtained by traditional methods.

During 2006 further developments were made in the separation of 'non-traditional' isotopes, with significant improvements in the separation of Cu and Ni isotopes. 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 ^{210}Pb.

5. Centre for Isotope Studies (CIS)

The Centre for Isotope Studies (CIS) was a consortium operated by the geoscience departments of the New South Wales Universities, CSIRO Exploration and Mining, and Petroleum Resources using jointly-purchased mass-spectrometers housed at the CSIRO in North Ryde. Dr Anita Andrew developed techniques for C-isotope analysis of diamonds using very small sample sizes (0.1 mg), which allows analysis of microdiamonds or multiple fragments of different zones of small stones. This is now an essential part of GEMOC capabilities. CSIRO's North Ryde site was closed in 2004, but the laboratories are still in operation. A plan is in place for Dr Andrew to move the stable isotope facilities to GEMOC, where they will form a self-funded entity, and GEMOC will continue to benefit from this collaboration.

Industry interaction




INDUSTRY INTERACTION, TECHNOLOGY TRANSFER AND COMMERCIALISATION PROGRAM

GEMOC 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 consultancies 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 both through New Wave Research and 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
- 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 2006

10 Industry Reports were completed for collaborative industry projects.

TerraneChron® 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.

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 2006. Dr Graham Begg spent significant research time at GEMOC through 2006 as part of the close collaborative working pattern for this project.

The 'Diamond Mafia' - Simon Shee (De Beers Australia), Bill Griffin, Debora Araujo, Suzy Elhlou, Tin Tin Win and Yakov Weiss (Hebrew University of Jerusalem, Israel).

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 application on Diamond Fingerprinting.

A continuing collaborative research relationship with New South Wales Geological Survey is applying *TerraneChron*® 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 2006, following the previous successful project with WMC on Continental Flood Basalts related to Ni and PGE deposits.

The alliance with PIRSA (Primary Industries and Resources, South Australia) applying *TerraneChron*® to collaborative projects has expanded.

Industry visitors spent varying periods at GEMOC in 2006 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.

Norm Pearson, Alan Kobussen, Dave Apter, Bill Griffin, Sue O'Reilly and Gaby Similane with (literally) a tonne of samples collected to study the deep structure of the Kaapvaal Craton (see Research Highlights pp. 40-41).

CURRENT INDUSTRY-FUNDED COLLABORATIVE RESEARCH PROJECTS

THESE ARE BRIEF DESCRIPTIONS of current GEMOC projects that have direct cash support from industry and timeframes of at least one year. Projects are both national and global.

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. *TerraneChron®* (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.

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. Innovations in imaging the deep Earth beneath continents, and in numerical modelling, will maintain our high international profile in research relevant to National Priority 1.6 (Developing Deep Earth Resources). Unique geological maps of regions down to 250 km will make the composition of deep Earth regions newly accessible to geoscientists and all potential endusers.**

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.

Active projects in 2006:

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 will be constrained by comparing *TerraneChron*® analysis of zircons from modern streams, and the kimberlites themselves, with existing Re-Os ages for mantle rocks.

Just a few of the ecligite and peridotite xenoliths collected to study the deep structure of the Kaapvaal Craton (see Research Highlight pp. 40-41).

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 will provide fundamental insights into Earth processes and a basis for the targeting of mineral exploration. We will integrate mantle petrology, tectonic synthesis and geophysical analysis to produce the first maps of the architecture of the continental lithosphere, to depths of ca 250 km. These maps will provide a unique perspective on global dynamics and continental evolution, and on the relationships between lithosphere domains and large-scale mineralisation.

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, will be 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).

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 will test 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.

Developing a geochronological framework for the Gawler Craton, South Australia

Supported by a matching Macquarie University Collaborative grant (2004-2005)

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

Summary: The aim of the project is to supply a geochronological framework for the evolution of the Gawler Craton of South Australia, by dating major Archean and Proterozoic magmatic and tectonic events across the Craton. At present, the geochronology of this large region is poorly known, and this is one main reason why the minerals industry is choosing better-known regions to explore. The development of a better geochronological base will support the industry partner's goal of establishing an integrated tectonic model as an aid to mineral exploration, and provide new insights into crustal evolution.

Application of metal isotopes in exploration for magmatic nickel and volcanic-hosted copper deposits

Supported by a matching Macquarie University Collaborative grant (2004-2005)

Industry Collaborator: Anglo-American PLC

Summary: The major aim is to study, for the first time, the isotope geochemistry of Ni and Pd in a magmatic nickel deposit. Cu and Fe isotopic studies will also be carried out on a volcanic-hosted copper deposit. The aims are to determine whether isotopic data for commodity metals can be used to discriminate between barren and fertile host rocks and whether these isotopic ratios can provide vectors to ore within a mineralised system. The expected outcomes are development of new analytical methodologies and new isotopic exploration tools for blind ore deposits, which could be adopted by the Australian mineral exploration industry.

Improving mineral exploration performance by superior management of risk, uncertainty and value

Supported by Macquarie University Industry Collaborative Grant

Industry Sponsors: BHP Billiton, Codelco, Geoinformatics Exploration, Gold Fields, Jackaroo Drill Fund, Newmont, Placer Dome, Teck Cominco, WMC Resources.

Summary: Mineral exploration performance has deteriorated significantly over the past 15-20 years, especially with respect to the rate and cost of the large, 'greenfields' discoveries that generate so much value for the industry and underpin its future resource base. This research project is analysing past industry performance to identify opportunities for improvement, building probabilistic models of the mineral exploration business to provide a better decision framework, investigating the role of the high natural uncertainty and complexity on decision making, and developing a range of tools to improve risk and value management. The project involves collaboration between geoscientists, statisticians, psychologists and business management across the university.

Mechanisms of PGE fractionation and concentration in mafic and ultramafic melts

Supported by: AMIRA and MERIWA
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.

GEMOC's international links




BACKGROUND

GEMOC HAS STRONG INTERNATIONAL LINKS and these broadened through 2006. Active links include funded projects and substantial collaborative programs in France, Norway, Germany, United Kingdom, Canada, USA, Taiwan, Italy, South Africa, China, Brazil, Japan, Thailand and the former USSR.

EXAMPLES OF PROJECTS IN ASIA

In the petrified forest at the China University of Geosciences at Wuhan: L-R, Ming Zhang, Sue O'Reilly, Chun-Mei Yu and Jianping Zhang.

- terrane analysis and lithosphere structure in southeastern China
- crust-mantle interaction in southeastern China: the origin of the Yanshanian Granites and related rocks
- crustal evolution and mantle modification in the North China Craton
- trace element and isotopic characteristics of zircon as indicators of granitoid magma evolution
- evolution of the lithosphere in northwestern China (Tienshan Mountains in Xinjian)
- metallogenesis of southeastern China
- diamond exploration, tectonism, and geophysics of the lithosphere, Siberia and East Asia
- mantle terranes, tectonic analysis and interpretation of seismic tomography, Siberia
- lithosphere extension and geodynamic processes in east Asia (including the Taiwan region and Tibet)
- terranes and tectonism in the Altaids

FUNDED COLLABORATIVE PROJECTS COMMENCED OR ONGOING IN 2006 INCLUDE:

- The time scales of magmatic and erosional cycles, with Professor C. Hawkesworth (Bristol University), Dr M. Reagan (University of Iowa) and Dr J. Kirchner (University of California).
- The nature of lithosphere extension in the Taiwan region and implications for geodynamics in eastern China, with Professor S-L Chung, National University of Taiwan, and Dr Kuo-Lung Wang (Macquarie University Research Fellow).

- *TerraneChron*® study to unravel the timing and tectonic history of regions in Tibet was initiated as a collaborative program with the National University of Taiwan, and has expanded to include collaboration with Nanjing University.
- Collaboration with colleagues at the University of Jean Monnet, St Etienne, including Professor Jean-Yves Cottin and Dr Bertrand Moine (with reciprocal funding from both sides). 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. A field trip to Kerguelen was arranged by the France collaborators in 2006 and involved June Chevet, a GEMOC-Jean Monnet co-tutelle PhD student.

Visit to the China University of Geosciences at Wuhan where we negotiated a formal agreement for co-badged PhD programs.

- The age of the Earth's core as estimated from ^{182}Hf-^{182}W and ^{238,235}U-^{206,207}Pb chronometers, a collaborative project with Professsor A. Halliday (University of Oxford).
- 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.
- Trace-element signatures of diamonds, with applications to the origin of diamonds, exploration models and forensics: a collaborative project with Rio Tinto.
- 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 WMC and BHP Billiton.
- 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. Professor Coltorti, Dr Costanza Bonadiman and Dr Barbara Faccini from the University of Ferrara visited GEMOC in 2006, supported by a European Union Grant. Funding from Italy was obtained for a GEMOC-Ferrara Workshop to be held at the University of Ferrara in 2007 (http://www.geoitalia.org/index.php?action=doc_detail&doc_id=676&folder_id=67).
- 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 and sponsored visits to GEMOC by Professors Xisheng Xu, Dr Xiaolei Wang and Dr Hu Xiumian in 2006.
- Studies with Professor Jianping Zheng (China University of Geosciences, Wuhan) on the evolution of the lithosphere beneath several parts of China, and the UHP metamorphism of Dabie-Sulu peridotites.

Bill Griffin, Simon Shee, Yakov Weiss and Debora Araujo talk diamonds.

- Studies commenced 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.
- 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*® analysis of Proterozoic terrains in Africa, North America and Europe, with WMC Resources, BHP-Billiton and several other mineral-exploration companies.

Dr Maitha S. Al-Shams (3rd from left) and Mr Ashraf Shad (left), visited GEMOC from the United Arab Emirates University to formulate collaborative research with GEMOC.

- Tectonic domains in southern Norway and Mozambique using *TerraneChron*®, with Professor T. Andersen (University of Oslo) and Dr B. Bingen (Norwegian Geological Survey).
- Age and magma sources of Chilean Cu-porphyries, with Codelco (Chile) and the CSIRO Division of Exploration and Mining (Perth)
- A new MOU with the United Arab Emirates University was signed off in early 2006, opening the way for funded collaborative projects.

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

WAS THE FUNDING STRATEGY FOR GEMOC CONTINUATION (AFTER COMMONWEALTH CENTRE FUNDING CEASED) SUCCESSFUL?

GEMOC'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:

- Macquarie University Postgraduate Scholarships for Australian and international students
- ARC Discovery and Linkage successes
- DEST Systemic Infrastructure Initiative Grant ($5.125 million) for 2002-2004
- Award of two Federation Fellowships (Professors Simon Turner and Bernard Wood)
- Industry funding has increased through substantial collaborative ventures
- 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
- 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
- Postgraduate funding strategy exceeded goals
- Strategy for equipment and analytical funding exceeded goals

Macquarie University has been supportive in all areas including cash, in-kind and space guarantees, and in policy support. A new initiative in 2006 by the new Vice-Chancellor has recognised GEMOC as one of five CoREs (Concentrations of Research Excellence) and strategies are being planned for significant support and expansion.

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:

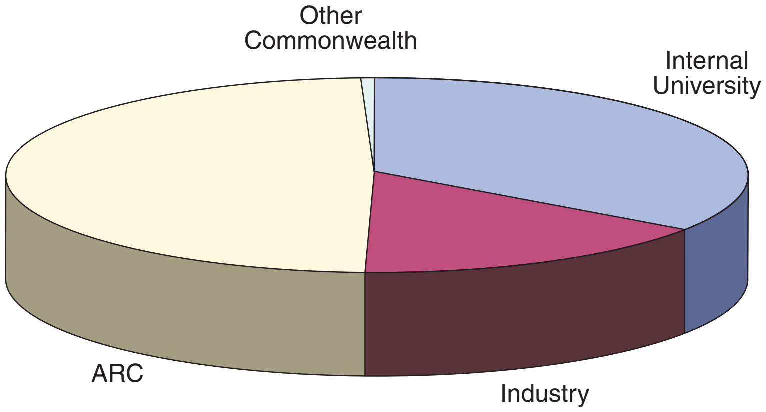
- User-pays system for running, maintenance and development costs
- University annual contributions through competitive schemes and capital equipment allocations
- Annual contribution from the Department of Earth and Planetary Sciences

- Macquarie University'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
- 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
- Industry capital investment in return for access equity, negotiated intellectual property and collaborative rates

GEMOC INCOME 2006

This is a summary of 2006 income. A full, audited statement of detailed expenditure and income is prepared by Macquarie University. *No in-kind support is included here.*

	$K
ARC	
Discovery (including Fellowships), Linkage (Project and International), Federation Fellowships	1,766.0
OTHER COMMONWEALTH	
Postgraduate awards	19.2
INDUSTRY	
Collaborative Research grants (MUECRG industry components and direct industry)	223.0
Collaborative and commercial (GLITTER) through AccessMQ	350.1
INTERNAL UNIVERSITY	
GAU maintenance (Department)	30.0
Internal competitive schemes	
Macquarie Fellowships	155.6
Matching to ARC schemes	348.4
Research grants	157.6
Postgraduate awards	383.9
Postgraduate research grants	8.0
Infrastructure (RIBG)	32.0
Capital Equipment	107.1
TOTAL	3,580.9



PIE-CHART OF INCOME SOURCES 2006

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 2006/2007

MACQUARIE UNIVERSITY

Department of Earth and Planetary Sciences

Academic and GEMOC Managerial Staff (Teaching and Research)

Dr Kelsie Dadd (Physical vulcanology, geochemistry, tectonics)

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

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)

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

Dr Norman Pearson (Manager, GAU)

Professor Simon Turner (Isotopic Geochemistry)

Professor Bernard Wood (Experimental Petrology)

Research Staff

Dr Olivier Alard

Dr Debora Araujo

Dr Elena Belousova

Dr Alex Corgne

Dr Anthony Dosseto

Dr Kevin Grant

Emeritus Professor Trevor Green

Dr Heather Handley

Dr Kierran Maher

Dr Vladimir Malkovets

Dr Laure Martin

Dr Sune Nielsen

Dr Lev Natapov

Dr Craig O'Neill

Emeritus Professor John Veevers

Emeritus Professor Ron Vernon

Dr Kuo-Lung Wang

Dr Helen Williams

Dr Ming Zhang

Professional Staff

Ms Manal Bebbington (rock preparation)

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)

Ms Maureen McMahon (Research Officer)

Mrs Carol McMahon (Administrator)

Dr Norman Pearson (Manager, GAU)

Dr William Powell (Research Officer)

Dr Ayesha Saeed (Geochemist)

Mr Peter Wieland (Geochemist)

Ms Tin Tin Win (Geochemist)

Adjunct Professors

Professor Bruce Chappell (Granite petrogenesis, geochemistry)

Professor Mike Etheridge

Dr Richard Glen

Professor W.L. Griffin

Dr Jingfeng Guo

Dr John Hronsky (BHP-Billiton)

Professor Else-Ragnhild Neumann

Professor Xisheng Xu

Visiting Fellows

Associate Professor Ian Metcalfe (Tectonics, Asian terrain reconstructions, Gondwana breakup)

Dr Hans-Rudolf Kuhn

Honorary Associates

Dr John Adam

Professor Tom Andersen

Dr Kari Anderson

Dr Anita Andrew

Dr Sonja Aulbach

Dr E.V.S.S.K. Babu

Dr Graham Begg

Dr Kim Berlo

Dr Yerraguntia Bhaskar Rao

Dr Phillip L. Blevin

Dr Rosa Maria Bomparola

Professor Hannes Brueckner

Dr Robert Bultitude

Dr Gilles Chazot

Professor Massimo Coltorti

Professor Kent Condie

Dr Jean-Yves Cottin

Dr Karsten Gohl

Dr Michel Grégoire

Dr Bin Guo

Dr Hu Xiumian

Dr Bram Janse

Dr Felix Kaminsky

Dr Oliver Kreuzer

Dr Bertrand Moine

Dr Geoff Nichols

Dr Mark C. Pirlo

Dr Yvette Poudjom Djomani

Dr Peter Robinson

Dr Sonal Rege

Dr Chris Ryan

Dr Bruce Schaefer

Dr Stirling Shaw

Dr Simon Shee

Dr Zdislav Spetsius

Dr Nancy van Wagoner

Dr Steve Walters

Dr Kuo-Lung Wang

Professor Xiang Wang

Mr Bruce Wyatt

Ms Chunmei Yu

Professor Jin-Hai Yu

Professor Jianping Zheng

FORMAL COLLABORATORS

University of Wollongong

Professor Allan Chivas (DEST Systemic Infrastructure partner)

Monash University

Dr Bruce Schaefer (LIEF and Research partner)

University of Newcastle and James Cook University

Professor W. Collins (DEST Systemic Infrastructure partner)

University of Sydney

Dr G. Clarke (DEST Systemic Infrastructure partner)

Dr Dietmar Muller

University of Western Sydney

Professor Peter Williams (DEST Systemic Infrastructure partner)

Australian National University (Research School of Earth Sciences)

Professor Geoff Davies

Professor Brian Kennett

Professor Gordon Lister

Professor Hugh O'Neill

University of Western Australia

Dr Marco Fiorentini

GA

Dr L. Wyborn (Crustal evolution, metallogeny through time, implementation of GPS/GIS)

PIRSA (South Australian Geological Survey)

Dr Anthony Reid

Dr Justin Gum

OTHER COLLABORATORS ON PROJECT BASIS

Dr Bernard Bingen (Geological Survey of Norway, Trondheim)

Professor J.-L. Bodinier (Universitè Montpellier, France)

Professor Chen-Hong Chen, (National Taiwan University)

Professor Sun-Lin Chung (National Taiwan University)

Dr Yuriy Erinchek (VSEGEI)

Professor Weiming Fan (Resource and Environment Department, Chinese Academy of Sciences)

Dr Marie-Christine Gerbe (Université Jean Monnet, St Etienne)

Dr J.-P. Lorand (Museum National d'Histoire Naturelle)

Dr Patrice Rey (University of Sydney)

Dr Csaba Szabo (Eotvos University, Budapest)

Professor O.T. Tobisch (University of California, Santa Cruz)

Professor P. F. Williams (University of New Brunswick)

Professor Yuan Xuecheng (China Geological Survey)

Professor Zhou Xinmin (Nanjing University)

Technology Partners

Agilent Technologies (Hewlett Packard)

New Wave Research

Spectro Instruments

Nu Instruments

Appendix 2: Publications 2006/2007

A full list of GEMOC Publications is available at http://www.es.mq.edu.au/GEMOC/

385. **Griffin, W.L., Belousova, E., Walters, S.G and O'Reilly, S.Y.** 2006. Archaean and Proterozoic crustal evolution in the Eastern Succession of the Mt Isa district, Australia: U-Pb and Hf-isotope studies of detrital zircons. *Australian Journal of Earth Sciences, (Mt Isa Special Volume), 53, 125-149.*

402. **Yu, J., O'Reilly, S.Y., Xu X. and Wang, R.** 2006. Element diffusion ability in metasomatic agents and its effect on chemical characteristics of metasomatized peridotites. *Science in China Series D: Earth Sciences, 49, 926-937.*

406. **Belousova, E.A., Griffin, W.L. and O'Reilly, S.Y.** 2006. Zircon crystal morphology, trace element signatures and Hf isotope composition as a tool for petrogenetic modelling: examples from eastern Australian granitoids. *Journal of Petrology, 47, 329-353.*

408. **Pearson, N.J., Griffin, W.L., Alard, O. and O'Reilly, S.Y.** 2006. The isotopic composition of magnesium in mantle olivine: Records of depletion and metasomatism. *Chemical Geology, 226, 115-133.*

409. **O'Reilly, S.Y. and Griffin, W.L.** 2006. Imaging global chemical and thermal heterogeneity in the subcontinental lithospheric mantle with garnets and xenoliths: Geophysical implications. *Tectonophysics, 416, 289-309.*

410. **Kaminsky, F.V., Zakharchenko, O.D., Khachatryan, G.K., Griffin, W.L. and Dominic M. Der. Channer.** 2006. Diamond from the Los Coquitos area, Bolivar State, Venezuela. *The Canadian Mineralogist, 44, 323-340.*

415. **Yu, J.-H., O'Reilly, S.Y., Zhang, M., Griffin, W.L. and Xu. X.** 2006. Roles of melting and metasomatism in the formation of the lithospheric mantle beneath the Leizhou Peninsula, South China. *Journal of Petrology, 47, 355-383.*

417. **Veevers, J.J, Belousova, E.A., Saeed, A., Sircombe, K., Cooper, A.F. and Read, S.E.** 2006. Pan-Gondwanaland detrital zircons from Australia analysed for Hf-isotopes and trace elements reflect an ice-covered Antarctic provenance of 700-500 Ma age, TDM of 2.0-1.0 Ga, and alkaline affinity. *Earth-Science Reviews, 76, 135-174.*

418. **Veevers J.J.** 2006. Updated Gondwana (Permian–Cretaceous) earth history of Australia. *Gondwana Research, 9, 231-260.*

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, 1-4, 132-147.*

421. **Zheng, J., Griffin, W.L., O'Reilly, S.Y., Zhang, M. and Pearson, N.J.** 2006. Granulite xenoliths and their zircons, Tuoyun, NW China: Insights into southwestern Tianshan lower crust. *Precambrian Research, 145, 159-181.*

422. **Zheng, J., Griffin, W.L., O'Reilly, S.Y., Zhang, M., Pearson, N.J. and Pan, Y.** 2006. Widespread Archean basement beneath the Yangtze craton. *Geology, 34, 417-420.*

423. **Deen, T., Griffin, W.L., Begg, G., O'Reilly, S.Y., Natapov, L.M. and Hronsky, J.** 2006. Thermal and compositional structure of the subcontinental lithospheric mantle: Derivation from shear-wave seismic tomography. *Geochemistry, Geophysics and Geosystems, 7, Q07003, doi:10.1029/2005GC001120.*

424. **Zheng, J., Griffin, W.L., O'Reilly, S.Y., Zhang, M., Pearson, N.J. and Luo, Z.** 2006. The lithospheric mantle beneath the southwestern Tianshan area, northwest China. *Contributions to Mineralogy and Petrology, 151, 457-479.*

425. **Nielsen, S.G., Rehkämper, M. and Halliday, A.N.** 2006. Large thallium isotopic variations in iron meteorites and evidence for lead-205 in the early solar system. *Geochimica et Cosmochimica Acta, 70, 2643-2657.*

426. **Beyer, E., Griffin, W.L. and O'Reilly, S.Y.** 2006. Transformation of Archean lithospheric mantle by refertilisation: Evidence from exposed peridotites in the Western Gneiss Region, Norway. *Journal of Petrology, 47, 1611-1636.*

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.*

428. **Griffin, W.L., Pearson, N.J., Belousova, E.A. and Saeed, A.** 2006. Comment: Hf-isotope heterogeneity in zircon 91500. *Chemical Geology, 233, 358-363.*

429. **Adam, J. and Green, T.** 2006. Trace element partitioning between mica- and amphibole-bearing garnet lherzolite and hydrous basanitic melt: 1. Experimental results and the investigation of controls on partitioning behaviour. *Contributions to Mineralogy and Petrology, 152, 1-17.*

430. **McMahon, K.L. and Lackie, M.A.** 2006. Seismic reflection studies of the Amery Ice Shelf, East Antarctica: delineating meteoric and marine ice. *Geophysical Journal International, 166, 757-766.*

431. **Zheng, J., Griffin, W.L., O'Reilly, S.Y., Yang, J.S. and Zhang, R.Y.** 2006. A refractory mantle protolith in younger continental crust, east-central China: Age and composition of zircon in the Sulu ultrahigh-pressure peridotite. *Geology, 34, 705-708.*

434. **Zheng, J., Griffin, W.L., O'Reilly, S.Y., Zhang, M. and Pearson, N.** 2006. Zircons in mantle xenoliths record the Triassic Yangtze-North China continental collision. *Earth and Planetary Science Letters, 247, 130-142.*

435. **Andersen, T., Griffin, W.L. and Sylvester, A.G.** 2007. Sveconorwegian underplating in southwestern Fennoscandia: LAM-ICPMS Hf isotope evidence from granites and gneisses in Telemark, southern Norway. *Lithos, 93, 273-287.*

436. **Chu, M.-F., Chung, S.-L., Song, B., Liu, D., O'Reilly, S.Y., Pearson, N.J., Ji, J. and When, D.** 2006. Zircon U-Pb and Hf isotope constraints on the Mesozoic tectonics and crustal evolution of southern Tibet. *Geology, 34, 745–748.*

437. **Dosseto, A., Turner, S.P. and Douglas, G.B.** 2006. Uranium-series isotopes in colloids and suspended sediments: Timescale for sediment production and transport in the Murray-Darling River system. *Earth and Planetary Science Letters, 246, 418-431.*

438. **Zheng, J., Griffin, W.L., O'Reilly, S.Y., Yang, J., Li, T., Zhang, M., Zhang, R.Y. and Liou, J.G.** 2006. Mineral chemistry of peridotites from Paleozoic, Mesozoic and Cenozoic lithosphere: Constraints on mantle evolution beneath Eastern China. *Journal of Petrology, 47, 2233-2256.*

439. **Hauri, E.H., Gaetani, G.A. and Green, T.H.** 2006. Partitioning of water during melting of the Earth's upper mantle at H_2O-undersaturated conditions. *Earth and Planetary Science Letters, 248, 715-734.*

440. **Belousova, E.A., Preiss, W.V., Schwarz, M.P. and Griffin, W.L.** 2006. Tectonic affinities of the Houghton Inlier, South Australia: U-Pb and Hf-isotope data from zircons in modern stream sediments. *Australian Journal of Earth Sciences, 53, 6, 971-989.*

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.*

443. **Chappell, B. and Hine, R.** 2006. The Cornubian Batholith: an example of magmatic fractionation on a crustal scale. *Resource Geology, 56, 203-244.*

444. **Arora, M., Kennedy, B.J., Elhlou, S., Pearson, N.J., Walker, D.M., Bayl, P. and Chan S.W.Y.** 2006. Spatial distribution of lead in human primary teeth as a biomarker of pre- and neonatal lead exposure. *Science of the Total Environment, 371, 55-62.*

445. **Bomparola, R.M., Ghezzo, C., Belousova, E., Griffin, W.L. and O'Reilly, S.Y.** 2007. Resetting of the U-Pb zircon system in the Cambro-Ordovician intrusives of the Deep Freeze Range, Northern Victoria Land, Antarctica. *Journal of Petrology, 48, 327-346.*

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.*

447. **Adams, C.J., Campbell, H.J. and Griffin, W.L.** 2007. Provenance comparisons of Permian to Jurassic tectonostratigraphic terranes in New Zealand: perspectives from detrital zircon age patterns. *Geological Magazine.* (in press)

448. **Yu, J.H., O'Reilly, S.Y., Zhao, L., Griffin, W.L., Zhang, M., Zhou, X., Jiang, S., Wang, L. and Wang, R.** 2007. Origin and evolution of topaz-bearing granites from the Nanling Range, South China: a geochemical and Sr-Nd-Hf isotopic study. *Mineralogy and Petrology.* (in press, online first)

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, 4, 339-342.*

450. **Guo, B., Lackie, M.A. and Flood, R.H.** 2007. Upper crustal structure of the Tamworth Belt and its bounding faults, constraints from new gravity data. *Australian Journal of Earth Sciences.* (in press)

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.* (in press)

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.*

453. **Yaxley, G.M., Kamenetsky, V., Nichols, G., Maas, R. and Norman, M.D.** 2007. Mantle-derived, carbonate-bearing picritic magma in east Antarctica – a possible parental melt to carbonatite. *Lithos.* (submitted)

454. **Zedgenizov, D.A., Rege, S., Griffin, W.L., Kagi, H. and Shatsky, V.S.** 2007. Compositional variations of fluid micro-inclusions in cuboid fibrous diamonds from Udachnaya kimberlite pipe revealed by 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.*

456. **Wood, B.J., Walter, M.J. and Wade, J.** 2006. Accretion of the Earth and segregation of its core. *Nature, 441, 825-833.*

457. **Turner, S., Regelous, M., Hawkesworth, C. and Rostami, K.** 2006. Partial melting processes above subducting plates: constraints from ^{231}Pa-^{235}U disequilibria. *Geochimica et Cosmochimica Acta, 70, 480-503.*

458. **Garrison, J., Davidson, J., Reid, M. and Turner, S.** 2006. Source versus differentiation controls on U-series disequilibria: insights from Cotopaxi volcano, Ecuador. *Earth and Planetary Science Letters, 244, 548-565.*

459. **Berlo, K., Turner, S., Black, S., Hawkesworth, C., and Blundy, J.** 2006. Tracing pre-eruptive magma degassing using (^{210}Pb/^{226}Ra) disequilibria in volcanic deposits of the 1980-1986 eruptions of Mount St. Helens. *Earth and Planetary Science Letters, 249, 337-349.*

460. **Bourdon, B., Ribe, N.M., Stracke, A., Saal, A.E., and Turner, S.P.** 2006. Insights into the dynamics of mantle plumes from uranium-series geochemistry. *Nature, 444, 713-717.*

461. **Griffin, W.L. and O'Reilly, S.Y.** 2007. Cratonic lithospheric mantle: Is anything subducted? *Episodes, 30, 1, 43-53.*

462. **Kuhn, H.-R., Pearson, N.J. and Jackson, S.E.** 2007. The influence of the laser ablation process on isotopic fractionation of copper in LA-MC-ICP-MS. *Journal of Analytical Atomic Spectrometry, 22, 547-552.*

463. **O'Neill, C., Lenardic, L., 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.* (in press).

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.*

465. **O'Reilly, S.Y., Griffin, W.L., Pearson, N.J., Jackson, S.E., Belousova, E.A., Alard, O. and Saeed, A.** 2007. Taking the pulse of the earth: linking crustal and mantle events. *Australian Journal of Earth Sciences.* (in press)

466. **Turner, S., Tonarini, S., Bindeman, I., Leeman, W.P. and Schaefer, B.F.** 2007. Boron and oxygen isotope evidence for recycling of subducted components through the Earth's mantle since 2.5 Ga. *Nature, 447, 702-705.*

467. **Demidjuk, Z., Turner, S., Sandiford, M., George, R., Foden, J. and Etheridge, M.** 2007. U-series isotope and geodynamic constraints on mantle melting processes beneath the Newer Volcanic Province in South Australia. *Earth and Planetary Science Letters.* (in press)

468. **Heyworth, Z., Turner, S., Schaefer, B., Wood, B., George, R., Berlo, K., Cunningham, H., Price, R., Cook, C. and Gamble, J.** 2007. ^{238}U-^{230}Th-^{226}Ra-^{210}Pb constraints on the genesis of high-Mg andesites at White Island, New Zealand. *Chemical Geology.* (in press, cor. proof online)

469. **Aulbach, S., Griffin, W.L., Pearson, N.J., O'Reilly, S.Y. and Doyle, B.J.** 2007. Lithosphere formation in the central Slave Craton (Canada): Plume subcretion or lithosphere accretion? *Contributions to Mineralogy and Petrology.* (Online First)

470. **Veevers, J.J. and Saeed, A.** 2007. Dronning Maud Land Antarctica and southeastern Africa linked by detrital zircons of similar U-Pb age and host-rock affinity in Early Permian sandstones. *Sedimentary Geology.* (in press)

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.* (in press, cor. proof online)

472. **Veevers, J.J.** 2007. Pan-Gondwanaland post-collisional extension marked by 650-500 Ma alkaline rocks and carbonatites and related detrital zircons: A review. *Earth Science Reviews, 83, 1-47.*

473. **Zhang, M., O'Reilly, S.Y., Wang, K.-L., Hronsky, J. and Griffin, W.L.** 2007. Flood basalts and metallogeny: the lithospheric mantle connection. *Earth Science Reviews.* (in press)

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-H_2O. *Earth and Planetary Science Letters, 260, 227-241.*

475. **Gladkochub, D., Pisarevsky, S., Donskaya, T., Natapov, L., Mazukabzov, A., Stanevich, A. and Sklyarov, E.** 2006. The Siberian Craton and the Rodinia hypothesis. *Episodes, 29, 169-174.*

476. **Natapov, L.M., Pisarevsky, S.A., Gladkochub, D.P., Stanevich, A.M. and Mazukabzov, A.M.** 2006. Comment on "Linking the Mesoproterozoic Belt-Purcell and Udzha basins across the west Laurentia–Siberia connection". *Precambrian Research, 145, 155–156.*

477. **Xu, X., O'Reilly, S.Y. Griffin, W.L., Xiaolei Wang, X., Pearson, N.J. and He, Z.** 2007. The crust of Cathaysia : Age, assembly and reworking of two terranes. *Precambrian Research.* (in press, cor. proof online)

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.* (in press)

479. **O'Neill, C.J., Lenardic, A., Griffin, W.L. and O'Reilly, S.Y.** 2007. Dynamics of cratons in an evolving mantle. *Lithos.* (in press, cor. proof online)

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.* (Online First)

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.* (in press)

482. **Shi, R., Alard, O., Zhi, X., O'Reilly, S.Y., Pearson, N.J., Griffin, W.L., Zhang, M. and Chen, X.** 2007. Multiple events in the Neo-Tethyan Oceanic upper mantle: Evidence from Ru-Os-Ir alloys in the Luobusa and Dongqiao ophiolitic podiform chromitites, Tibet. *Earth and Planetary Science Letters.* (in press)

483. **Wyman D.A., O'Neill C. and Ayer, J.A.** 2007. 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.* (in press).

485. **Griffin, W.L. and O'Reilly, S.Y** 2007. The earliest subcontinental mantle. In M. Van Kranendonk (ed.) *The Earth's Oldest Rocks. Elsevier, Amsterdam.* (in press)

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.* (in press).

487. **Veevers, J.J, Saeed, A., Pearson, N., Belousova, E. and Kinny, P.** 2007. 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)

488. **Turner, S., Sims, K.W.W., Reagan, M. and Cook, C.** 2007. A ^{210}Pb-^{226}Ra-^{230}Th-^{238}U study of Klyuchevskoy and Bezymianny volcanoes, Kamchatka. *Geochimica et Cosmochimica Acta.* (in press)

489. **Murgulov, V., O'Reilly, S.Y., Griffin, W.L. and Blevin, P.L.** 2007. Magma sources and gold mineralisation in the Mount Leyshon and Tuckers Igneous Complexes, Queensland, Australia: U-Pb and Hf isotope evidence. *Lithos.* (in press)

Appendix 3: Visitors/GAU users

GEMOC VISITORS 2006 (Excluding Participants in Conferences and Workshops) Macquarie

Dr Maitha S. Al-Shams (United Arab Emirates University)

Dr David Apter (DeBeers, Johannesburg)

Dr Graham Begg (BHP Billiton, Perth, WA)

Dr Melanie Barnes (Dept of Geosciences, Tech University, Lubbock, Texas, USA)

Dr Kim Berlo (Department of Earth Sciences, University of Bristol)

Dr Costanza Bonadiman (Università di Ferrara, Italy)

Prof Peter Cawood (University of Western Australia)

Prof Massimo Coltorti (Università di Ferrara, Italy)

Dr Craig Cook (University of Waikato, New Zealand)

Dr Shane Cronin (Massey University, Palmerston North, NZ)

Prof Laura Crossey (Earth and Planetary Sciences Dept, University of New Mexico, Albuquerque, USA)

Prof Jon Davidson (University of Durham, UK)

Dr Barbara Faccini (Università di Ferrara, Italy)

Prof Andy Gleadow (University of Melbourne)

Dr Herman Grutter (BHP Billiton World Exploration, Vancouver, Canada)

Dr Justin Gum (Geological Survey Branch, Minerals and Energy, Primary Industries and Resources South Australia)

Dr Xiumian Hu (Dept of Earth Sciences, Nanjing University, China)

Dr Trevor Ireland (Australian National University, ACT)

Dr George Jenner (Dept of Earth Sciences, Memorial University of Newfoundland, St John's, Newfoundland, Canada)

Prof Karl Karlstrom (Earth and Planetary Sciences Dept, University of New Mexico, Albuquerque, USA)

Ms Chuma Keswa (De Beers Group Exploration Services, South Africa)

Dr Kurt Knesel (University of Queensland)

Mr Navot Morag (Hebrew University of Jerusalem, Israel)

Prof Shigenore Maruyama (Dept of Earth and Planetary Sciences, Tokyo Institute of Technology, Japan)

Jacinta Ogilvie (Monash University)

Mr Grant Osborne (Chief Geologist, Albidon Limited, Perth, WA)

Prof Roger Powell (University of Melbourne)

Dr Mark Reagan (University of Iowa, USA)

Prof Richard Price (University of Waikato, NZ)

Dr Tracy Rushmer (University of Vermont, Vermont, USA)

Prof Mike Sandiford (University of Melbourne)

Dr D. Srinivasa Sarma (Centre for Exploration Targeting, School of Earth and Geographical Sciences, University of WA)

Mr Ashraf Shad (United Arab Emirates University)

Ms Rebekah Shafton (Monash University)

Dr Simon Shee (DeBeers)

Dr Rendeng Shi (School of Earth Sciences, University of Science and Technology, China)

Assoc. Prof Ian Smith (University of Auckland, NZ)

Dr Frazer Tabeart (Chief Geologist, Albidon Limited, Perth, WA)

Mr Yakov Weiss (Hebrew University of Jerusalem, Israel)

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

Mr Bruce Wyatt (Wyatt Geology Consulting Ltd., Melbourne, Vic.)

EXTERNAL USERS OF THE GEOCHEMICAL ANALYSIS UNIT FACILITIES IN 2006

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

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

Dr Manish Arora (Faculty of Dentistry, University of Sydney)

Dr Deepanker Asthana (Indian School of Mines, India)

Dr Melanie Barnes (Texas Tech University, USA)

Dr Costanza Bonadiman (Università di Ferrara, Italy)

Dr David Champion (Geoscience Australia)

Prof Massimo Coltorti (Università di Ferrara, Italy)

Dr Craig Cook (University of Waikato, New Zealand)

Dr Barbara Faccini (Università di Ferrara, Italy)

Mr Dominic Hare (University of Technology, Sydney)

Dr Matt Horstwood (NIGL, UK)

Ms Katie Howard (Adelaide University)

Dr Xiumian Hu (Nanjing University, China)

Dr Chuma Keswa (De Beers Group Exploration Services, South Africa)

Dr Geordie Mark (School of Geosciences, Monash Univesity)

Dr Terry Mernagh (Geoscience Australia)

Mr Navot Morag (Hebrew University of Jerusalem, Israel)

Mr Lawrence Neufeld (New Wave Research Inc, USA)

Ms Jacinta Ogilvie (Monash University)

Mr Bill Pappas (Geoscience Australia)

Mr John Pyke (Geoscience Australia)

Dr D. Srinivasa Sarma (Centre for Exploration Targeting, School of Earth and Geographical Sciences, University of WA)

Dr Bruce Schaefer (School of Geosciences, Monash University)

Ms Bec Shafton (Monash University)

Dr Rendang Shi (University of Science and Technology, Hefei, China)

Dr Thomas Stachel (University of Alberta, Canada)

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

Dr Xiang Wang (Nanjing University, China)

Ms Liz Webber (Geoscience Australia)

Mr Yakov Weiss (Hebrew University of Jerusalem, Israel)

Mr Ben Wright (Diakyne, Australia)

Dr Wang Xiaolei (Nanjing University, China)

Prof Xisheng Xu (Nanjing University, China)

Appendix 4: Abstract titles

TITLES OF ABSTRACTS FOR CONFERENCE PRESENTATIONS IN 2006

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

EUROPEAN GEOSCIENCES UNION GENERAL ASSEMBLY 2006, VIENNA, AUSTRIA, APRIL 2-7, 2006

***TerraneChron*® applications in the crustal evolution studies: Australian ancient and young terranes** Keynote

E.A. Belousova[1], S.Y. O'Reilly[1] and W.L. Griffin[1,2]
1. GEMOC Macquarie, 2. CSIRO Exploration and Mining, North Ryde, NSW, Australia

In-situ major, trace elements and Sr isotopes in clinopyroxenes from the oceanic lithosphere beneath Kerguelen Islands (Indian Ocean)

G. Delpech[1,2], S.Y. O'Reilly[2], B.N. Moine[3], M. Grégoire[4], J.Y. Cottin[3] and N.J. Pearson[2]
1. Université Orsay-Paris XI, France, 2. GEMOC Macquarie, 3. Département de Géologie-Pétrologie-Géochimie, Université Jean Monnet, Saint-Etienne, France, 4. "Dynamique Terrestre et Planétaire", Observatoire Midi-Pyrénées, Toulouse, France

Armalcolite and rutile-bearing mantle peridotites, Vitim volcanic field, South Russia: petrography and mineralogy

V.G. Malkovets[1], K.D. Litasov[2], W.L. Griffin[1,3] and S.Y. O'Reilly[1]
1. GEMOC Macquarie, 2. Institute of Mineralogy, Petrology, and Economic Geology, Tohoku University, Sendai, Japan, 3. CSIRO Exploration and Mining, North Ryde, NSW, Australia

Carbonatite melt in the Indian oceanic upper mantle (Kerguelen Archipelago, TAAF)

B.N. Moine[1,4], G.Delpech[2], M. Gregoire[3], S.Y. O'Reilly[4], J.P. Lorand[5], C. Renac[1], and J.Y. Cottin[1,4]
1. Université Jean Monnet, Département de Géologie-Pétrologie-Géochimie, St. Etienne, France, 2. Université Paris Sud-Orsay, Paris France, 3. Laboratoire Dynamique Terrestre et Planétaire, Observatoire Midi-Pyrénées, Toulouse, France, 4. GEMOC Macquarie, 5. Muséum National d'Histoire Naturelle, Paris

New insights into mantle metasomatism using *in-situ* isotopic analysis Keynote

N.J. Pearson[1], W.L. Griffin[1], S.Y. O'Reilly[1] and O. Alard[1,2]
1. GEMOC Macquarie, 2. CNRS, Université de Montpellier, Montpellier, France

The Archean Salma eclogites, Kola Peninsula, Russia: Petrology, geochronology and significance for insight into the Archean crust-forming processes

A. Shchipansky[1], A. Konilov[1], M. Mints[1], E. Belousova[2], L. Natapov[2], W.L. Griffin[2] and S.Y. O'Reilly[2]
1. Geological Institute, RAS, Moscow, Russia, 2. GEMOC Macquarie University, NSW, Australia

Characterisation of metasomatic agents using *in-situ* trace-element and stable isotope compositions in mantle xenoliths from Devès, Massif Central (France)

S. Touron[1,2], C. Renac[2], S.Y. O'Reilly[1], J.Y. Cottin[2] and W.L. Griffin[1]
1. GEMOC Macquarie, 2. Laboratoire Transferts lithosphériques, Université Jean Monnet, St-Etienne, France

INTERNATIONAL CONFERENCE ON CONTINENTAL VOLCANISM - IAVCEI 2006, GUANGZHOU, CHINA, MAY 14-18, 2006

How primitive is the "primitive" upper mantle: Revisiting the lherzolite-harzburgite relationships of the Lherz massif

O. Alard[1,2], A.J.V. Riches[3], V. Le Roux[1] and J-L. Bodinier[1]
1. Lab. Tectonophysique (UMR 5569), CNRS, U. Montpellier II, France, 2. GEMOC, Macquarie University, Sydney, Australia, 3. Dept. Earth Sciences, The Open University, Milton Keynes, United Kingdom

Ubiquitous old depleted mantle in the oceanic mantle Invited

O. Alard[1,2], Y. Gréau[2], A. Luguet[3], J.-P. Lorand[4], M. Godard[2], W.L. Griffin[1] and S.Y. O'Reilly[1]
1. GEMOC, Macquarie University, Sydney, Australia, 2. Lab. Tectonophysique, Universite de Montpellier II, France, 3. Dept. of Earth Sciences, University of Durham, UK, 4. Muséum National d'Histoire Naturelle de Paris, CNRS, France

Eclogites in the SCLM: The subduction myth Keynote

W.L. Griffin[1,2] and S.Y. O'Reilly[1]
1. GEMOC Macquarie, 2. CSIRO Exploration and Mining, North Ryde, NSW, Australia

SCLM age, composition and evolution Invited

W.L. Griffin[1,2], S.Y. O'Reilly[1], G. Begg[1], E.A. Belousova[1], E. Beyer[1], J. Hronsky[1], X. Xu[1] and J. Zheng[1]
1. GEMOC Macquarie, 2. CSIRO Exploration and Mining, North Ryde, NSW, Australia

Survival of cratonic roots in an evolving mantle: dependence on mantle structure and tectonic regime Keynote

C. O'Neill
GEMOC Macquarie

The use of thallium isotopes to trace ferromanganese sediments in the mantle sources of ocean island basalts Invited

S.G. Nielsen[1,2], M. Rehkamper[1,3], M.D. Norman[4] and A.N. Halliday[1,5]
1. Department of Earth Sciences, ETH-Zürich, Zurich, Switzerland, 2. GEMOC Macqaurie, 3. Imperial College, London, United Kingdom, 4. Research School of Earth Sciences, Australian National University, Canberra, ACT, Australia, 5. Dept. of Earth Sciences, University of Oxford, Oxford, United Kingdom

Ultradeep and oceanic domains of ancient lithospheric blobs: consequences for basalt source regions and geodynamics Invited

S.Y. O'Reilly[1], W.L. Griffin[1,2], M. Zhang[1] and S. Grand[3]
1. GEMOC Macquarie, 2. CSIRO Exploration and Mining, North Ryde, NSW, Australia, 3. Department of Geological Sciences, University of Texas at Austin, USA

New insights into the age, composition and evolution of the lithospheric mantle using *in-situ* isotopic analysis Invited

N.J. Pearson[1], W.L. Griffin[1], S.Y. O'Reilly[1] and O. Alard[1,2]
1. GEMOC Macquarie, 2 . CNRS, Université de Montpellier, Montpellier, France

Multiple events in the Neo-Tethyan Oceanic upper mantle: Ru-Os-Ir alloys in the Luobusa and Dongqiao ophiolitic podiform chromitites, Tibet

R. Shi[1,2], X. Zhi[1], S.Y. O'Reilly[3], W.L. Griffin[3], N.J. Pearson[3], W. Bai[4], Q. Fang[4], O. Alard[3] and M. Zhang[3]
1. CAS Key Laboratory of Crust-Mantle Materials and Environments, School of Earth and Space Sciences, University of Science and Technology of China, Hefei, China, 2. State Key Laboratory of Mineral Deposit Research, Nanjing University, Nanjing, 3. GEMOC Macquarie, 4. Institute of Geology, Chinese Academy of Geological Sciences, Beijing, China

Continental mafic magmatism: internal versus external sources and triggers Keynote

S. Turner and H. Williams
GEMOC Macquarie

Mantle composition and processes beneath the Taiwan Strait, SE Asia Invited

K.L. Wang[1,2], S.Y. O'Reilly[1], W.L. Griffin[1,3], N.J. Pearson[1] and M. Zhang[1]
1. GEMOC Macquarie, 2. Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, 3. CSIRO Exploration and Mining, North Ryde, Australia

Iron isotope fractionation in mantle minerals and the effects of partial melting and oxygen fugacity Invited

H.M. Williams[1], C. McCammon[2], A.H. Peslier[3], A.N. Halliday[4], S. Levasseur[5], N. Teutsch[5], J.-P. Burg[5] and S.Y. O'Reilly[1]
1. GEMOC Macquarie, 2. Bayerisches Geoinstitut Universitat Bayreuth, Bayreuth, Germany, 3. Texas Center for Superconductivity, University of Houston, USA, 4. Department of Earth Sciences, University of Oxford, Oxford, United Kingdom. 5. Department of Earth Sciences, ETH-Zürich, Switzerland

Rutile stability and rutile/melt HFSE partitioning during partial melting of hydrous basalt: Implications for Adakite/TTG genesis

X.-L. Xiong[1], J. Adam[2] and T.H. Green[2]
1. Bavarian Research Institute of Experimental Geochemistry and Geophysics, University of Bayreuth, Germany, 2. GEMOC Macquarie

Modification of sub-continental lithospheric mantle in SE China Invited

X. Xu[1,2], W.L. Griffin[2], D. Zhao[3] and S.Y. O'Reilly[2]
1. State Key Laboratory of Mineral Deposit Research, Nanjing University, Nanjing, 2. GEMOC Macquarie, 3. Department of Geological Sciences, University of South Carolina, SC, USA

Are all mantle plumes equal in Nickel and PGE potential Invited

M. Zhang[1], K.-L. Wang[1], S.Y. O'Reilly[1], J. Hronsky[1,2] and W.L. Griffin[1,3]
1. GEMOC Macquarie, 2. BHP Billiton, Perth, WA, Australia, 3. CSIRO Exploration and Mining, North Ryde, NSW, Australia

Mineral chemistry of peridotites from Paleozoic, Mesozoic and Cenozoic lithosphere: constraints on lithospheric mantle evolution, eastern China

J.P. Zheng[1,2], W.L. Griffin[2,3], S.Y. O'Reilly[2] and M. Zhang[2]
1. China University of Geosciences, Wuhan, China, 2. GEMOC Macquarie, 3. CSIRO Exploration and Mining, North Ryde, NSW, Australia

AESC (AUSTRALIAN EARTH SCIENCES CONVENTION), MELBOURNE, JULY 2-6, 2006

Musgrave Province reconnaissance using *TerraneChron*®

J.C. Gum[1] and E.A. Belousova[2]
1. PIRSA, Geological Survey Branch, Adelaide, SA, Australia, 2. GEMOC Macquarie

GRANULITES AND GRANITES 2006, BRASIL, JULY 10-12, 2006

High-pressure mafic granulites of Fiordland, New Zealand – A transient granulite event

N. Daczko[1], L. Milan[1] and G. Clarke[2]
1. GEMOC Macquarie, 2. School of Geosciences, University of Sydney, NSW, Australia

Kinematic and finite strain analysis in high-pressure mafic granulites of Fiordland, New Zealand

N. Daczko[1], G. Clarke[2] and K. Klepeis[3]
1. GEMOC Macquarie, 2. School of Geosciences, University of Sydney, NSW, Australia, 3. Department of Geology, University of Vermont, VT, USA

Heterogeneity in the lower crust, Fiordland, New Zealand: An atypical granulite belt?
L. Milan[1], N. Daczko[1], G. Clarke[2], I. Turnbull[3] and A. Allibone[3]
1. GEMOC Macquarie, 2. School of Geosciences, University of Sydney, NSW, Australia, 3. Institute of Geological and Nuclear Sciences, Dunedin, New Zealand

AOGS, ASIA OCEANIA GEOSCIENCES SOCIETY 3RD ANNUAL MEETING, SINGAPORE, JULY 10-14, 2006

The age and evolution of the SCLM
Keynote
W.L Griffin[1], S.Y. O'Reilly[1], G. Begg[1,2], E. Belousova[1], E. Beyer[1], J. Hronsky[1,2], X. Xu[1,3] and J. Zheng[1,4]
1. GEMOC Macquarie, 2. BHP Billiton, Perth, WA, Australia, 3. Department of Earth Sciences, Nanjing University, Nanjing, P.R. China, 4. Faculty of Earth Sciences, China University of Geosciences, Wuhan, China

Geochemical and geophysical evidence for lithospheric processes
Invited
S.Y. O'Reilly[1], W.L. Griffin[1], S. Grand[2], G. Begg[1] and J. Hronsky[1]
1. GEMOC Macquarie, 2. Dept. of Geological Sciences, University of Texas, Austin, USA

Evolution of lithospheric mantle beneath SE margin of South China Block: *in situ* Re-Os evidence
Invited
K.-L. Wang[1,2], S.Y. O'Reilly[1], W.L. Griffin[1,3], N.J. Pearson[1] and M. Zhang[1]
1. GEMOC Macquarie, 2. Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, 3. CSIRO Exploration and Mining, North Ryde, Australia

Chemical characteristics of emeralds from various localities
V. Pisutha-Arnond[1,2], T. Leelawatanasuk-Pavaro[1], P. Wathanakul[1,3], W. Atichat[1], D. Schwarz[4] and T. Win[5]
1. Gem and Jewelry Institute of Thailand (GIT), Thailand, 2. Dept. of Geology, Faculty of Science, Chulalongkorn University, Bangkok, Thailand, 3. Faculty of Science, Kasetsart University, Bangkok, Thailand, 4. Gubelin Gem Lab, Lucerne, Switzerland, 5. GEMOC Macquarie

Trace element analysis of alluvial diamonds from Myanmar and Thailand by LA- ICPMS
T. Win[1], P. Wathanakul[2] and S. Elhlou[1]
1. GEMOC Macquarie, 2. Kasetsart University, Thailand

Guidelines for lithospheric origins of emeralds
P. Wathanakul[1], D. Schwarz[3], V. Pisutha-Arnond[4], W. Atichat[2], T. Win[5] and W. Hofmeister[6]
1. Kasetsart University, Thailand, 2. Gem and Jewelry Institute, Thailand, 3. Gubelin Gem Lab, Switzerland, 4. Chulalongkorn University, Thailand, 5. GEMOC Macquarie, 6. University of Mainz, Germany

16TH ANNUAL V. M. GOLDSCHMIDT CONFERENCE, MELBOURNE, AUSTRALIA, AUGUST 27-SEPTEMBER 1, 2006

Combined experimental and geochemical evidence for the origins of Tasmanian intraplate basalts
J. Adam and T.H. Green
GEMOC Macquarie

Most abyssal peridotites are old!
O. Alard[1,2]
1. GEMOC Macquarie, 2. Lab. Tectonophysisque, CNRS-Université de Montpellier, France

Proterozoic rejuvenation of the Archean crust tracked by U-Pb and Hf-isotopes in detrital zircon
E.A. Belousova[1], A.J. Reid[2], W.L. Griffin[1] and S.Y. O'Reilly[1]
1. GEMOC Macquarie, 2. Geological Survey Branch, PIRSA, SA, Australia

Archean to Proterozoic depletion in Cape Verde lithospheric mantle
C. Bonadiman[1], M. Coltorti[1], F. Siena[1], S.Y. O'Reilly[2], W.L. Griffin[2] and N.J. Pearson[2]
1. Department of Earth Sciences, University of Ferrara, Ferrara, Italy, 2. GEMOC Macquarie

The trace element geochemistry of magnetite and pyrite in Fe oxide (±Cu-Au) mineralised systems: Insights into the geochemistry of ore-forming fluids
M.J. Carew[1], G. Mark[1,2], N.H.S. Oliver[1] and N. Pearson[3]
1. EGRU, School of Earth Sciences, James Cook University, 2. Monash Ore Geology Research and Exploration Group, School of Geosciences, Monash University, 3. GEMOC Macquarie

Infrared investigation of Timber Creek 01 Kimberlite diamonds
S.A. Cooper[1,2], W.L. Griffin[1] and S.Y. O'Reilly[1]
1. GEMOC Macquarie, 2. Orogenic Exploration Pty Ltd, Burwood, Victoria, Australia

Timescales of petrogenesis in an active caldera, Rabaul, Papua New Guinea
H.S. Cunningham[1], S.P. Turner[1], A. Dosseto[1] and S. Eggins[2]
1. GEMOC Macquarie, 2. Department of Geology, Australian National University, Canberra, ACT, Australia

A high-Nb OIB-like mafic province in northwestern NSW, Australia
K.A. Dadd
GEMOC Macquarie

Amphibole fractionation - A constraint on the depth of arc magma evolution?
J.P. Davidson[1], A. Dosseto[2] and S.P. Turner[2]
1. Dept. of Earth Sciences, University of Durham, UK, 2. GEMOC Macquarie

The timescale of soil and saprolite production inferred from uranium-series isotopes: Case study in temperate Australia
A. Dosseto and S.P. Turner
GEMOC Macquarie

Trace element and isotopic composition of GJ-red zircon standard by laser ablation
S. Elhlou, E. Belousova, W.L. Griffin, N.J. Pearson and S.Y. O'Reilly
GEMOC Macquarie

The role of water in Precambrian ultramafic magmatism: Insights from an *in situ* microbeam and nanobeam assessment of hydromagmatic amphibole
M.L. Fiorentini[1], S.W. Beresford[2], E. Deloule[3], W.E. Stone[4], E. Hanski[5], and N. Pearson[6]
1. School of Earth and Geographical Sciences, UWA, Crawley, Western Australia, 2. Department of Earth Sciences, Monash University, Victoria, 3. CRPG-CNRS, BP20, Vandoeuvre les Nancy Cedex, France, 4. Nevadastar, Vancouver, Canada, 5. Department of Geosciences, University of Oulu, Finland, 6. GEMOC Macquarie

Evidence that some microgranitoid enclaves are felsic magma cumulates
R.H. Flood and S.E. Shaw
GEMOC Macquarie

The role of the Béni floodplain on the chemical weathering fluxes in the upper Madeira basin, Bolivia
J. Gaillardet[1], L. Maurice-Bourgoin[2], J.L. Guyot[3] and A. Dosseto[4]
1. Laboratoire de Geochimie et Cosmochimie, IPGP-CNRS, France, 2. Observatoire Midi Pyrenees, Toulouse, France, 3. Institut de Recherche pour le Development, Lima, Peru, 4. GEMOC Macquarie

Trace element substitution mechanisms in olivine
K.J. Grant and B.J. Wood
GEMOC Macquarie

Experimentally determined mineral/melt partition coefficients for a Tasmanian nepheline basanite
T.H. Green and J. Adam
GEMOC Macquarie

New calculations on water storage in the upper mantle, and implications for mantle melting models
T.H. Green[1], E.H. Hauri[2], G.A. Gaetani[3] and J. Adam[2]
1. GEMOC Macquarie, 2. DTM, Carnegie Inst. Washington, Washington DC, USA, 3. Dept. Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, MA, USA

Trace-element patterns of diamond: Toward a unified genetic model Keynote
W.L. Griffin[1], S. Rege[1], S.Y. O'Reilly[1], S.E. Jackson[1], N.J. Pearson[1], D. Zedgenizov[2] and G. Kurat[3]
1. GEMOC Macquarie, 2. Inst. Mineralogy and Petrography, Novosibirsk, Russia, 3. Naturhistorisches Museum, Vienna, Austria

Tungsten isotopes and oxidation in early planetary mantles
A.N. Halliday[1], B.J. Wood[2] and A. Markowski[3]
1. Department of Earth Sciences, University of Oxford, Oxford, UK, 2. GEMOC Macquarie, 3. Department Earth Sciences, ETH-Zürich, Switzerland

H profiles in mantle xenoliths: Constraints from diffusion data
J. Ingrin[1] and K.J. Grant[2]
1. Minéralogie, LMTG, Univ. Paul Sabatier, Toulouse, France, 2. GEMOC Macquarie

Hf isotopes and zircon recrystallization: A case study
P.D. Kinny[1], G.J. Love[1] and N.J. Pearson[2]
1. Applied Geology, Curtin University, Perth, Australia, 2. GEMOC Macquarie

U-series isotopic disequilibrium produced during experimental melting of granitic crust: Implications for shallow-level assimilation and pluton remobilisation
K. Knesel[1], S. Turner[2] and J.P. Davidson[2,3]
1. Department of Earth Sciences, University of Queensland, Brisbane, Australia, 2. GEMOC Macquarie, 3. Department of Earth Sciences, University of Durham, UK

Laser Ablation ICP-MS: Particle size-dependent isotopic fractionation of copper in laser-generated aerosols
H.-R. Kuhn, N.J. Pearson and S.E. Jackson
GEMOC Macquarie

Petrology and geochemistry of peridotite xenoliths from Vietnam, Indochina block
C.Y. Lan[1], Y. Iizuka[1], T. Usuki[1], K.L. Wang[1], Tran Tuan Anh[2], Trinh Van Long[3] and S.Y. O'Reilly[4]
1. Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, 2. Institute of Geological Sciences, NCNST, Vietnam, 3. South Vietnam Geological Mapping Division, Ho Chi Minh City, Vietnam, 4. GEMOC Macquarie

Oxygen isotopes, REE and U-Pb behaviour during metamorphic zircon formation
L. Martin[1], S. Duchêne[2], E. Deloule[2] and O. Vanderhaeghe[3]
1. GEMOC Macquarie, 2. CRPG, Vandoeuvre-les-Nancy, France, 3. UHP-G2R, Vandoeuvre-les-Nancy, France

Appendix 4: Abstract titles

Use of *in situ* Hf–isotope analyses of zircon to interpret granitoid magma genesis
V. Murgulov, W.L. Griffin and S.Y. O'Reilly
GEMOC Macquarie

Crust-mantle evolution in NW Spitsbergen: Re-Os, U-Pb and Hf isotope data
N. Nikolic, S.Y. O'Reilly and W.L. Griffin
GEMOC Macquarie

The nature of subduction on the early Earth Invited
C. O'Neill[1], A. Lenardic[2], L. Moresi[3], T. Torsvik[4] and C.-T. Lee[2]
1. GEMOC Macquarie, 2. Department of Earth Sciences, Rice University, Houston, TX, USA, 3. MCC, Monash University, Melbourne, Australia, 4. Centre for Geodynamics, NGU, Trondheim, Norway

Ancient lithosphere domains in ocean basins are key geochemical "reservoirs" Invited
S.Y. O'Reilly[1], M. Zhang[1], W.L. Griffin[1], G. Begg[1,2] and J. Hronsky[1,2]
1. GEMOC, Macquarie, 2. BHP Billiton, Perth, WA, Australia

Linking crustal and mantle events using *in situ* trace-element and isotope analysis Invited
N.J. Pearson[1], S.Y. O'Reilly[1], W.L. Griffin[1], O. Alard[1,2] and E. Belousova[1]
1. GEMOC, Macquarie, 2. CNRS, Université de Montpellier, France

Mixing, fractionation and crustal assimilation in andesites: Evidence from U-Th disequilibrium data, Ruapehu, New Zealand
R.C. Price[1], J.A. Gamble[2], R. George[3], S. Turner[3], I.E.M. Smith[4] and C. Cook[1]
1. Dept. of Science and Engineering, University of Waikato, Hamilton, New Zealand, 2. Dept. of Geology, National University Ireland, University College Cork, Ireland, 3. GEMOC Macquarie, 4. Department of Geology, University of Auckland, NZ

England Batholith, NSW, Australia: Age implications for the Crust
S.E. Shaw and R.H. Flood
GEMOC Macquarie

Multiple events in oceanic upper mantle: Ru-Os-Ir alloys in Tibetan ophiolites
R.D. Shi[1], X.C. Zhi[1], S.Y. O'Reilly[2], W.L. Griffin[2], N.J. Pearson[2], W.J. Bai[3], Q.S. Fang[3], O. Alard[2] and M. Zhang[2]
1. CAS Key Laboratory of Crust-Mantle Materials and Environments, School of Earth and Space Sciences, University of Science and Technology of China, Hefei, China, 2. GEMOC Macquarie, 3. Institute of Geology, CAGS, Beijing, China

Enriched mantle component in high Sr/Y ("TTG") granites: Hf, Sr, Nd, O, isotopic compositions of Cretaceous arc magmas from New Zealand
A.J. Tulloch[1], W.L. Griffin[2], D.L. Kimbrough[3], K. Faure[4] and A. Saeed[2]
1. GNS Science, Dunedin, NZ, 2. GEMOC Macquarie, 3. San Diego State University, 4. GNS Science, Lower Hutt, NZ

Boron and oxygen isotopic evidence for recycling of subducted components through the Earth's mantle since 2.5 Ga
S. Turner[1], S. Tonarini[2], I. Bindeman[3], W.P. Leeman[4] and B.F. Schaefer[4]
1. GEMOC Macquarie, 2. Instituto di Geoscienze e Georisorse, Pisa, Italy, 3. Department of Geology and Geophysics, University of Wisconsin, Madison, Wisconsin, U.S.A, 4. National Science Foundation, Arlington, U.S.A, 5. School of Geosciences, Monash University, Australia

A ^{210}Pb-^{226}Ra-^{230}Th-^{238}U study of Klyuchevskoy and Bezymianny volcanoes, Kamchatka
S.P. Turner[1], K.W.W. Sims[2] and M.K. Reagan[3]
1. GEMOC Macquarie, 2. Department of Geology and Geophysics, Woods Hole Oceanographic Institution, MA, USA, 3. Department of Geoscience, University of Iowa, IA, USA

The origin of fertile enstatite by deep-seated carbonatite metasomatism
E. Van Achterbergh[1,2], S.Y. O'Reilly[1] and W.L. Griffin[1]
1. GEMOC Macquarie, 2. Rio Tinto OTX, Bundoora, VIC, Australia

***In situ* Os dating of peridotite xenoliths, Tariat, northern Mongolia**
K.-L. Wang[1,2], S.Y. O'Reilly[2], W.L. Griffin[2] and N.J. Pearson[2]
1. Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, 2. GEMOC Macquarie

Evaluation of a method for the separation of Ni in geological samples
P.R. Wieland, E. Beyer, S.E. Jackson, N.J. Pearson and S.Y. O'Reilly
GEMOC Macquarie

Emplacement, uplift and exhumation histories of Tibetan porphyry Cu-Mo-Au deposits
J.-F. Xu[1], B.I.A. McInnes[2], N.J. Evans[2] and W.L. Griffin[3]
1. Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, China, 2. CSIRO Exploration and Mining, ARRC, Kensington, WA, Australia, 3. GEMOC Macquarie

Modification of subcontinental lithospheric mantle in SE China
X. Xu[1,2], W.L. Griffin[2], D. Zhao[3] and S.Y. O'Reilly[2]
1. State Key Laboratory for Mineral Deposit Research, Department of Earth Sciences, Nanjing University, P.R. China, 2. GEMOC Macquarie, 3. Department of Geological Sciences, University of South Carolina, USA

Provinciality of lithospheric mantle, E. Australia: Source of enriched components in the Cenozoic basalts Invited
M. Zhang and S.Y. O'Reilly
GEMOC Macquarie

11TH INTERNATIONAL CONFERENCE ON EXPERIMENTAL MINERALOGY, PETROLOGY AND GEOCHEMISTRY, BRISTOL, UK, SEPTEMBER 11-13, 2006

An electron microprobe, LAM ICP-MS and single-crystal X-ray study of the effects of pressure, H_2O concentration and fO_2 on experimentally produced basaltic amphiboles
J. Adam[1], R. Oberti[2], F. Camara[2] and T.H. Green[3]
1. Blakehurst, N.S.W., Australia, 2. CNR-Instituto di Geoscienze e Georisorse, unità di Pavia, Italy, 3. GEMOC Macquarie

Olivine-melt partitioning and Henry's Law revisited
K.J. Grant and B.J. Wood
GEMOC Macquarie

An experimental study of thallium partitioning and isotope fractionation during planetary core formation processes
S.G. Nielsen[1], B.J. Wood[2], M. Rehkämper[3] and A.N. Halliday[1]
1. Department of Earth Sciences, University of Oxford, Oxford, UK, 2. GEMOC Macquarie, 3. Department of Earth Science and Engineering, Imperial College, UK

Partitioning of weakly siderophile elements during core formation
B.J. Wood, A. Corgne and J. Wade
GEMOC, Macquarie

MSA/GS SHORT COURSE WATER IN NOMINALLY HYDROUS MINERALS, VERBANIA, ITALY, OCTOBER 1-4, 2006

Mineral-Melt Partitioning of Water at H_2O-Undersaturated Conditions: Implications for Water Storage, Transport and Melting
E.H. Hauri[1], G.A. Gaetani[2], T.H. Green[3]
1. Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, USA, 2. Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, USA, 3. GEMOC Macquarie

GEOLOGICAL SOCIETY OF AMERICA, GSA ANNUAL MEETING AND EXPOSITION, PHILADELPHIA, OCTOBER 22-25, 2006

Detrital record of lower crust exhumation in a fossil mid-ocean spreading center: Macquarie Island, Southern Ocean, 54°30'S, 158°56'E
R. Portner[1], N.R. Daczko[1], J.A. Dickinson[2] and N. Harb[1]
1. GEMOC Macquarie, 2. School of Geosciences, University of Sydney, Sydney, Australia

AGU FALL MEETING, SAN FRANCISCO, CA, USA, DECEMBER 11-15, 2006

The evolution of a weathering profile and the rates of soil and saprolite production
A. Dosseto[1], J. Chappell[2], E.G. Green[3] and S.P. Turner[1]
1. GEMOC Macquarie, 2. Research School of Earth Sciences, ANU, Canberra, ACT, Australia, 3. Department of Earth and Planetary Sciences, University of California, Berkeley, USA

U-series constraints on the genesis of high-Mg andesites at White Island, New Zealand
S. Turner[1], H. Zarah[2], B. Schaefer[3], R. George[1], K. Berlo[1], H. Cunningham[1], R. Price[3] and S. Gamble[4]
1. GEMOC Macquarie, 2. School of Geosciences, Monash University, Melbourne, Australia, 3. School of Science and Technology, University of Waikato, NZ, 4. Department of Geology, University College Cork, Ireland

Appendix 5: Funded research projects

GRANTS AND OTHER INCOME FOR 2006

2006 Funding Source	Investigators	Project Title	Amount
ARC Discovery	Alard	Toward the use of metal stable isotopes in geosciences	$121,378
ARC Discovery	Daczko	A new approach to understanding the mechanisms and deep crustal controls of continental rifting	$36,414
ARC Discovery	Daczko, Dickinson	Spreading ridge sedimentation processes: a novel approach using Macquarie Island as a natural laboratory	$61,140
ARC Discovery	Jackson, Mountain	Isotopic fractionation of the ore minerals (Cu, Fe, Zn): A new window on ore-forming processes	$62,424
ARC Discovery	O'Reilly, Griffin, Gohl, Morgan, Cottin, Neumann, Xu	How has the continental lithosphere evolved? Processes of assembly, growth, transformation and destruction	$284,375
ARC Discovery	Turner, Hawkesworth, Kirchner	The time scales of magmatic and erosional cycles	$90,503
ARC Discovery	Nielsen	Thallium isotopes: a novel geochemical tracer to map recycling in Earth's mantle	$105,000
ARC Discovery	Wood, Rubie, Kelley, Hervig	The behaviour of geochemical tracers during differentiation of the Earth	$150,000
ARC Discovery	O'Neill, Wood, Irifune	Discovery of deep mantle: experimental petrology at very high pressures	$20,000
ARC Linkage International	O'Reilly, Griffin, Cottin, Grégoire, Xu	How has the continental lithosphere evolved? Processes of assembly, growth, transformation and destruction	$42,590
ARC Linkage Project	O'Reilly, Griffin, WMC	Global lithosphere architecture mapping (including industry contribution)	$199,711
ARC Federation Fellowship	Wood	Origin and evolution of Earth's chemical reservoirs	$316,222
ARC Federation Fellowship (MU 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	$316,222
ARC Federation Fellowship (MU contribution)	Turner	The time scales of geochemical cycles and Earth processes	$168,390

2006 Funding Source	Investigators	Project Title	Amount
VC Innovation Fellowship Research Grant	Belousova	Tomorrow's *TerraneChron*®: new developments, new deliverables and new destinations	$19,500
VC Innovation Fellowship	Belousova	Tomorrow's *TerraneChron*®: new developments, new deliverables and new destinations	$66,831
MQECRG	O'Reilly, Griffin	Trace-element analysis of diamonds	$50,000
MQECRG (Rio Tinto)	O'Reilly, Griffin	Trace-element analysis of diamonds	$102,000
MQECRG	Griffin, O'Reilly	Lithosphere evolution across a craton margin, southern Africa	$50,000
MQECRG (de Beers)	Griffin, O'Reilly	Lithosphere evolution across a craton margin, southern Africa	$81,000
MQRF Research Grant	O'Neill	Episodicity in mantle convection: effects on continent formation and metallogenesis	$18,400
MQ Research Fellowship	O'Neill	Episodicity in mantle convection: effects on continent formation and metallogenesis	$66,136
MURF	Malkovets	Age and evolution of the upper mantle beneath the Siberian Craton and Siberian Platform	$22,695
MU Safety Net	Turner	Mantle melting dynamics and the influence of recycled components	$19,700
MQRIBG	Turner et al.	Installation of argon and helium gas pipelines for high-technology instruments in the Geochemical Analysis Unit	$31,911
Dept. EPS	O'Reilly, DEPS	GAU Maintenance contribution	$30,000
Capital equipment	Lackie	Ground penetrating radar system	$64,550
Capital equipment	Flood	Rocklab grinding mill	$19,500
Capital equipment	Flood	Portable computer laboratory upgrade	$23,100
LIEF	Kennett, Heinson and O'Reilly	Instrumentation for combined seismic and electromagnetic Earth sounding	$350,000
PGRF	Milan	The emplacement, presure-temperature-time path and structural evolution of lower crustal gneiss in Fiordland, New Zealand	$4,000
PGRF	Nikolic	Evolution of crust-mantle systems near a young rift: NW Spitsbergen, Norway	$4,000
APA	Murgulov	Crust-mantle evolution and metallogeny, E. Australia	$19,231

Appendix 5: Funded research projects 2006

2006 Funding Source	Investigators	Project Title	Amount
iMURS	Caulfield	Tofua volcano- Tonga Arc, Eruption history and timescales of Magma Chamber Processes	$42,231
iMURS	Chevet	Gabbroic rocks from the Kerguelen Island (Indian Ocean): a petrologic, geochemical and isotopic investigation of their origin	$42,231
iMURS	Cunningham	A U-series isotope study of magma residence times, and petrogenesis of Rabaul Caldera, Papua New Gunea	$42,231
iMURS	Kobussen	Composition, structure and evolution of the lithospheric mantle beneath Southern Africa	$42,231
IPRS	Li	Stable metal isotope geochemistry of the Cadia and Northparkes porphyry Cu-Au deposits	$42,231
iMURS	Locmelis	Understanding nickel deposits using platinum group element geochemistry	$7,666
IPRS	Mwandu Batumike	The origin of kimberlites from the Kundelungu region (D.R. Congo) and the nature of the underlying lithospheric mantle	$42,231
iMURS	Nikolic	Evolution of crust-mantle systems near a young rift: NW Spitsbergen, Norway	$42,231
iMURS	Portner	Spreading ridge sedimentation processes: a novel approach using Macquarie Island as a natural laboratory	$42,231
RAACE	Carroll	The mechanisms and deep-crustal controls on continental rifting	$19,165
RAACE	Milan	The emplacement, pressure-temperature-time path and structural evolution of lower crust gneisses in Fiordland, New Zealand	$19,231
AIG Student Bursary	Harb	Fragmentation processes, depositional mechanisms and lithification of glassy fragmental rocks, Macquarie Island	$1,500

FUNDED RESEARCH PROJECTS 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	Discovering the deep mantle: experimental petrology at very high pressures	$10,000
ARC Linkage Project	O'Reilly, Griffin	Global lithosphere architecture mapping (Extra Industry Contribution)	$30,000
ARC Linkage Project	O'Reilly, Griffin, O'Neill	Global Lithospheric Architecture Mapping II (Including Industry Contribution)	77,000
ARC Linkage Project	O'Reilly, Griffin, Pearson	Trace-element analysis of diamonds: new applications to diamond fingerprinting and genesis (Including Industry Contribution)	$128,823
ARC Federation Fellowship	Wood	Origin and evolution of Earth's chemical reservoirs	$316,222
ARC Federation Fellowship (uni contribution)	Wood	Origin and evolution of Earth's chemical reservoirs (Mu contribution)	$180,000
ARC Federation Fellowship	Turner	The time scales of geochemical cycles and Earth processes	$316,222
ARC Federation Fellowship (Uni Contribution)	Turner	The time scales of geochemical cycles and Earth processes	$168,390
DEST RIBG	O'Reilly	GEMOC-Geochemical Analyst	$60,000
Aust. Antarctic Division	Daczko, Mosher	The environmental and tectonic implications of volcaniclastic deposits on Macquarie Island	$70,000 (in kind)

Appendix 5: Funded research projects 2007

2007 Funding Source	Investigators	Project Title	Amount
MQVC Innovation Fellowship Research Grant	Belousova	Tomorrow's *TerraneChron*®: new developments, new deliverables and new destinations	$19,684
MQVC Innovation Fellowship	Belousova	Tomorrow's *TerraneChron*®: new developments, new deliverables and new destinations	$66,831
Safety Net	Belousova	The growth of the continental crust: a global approach	$19,350
Department of EPS	O'Reilly, DEPS	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	$66,136
DVC (Research) Discretionary Fund	Turner	Support for Fellow in Feodor Lynen Project (Christoph Beier)	$20,000
Capital equipment	Lackie	Time-Domain EM system	$52,495
LIEF	Honda et al.	A New Generation Noble Gas Mass Spectrometer Facility for Advanced Research in the Earth, Planetary and Environmental Sciences	$700,000
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
iMURS	Cunningham	A U-series isotope study of magma residence times, degassing and petrogenesis of Rabaul Caldera, Papua New Guinea	$43,116
iMURS	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

2007 Funding Source	Investigators	Project Title	Amount
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	Mwandu 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, presure-temperature-time path and structural evolution of lower crustal gneiss in Fiordland, New Zealand	$11,880

ARC Research Projects initiated prior to 2006 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: Flowsheets for courses in geology and geophysics

Bachelor of Science

ENVIRONMENTAL GEOLOGY

Other variations available. Approximate load of 24 credit points per year.

Earth and Planetary Sciences

Are you interested in:
- ***Earth's Environment***
- ***Contaminated Land Remediation***
- ***Geochemistry***
- ***Groundwater Contamination***

Environmental geology explores the interaction of people and the geologic environment. This field covers the movement of toxins into the ground and through the groundwater system; the identification of these toxins and the remediation of the site. Environmental Geology combines the classic observation skills of geology with those of geochemistry, geophysics, land use planning and government policy implementation.

FIRST YEAR

Units: GEOS112 Planet Earth
GEOS114 Global Environmental Crises
GEOS115 Earth Dynamics, Materials and the Environment
GEOS224 Introduction to Field Geology (vacation unit)
CHEM103, BIOL114

SECOND YEAR

Units: GEOS230 Field and Laboratory Studis in Geoscience
GEOS260 Marine Depositional Environments
GEOS265 Introduction to Resource and Environmental Management
GEOS266 Earth Surface Processes
GEOS268 Introduction to Geophysics
GEOS251 Minerals, Energy and the Environment

THIRD YEAR

Units: GEOS315 Environmental and Groundwater Geophysics
GEOS377 Environmental Geology
GEOS399 Soils
GEOS437 Geochemical Applications
GEOS398 Applied Geomorphology *or*
GEOS307 Field Geology and Mapping *or*
GEOS328 Land Management

FOURTH YEAR (HONOURS)

1. **HONOURS:** The honours year consists of an 8 or 16 credit point research thesis and 8 or 16 credit points of coursework, generally at 400 or 800 level.
2. **MASTERS PROGRAM:** A research MSc is undertaken over a two year period; this may include up to 4 units and a major research project. A coursework program is possible.

These notes are only intended to guide your selection, and you should seek Academic advice and read the Calendar's Unit descriptions and coherencies for details. The offering of Units may change from year to year.

For more information please contact: The Executive Officer, Earth and Planetary Science
Ph. 61-2-9850 8373 Fax. 61-2-9850 6904
Email: eps@mq.edu.au

MACQUARIE UNIVERSITY SYDNEY

Bachelor of Science or Arts

GEOLOGY MAJOR

Other variations available. Approximate load of 24 credit points per year.

Earth and Planetary Sciences

Are you interested in:
- ***Volcanoes***
- ***Earthquakes***
- ***Seismology***
- ***Exploration***
- ***Earth History***

Geologists aim to understand the way the earth works and how it has evolved over the 4·6 billion years since its formation. Geology can be combined with geophysics, biology, archaeology, history, chemistry, maths, physics and law. Employment can be found in areas such as Mining and Exploration companies, teaching, public service, law, conservation and environment, stock market, engineering and research.

FIRST YEAR

Core: GEOS115 Earth Dynamics, Materials and the Environment
GEOS112 Planet Earth *or* GEOS116 Marine Geosciences and
GEOS224 Introduction to Field Geology (vacation unit)

Plus additional units from:
BIOL, CHEM, MATH, PHYS140 or PHYS, COMP, or other.

SECOND YEAR

Core: GEOS235 Palaeontology
GEOS230 Field and Laboratory Studies in Geoscience
GEOS260 Marine Depositional Environments
GEOS268 Introduction to Geophysics

Optional: GEOS251 Minerals, Energy and the Environment
GEOS272 Earth's Evolving Environment
GEOS266 Earth Surface Processes
GEOS237 Natural Hazards
GEOS264 Geographic Information Systems

THIRD YEAR

Core: Geos307 Field Geology and Mapping

And at least 3 units from:
GEOS308 Structural and Metamorphic Geology
GEOS312 Invertebrate Palaeontology
GEOS314 Magmas, Fluids and Ore Deposits
GEOS385 Global Tectonics
GEOS397 Applied Palaeontology and Biogenic Sediments

Suggested additional units: GEOS373 Volcanic Geology Fieldwork
GEOS528 Coral Reef Environment

FOURTH YEAR (HONOURS)

1. **HONOURS:** The honours year consists of an 8 or 16 credit point research thesis and 8 or 16 credit points of coursework, generally at 400 or 800 level.
2. **MASTERS PROGRAM:** A research MSc is undertaken over a two year period; this may include up to 4 units and a major research project. A coursework program is possible.

These notes are only intended to guide your selection, and you should seek Academic advice and read the Calendar's Unit descriptions and coherencies for details. The offering of Units may change from year to year.

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Email: eps@mq.edu.au

MACQUARIE UNIVERSITY SYDNEY

Bachelor of Science

GEOPHYSICS MAJOR

Other variations available. Approximate load of 24 credit points per year.

Earth and Planetary Sciences

Are you interested in:
- ***How the Earth Works***
- ***Earthquakes***
- ***Earth's Environment***
- ***Exploration***

Geophysics is the study of the physics of the Earth. The field of geophysics can be split into two broad areas -"Global" — the study of the Earth's structure and evolution, and "Exploration" — with near surface study in the fields of mineral, petroleum, environmental, groundwater and engineering geophysics.

FIRST YEAR

Core: GEOS115 Earth Dynamics, Materials and the Environment

Optional: GEOS112 Planet Earth
GEOS116 Marine Geoscience
GEOS224 Introduction to Field Geology (vacation unit)
MATH130, MATH135, MATH136, PHYS140, PHYS143
COMP115 *or* ISYS123 *or* COMP125, CHEM101

SECOND YEAR

Core: GEOS268 Introduction to Geophysics

Optional: GEOS260 Marine Depositional Environments
GEOS251 Minerals, Energy and the Environment
GEOS230 Field and Laboratory Studies in Geoscience
GEOS272 Earth's Evolving Environment
MATH235, MATH236, PHYS201, COMP238

THIRD YEAR

Core: GEOS315 Environmental and Groundwater Geophysics *or*
GEOS316 Exploration Geophysics
GEOS385 Golbal Tectonics
GEOS420 Data Image and Processing in Geophysics and Exploration

Optional: Appropriate Geology, Atmospheric Science or Maths, Physics and Computing units, depending on individual interest.

FOURTH YEAR (HONOURS)

1. **HONOURS:** The honours year consists of an 8 or 16 credit point research thesis and 8 or 16 credit points of coursework, generally at 400 or 800 level.
2. **MASTERS PROGRAM:** A research MSc is undertaken over a two year period; this may include up to 4 units and a major research project. A coursework program is possible.

These notes are only intended to guide your selection, and you should seek Academic advice and read the Calendar's Unit descriptions and coherencies for details. The offering of Units may change from year to year.

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Email: eps@mq.edu.au

MACQUARIE UNIVERSITY SYDNEY

Bachelor of Technology

EXPLORATION GEOSCIENCE - Geochemistry Strand

72 Credit points required

Earth and Planetary Sciences

Are you interested in:

- ***Exploration and Technology***
- ***Environment***
- ***Mining***
- ***Earth's Internal Processes***

Exploration geoscientists seek to apply modern techniques that interface between geology, geophysics and geochemistry to assist in targeting major prospective areas on or near the surface and ensuring environmental best practice in developing such areas. This is vital to Australia's future export earnings. Employment can be found in mining exploration and environmental consultancy companies, geoanalytical laboratories, government advisory bodies, research and teaching

FIRST YEAR

Core: GEOS115 Earth Dynamics, Materials and the Environment
GEOS116 Marine Geosciences and
GEOS224 Introduction to Field Geology (vacation unit)
CHEM101

And one of: PHYS140, PHYS143, MATH135, MATH136, COMP115

SECOND YEAR

Core: GEOS260 Marine Depositional Environments
GEOS268 Introduction to Geophysics
GEOS230 Field and Lavoratory Studies in Geoscience
CHEM207

Optional: GEOS266 Earth Surface Processes
GEOS272 Earth's Evolving Environment
GEOS315 Environment and Groundwater Geophysics or
GEOS316 Exploration Geophysics
STAT170 or STAT171

THIRD YEAR

Core: GEOS307 Field Geology Mapping
GEOS314 Magmas, Fluids and Ore Deposits
GEOS377 Environmental Geology
GEOS437 Geochemical Applications and Techniques
MPCE360

Optional: GEOS315 Environmental and Groundwater Geophysics or
GEOS316 Exploration Geophysics
GEOS373 Volcanic Geology Fieldwork
COMP238

FOURTH YEAR (HONOURS)

HONOURS: Honours year consists of a thesis of 16 credit points based on research using the latest equipment and 8 credit points of coursework, generally at 400 or 800 level.

These notes are only intended to guide your selection, and you should seek Academic advice and read the Calendar's Unit descriptions and coherencies for details. The offering of Units may change from year to year.

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MACQUARIE UNIVERSITY SYDNEY

Bachelor of Technology

EXPLORATION GEOSCIENCE - Geophysics Strand

72 Credit points required

Earth and Planetary Sciences

Are you interested in:

- ***Exploration and Technology***
- ***Environment***
- ***Mining***
- ***Earth's Internal Processes***

Exploration geoscientists seek to apply modern techniques that interface between geology, geophysics and geochemistry to assist in targeting major prospective areas on or near the surface and ensuring environmental best practice in developing such areas. Employment can be found in mining, exploration and environmental consultancy companies, geoanalytical laboratories, government advisory bodies and teaching.

FIRST YEAR

Units: GEOS115 Earth Dynamics, Materials and the Environment
GEOS116 Marine Geosciences and
GEOS224 Introduction to Field Geology (vacation unit)
PHYS140, PHYS143, MATH135, MATH136, COMP115
And one of CHEM101,CHEM103

SECOND YEAR

Core: GEOS260 Marine Depositional Environments
GEOS268 Introduction to Geophysics
MATH235, MATH236, ELEC166
GEOS315 Environmental and Groundwater Geophysics or
GEOS316 Exploration Geophysics

Optional: GEOS230 Field and Laboratory Studies in Geoscience
PHYS201, PHYS202

THIRD YEAR

Core: GEOS385 Global Tectonics
GEOS420 Data and Image Processing in Geophysics and Exploration
GEOS315 Environmental and Groundwater Geophysics or
GEOS316 Exploration Geophysics
GEOS460 Solid Earth Geophysics
MPCE360 Technology Management

Optional: GEOS314 Magmas, Fluids and Ore Deposits
GEOS307 Field geology and Mapping
GEOS373 Volcanic Geology Fieldwork
COMP238, ELEC274

FOURTH YEAR (HONOURS)

HONOURS: Honours year consists of a thesis of 16 credit points based on research using the latest equipment and 8 credit points of coursework, generally at 400 or 800 level.

These notes are only intended to guide your selection, and you should seek Academic advice and read the Calendar's Unit descriptions and coherencies for details. The offering of Units may change from year to year.

For more information please contact: The Executive Officer, Earth and Planetary Science
Ph. 61-2-9850 8373 Fax. 61-2-9850 6904
Email: eps@mq.edu.au

MACQUARIE UNIVERSITY SYDNEY

Bachelor of Marine Science

MARINE GEOSCIENCE MAJOR

Earth and Planetary Sciences

Are you interested in:

- ***Origin and evolution of the ocean basins***
- ***Ocean circulation and global climate***
- ***Evolution of the marine biosphere***
- ***Sediments and laves of the ocean basins***
- ***Marine fossil fuels***
- ***Marine Ore deposits***

Marine geoscientists aim to understand how and when the present ocean basins, the water that fills them and the biota that inhabit them were generated. Oceans are intimately connected with the atmosphere; circulation in each effects the other. The atmosphere and oceans exert a vital influence on global climate. A knowledge of the oceans is vital as the present oceans influence the redistribution of solar energy away from the equator, supply a significant amount of the world's food, act as sinks for carbon dioxide and modern and ancient oceans have produced much of the fossil fuel and mineral resources used by modern societies. The marine realm is still imperfectly understood and even more imperfectly managed in an environmental sense. Scientists who understand this huge part of the Earth's surface are needed to conduct research and to advise the increasing number of private and public groups who use the marine environment.

FIRST YEAR

Core: GEOS115 Earth Dynamics, Materials and the Environment
GEOS116 Marine Geoscience
GEOS117 Biophysical Environments
BIOL114 Evolution and Biodiversity

One from each line: CHEM102 or CHEM103
ATH130 or MATH135 or MATH136
GEOS112, PHYS140, PHYS143, PHYS159, STAT170, STAT171

SECOND YEAR

Core: GEOS216 The Atmospheric Environment
ELS201 Marine Science
GEOS260 Marine Depositional Environments

Plus at least 10 credit points from:
GEOS224 Introduction to field geology
GEOS235 Palaeontology
GEOS264 Geographic Information Systems
GEOS266 Earth Surface Processes
And any 200 level physics, chemistry or mathematics unit

THIRD YEAR

Core: ELS3YY Oceanography
ELS3XX Advanced Marine Science

Plus at least 12 credit points from:
GEOS301 Global Climates
GEOS312 Invertebrate Palaeontology
GEOS371 Geographic Information Systems: technical Issues
GEOS397 Applied Palaeontology and Biogenic Sediments
GEOS428 Coral Reef Dynamics
And any 300 level mathematics unit

These notes are only intended to guide your selection, and you should seek Academic advice and read the Calendar's Unit descriptions and coherencies for details. The offering of Units may change from year to year.

For more information please contact: The Executive Officer, Earth and Planetary Science
Ph. 61-2-9850 8373 Fax. 61-2-9850 6904
Email: eps@mq.edu.au

MACQUARIE UNIVERSITY SYDNEY

Appendix 7: 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

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 (eg 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

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

ACILP	Australia China Institutional Links Program
AGU	American Geophysical Union
AMIRA	Australian Mineral Industry Research Association
ANU	Australian National University
APA (I)	Australian Postgraduate Award (Industry)
APD	Australian Postdoctoral Fellowship
ARC (DP)	Australian Research Council (Discovery Project)
ARC LIEF	Australian Research Council Linkage Infrastructure Equipment and Facilities
BSE	Backscattered Electrons
CNRS	French National Research Foundation
CORES	Concentrations of Research Excellence
CRC	Co-operative Research Centre
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
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 - Inductively Coupled Plasma Mass Spectrometer
LIEF	Linkage Infrastructure, Equipment and Facilities
MC-ICPMS	Multi-Collector ICPMS
MOUs	Memoranda of Understanding
MQECRG	Macquarie University External Collaborative Research Grants (formerly MUECRG)
MUIPRA	Macquarie University International Postgraduate Research Award
MURAACE	Macquarie University Research Award for Areas and Centres of Excellence
MQRF	Macquarie University Research Fellowship (formerly MURF)
MQVC	Macquarie University Vice Chancellor
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
TPBL	Tailored Problem-Based Learning
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