2008 Annual Report
ARC National Key Centre for the Geochemical Evolution and Metallogeny of Continents

GEMOC
MACQUARIE UNIVERSITY
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www.es.mq.edu.au/GEMOC/ as a downloadable pdf file or in html format, and by mail as a CD on request. Our previous Annual Reports are also available at that web address, as well as a consolidated version of all GEMOC’s Research Highlights for 12 years.

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

Front Cover: Examining the entrails --- To understand the lithospheric architecture of Africa (see Research Highlight, p28) Craig O’Neill constructed this 3-D model of the high-velocity cratonic roots down to 400 km, using Steve Grand’s seismic tomography model. The West African and Congo cratons have deep robust roots; the root beneath the Kalahari craton has been greatly reduced by tectonism and metasomatism.
His report summarises GEMOC’s 2008 activities including research, technology development, strategic applications, 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 yearly goals, and submits an Annual Report fulfilling ARC reporting requirements.

GEMOC’s strategic vision of integrating geophysical, geochemical, petrologic, tectonic and geodynamic modelling to gain a better knowledge of our Earth system is being fulfilled; one example is our strong presence at the 33rd International Geological Congress in Oslo in 2008. Two major sessions (with GEMOC convenors) focussed on different aspects of geophysical and geochemical synergies and one on deep Earth geochemistry (also with a GEMOC convener) attracted stellar contributions and large audiences; participants included many of GEMOC’s international collaborators (see “GEMOC communications” section). A Lithos volume on the “Nature of the lithosphere-asthenosphere boundary through time” is being prepared as a result, and this Annual Report highlights a milestone achievement - the first major integrated paper from the GLAM (Global Lithospheric Architecture Mapping) program funded by WMC Exploration and then BHP-Billiton with ARC Linkage support (see cover and Research Highlight, page 28). GEMOC’s success in linking interdisciplinary knowledge and data is also evident in many of the 54 articles published in high-impact journals including Nature, Geology, Earth and Planetary Science Letters, Journal of Petrology, Geochimica et Cosmochimica Acta, G-cubed, Chemical Geology and Geophysical Research Letters. GEMOC also had prominent representation at all peak relevant conferences with keynote, invited and presented lectures.

The continuing support of GEMOC through the Earth and Planetary Evolution CoRE (Concentration of Research Excellence), as part of the initiative by Vice-Chancellor Professor Stephen Schwartz to expand Macquarie’s research activity and profile has resulted in six new academic positions in place (Professor Bill Griffin, Dr Tracy Rushmer and Dr Craig O’Neill from 2007, Professor Simon Turner, Dr Bruce Schaefer, Dr Juan Carlos Afnson) and one under recruitment (a geophysics position). This Earth and Planetary Evolution CoRE is extending and enhancing our research profile in: isotope and trace element geochemistry; lithosphere and Earth dynamics; geophysical imaging of Earth’s interior; dynamic modelling of Earth’s mantle; rheology of rocks and minerals; and cosmochemistry and meteoritics.

In 2008, GEMOC was again successful with ARC Discovery Projects (a 50% success rate) and Linkage Projects (reported in Appendix 5 and in the section on Industry Interaction). All of these projects involve international Partner Investigators, collaborators who extend our breadth and depth of expertise. We are maintaining our diversified portfolio of robust funding and resource bases ranging across direct funding from government sources and industry partners, collaborative projects and alliances with international researchers, institutions and industry, and strategic alliances with technology and instrument manufacturers.

GEMOC’s high visibility internationally is attracting a growing postgraduate group, strongly supported by Macquarie’s generous PhD scholarship schemes. Our postgraduate students had a high participation rate at national and international conferences, and gained three awards for outstanding student talks (see “GEMOC Communications” on page 23 and Appendix 4). They also had a high rate of publication in high-impact journals in 2008 (9 papers). There is a continuing contingent of postdoctoral researchers with independent funding. In 2008 these included international Postdoctoral Fellowships funded from Germany, Spain and Taiwan supplementing national and Macquarie sources.

GEMOC’s world-class geochemical and high-pressure experimental infrastructure (see page 67) is the critical core of most of our research and allows us to maintain a leading profile in geochemical analysis developments, especially in situ trace element and isotopic analysis.

The teamwork and dedication of all GEMOC participants is the key to our ongoing productivity and creativity, and I would like to acknowledge all of the efforts of those involved.
GEMOC in 2008

GEMOC’s research success and distinctiveness lie in its interdisciplinary approach to understanding the way the Earth works, integrating information across traditional discipline boundaries including geochemistry, geophysics, geodynamics and tectonics. This perspective has made GEMOC a world leader in understanding the complex evolution of the uppermost 200 km of the Earth (the lithosphere), its global geodynamic behaviour, the timing of important Earth episodes, and its origins. The addition in the last two years of six staff resulting from GEMOC’s status within Macquarie University as a Concentration of Research Excellence (CoRE, see below) has broadened GEMOC’s horizons, expertise and infrastructure. GEMOC now has world-class facilities with leading-edge technology in geochemical analysis (including novel laser-sampling capabilities), Australia’s first state-of-the-art U-series isotope laboratory, and a versatile high pressure/high temperature experimental facility to simulate the physical conditions of the Earth’s interior. These experimental studies can probe the early history and evolution of the Earth’s core, mantle and crust and illuminate planetary analogues.

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

During 2008, GEMOC’s research expertise and capabilities were further enhanced through the continuing implementation of Macquarie’s Concentration of Research Excellence strategy and resulted in the expansion of our in-house expertise to included geodynamic and geophysical modelling and computational Earth simulations.

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

GEMOC AND THE EARTH AND PLANETARY EVOLUTION CoRE STRATEGY

In 2006, Vice-Chancellor Professor Steven Schwartz designated GEMOC as an existing Concentration of Research Excellence (CoRE) in Earth and Planetary Evolution (EAPE) at Macquarie. The CoRE is being supported by new staff appointed from 2007 to enhance and expand research expertise and performance. GEMOC had built up an interdisciplinary approach to understanding the way the Earth works, integrating the traditional disciplines of geochemistry, geophysics, geodynamics and tectonics. We had developed cutting-edge isotope, geochemical and experimental instrumentation and strong collaborations with national and international researchers and industry. The Earth and Planetary Evolution CoRE seeks to build on these strengths to define the processes driving Earth’s global internal dynamics, and to understand how these have generated the present chemical and physical structure of our planet through time. New and reinforcing expertise from five CoRE recruits will now allow expansion into realistic geodynamic modelling and geologically significant modelling of geophysical datasets by combining new computational expertise with existing geochemical, petrological, tectonic and experimental knowledge bases. It will also enable continuing development of world-leading methodologies and applications in geochemistry (including isotopic) and especially for in situ (laser-ablation) analysis.
Advertisements sought applicants in the fields of rheology of rocks and minerals; geochemical analysis, lithosphere and Earth dynamics; geophysical imaging of Earth's interior; dynamic modelling of Earth's mantle; isotope and trace element geochemistry; cosmochemistry and meteoritics. Professor Bill Griffin, Dr Tracy Rushmer, and Dr Craig O'Neill commenced in 2007 and Dr Juan Carlos Afonso, Dr Bruce Schaefer and Professor Simon Turner commenced as CoRE staff in 2008. Recruitment is underway for another CoRE appointment.

**Mission**

- to define the processes driving Earth's internal dynamics, and understand how these have generated the present chemical and physical structure of our planet through time, integrating petrological, geochemical and geophysical information
- to provide a leading interdisciplinary research environment for the development of the next generation of Australia's geoscientists
- to deliver new concepts about the spatial and temporal distribution of Earth resources

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

**GEMOC’S STRATEGIC FOCUS**

The main targets of GEMOC’s original activities addressed large-scale problems related to lithosphere evolution and understanding the relevance of different types of crust-mantle domains to area selection for mineral exploration. These have broadened since GEMOC became self-funded in 2002, to involve whole-mantle perspectives of geodynamics, far-field and feedback effects on the lithosphere that shape Earth’s crust, and planetary studies that relate to Earth’s formation, differentiation and geochemical/geodynamic evolution. New ways of measuring the timing of Earth processes are defining the fourth dimension (time) with increasing clarity for crust, mantle, core and magmatic events. New capabilities in high-pressure experimental work are simulating deep Earth conditions, another complementary approach to probing Earth’s early history and evolution and understanding planetary analogues.

Sue O’Reilly gave a presentation on behalf of GEMOC at the Australian Research Council Graeme Clarke Outcomes Award Day at Parliament House, Canberra, May 2008 (see GEMOC Communications 2008).
Industry collaboration has increased with funded large-scale collaborative projects related to lithosphere evolution, crustal generation and diamond formation and fingerprinting. The delivery of new tools and a new framework of terrane analysis to the mineral exploration industry has generated much collaboration. Funded projects dealing with magma-related Ni deposits, plume magmatism and PGE deposits, diamond exploration, and deep-lithosphere structure through time capitalise on our depth of intellectual property about deep Earth processes from the lithosphere to the core.

**SCIENTIFIC PHILOSOPHY**

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

- petrology and geochemistry
- experimental petrology and petrophysics
- geophysics
- petrophysics
- tectonics
- numerical and dynamical modelling

within the important contexts of...

- time
- thermal state

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

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

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

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

*This report documents achievement of these goals in 2008 and aims for 2009*
GEMOC is based at Macquarie University (in the Department of Earth and Planetary Sciences).

There is active national collaboration with state Geological Surveys, GA (Geoscience Australia), CSIRO, ANU/RSES and other national universities, and several major industry collaborators, across a broad range of projects related to GEMOC’s strategic goals. A distinctive feature of GEMOC is the high level of active international collaborations and reciprocal links.

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

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

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

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

Changes in 2008

2008 arrivals and appointments in the EAPE CoRE

Dr Juan Carlos Afonso

Dr Juan Carlos Afonso accepted his offer of a position at GEMOC in the Department of Earth and Planetary Sciences in mid 2008. After graduating with a PhD from Carleton University (Ottawa), he undertook postdoctoral research at the Institute of Earth Sciences Jaume Almera (CSIC, Barcelona) on the development of new methods to study the thermal and compositional structures of the lithospheric/sublithospheric upper mantle. His background is in theoretical and computational geophysics/geodynamics. His current research integrates different disciplines such as mineral physics, potential field modelling, thermodynamics, and physics of the mantle in general, to explore and improve our understanding of plate tectonics. In particular, he is interested in the evolution of the lithospheric mantle, the mechanical and geochemical interactions between tectonic plates and the sublithospheric mantle, and their effects on small- and large-scale tectonic processes.
Dr Bruce Schaefer moved from Monash University to start his position at GEMOC in the Department of Earth and Planetary Sciences in September, 2008. Bruce has research interests centred around understanding geodynamic processes through the application of isotope geochemistry. In recent times this has involved the application of Os isotopes to investigation of the large scale Earth, including the convecting Earth, core-mantle interaction and the growth and stabilisation of continents and their underlying lithospheric mantle. More specialised applications have included investigation of Precambrian organic rich sedimentary systems, the “Snowball Earth” and extraterrestrial studies; in addition to investigation of Proterozoic terranes by conventional isotopes. He will be continuing to develop Os isotope capabilities at Macquarie in order to expand the range of problems able to be addressed by such techniques.

Professor Simon Turner transitioned during 2008 to Professor in the EAPE CoRE following his Federation Fellowship. Forefront in a range of research interests is the use of uranium series isotopes to constrain the time scales of magmatic and erosional processes. These can be used to assess the physical mechanisms of melt formation, transport, differentiation and degassing within the Earth. Other research interests include orogenic and post-orogenic granite petrogenesis, sediment provenance, crustal growth, continental flood basalts, potassic lavas associated with high plateau formation, ocean island basalts and island arc lavas.

Other new arrivals and appointments in 2008

Dr Tony Dosseto was awarded an independent Macquarie University Research Fellowship after 4 years as a Research Associate at GEMOC. Tony’s research during 2008 focussed on surface processes through application of U-series isotopic analysis. These included: catchment erosion response to climate change over the last glacial cycle and investigation of how the landscape responds/adapts to climate change; combined use of uranium-series and cosmogenic isotopes to study the controls on the evolution of weathering profiles and soil resources; and studies of small and large catchments under various climates to understand how fast sediments are produced, stored and exported.
Dr Claudio Marchesi joined GEMOC in January 2008 with a 1-year fellowship from the University of Granada. He was subsequently awarded a Marie Curie Fellowship (2009-2010) that will be jointly held at Montpellier and Macquarie Universities. During 2008 his research focussed on the nature of the exposed lithospheric mantle in the Ronda Massif, southern Spain (see Research Highlight). The Ronda Massif is a peridotite-pyroxenite complex that provides a unique natural laboratory to study the interaction of mafic melts with ultramafic wall rocks. These mantle-derived rocks, now thrust onto the Earth’s surface, reveal a sharp melt-infiltration interface that has been frozen in a domain containing both peridotite and garnet pyroxenite. This potentially provides the key to identifying how different elements behave during partial melting of a heterogeneous mantle region, and the length-scales of their homogenisation and/or decoupling during melting.

Dr Justin Payne started his position as geochemist at GEMOC in the Department of Earth and Planetary Sciences in April 2008. He graduated from the University of Adelaide in 2008 with a PhD that explored the tectonic evolution of the Gawler Craton and broader Mawson Continent during the late Archaean and early Proterozoic. His research uses geochemistry, isotope geochemistry and geochronology to understand mechanisms of crustal growth and recycling with emphasis placed upon global tectonic regimes of the early Proterozoic. He has extensive experience with laser-ablation inductively coupled mass-spectrometer analysis.
GEMOC’s organisation

GEMOC’s organisation involves four interlinked programs: Research, Teaching and Training, Technology Development and Industry Interaction. Basic research strands are supported by parallel applied collaborative research with industry partners: these provide the impetus for technology development. This development is in turn supported by strategic alliances with front-line instrument designers and manufacturers (e.g. Nu Instruments, Agilent Technologies, New Wave Research). Teaching and training benefit directly from these new advances. Technology development has been transferred to relevant end-users, applied in postgraduate research programs, and is the essential core that provides the data underpinning the conceptual advances about lithosphere architecture and evolution, core formation and planetary origins in GEMOC.
SCIENTIFIC CONTEXT

HERMAL ENERGY TRANSMITTED FROM THE DEEP EARTH (core and convecting mantle) provides the energy to drive lithosphere-scale processes. Mantle-derived fluids and the tectonic environment control element transfer across the crust-mantle boundary and control commodity distribution in the accessible crust. The nature of mantle heat transmission reveals information on fundamental deep Earth processes from the core-mantle boundary to the surface. The lithology of the Earth’s lithosphere can be mapped using fragments of deep materials such as mantle rocks and diamonds, and the compositions of mantle-derived magmas. Timescales can be measured 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 concentrations 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 STRATEGY

The Research Program for 2008 follows the topics of the funded projects listed in Appendix 5; all contribute to the four strands (described below) that were established to achieve GEMOC’s vision and goals. Summaries of funded basic research projects are given 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 focussed on four strands: the current Research Program has extended the scope of these original strands and is pushing into new conceptual and technology frontiers, building on our intellectual capital from the first phase of GEMOC and the new expertise in the Earth and Planetary Evolution CoRE.
Mantle Dynamics and Composition

forms the framework for advancing our knowledge of Earth’s geochemical and physical evolution. The thermal output driving Earth’s “engine” has declined exponentially through time, and the distribution of heat sources must have changed with the geochemical evolution of Earth. How has this secular cooling of Earth affected the internal driving forces, and what does this imply about changes in Earth dynamics through time? When did subduction processes begin? Novel approaches using redox-sensitive metal-isotope systems will be used to examine changes in the mantle’s oxidation state, and potentially provide, in combination with geochemical-petrological-thermomechanical models, constraints for the role and processes of subduction. These models will be used to study the evolution and stability of both oceanic and continental lithosphere.

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, the nature of the accretion process, and the effects of core differentiation.

Lithosphere Mapping provides the fundamental data for defining lithospheric mantle domains in terms of composition, structure and thermal state. It represents the basis for any evolutionary model of the Earth, as well as for understanding the relationships between geophysical observables (e.g. electrical conductivity, seismic velocity, etc) and the physical state of the Earth’s interior. Lithosphere profiles built up from this information are interpreted in the context of geophysical datasets (especially seismic tomography) to extrapolate laterally.

Recent developments towards an internally consistent geochemical-petrological-geophysical methodology to map lithospheric and sublithospheric upper mantle domains link with the other three Research Strands and are helping to define the large-scale evolution of mantle processes through time, and their influence on the development of the crust and metallogenic provinces (see cover and Research Highlights). 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. State-of-the-art numerical techniques that combine realistic rheologies, metamorphic reactions, and partial melting, are being used in 2D and 3D numerical simulations 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 Metallogenic Provinces strands.
RESEARCH PROJECTS FEEDING MAJOR PROGRAMS

Mantle Dynamics and Composition

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

U-series applications to timescales of lithosphere processes  (see Research Highlights)

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

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

Origin of mantle eclogites

The composition of Earth’s core and timing of core formation; core-mantle interaction

Interpretation of deep seismic tomography  (see Research Highlights and cover)

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

Diamonds: origin and clues to deep mantle and lithosphere evolution and structure

Basalts as lithosphere/asthenosphere probes  (see Research Highlights)

Plume compositions, sources and origins

Thermal framework of the lithosphere: paleogeotherms, heat production, conductivity, thermal evolution  (see Research Highlights)

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

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

Metal isotopes as tracers of lithosphere processes and Earth evolution  (see Research Highlights)

Crustal Evolution and Crustal Processes

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

U-series analysis of weathering and erosion processes

Dating lower crust domains and tracking extent of Archean crust  (see Research Highlights)

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

Tracers of magmatic processes: trace elements in accessory minerals

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.
GEMOC’s research program

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

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®, eastern China, South America, Canada, South Africa, Australia, India, Norway (see Research Highlights)

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

Formation of Earth’s first silicic crust

Metallogensis

U-series applications to timescales of fluid movement

Metal isotope applications to ore genesis (see Research Highlights)

Geochemistry of mantle sulfides

Area selection and evaluation for diamond exploration

Diamond trace elements as clues to diamond formation

Lithosphere domains through time and location of ore deposits (see Research Highlights)

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 metallogensis through time

Re-Os dating of mantle sulfides in situ and timing of mantle processes (see Research Highlights)

Application of $^{186}$Os to geochemistry and cosmochemistry (see Research Highlights)

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

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

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 (see Research Highlights and cover)

Tasman Fold Belt: terrane analysis

Paleomagnetic studies of the northern New England Orogen

Subsurface pluton shape: Gravity studies

Antarctic seismic studies

Deep crustal processes (New Zealand) (see Research Highlights)

Plate margin processes (Papua New Guinea, Macquarie Island)

Geodynamic modelling of large-scale processes, integrating constraints from 4-D Lithosphere Mapping (see Research Highlights)

Evolution of lithospheric composition and Earth geodynamics through time (see Research Highlights)
Funded basic research projects for 2008/2009

Unded research projects within GEMOC are formulated to contribute to the long-term, large-scale strategic goals and determine the short-term research plan. Research goals for each year are linked to the aims of funded projects. Summaries of these projects are given here.

Diamond genesis: cracking the code for deep-Earth processes
Bill Griffin, Sue O’Reilly, Norman Pearson, Thomas Stachel, Oded Navon, Jeff Harris: Supported by ARC Discovery (commenced 2009)
Summary: Diamonds carry unique, but cryptic, information on Deep Earth processes. We will take a new approach to the question of how diamond forms deep in the Earth. We will integrate our recently developed techniques for trace-element analysis and new types of compositional imaging with in situ analysis of the isotopic composition of C, O, H and N in a range of diamond types, and in genetically related silicate, sulfide and oxide minerals. This innovative approach will provide new insights into the nature and origin of the fluids that precipitate diamond in the Earth’s lithosphere, the transition zone and the lower mantle. These data and insights will become the basis for new geochemical approaches to diamond exploration and target evaluation.

Partial melting in natural metal-silicate and silicate systems: rheological and geochemical implications for the Earth and other planets
Tracy Rushmer: Supported by ARC Discovery (commenced 2009)
Summary: Differentiation is the separation of a melt or fluid from its host. It is the fundamental mechanism by which the terrestrial planets have evolved both chemically and physically through time and central to how the crust has evolved from mantle, how metallic cores are formed from undifferentiated planetary bodies and how economic elements can be concentrated. This proposal tackles this primary process by using the true (observed) rock textures and compositions as templates uniquely constrained by experiment so that numerical modelling can quantify flow processes and deformation regimes. It provides a basis for understanding fluid migration in dynamically evolving permeable networks.

Application of very short-lived Uranium-series isotopes to constraining Earth system processes
Simon Turner, Tony Dosseto, Mark Reagan: Supported by ARC Discovery (commenced 2009)
Summary: Precise information on time scales is fundamental to understanding natural processes. 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 will establish new procedures at the recently founded world-class Uranium-series research facility at Macquarie University for analysing very short-lived isotopes (22 years). These new abilities will be utilised to determine the mechanisms of melt/fluid migration and volcano degassing and to ascertain rates of soil production and erosion over time. The methodologies developed will also have application to Uranium exploration and nuclear safeguarding.
Basin development in Proterozoic South Australia: developing a time-integrated, compositional framework to assist mineral exploration

Elena Belousova, Bill Griffin, Anthony Reid (PIRSA) and Alsa Schwarz (PIRSA) (commenced 2008)

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

Episodicity in mantle convection: effects on continent formation and metallogenesis

Craig O’Neill: Supported by ARC Discovery (commenced 2008)

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

Global lithospheric architecture mapping II

Sue O’Reilly, Bill Griffin and Craig O’Neill: Supported by ARC Linkage and BHP Billiton (commenced 2008)

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

Tomorrow’s TerraneChron®: new developments, new deliverables and new destinations

Elena Belousova: Supported by Macquarie University Innovation Fellowship Program (commenced 2006)

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.
Forming Earth's first silicic crust

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

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

Earth's internal system: deep processes and crustal consequences

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

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

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

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

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

Nathan Daczko and Julie Dickinson (University of Sydney): Supported by ARC Discovery (ended 2008)
Summary: This project is the first that aims to understand the generation, deposition and lithification of sedimentary rocks at mid-ocean spreading ridges. It will improve our understanding of the construction of significant volumes of oceanic crust that commonly host important economic resources such as cupferiferous sulfides. The project will examine spreading-related sedimentary rocks, including processes relating to their depositional system, utilising unique exposures on Macquarie Island, where in situ oceanic crust still lies within the basin in which it formed. This research will examine the south eastern tectonic plate boundary of Australia, providing analogues for seafloor-spreading-related crustal processes at present plate boundaries and ancient examples now joined to the Australian continent. The scientific innovation represented by this project will help Australian scientists to better understand an important part of the plate tectonic cycle. This project will be of direct relevance to the Australian minerals exploration industry and will provide better constraints on rift-related metallogenesis.

Mantle melting dynamics and the influence of recycled components

Simon Turner: Supported by ARC Discovery (ended 2008)
Summary: Precise information on time scales and rates of change is fundamental to understanding natural processes and central to developing and testing physical models in the earth sciences. Uranium series isotopes have revolutionised the way we think about time scales because they can date processes which occurred in the last 10-350 000 years. This proposal aims to use U-series isotopes to constrain the rates of mantle melting and residual porosity beneath the Manus Basin, Papua New Guinea and the East Pacific Rise. By contrasting normal and enriched basalts we aim to constrain the effect of heterogeneities, including volatiles, on mantle melting. This will radically improve our understanding of mantle melting, which powers the Earth’s dynamics. This proposal is directly concerned with the continuing aim of building a sustainable Australia through knowledge of deep earth resources. The more we know about the processes of melting and melt and fluid migration the better we will be able to form 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 (ended 2008)
Summary: The aims of this project are to understand the processes by which the Earth separated its metallic core, to test models of how it developed ‘enriched’ and ‘depleted’ mantle components and to constrain the nature of continuing interactions between near-surface geochemical reservoirs and Earth’s deep interior. These processes have traditionally been followed using chemical tracers, but lack of understanding of chemical behaviour under the conditions of the deep Earth limits their application. This project is aimed at filling the gap, by determining experimentally, at high pressures and temperatures, the chemical behaviour of those trace elements which are central to our understanding of geochemical processes in Earth’s interior. The project is aimed at providing fundamental data which Earth Scientists will use to understand the processes by which Earth separated into its chemically-distinct layers (core, mantle, crust, atmosphere, oceans) and to determine the nature of the continuing interactions between the surface environment in which we live and the deep interior.
Discovering the deep mantle: experimental petrology at very high pressures

Bernard Wood (CI on project based at ANU with H.S. O’Neill and T. Irfune): Supported by ARC Discovery (ended 2008)

Summary: A novel super-hard diamond composite material will be used to double the pressures accessible to experimental investigation under carefully controlled conditions in the 'multi-anvil' apparatus, in order to study the Earth’s lower mantle (below 670 km depth). Anticipated results include a better understanding of how the Earth’s core formed, how the mineralogy of the lower mantle changes with depth and with redox state, and what controls the strength of the lower mantle, and thus how the mantle convects and how long-lived geochemical heterogeneities might be preserved. The great processes that shape the Earth at its surface, including plate tectonics and continental drift, can only be understood by appreciating how the interior of the Earth works. However, studying the deep Earth is difficult because of the enormous pressures and temperatures involved. This research proposes to simulate conditions in the Earth’s lower mantle (that is, below 670 km in depth) by making use of an Australian invented diamond-based ceramic, to double the pressure at which experiments can be performed.
GEMOC’s context in 2008

A SHORT HISTORY OF GEMOC

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

GEMOC’S FUNDING BASE FROM 2002

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

GEMOC’S LINKAGES AND ALLIANCES

GEMOC has significantly evolved and expanded from its original base with shifts in the original linkages and expansion in collaborations. Strong new national and international collaborative research links and programs have emerged, and robust ongoing engagement with industry (mineral exploration and technology manufacturing) partners through collaborative projects continues to fulfil one of GEMOC’s original goals and extend our intellectual and funding base.

On a break from fieldwork in Sezchuan, a visit to the Tiger Leaping Gorge of the upper Yangtze River. Right to left, Bill Griffin, Lijuan Wang (co-tutelle PhD student from Nanjing University), Jin-Hai Yu (Lijuan’s other supervisor) and Ming Zhang.
GEMOC’s 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 Concentration of Research Excellence within Macquarie University.

2008 MANAGEMENT ROLES

Professor Suzanne O’Reilly: Director of GEMOC.

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

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

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

Dr Richard Flood: represents Department Staff.
**Professor 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 (2008)**

**Board Members at Macquarie**

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

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

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

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

**Dr Kelsie Dadd** – *EPS Macquarie*

**Federation Fellows Professors Bernard Wood and Simon Turner** and

**GAU Manager Dr Norman Pearson** are ex officio members

**External Board Members**

**Adjunct Professor Michael Etheridge** – *Company Director*

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

**Dr Paul Heitherseay** – representative of PIRSA

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

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

“Annual Reports from 2003 are available as downloadable pdf files on the GEMOC website as well as in html format. All previous Annual Reports are available in html format.”
GEMOC WEB RESOURCES provide past Annual Reports, updated details on methods for new analytical advances and software updates (GLITTER), activities of research teams within GEMOC, synthesised summaries of selected research outcomes and items for secondary school resources. In addition, undergraduate teaching is web-based. Annual Reports from 2003 are available as downloadable pdf files on the GEMOC website as well as in html format. All previous Annual Reports are available in html format. Strong industry interaction in 2008 ranged from presentations to specific industry groups in their offices to numerous formal and informal workshops at GEMOC, and invited presentations at peak industry symposia, workshops and conferences nationally and internationally.

AWARDS
Professor Bill Griffin was elected a Geochemistry Fellow by the Geochemical Society and the European Association for Geochemistry. The citation included the following: “Our societies bestow this honor upon outstanding scientists who over the years, have made a major contribution to the field of geochemistry. As you are doubtless aware, this is a significant honor; the number of Fellows elected each year is limited to less than 1% of the membership of our combined societies and is typically significantly fewer. Your work has been recognized by your colleagues as rising to this stature.”

Professor Sue O’Reilly was awarded the W.B. Clarke Medal by the Royal Society of NSW for outstanding contributions to Geoscience in Australia.

GEMOC PUBLICATIONS FOR 2008 ARE GIVEN IN APPENDIX 2

The 88 GEMOC Publications that were published or in press for 2008 are mainly in high-impact international journals as listed by the internationally recognised Thomson ISI Citation data, and designated as A* and A journals by the ARC ERA (Excellence in Research) official journal ranking.

PARTICIPATION IN WORKSHOPS, CONFERENCES AND INTERNATIONAL MEETINGS IN 2008 (AND BEYOND)

GEMOC staff, postdoctoral researchers and postgraduates again increased their profile at peak metallogenic, geodynamic and geochemical conferences as convenors, invited speakers, or presenters, with 103 presentations including:

- International Conference of Arc-Continent Collisions IGCP 524 (National Cheng Kung University, Tainan, Taiwan)
- 13th ANZGG Conference (Queenstown, Tasmania)
- The Geological Society of America, Northeastern Section, 43rd Annual Meeting, (New York, USA)
- 39th Lunar And Planetary Science Conference (League City, Texas, USA)
- RST (Réunion Des Sciences De La Terre, Nancy, France)
• 5th Annual K-8 science and technology conference (Sydney)
• The 18th V.M. Goldschmidt Conference: From Sea To Sky (Vancouver, Canada)
• 19th AGC and The Australian Earth Science Convention (Perth, Australia)
• 33rd International Geological Congress (IGC) (Oslo, Norway)
• 9th International Kimberlite Conference (Frankfurt, Germany)
• 2008 IAVCEI General Assembly (Reykjavik, Iceland)
• 2008 Joint Meeting of The Geological Society of America, Soil Science Society of America, American Society of Agronomy, Crop Science Society of America, Gulf Coast Association of Geological Societies with the Gulf Coast Section of SEPM (Houston, Texas, USA)
• Annual National Symposium on Petrology and Geodynamics (Guiyang, China)
• Geosciences ‘08, The Joint Annual Conference of the Geological Society of New Zealand, the New Zealand Geophysical Society and the New Zealand Geochemical and Mineralogical Society (Te Papa, Wellington, New Zealand)
• AGU Fall Meeting (San Francisco, USA)

A full list of abstract titles for Conferences and Workshops attended is given in Appendix 4 and on the GEMOC website where full-text versions of many of the abstracts can also be found.

Keynote talks in 2008 included (first author given; see Appendix 4 for titles and full authorship): 19th Australian Earth Science Convention – Belousova, O’Reilly, Griffin; 33rd International Geological Congress in Oslo – Pearson, Griffin; 18th Annual V.M. Goldschmidt Conference (Vancouver) – Corgne, O’Neill; 5th Annual K-8 Science and Technology Conference – O’Neill; New Zealand Geological Society Conference - Turner. GEMOC research was represented by 27 talks at the peak 9th International Kimberlite Conference in Frankfurt.

Norman Pearson was an invited presenter at the Mineralogical Association of Canada Short Course on Laser Ablation ICP-MS at the 18th Annual Goldschmidt Conference.

Tracy Rushmer continued as a “Member at Large” on the Geological Society of America Penrose Committee, appointed for 2007-2010.

Tracy Rushmer was a member of the Mineralogical Society of America Distinguished Lecture Program Committee for term 2006-2008.

Sue O’Reilly continued as a member of the International Kimberlite Conference Committee.

Simon Turner was appointed as a director of the Geochemical Society.

Bill Griffin continued as a member of the Australian Research Council (ARC) Expert Advisory Committee.

Nathan Daczko is chair of the Geological Society of Australia Specialist Group in Tectonics and Structural Geology (SGTSG) and chair of the organising committee for the 2010 field conference.
Bill Griffin was co-convenor for the session on “The continental lithosphere from geophysical and geochemical data” at the 33rd IGC in Oslo (August, 2008).

Sue O’Reilly was chief convenor for the session on “The lithosphere-asthenosphere boundary: nature, formation and evolution from Hadean to now” at the 33rd IGC in Oslo (August, 2008).

Elena Belousova was co-convener for a special session on “Sedimentary Constraints on Composition and Evolution of the Continents, Continental Reconstructions and Basin Evolution” at the 18th Annual V.M. Goldschmidt Conference, (Vancouver).

Bill Griffin is co-convenor for the session “Crust Coming of Age: From Accretion to Craton” at the 19th Annual V.M. Goldschmidt Conference to be held in Davos, Switzerland in June 2009.

Craig O’Neill was a convenor for the Theme “Plate Tectonic Processes and The Dynamic Mantle” at the Australian Earth Sciences Convention (Perth); the Session on “Subduction Processes” at the Western Pacific Geophysics Meeting (Cairns); and the Session on “Geochemical Heterogeneities in OIB and MORB Sources: Implications” at the American Geophysical Union Fall Meeting (San Francisco).

Tracy Rushmer will be a co-convenor for the Penrose Conference “Plumes and their role in whole mantle convection and recycling” to be held in the Azores in May 2009.

Norman Pearson was invited Guest Professor at the University of Vienna and presented a Short Course on “Laser Ablation Multi-collector ICPMS: Theory and Applications in the Earth Sciences”.

Sue O’Reilly gave a presentation on behalf of GEMOC at the Australian Research Council Graeme Clarke Outcomes Award Day at Parliament House, Canberra, May 2008. This award to GEMOC for “Scientific Advancement Outcomes” recognised the success of GEMOC’s TerraneChron®.

Norman Pearson is a founding member of the international organising committee of the ‘Working Group on Data Acquisition, Handling and Interpretation in Laser Ablation U(-Th)-Pb Geochronology’.

Craig O’Neill continued as Honorary Secretary of the NSW Division of the Geological Society of Australia.

Sue O’Reilly was an invited editor of a Special Volume of the Geological Society of London on the “Nature of the European Mantle” and is Chief Editor by invitation of the international journal, Lithos, of a thematic volume on the Nature of the Lithosphere-Asthenosphere Boundary.

Craig O’Neill authored an article titled “Evolution of a Habitable Planet” for the popular science journal Australasian Science.

Representation on editorial boards include: Lithos (Griffin, O’Reilly, Rushmer); Geological Society of America Bulletin (Griffin); Journal of Petrology (Turner); Chemical Geology (Griffin, O’Reilly); Elements (Schaefer); Acta Geologica Sinica (Griffin).
GEMOC PhD and honours students gave 15 presentations at international conferences in 2008 resulting in three awards:

- PhD student Weiqiang Li was awarded Best Student Presentation at the 18th Annual V.M. Goldschmidt Conference (Vancouver) for his paper “Cu isotopic anomalies around porphyry Cu deposits”.

- PhD student Lijuan Wang was awarded “Outstanding Student Presentation” at the Annual National Symposium on Petrology and Geodynamics, at Guizhou in October 2008 for her paper “U-Pb ages and Hf isotopic composition of detrital zircons in Proterozoic sandstones from southeastern Yangtze Block: Implications for crustal evolution”.

- Honours student Melissa Murphy was awarded Best Student Paper at the 19th Australian Geological Convention and Australian Earth Sciences Convention (Perth, Australia) for her honours research on Macquarie Island: “Provenance of ophiolitic sand: comparison of ancient and modern sand”.

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

Two volumes highlight the papers presented at the European Mantle Workshop in Ferrara

GEMOC had a high profile in both the organisation and scientific program at the 2007 European Mantle Workshop (EMAW) on the “Petrological Evolution of the European Lithospheric Mantle from Archean to Present Day”, held in Ferrara in August 2007. The event was organised by M. Coltorti (University of Ferrara), H. Downes (London University), M. Grégoire (Toulouse) and S.Y. O’Reilly (GEMOC) and was sponsored by the University of Ferrara, the Instituto Universitario di Studi Superiori (IUSS) of the same university, the Gruppo Nazionale di Petrografia (GNP) and the Federazione Italiana di Scienze della Terra (FIST). Abstracts, photographs and some presentations in pdf format are available at: http://www.unife.it/dipartimento/scienze-terra/emaw-2007. During 2008, the organisers have edited two proceedings volumes, one in the Journal of Petrology, the other, a Geological Society of London Special Publication.
**Research highlights 2008**

**TerraneChron®** is GEMOC’s unique methodology for terrane evaluation. During 2008 a range of new studies including collaborative research projects with industry using **TerraneChron®** expanded our knowledge of crustal evolution and the timing of tectonic events. **TerraneChron®**’s success was recognised at the Australian Research Council Graeme Clarke Outcomes Award Day held at Parliament House, Canberra in May 2008.

**What is TerraneChron®?**
- The methodology was developed by GEMOC to provide rapid, cost-effective characterisation of crustal history on regional (10-1000 km²) scales. It is based on U-Pb, Hf-isotope and trace-element analysis of single zircon grains by laser-ablation ICPMS (single- and multi-collector) methods.
  - U-Pb ages, with precision equivalent to SHRIMP.
  - Hf isotopes trace magma sources (crustal vs juvenile mantle input)
  - Trace elements identify parental rock types of detrital zircons

**What kind of samples?**
- Regional heavy-mineral sampling (modern drainages: terrane analysis)
- Sedimentary rocks (basin analysis)
- Igneous rocks (dating, specialised genetic studies)

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

**Applications to oil and gas exploration**
In provenance studies, the information from Hf isotopes and trace elements provides a more detailed source signature than U-Pb ages alone.
- **TerraneChron®** defines the crustal history of the source region of the sediment
- Changes in direction of basin filling track regional tilting, subsidence
- Stratigraphic markers in thick non-fossiliferous sediment packages
- Proven applications in the North Sea

**Visit the TerraneChron® web page at**
www.es.mq.edu.au/GEMOC/TerraneChron.html

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How the world was made: The GLAM project

The cover of this year’s Annual Report features one of the recent outputs of GEMOC’s Global Lithospheric Architecture Mapping (GLAM) project. This major effort began 5 years ago as a collaborative research project with WMC, funded by an ARC Linkage grant. When WMC was taken over by BHP Billiton, the project continued, with BHP sponsoring a second Linkage project that started work in 2008.

The GLAM project arose from WMC’s recognition that major ore deposits represent major transfers of mass and energy from the deep Earth, and that these fluxes require focusing by major, probably translithospheric, structures. This means that the most significant concepts and observations for predicting the localisation of giant ore systems are those related not to the deposit environment itself, but to the much larger entity – the ore system. GEMOC was brought into the project because of our broad expertise in the composition, origin and structure of the lithospheric mantle.

The aims of the project are ambitious:

- To map the fundamental lithospheric architecture of the continents to depths of about 250 km
- To combine these maps with 3-D imagery and numerical dynamic modeling, to explore major geodynamic processes related to the formation and breakup of continents
- To test the relationships between lithospheric architecture, Earth dynamics and the localisation of large ore deposits

The expected outcomes include maps of lithospheric architecture at three levels: 0-100 km, 100-175 km and 175-250 km, and 3-D visualisations of selected regions (see cover). The construction of these maps is proceeding through several stages, which can be illustrated by our recently completed analysis of Africa (see GEMOC Publication 547).

(1) A new tectonic analysis of each target area, integrating crustal geology, geochronology and tectonics. This is based on an exhaustive literature review, using resources from GEMOC (especially Lev Natapov), the industrial sponsor, and independent consultants for specific areas. Where existing geochronology is inadequate, GEMOC’s TerraneChron® technology is being deployed to provide new information on crustal genesis in key areas, and in particular to distinguish areas/periods where new crust was generated, or older crust was reworked. Our new map of Africa (Fig. 1) shows the type of information that is assembled and digitised in this first stage.

(2) A map is prepared showing upper lithospheric domains (crust + uppermost mantle, to = 100 km). The boundaries of these domains are defined on the basis of geology, topography, gravity, magnetics and derivatives of these. Using geochronological and geological data from the first stage, each domain is classified in terms of its origins and subsequent tectonic history. In Figure 2,
Archons (A) are volumes of the upper lithosphere that were formed before 2.5 Ga ago, and have escaped significant reworking since 2.5 Ga. Protons (P) are volumes generated between 2.5 and 1.0 Ga; Tectons (T) are younger than 1.0 Ga. It is especially important to recognise episodes of tectonothermal reworking; thus Archons reworked in Proterozoic time are shown as P/A, Protons reworked since 1.0 Ga become T/P, and so on. The definition of these domain boundaries is a key element in building a predictive model; Africa alone contains ca 200 upper lithospheric domains. The map in Figure 2 is a simplified version of the working files, lumping together adjacent domains with similar classifications.

(3) Lower lithospheric domains (100-175 km) are mapped, using a combination of seismic tomography and mantle petrology. The primary dataset is a global Vs tomographic model, generated by Prof Steve Grand (Univ of Texas, Austin) and enhanced through regridding and 3-D interpolation by WMC/BHPB geophysicists to provide exceptional resolution (see Research Highlight, p 31). This dataset is supplemented wherever possible with information derived from studies of mantle-derived xenoliths in kimberlites, basalts and other deep-seated igneous rocks. The interpretation of the seismic data in terms of mantle composition, and by inference its age, has made significant progress during the project (see GEMOC publication #548). New Re-Os studies are being carried out on xenolith suites from a variety of areas to nail down mantle history in some contentious areas. Beneath Africa (Fig. 3) this approach has allowed the division of the subcontinental lithospheric mantle (SCLM) into volumes that are classified in the same way as the upper lithospheric domains. This analysis has outlined three major blocks of highly depleted Archon SCLM, surrounded by relatively narrow zones that have been reworked/refertilised during Proterozoic time (and probably later).

A major conclusion from the African study has been that much of the SCLM beneath upper lithospheric domains classified as P/A, T/A or even T/P represents strongly reworked Archean SCLM.

(4) Next, the project attempts to outline and classify lower lithospheric domains (175-250 km). This process integrates the seismic tomography and mantle petrology to map the depth of the “lithosphere-asthenosphere boundary” – which beneath cratonic areas, at least, may simply be a zone of intense melt-related metasomatism (see GEMOC Publication #409). 2-D cross-sections (Fig. 4) and 3-D images of Vs isosurfaces in the tomography (see cover) emphasise the deep roots beneath some cratonic areas.
the steep sides of these highly depleted volumes, and the highly variable depth of the “lithosphere-asthenosphere boundary”.

(5) The maps are then interpreted in terms of mantle processes: the primary origin of the SCLM in each domain, the location and nature of zones of mantle reworking, the tectonic environments along domain margins through time, and the “event limits” of events such as mantle plumes that have affected the SCLM. The integration of these datasets and maps results in 4-D event charts for each continental landmass, derived from the history of both mantle and crustal domains. The principle can be illustrated by a cartoon showing the changing relationships between the different domains of Africa through time (Fig. 5). This analysis emphasises that Africa is made up of several major blocks, some of which have repeatedly joined and separated along some clearly recognisable domain boundaries. These major translithospheric structures then become major foci for exploration targeting.

In the new GLAM project, numerical modeling will be used to explore how and why domain boundaries open and close, how continents extend or deform during collisions, and what mechanisms lead to the extension of some cratons out under ocean basins, and the incorporation of ancient SCLM relics beneath the Atlantic ocean (Research Highlight, p31). A specific aim is to incorporate realistic temperature- and depth-dependent rheology for the SCLM and the convecting mantle, and realistic strain-weakening mechanisms.

Key questions remain: why do some domains and boundaries become the sites of large-scale mineralisation and others do not? Work is in progress to assess sites of preferential magma/fluid flow along lithospheric discontinuities, the differing fertility of lithospheric domains, and how heat distribution in the lithosphere controls magmatism and hydrothermal circulation.

Ultimately, the products of the GLAM project will be collated into an atlas, accessible online.

Contacts: Sue O’Reilly, Bill Griffin, Graham Begg, Jon Hronsky
Funded by: ARC Linkage, ARC Discovery, WMC Resources, BHPB, international collaborators.
Ancient lithosphere blobs beneath the oceans: spelling out the geochemists’ alphabet

The Nature of Continental Archean Lithospheric Mantle

Archean subcontinental lithospheric mantle (SCLM) is distinctive in its highly depleted composition, commonly strong stratification, and the presence of rock types (e.g. depleted, low-Fe harzburgite) absent in younger SCLM (see GEMOC Publications #90, #132, #234, #485, #542). Primary (unmetasomatised) Archean lithosphere is very low in basaltic components such as Al, Ca, Fe, consists dominantly of dunite and Ca-poor harzburgite and has high seismic wave velocities, mainly due to the high proportion of Mg-rich olivine (Fo 92-94). Archean lithosphere is significantly less dense than asthenosphere at any depth, and this buoyancy means that it cannot be gravitationally delaminated; it needs mechanical disaggregation (e.g. rifting) and/or metasomatic reworking to be disrupted.

Oceanic Archean Mantle Revealed in Tomographic Models

Figure 1 shows tomographic slices through the oceanic lithosphere and upper mantle of the Atlantic Ocean Basin at 0-100 km, 100-175 km and 175-250 km.

In the 0-100 km section, high-velocity regions are obvious. Some are apparently continuous with continental regions (especially off southwestern Africa and southeastern South America) and some occur as discrete “blobs” within the ocean basin, from the continental margins to the mid-ocean ridge. In the layer from 100-175 km, these fast domains persist, and some also show velocity contrasts in the 175-250 km layer.

A traditional interpretation for high-velocity regions at the margins of ocean basins is the effect of cooling of the oceanic lithosphere with time and distance from the ridge. However, this cannot be the explanation for the discrete blobs that lie within the ocean basin, both away from the original rift margins and near the present-day ridge, with some extending to depths of 250 km.

We suggest that these high-velocity volumes represent remnants of depleted (buoyant), ancient continental lithosphere, fragmented and stranded during the rifting process at the opening of the ocean basin. The high-velocity domains extending out from the coastlines are not uniformly distributed along the basin edge. The most marked high-velocity regions, off SE South America and northwest and southwest Africa, appear to be continuous with their respective continental deep structure as seen in the oceanic tomographic images.
in the tomographic models. The new global magnetic-anomaly map (Fig. 3) shows that these regions have a complex magnetic signature that is consistent with extended continental crust, and distinct from that of oceanic lithosphere, which is characterised by the regular magnetic striping produced at spreading centres.

Old Re-Os ages for mantle sulfides in some depleted mantle rock types beneath rift zones and oceanic areas (see references in GEMOC Publication #576) suggest that these high-velocity blobs (inferred to have high Mg# and low density) represent relict Archean to Proterozoic SCLM (now refertilised to varying degrees, during episodes of mantle fluid infiltration reflecting larger-scale tectonic events) that was mechanically disrupted and thinned during the formation of the oceanic lithosphere. This interpretation implies that ocean basins do not form by clean breaks at now-observed continental boundaries, but that significant volumes of buoyant old mantle are embedded within the newly generated oceanic lithosphere. The opening of ocean basins may be largely by listric faulting mechanisms, leaving significant wedges of continental lithosphere at rifted margins, and stranding domains of ancient lithosphere in the upper part of the new oceanic crust-mantle system, where they would remain as buoyant blobs.

If the higher-velocity coherent blobs observed at depths up to >150 km in the upper mantle of the Atlantic Ocean do represent remnant Archean mantle roots, this has important implications for the nature of global convection. Models involving large-scale horizontal movement would be difficult to reconcile with these observations. Instead, convection may be dominantly in the form of upwelling vertical conduits with shallow horizontal flow (Fig. 3). The locus of these conduits may be controlled by the geometry of the margins and the coherence of the buoyant lithospheric blobs.

**Ocean island basalt geochemical signatures**

The localised persistence of ancient SCLM beneath oceans also provides a logical explanation for the “alphabet soup” of mantle sources created by geochemists to describe the isotopic
signatures of basalts (EM1, EM2, HIMU, DMM; Fig. 4). These components are generally attributed to different geochemical reservoirs within the convecting mantle. However, all of these geochemical fingerprints are found in lithospheric material and have been well characterised in mantle xenolith studies (e.g. GEMOC publications #60, #219). If lithospheric volumes persist to deep mantle levels (>150 km) in ocean basins, then interaction with upwelling mantle plumes can “contaminate” magmas and fluids (Fig. 3), imposing a range of isotopic and trace-element signatures. A detailed examination of the ocean-island database from the Atlantic shows a strong correlation between “continental” signatures (EM1, EM2, etc) and the presence of high-velocity blobs in the seismic tomography (see GEMOC Publication #576).

This model removes the requirement for hidden source regions embedded within the convecting mantle. Magma interaction with deep ancient SCLM roots also provides a simple explanation for observations such as Archean Re-depletion model ages in oceanic basalts.

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Figure 4. Isotopic components commonly observed in basaltic magmas and their fields in Nd and Sr isotopic space (for more detail see GEMOC publication #576).

Isotopic variability in mantle sources: the melt percolation recipe

MANTLE ROCKS THAT OUTCROP AT THE EARTH’S SURFACE provide direct information on the composition and evolution of the Earth’s mantle. The isotopic systematics of most peridotite massifs and mantle xenoliths show a wide range of variation compared with single suites of mantle-derived lavas. Some of the isotopic variations observed in peridotite massifs are correlated with lithology, e.g. pyroxenites vs peridotites, and have been ascribed to convective mingling of subducted material with pristine material. Other small-scale heterogeneities have been ascribed to time-integrated enrichment in radioactive parent elements by percolating melts/fluids, superimposed on previously depleted rocks.

However the “instantaneous” (as opposed to “time-integrated”) effect of melt transport on isotopic systematics is usually neglected, although it may theoretically generate drastic fractionation of daughter elements from different isotopic systems. Under the temperature conditions of the lithosphere–asthenosphere transition, diffusional processes may be slow, and therefore chemical and isotopic equilibrium between minerals and percolating melts may not be reached.

This type of disequilibrium has been observed in the Lherz massif, the type locality of lherzolite, located in the French Pyrenees. The lherzolites have been shown to be secondary products, produced when melts refertilised a depleted harzburgite matrix (see Annual Report 2007; GEMOC Publication #544). The transition zone between the harzburgites and the
refertilised material represents a frozen melt-percolation front that moved through the subcontinental lithospheric mantle. Isotopic signatures at the melt percolation front show a strong decoupling of Hf from Nd isotopes (Fig. 1). This decoupling cannot be accounted for by simple mixing involving the harzburgite protolith and the percolating melt (dashed line between the two circled end-members), nor by the unlikely presence of OIB-type melts at the contact, nor by a chromatographic effect.

Using one-dimensional percolation–diffusion and percolation–reaction models, we can show that these signatures represent transient isotopic compositions generated by porous melt flow (Fig. 2).

The isotopic heterogeneity observed in the transition zone between harzburgites and lherzolites can be reproduced with a realistic range of physical parameters: a melt fraction of a few percent, a percolation rate of several cm/year, percolation over distances of tens to several hundreds of meters. The Lherz example suggests that a large range of isotopic signatures may be generated at a melt percolation front, depending on chemical diffusion, isotopic homogenisation and peridotite-melt compositions. Full details are given in GEMOC Publication #558.

Therefore, under certain circumstances, melt-rock interactions can generate enriched, “intraplate-like” isotopic signatures in the transition zone between the two contrasting components. These results suggest that some of the isotopic signatures of mantle-related rocks could be generated by diffusional processes associated with melt transport.

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Application of $^{186}$Os to geochemistry and cosmochemistry

$^{187}$ RE-$^{187}$Os ISOTOPE GEOCHEMISTRY has gained widespread utility in the geosciences over the past decade. Applications in studies of the mantle, ore deposits, organic rich sediments and meteoritics testify to the diversity of problems that can be tackled with this technique. However, another radiogenic Os isotope ($^{186}$Os) is formed by the decay of $^{190}$Pt. This decay scheme has not been widely applied as it is technically exceedingly challenging to measure $^{186}$Os anomalies. This is due largely to the combination of two factors; the half life of $^{190}$Pt is $\sim$430 billion years (ca 30 times the age of the universe) and $^{190}$Pt makes up only 0.01296% of naturally occurring Pt. Therefore the amount of radiogenic $^{186}$Os on the Earth is very small, and to detect any ingrowth due to this decay, we must use geochemical reservoirs that have had very high Pt/Os ratios for long periods of time. Historically the only such terrestrial reservoir was considered to be the outer core, but geochemists are increasingly recognising the presence of $^{186}$Os anomalies in other terrestrial materials, such as sulfides in the lithospheric mantle.

Over the past two years, GEMOC has been attempting to establish a protocol for $^{186}$Os analyses on the Triton TIMS housed in the GAU. Refinements in loading and acquisition routines have resulted in an increase in internal precision on individual analyses by an order of magnitude to $\pm 0.0000025$ on 20 ng sample loads, a precision equivalent to that achieved by other groups conducting such work. However, this precision has been achieved on smaller sample sizes than other groups are using routinely.

With this capability we can investigate a large range of earth science problems. For example, preliminary data from Proterozoic organic rich sediments tantalisingly suggest that there may be a significant crustal reservoir of $^{186}$Os which has been hitherto ignored in investigations involving potential contributions to plume derived basaltic magmatism (see cartoon). Furthermore, there is the potential to integrate the Pt-Os technique with $^{186}$Os isotopic data to map out distinct lithological domains in the mantle, providing another aspect to the debate regarding the relative role(s) of the subcontinental lithospheric mantle, the asthenosphere and recycled components in mantle plumes. Finally, Pt-Os studies of differentiated meteorites can place independent constraints on the timing and rates of core formation and segregation during planetary formation. We anticipate that with further refinements in both chemistry and mass spectrometry, GEMOC will become the first laboratory in the Southern Hemisphere to routinely apply this technology, and will become a world leader in its application.

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Journey in time and space beneath Kimberley South Africa

The "4-D" Lithospheric Mapping methodology developed at GEMOC describes the vertical and lateral variation in lithospheric mantle chemistry using mantle xenoliths or xenocrysts carried to the surface in volcanic eruptions. Where more than one episode of magmatism occurs in the same area, this methodology also can provide insights into the temporal evolution of the lithosphere. The Kaapvaal Craton in southern Africa is an ideal natural laboratory for this methodology because many kimberlites provide samples of the lithospheric mantle. The Kimberley area in particular contains kimberlites that have erupted during two episodes of magmatism, the first at approximately 120 ± 5 Ma (Group II kimberlites), and the other at approximately 90 ± 10 Ma (Group I kimberlites). The spatial coincidence of kimberlites with different ages provides samples of the lithospheric mantle during each eruptive episode; comparison of these samples tracks the chemical evolution of the lithospheric mantle during this interval (Fig. 1).

Peridotitic garnet xenocrysts are a common component of kimberlites and are collected extensively in diamond prospecting. Application of the garnet geotherm method to suites of garnets from each kimberlite in Figure 1 places these grains in a depth context, and gives a "train" of garnets below each kimberlite, similar to a vertical borehole (Fig. 2). In addition to temperature information, the garnets also contain information on depletion and metasomatism processes in the mantle, which is the basis of chemical tomography.

Previous applications of chemical tomography have involved constructing a local paleogeotherm and then plotting garnet-derived geochemical signatures as a function of depth for each locality considered. A natural extension of this method is to correlate the compositional and metasomatic processes from 50 to 250 km. In this volume the individual garnet xenocrysts are plotted at their calculated depths, with hotter colours indicating greater depth. The yellow rectangle indicates where the box would intersect the surface if projected upward. The angle of perspective is approximately 45° above the horizon.
signatures across multiple localities, to derive the three-dimensional distribution of rock types and metasomatism in the lithospheric mantle.

We have mapped several measures of depletion and metasomatism throughout the mantle volume sampled by kimberlites in the Kimberley-Prieska region using the Discrete Smooth Interpolation algorithm. Values for the older and younger group of kimberlites were estimated separately. One of these measures is shown in Figure 3.

Highly magnesian olivine ($X_{Mg} > 0.925$) is thought to represent ancient melt-depleted cratonic mantle; values less magnesian than this probably reflect later metasomatic modification. The marked shrinkage in the volume of highly magnesian mantle in the interval between the eruption of the Group II and Group I kimberlites indicates that a significant metasomatic event during this interval added iron to the mantle. This metasomatism is probably the result of interaction of the depleted mantle with mafic silicate melts (see GEMOC publications #522 and #578). The timing of this metasomatic event (120-90 Ma) suggests that it is related to changes in the regional stress field associated with the opening of the southern Atlantic Ocean.

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Funded by: De Beers, ARC Discovery (O’Reilly, Griffin et al.), iMURS/IPRS (Kobussen)

Figure 3. Perspective views of isosurfaces of $X_{Mg}$ olivine resulting from the DSI algorithm. Areas within the shaded volumes have $X_{Mg} > 0.925$ (a depleted peridotite composition) and areas outside have less. (A) The view due north of the volume resulting from interpolation using garnets from the Group II kimberlites. The angle of perspective is now approximately 15°. Map symbols are the same as Figure 2. (B) The same view and perspective as (A), but this time using the garnets from the younger Group I kimberlites. (C) The same volume as in (A), but viewed toward the southeast. (D) The same volume as in (B), but viewed toward the southeast.
Granites form a significant part of the continental crust, yet their origin and the relative contribution of crustal and mantle-derived components to these rocks has long been hotly debated. The classification of granites into “I-type” (igneous), “S-type” (sedimentary) and “M-type” (mantle) in the 1970s went some way to recognising mineralogical and bulk-rock chemical differences that reflect source-rock characteristics. A number of studies have focussed on experimental and numerical modelling related to silicic magma generation and the ultimate source and level of magma generation. These studies have shown that both felsic residual melt fractionated from injected basalt and partial melt derived from crust adjacent to the injected basalt can be present under certain conditions in the crust.

The development of in situ Hf-isotope analysis in the MC-ICPMS laboratory at GEMOC (GEMOC publication #179) allowed reliable single-grain Hf-isotope analysis of zircon to determine the degree of $^{176}$Hf/$^{177}$Hf variation within a zircon population. This technique can be applied on the scale of a hand specimen, and then extended to the pluton scale and ultimately to the total variation within a supersuite of plutons. The $^{176}$Hf/$^{177}$Hf ratio of a magma, and hence of the zircon crystallised from it, is a reflection of the source(s) of the magma. Higher ratios reflect more juvenile (mantle-derived) source rocks, and lower ratios the involvement of older material (either mantle or crust). The zircons thus can record the sources of individual magma batches that went into the construction of a single pluton, or a batholith (GEMOC publication #251).

Single-grain zircon analyses on the large zoned Walcha Road pluton (249±3 Ma) in northern NSW (GEMOC publication 555) have revealed that it represents a mixture of (1) magmas derived from Neoproterozoic lower crust (I-type) and (2) residual silicic magmas (M-type) of Late Palaeozoic age (Fig. 1). The central part of the pluton has the most M-type signature, as shown in the plot of $^{176}$Hf/$^{177}$Hf ratios (Fig. 2). Significantly, the mantle-derived melt component in the felsic centre of the Walcha Road pluton is silicic, rather than mafic. Wider studies have shown this to also be the case for the voluminous leucocratic Stanthorpe granite in the northern part of the batholith.

These results highlight the danger of associating mantle-like isotopic values with the
direct involvement of mafic magma. Because of the silicic composition of the residual and crustal partial melts, the mixed magma may not show the major textural and major element variations that result from mixing or mingling of felsic and mafic magmas that may be markedly different in temperature and viscosity (e.g. GEMOC Publication #251). Indeed, the mixing of silicic residual melts and crustal partial melts may be difficult to detect within single plutons, except by isotopic studies of zircon and other minerals that preserve isotopic disequilibrium.

Powell and O’Reilly (GEMOC publication #419), used Re-Os analyses of sulfides in mantle-derived peridotite xenoliths from basalts, to establish that parts of the lithospheric mantle below the New England area are at least Proterozoic in age. The Hf model ages for the older component in the Walcha Road pluton indicate the presence in the lower crust of rocks as old as Neoproterozoic. The integration of these two data sets suggests that New England may represent a microcontinental block, with a Proterozoic mantle lithosphere overlain by Proterozoic lower crust (see GEMOC publication #555).

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Funded by: Macquarie University
“Decratonistion” of North China - a Mesozoic event

Cratons are old, stable parts of the continental crust that have survived at least since Proterozoic time and have not undergone strong magmatism or tectonism since their stabilisation. They owe much of their stability to thick roots of highly depleted peridotitic lithospheric mantle. Early in the 1990s it became apparent from studies of mantle xenoliths that the lithospheric root beneath the eastern half of the North China Craton (NCC) had been severely modified; a typical Archean root sampled by Paleozoic kimberlites had been largely replaced by a thinner, hotter and more fertile lithospheric mantle more typical of Phanerozoic mobile belts. Since those early days, the lithospheric mantle beneath the NCC has been the focus of increasingly intense research efforts, involving both petrological and geophysical studies. GEMOC and our Chinese collaborators have played a major role in this effort (see GEMOC Publications #64, 113, 225, 339, 384, 490, 493). Now studies of crustal rocks are providing new insights into the processes that have modified the roots of the NCC (see GEMOC Publication #512).

The crust of the NCC consists of several blocks of Archean rocks, stitched together in Paleoproterozoic time (1.8-1.9 Ga). The Liaodong Peninsula in the NE part of the NCC (Fig. 1) contains large volumes of Mesozoic igneous rocks, with widespread metamorphic core complexes and pull-apart basins. Hf isotope compositions of magmatic zircon grains (Fig. 2) indicate that the formation of the Mesozoic granitoids involved extensive partial melting of ancient crust. Most of the zircons from Triassic, and especially Jurassic, granitoids have $\varepsilon_{\text{Hf}}$ values <0, and could be derived from a variety of older mafic to felsic lithologies, which could be either Archean or Proterozoic in age. Many of these granitoids also contain inherited zircons with Archean to Paleoproterozoic ages. Similar low $\varepsilon_{\text{Hf}}$ values occur in Cretaceous granitoids, but these also show a range of positive $\varepsilon_{\text{Hf}}$, up to values typical of the convecting mantle. These large ranges imply significant input of a mantle component, via magma mixing and crustal assimilation.

The abundance of Mesozoic magmas, like the Tertiary basaltic volcanism, indicates that the NCC is no longer a craton in the usual sense of the term, and that the “decratonisation” of the NCC began at least 210 Ma ago. The dominance of the older crustal components in the early Mesozoic magmas suggests that the process began with heating and melting of the lower crust; heat was provided by thinning of the lithosphere and upwelling of the asthenosphere. Mantle-derived magmas may have been involved as well, but their geochemical signatures...
have been strongly diluted by interaction with crustal melts. The stronger juvenile signature in the Cretaceous magmas suggests that, by ca. 125 Ma, increasing degrees of extension allowed asthenosphere-derived magmas greater access into the crust, where they could mix with melts derived from the older crust. This process has continued to the present day, culminating in Tertiary to Holocene alkali basaltic magmatism (see GEMOC Publication #490). The North China Craton survived as a coherent block for at least 1.5 b.y.; its decratonisation may be related to major plate-tectonic processes, including both the Triassic collision between the NCC and the Yangtze Craton, and the subduction and rollback of the Pacific plate beneath the area.

The data from the Mesozoic granitoids in the NE part of the NCC give important clues to how a cratonic root might be destroyed by the extensional processes that may accompany subduction beneath a cratonic block. However, many other Archean cratonic blocks have survived repeated episodes of subduction, collision and breakup, with their roots intact (see Research Highlight on GLAM project, p. 27).

Why was the NCC different? The answer may lie farther back in time. Although much attention has focussed on the evidence for an Archean lithospheric root that was sampled by Ordovician kimberlites, those data represent only two limited areas in the eastern NCC. Extensive studies of Os-isotope systematics in mantle xenoliths from other parts of the NCC, using analyses of both sulfides and whole-rock samples, have found little evidence of Archean mantle, but widespread Proterozoic model ages (see GEMOC Publication #490). Perhaps the roots of many of the Archean fragments that were swept into the Proterozoic assembly of the NCC had already been severely modified in that process, leaving the NCC with a less robust lithospheric root than most cratons. This could have left it more vulnerable to extension and further modification forces during the Mesozoic collision-subduction-extension events.

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Figure 2. Plot of $\varepsilon_{\text{Nd}}$ versus inferred crystallisation age of the magmatic zircons analysed in this study (published in Yang et al., 2007b, 2007c). CHUR—chondrite uniform reservoir; MME—microgranular microdiorite enclaves (modified from GEMOC publication #512).
During burial or subduction, rocks experience pressure and temperature (P-T) conditions that are different from those of their formation. In response, minerals react with each other to form new minerals or to adapt their composition to one that is more stable under the new conditions. Microstructural relations among minerals and mineral composition, especially where zoning is preserved, are therefore witnesses to the geological history of the rocks and can be used to assess their P-T-time path for geodynamic reconstructions.

Garnet plays an important role in deciphering the history of metamorphic rocks because its composition can provide information about pressure, temperature and the timing of the metamorphism. Garnet is stable over a large range of bulk-rock compositions and P-T conditions. Its tight structure imposes relatively low diffusion rates on major elements and so garnet grains frequently preserve chemical zonation. A wealth of techniques has therefore been applied for deriving segments of P-T paths using the major-element composition of garnet. In addition, trace elements in garnet have been used to date metamorphic events either directly using the isotopic composition of garnet (Sm-Nd, Lu-Hf or Rb-Sr) or indirectly by linking the growth of datable accessory minerals, such as zircon or monazite, to that of garnet. However, all the above techniques rely on the assumptions of (i) equilibrium between the growing garnet and the surrounding matrix and (ii) the closure of the rock to external chemical exchange, for example via fluids. It is therefore important to understand the processes causing garnet zoning, acquired during garnet growth or during its re-equilibration. In the case of growth zoning, does it result from P-T or bulk-compositional changes? In case of re-equilibration zoning, how fast and efficient is the re-equilibration process and what is the vector of the chemical exchange between garnet and matrix?

Three unusual types of garnet have been studied in terms of their microstructures and their chemical and isotopic zoning.

a) Atoll garnets in an eclogite: dissolution-reprecipitation in an open system at peak P-T conditions (Fig. 1).

The proposed model for atoll garnet formation involves growth of complete garnet grains along the prograde path. These complete grains display pronounced chemical zonation and numerous inclusions in the cores of the garnet grains. With changing P-T conditions, the inclusions break down (or react with their host), liberating water and creating minute fractures that cut across the garnet grains. These fractures allow infiltration of an external fluid phase, promoting (i) dissolution of garnet cores simultaneously with continuing growth at the outer margins of the grains, and (ii) growth of glaucophane porphyroblasts. Geothermobarometry
using omphacite and phengite suggests that this process took place at peak P-T conditions (i.e. at about 20-25 kbar, 550°C), rather than during retrogression.  

b) Coupled dissolution-reprecipitation: zoning in oxygen isotopes and major elements in cloudy garnet from a metapelite (Fig. 2).

Cloudy garnet crystals are interpreted to grow during the prograde path and to experience a re-equilibration at the temperature peak that essentially decreases the Ca content and $\delta^{18}$O of garnet rims. On the basis of textural arguments (pseudomorphism, and the existence of porosity and a fluid-inclusion-free outer rim), garnet re-equilibration is explained by a process of coupled dissolution-reprecipitation. Such a process, although recognised in zircon or feldspar, has not previously been considered during re-equilibration of metamorphic garnet; it is attractive because it allows the re-equilibration of slowly-diffusing elements such as Ca and O. As a consequence, porosity appears to be an effective pathway for element exchange between garnet and the matrix.

c) Significance of oscillatory zoning in elongated garnet in an eclogite (Fig. 3).

Garnet shows an unusual orientation that defines the foliation of the eclogite. The “wings” of the garnets show oscillatory zoning in Ca. The proposed model for the formation of the elongated garnets includes (i) coalescence of several grains, (ii) plastic deformation of single garnet grains, and (iii) stress-induced dissolution-reprecipitation leading to anisotropic growth. Oscillatory zoning of major elements in garnet has previously been related to varying P-T conditions along the metamorphic path (Garcia-Casco et al., 2002). In this case, the effect of varying water pressure in the rock has been tested as an alternative hypothesis using thermodynamic modelling.

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ENOLITHS CARRIED UP TO THE SURFACE IN DEEP-SEATED MAGMATIC ROCKS provide us with windows into the composition and petrology of the deep crust and upper mantle, and tell us about processes at different depths in the Earth. It has proven much more difficult to get time constraints on these rocks – they are small, and often altered to the extent that conventional isotopic techniques give only ambiguous data. However, over recent years research with Prof Jianping Zheng, one of GEMOC’s co-workers, has shown that with patience and painstaking attention to detail, zircon can be separated from many of these xenoliths, even those with mafic to ultramafic compositions. In a series of studies, he has used this “deep drilling” approach to follow the development of both the subcontinental lithospheric mantle, and the deep crust. In 2008, this technique produced a unique record of crustal evolution in the Xinyang area, near the southern boundary of the North China Craton (GEMOC publication #519).

The Mesozoic (~160 Ma) Xinyang volcaniclastic diatremes lie at the intersection between the Trans-North China Orogen and the Qinling-Dabie Orogenic Belt (Fig. 1), and carry a suite of xenoliths including mafic to felsic granulite, eclogite, meta-gabbro, pyroxenite and peridotite. The xenolith data show that the crust is temporally and compositionally zoned (Fig. 2). Whereas the oldest outcropping rocks are ca 2.85 Ga old, the upper part of the lower crust (to ca 30 km depth) consists of felsic granulites and rare pyroxenites that contain zircons with ages of 3.4-3.6 Ga. This “inverted stratigraphy” implies that the older crust was extensively resurfaced in Neoarchean time. The deeper (ca 30-45 km) parts of the lower crust consist of high-pressure (HP) mafic to felsic granulites and meta-gabbro, and the $^{207}$Pb/$^{206}$Pb ages of most zircons in xenoliths derived from this deeper level are Paleoproterozoic (2.0-1.8 Ga). The presence of this younger layer beneath the 3.4-3.6 Ga crust suggests a major event of magmatic underplating. Hf-isotope data from the zircons (Fig. 2) indicate that this event involved both the addition of juvenile material (mafic granulites), and the remelting of older (3.0-3.8 Ga) rocks to produce intermediate to felsic granulates.

Important populations of Paleozoic (440-260 Ma) and Early Mesozoic (228-219 Ma) zircons are interpreted as representing metamorphic zircon growth in response to thermal/metasomatic events. Mantle-derived peridotite xenoliths contain dominantly Triassic (ca 230 Ma) zircons, but rare Neoarchean grains record earlier metasomatic events in the subcontinental lithospheric mantle.

The xenolith suite thus records the growth and modification of the continental crust by overplating, underplating and metamorphism of an originally Paleo-Mesoarchean nucleus. Significant events reflected in the zircon record (Fig. 2) include at least:

1) initial formation of Paleo-Mesoarchean crust; 2) formation of the upper crust in Neoarchean time; 3) assembly of the southern and northern parts of the Eastern Block of the North China Craton in Neoarchean time; 4) collision of the Western and Eastern Blocks of the North China Craton along the Trans-China Orogen in Paleoproterozoic time, with magmatic underplating and metamorphism in the lowermost crust; 5) subduction and collision of the Yangtze Craton with the North China Craton, which modified the lowermost crust and the upper mantle in Paleozoic and Early Mesozoic time.
This approach promises to provide many future surprises; results so far indicate that the lower crust may be significantly older than the upper crust in many parts of the world, and that the volume of ancient crust is greater than estimates derived from some models of crustal generation through time (e.g. GEMOC Publications #339, 354, 422).

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Funded by: ARC Discovery, China NSF

Figure 2. Cartoon showing the collision and accretion events recorded in the zircons of the Xinyang xenoliths. The original 3.5 Ga crust has been magmatically overplated (2.85 Ga) and underplated (ca 1.85-1.6 Ga), and this composite crust has been affected by Paleozoic to Mesozoic continental collision(s).
Evolutionary histories of Earth and Venus - coupled convection-degassing models

Our understanding of the divergent evolutionary histories of Earth and Venus is hindered by the sparsity of geological record - particularly the oceanic crustal record - in the deep Precambrian, and the almost complete lack of geological context on Venus. The Venera, Pioneer, and Magellan missions have increased our knowledge of Venus’ surface, but Venus shows no hallmarks of plate tectonics, so interpreting these features is difficult. Cratering counts suggest nearly the entire surface of Venus was created in one event ~750 million years ago. Analyses of surface samples by the Venera landers suggest a similar bulk composition and heat budget to Earth, so this lack of tectonic activity is puzzling. It has been suggested that since Venus is dry, it may lack the lubrication of near-surface faults that Earth has as a result of pore pressure or the hydrous alteration of minerals. This would result in significantly stronger faults, and may preclude plate tectonics, so that Venus is in an episodic-overturn regime in which the entire lid is periodically recycled; this is consistent with the cratering record.

Episodic mechanisms have also been postulated for the Precambrian Earth, based on the episodic nature of the preserved crustal record. While the meaning of these peaks in preservation is debated, these periods in Earth’s history are also associated with massive volcanic, tectonic, and paleomagnetic disturbances. This has led to the suggestion that some episodic mechanism was at work in the distant past. Previous ideas focussed on mantle avalanches originating from instabilities in the mantle phase change at 670 km depth. Work at GEMOC (see publication #499, 2007) posited a new mechanism for episodic subduction, whereby the system stresses decrease with increasing heat production in the past, tipping Earth into an episodic overturn regime.

This model would imply that Earth went through a transition from episodic subduction in the early Precambrian, to modern plate tectonics as the planet cooled. The simulations also predict Venus may have in fact evolved from a stagnant-lid planet into an episodic regime, a suggestion that is at odds with traditional views of planetary evolution. It is consistent with the continental geology of Earth, but in the absence of an oceanic record, the evidence is equivocal. Furthermore, the absence of any record on Venus prior to ~750 Ma-1.2 Ga limits our geological insight into Venus’ geodynamic evolution.

However, atmospheric compositions provide constraints on the history of volcanic degassing and the tectonic evolution of planets. Despite their superficial similarities, the atmospheres of Venus and Earth have evolved along significantly different paths. Without significant CO₂ sinks on Venus, ongoing volcanism has resulted in the buildup of extremely high CO₂ concentrations, which have contributed to the dehydration of Venus’ surface. This dehydration, and the high surface temperatures, may contribute to the cessation of plate tectonics, as the reduction of water-weakening effects causes strong dry faults.

Venus’ degassing history is to some extent recorded in its atmospheric argon signatures. Nonradiogenic ³⁶Ar is ~80 times that of Earth. Since most ³⁶Ar is primordial, this suggests...
very different initial atmospheric conditions for the two planets, with Venus retaining most of its initial atmosphere due to its fortuitous impact history. On the other hand, the deficit of radiogenic $^{40}\text{Ar}$ (~24% escaped from the mantle, compared with ~52% for Earth), hints at a very different volcanic and tectonic history, particularly in the deepest past.

Mantle convection simulations performed at GEMOC hint at the tectonic factors behind these differences in the $^{40}\text{Ar}$ deficits on Earth and Venus. By modelling mantle melting and argon partitioning and degassing under different tectonic regimes, we can show that mobile-lid convection is 1.8 times more effective than episodic overturn in degassing the mantle, and 20 times more efficient than stagnant-lid convection. Coupling these results with evolutionary models for volcanism and degassing allows us to test the sensitivity of atmospheric $^{40}\text{Ar}$ abundances to tectonic evolution. Venus’ argon budget is consistent with the planet having had stagnant-lid tectonics for the first 500 Myr of its history, and episodic overturn of the lid since then. It is not consistent with Venus having had plate tectonics for any significant portion of its history; this implies that Venus and Earth were never planetary twins but were very different planets from birth.

Earth’s atmospheric $^{40}\text{Ar}$ deficit has often been attributed to hidden “unmixed” reservoirs in the deep mantle. However, the models show that this deficit can have a tectonic cause. The current $^{40}\text{Ar}$ content of our atmosphere is consistent with episodic convection till the end of the Archean, and plate tectonics since then, in agreement with geological data and previous convection modelling. If Earth’s $^{40}\text{Ar}$ deficit does indeed have a tectonic cause, then the corollary is that its atmospheric $^{40}\text{Ar}$ budget is not consistent with Earth having had plate tectonics throughout the planet’s history.

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Figure 2. Time evolution of the temperature contours and depletion field for an episodic overturn simulation. Such a tectonic regime has been postulated for Venus today, and evidence suggests it has operated on Venus for the past 4 Gyr. Atmospheric and geological evidence suggest that it may have operated on Earth until the end of the Archaean, when it gave way to modern-style plate tectonics.
A guide to making high-magnesium andesites

Although the most primitive magmas from many arc volcanoes appear to be basaltic, there are a number of locations where primitive magmas are, or are inferred to be, more silica-rich andesites. Some of these are high-magnesium andesites with Mg# of around 0.7, which implies that such rocks are generated in, or equilibrated with, mantle peridotite under conditions that do not pertain beneath mid-ocean ridges. Geochemical data show that they did not form by slab melting. A review of experimental data on the melting of anhydrous peridotite showed that primitive high-Mg andesites also cannot be generated by anhydrous melting of Iherzolite. A review of existing experimental data demonstrates that addition of H₂O alone cannot explain the increases in both SiO₂ and MgO contents (on an anhydrous basis) required to shift from basaltic to high-Mg andesitic melts in equilibrium with Iherzolite residue. A much more plausible alternative is that these melts are extracted from a harzburgite residue. In order to study this further, experiments were performed at 0.6 GPa in the new high-pressure laboratories at GEMOC in which high-Mg andesitic melts were equilibrated with an olivine+orthopyroxene residue. The results showed (in the absence of H₂O) that MgO and SiO₂ contents increase in the ratio 2:1 as the degree of undersaturation in clinopyroxene increases. This is the right sign and magnitude of effect to explain the compositions of primitive high-Mg andesites. When the effects of H₂O and clinopyroxene undersaturation were added together it was possible to obtain a line in Pressure-H₂O space which describes the conditions under which a given high Mg-andesite could be in equilibrium with a harzburgite residue. Application to rocks from White Island (New Zealand), Amphlett Island (Papua New Guinea), Setouchi Belt (Japan), Mt. Shasta (USA), Adak Island and Piip volcano (Aleutians, USA) yield, for crustal thicknesses > 20 km, H₂O contents of the melts of 2-8%, in generally good agreement with the available compositions of melt inclusions.

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Photo: White Island volcano, New Zealand, where high-magnesium andesites erupted in 1977.
**Multiple magma processes and TTG genesis**

Geochemical studies tell us that tonalite-trondhjemite-granodiorite (TTG) plutonic complexes must be formed by partial melting of metabasaltic source material, but they cannot tell us the tectonic regime in which this crust was formed, nor how large volumes of TTG magma can be generated. A solution to TTG arc crust formation requires an interdisciplinary approach to resolve the tectonic setting (slab melt versus mafic lowermost crust sources), the time and length scales for melting and extraction, and the role of melt segregation mechanisms in the formation of both Archean TTGs and more recent adakite-like magmas. We have used an experimental approach that, when coupled with numerical models (Fig. 1), allows us to address some of these issues. The experiments are designed to reproduce the local changes in bulk composition that are predicted to occur in response to buoyancy-driven melt segregation along grain edges and the associated compaction of the solid residue. We observe changes in the melt composition and proportions of melt and solid phases between earlier direct partial melting (DPM) and the new segregation equilibration experiments (MSE) on metabasalt bulk compositions.

The MSE experimental results show distinct differences in the compositions of melts and solid phase and the stability of different solid phases when compared with the results from direct partial melting (DPM) experiments. The resulting melt compositions are lower in An and have higher Mg-numbers. Compared to DPM experiments, the MSE experiments show a significant reduction in hornblende and plagioclase abundances at lower temperatures (Fig. 2).

The results suggest that dynamic melt segregation and equilibrium processes may modify the modes, melt compositions, and geochemical indicators such as Mg-numbers. Both adakites and TTGs may form from partial melting of a hydrous mafic protolith, but their associated tectonic setting may be very different. This research does not support the hypothesis that links their petrogenesis through slab melting alone; nor models that require subsequent interaction of melts with the mantle wedge to increase Mg-number. The data from these melt segregation experiments demonstrate that it is possible to create variations in felsic melt compositions by partial melting and segregation processes within a mafic crustal underplate.

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**Figure 1.** Felsic partial melt may segregate from a mafic host during buoyancy-driven compaction of the matrix (Jackson et al., 2005). Previous studies which suggested that this segregation mechanism is too slow (e.g. McKenzie, 1984) to yield large volumes of felsic melt neglected the chemical interaction between the melt and its matrix.

**Figure 2.** Comparison between direct partial melting of SCS at 1.4 GPa and 975°C and MSE experiments. (A): JP3 melted at 1.4 GPa and at 975°C with 15% melt composition at 50:50 and 2.5 wt% water added. The synthetic (anhydrous) glass composition at 15vol% is from this SCS-8 experiment. JP3 contains 64% glass, 17% plagioclase, 12% garnet, 6% cpx, and 1% ilmenite; no hornblende is present (Table 3). (B): SCS-8 is composed of hornblende (40%), plagioclase (40%), melt (glass) 15% and garnet 5%. Glass composition in SCS-8 is granodioritic with Mg number of 26; JP3 glass is also granodioritic but with Mg-numbers averaging 31.
Copper isotopes blaze the trail to hidden ore deposits

Two fundamental goals of mineral deposit research are to identify the sources of the metals and to understand the processes that have mobilised, transported and deposited them. To this end, geochemists have used several isotopic systems, including light stable isotopes (e.g. H, O and S) and radiogenic isotopes (e.g. Nd, Pb and Os). However, the stable isotope ratios of the metals themselves (e.g. Fe, Cu and Zn) may provide the most direct answers to these long standing questions. In the last decade, the development of multi-collector inductively coupled plasma-mass spectrometry (MC-ICP-MS) has made the high-precision measurement of metal stable-isotope ratios possible. This technique can analyse subtle variations in the stable-isotope ratios of metals in rocks and metal-bearing minerals, providing the economic geologist with a powerful new tool for investigating mineralised systems (GEMOC publication #527).

Copper has two stable isotopes, and their ratio commonly is expressed in $\delta$ notation ($\delta^{65}\text{Cu} = (R_{\text{sample}}/R_{\text{NIST976-1}}) \times 1000$ where $R = ^{65}\text{Cu}/^{63}\text{Cu}$). The main area of application of Cu isotopes to date has been the study of ore-forming systems. However, the baseline values of $\delta^{65}\text{Cu}$ for different geological reservoirs (especially the crust) have not been well constrained, and this has been a major impediment to the interpretation of Cu isotope data. Furthermore, because mineralising systems influenced by low-temperature redox processes show much larger variations in $\delta^{65}\text{Cu}$ than the high-temperature mineralising systems, there is no consensus on whether Cu isotopes carry useful information for interpretation of mineralisation processes.

We have carried out the first systematic measurements of the $\delta^{65}\text{Cu}$ of granites (GEMOC publication #527). The chemical procedure developed at GEMOC has achieved quantitative recovery (100.6±1.6%), with a low total procedural blank (2.65±0.66ng) for Cu, allowing isotopic analysis of samples with as little as 10 ppm Cu. Well-characterised granites and related rocks from the Lachlan Fold Belt (LFB) in southeastern Australia were selected for analysis. The Cu-isotope ratios ($\delta^{65}\text{Cu}$ relative to NIST SRM 976) of 32 rock samples, ranging from mafic to felsic compositions, from 3 batholiths (2 I-type, 1 S-type) from the LFB, vary from -0.46‰ to 1.51‰. Most of them cluster around zero, with mean values for the I-type and S-type granites of 0.03±0.15‰ and -0.03±0.42‰ (2 sigma) respectively (Fig. 1). These data, together with Cu-isotope ratios of two loess samples, provide preliminary evidence that the baseline $\delta^{65}\text{Cu}$ of the crystalline part of upper continental crust is close to zero. The tight clustering of $\delta^{65}\text{Cu}$ in rocks from the I-type suites suggests that high-temperature magmatic processes do not produce significant Cu isotope fractionation. However, two granites with abnormally heavy Cu-isotope signatures ($\delta^{65}\text{Cu}$ up to 1.51‰) may have been affected by local hydrothermal alteration.

Copper isotopes also have been measured in sulfide minerals (chalcopyrite and bornite) from...
the Northparkes porphyry Cu-Au deposit in SE Australia by MC-ICP-MS and laser ablation MC-ICP-MS. The Cu-isotope data obtained by the two techniques are consistent (Fig. 2). The results from both methods show a variation in $\delta^{65}$Cu of hypogene sulfide minerals greater than 1 ‰. Significantly, the results from four drill holes through two separate ore bodies show strikingly similar patterns of Cu isotope variation with depth. There is a sharp down-hole decrease in $\delta^{65}$Cu from ~ 0.8 ‰ in the low-grade ore zones (or phyllic-propylitic alteration zone) to ~ -0.4 ‰ at the margins of the most mineralised zones (Cu grade > 1wt. %). In the high-grade cores of the systems, the $\delta^{65}$Cu values are more consistent at around 0.2 ‰ (Fig. 3). A number of hydrothermal processes, including diffusion driven by the Cu concentration gradient, precipitation of Cu sulfides from brine during cooling, partitioning of Cu into a vapour phase, and remobilisation of Cu by oxidising ground water during convection, may have contributed to the observed Cu isotopic variations (Fig. 3).

This work demonstrates that Cu isotopes show a large response to high-temperature porphyry mineralising processes, while the study on Cu isotopes in granites demonstrates that magmatic evolution does not produce significant Cu isotope fractionation. Taken together, these results suggest that Cu isotopes may be used as a vector to buried mineralisation.

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*Figure 3. A summary of the pattern of Cu isotope variation in the Northparkes deposit and possible mechanisms of Cu isotope fractionation in a conceptual model for porphyry Cu deposits.*
Re-Os in sulfides tracks deep fluid interactions in old Spanish mantle

The Ronda peridotite is the largest (~300 km²) known exposure of subcontinental mantle peridotites. It is located in the Betic Cordillera of southern Spain, the westernmost segment of the Alpine belt in Europe. One of the most remarkable features of this orogenic peridotite massif is the transition from highly foliated spinel-peridotite tectonites (Fig. 1a) to relatively undeformed granular peridotites (Fig. 1b), separated by a recrystallisation front. Compositional variations across this narrow transition zone indicate that the granular peridotites were produced in Cenozoic time, when partial melts derived from upwelling asthenosphere percolated into the subcontinental lithospheric mantle (the spinel tectonite domain). The Ronda massif thus constitutes a natural laboratory where we can investigate the geochemical behavior of isotopic systems during mantle lithosphere-asthenosphere interaction. We have used in situ isotopic analyses of sulfide minerals in the peridotites to study the effects of melt percolation on the Re-Os system.

Figure 1. Field pictures of mantle peridotites from the Ronda spinel tectonite (a) and coarse-granular (b) domains.

Figure 2 shows that sulfides from both microstructural domains and the recrystallisation front show large ranges in Re/Os and Os-isotope composition. $^{187}\text{Re}/^{188}\text{Os}$ and $^{187}\text{Os}/^{188}\text{Os}$ in sulfides from the coarse-granular domain largely overlap with values in the spinel tectonites and there is no significant difference between the isotopic composition and variability of sulfides from these domains. However, some grains in samples at the recrystallisation front show an apparent decoupling between relatively high $^{187}\text{Re}/^{188}\text{Os}$ and low $^{187}\text{Os}/^{188}\text{Os}$. These sulfides are probably products of refertilisation reactions induced by percolating melts at the front, which caused significant enrichment of Re relative to Os. Aside from these effects, Re-Os systematics in the Ronda mantle peridotites apparently were largely unaffected by partial melting and melt transport induced by the Cenozoic lithospheric thinning, and mostly record more ancient tectonothermal events.

Figure 3 shows the distribution of Re-depletion ages ($T_{\text{rd}}$) in individual sulfides from the Ronda massif. $T_{\text{rd}}$ ages cluster around three main peaks: 1.6-1.8 Ga, 1.2-1.4 Ga, and 0.7-0.8 Ga. Sulfides with relatively high Os contents and low Re/Os have Re-depletion ages that coincide with the two most ancient Proterozoic peaks. These grains are probably residual after variable degrees of melt extraction from the upper mantle and suggest that the Ronda peridotites underwent two main melting events at ~1.6-1.8 Ga and 1.2-1.4 Ga, respectively. One of these
Proterozoic episodes probably coincided with the incorporation of the massif into the refractory subcontinental lithosphere. Other grains, generally those with low Os contents and high Re/Os, suggest that a third generation of sulfides precipitated in the Ronda peridotites at ~ 0.7-0.8 Ga. These sulfides may have formed by interaction of ancient grains with younger metasomatic melts/fluids, or by crystallisation of sulfide melts and sulfide-rich fluids, and suggest the percolation of metasomatic melts/fluids in the Neoproterozoic when the massif was equilibrated at subsolidus conditions.

Considering the uncertainties inherent in model age calculations, the three “events” recognised in the Ronda sulfides correspond to the range of Nd model ages recorded in the crustal basement of Hercynian Europe and northern Africa (Fig. 3). The Proterozoic Os model ages exhibited by sulfides in the Ronda peridotites thus appear to reflect different stages in the evolution of the crustal mass of Gondwana, which was later recycled in the Paleozoic.

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Funding: University of Grenada and ARC
HIGH-P TERRANES commonly contain a mixture of high- and low-P assemblages. The high-P assemblages are variably interpreted as part of high-P crust (i) tectonically juxtaposed against low-P rocks that never experienced high-P; or (ii) associated with low-P assemblages in adjacent crust that (a) persisted metastably during the high-P event or (b) re-equilibrated extensively during exhumation. The distinction between these models is important, because a failure to distinguish widespread metastability or extensive retrogression may lead to invalid interpretations of the tectonic and metamorphic evolution of a terrane. Furthermore, misinterpretations of the metamorphic behaviour of large volumes of crust may lead to problems and inaccuracies in geodynamic modelling of large-scale tectonic events.

Recrystallisation of two-pyroxene hornblende granulite to garnet granulite is limited to a very small percentage (<10 %) of the crust in western Fiordland, New Zealand, suggesting that the assemblages in large parts of the deep crust persisted metastably under high-P conditions. Recrystallisation at high P is mostly associated with injection migmatite structures, in which narrow anorthositic or trondhjemitic veins and dykes cut two-pyroxene hornblende granulite facies orthogneiss. The host orthogneiss exhibits irregular, spatially restricted recrystallisation to garnet granulite along the edges of veins and dykes.

Recent research results:
A major arc batholith, the Western Fiordland Orthogneiss in Fiordland, New Zealand, exhibits irregular, spatially restricted cm-scale recrystallisation from two-pyroxene hornblende granulite to garnet granulite flanking felsic dykes (Fig. 1; see GEMOC Publication 556). At Lake Grave in northern Fiordland, the composition and texture of narrow (<10-20 mm across) felsic dykes that cut the orthogneiss are consistent with an igneous origin (Fig. 2) and injection of melt to form orthogneiss migmatite. New U-Pb geochronology suggests the injection of dykes and migmatisation occurred at ca 115 Ma (Fig. 3), during the latter stages of arc magmatism. Recrystallisation to garnet granulite is promoted by volatile extraction.
from the host two-pyroxene hornblende granulite via adjacent dykes and the patchily
developed garnet granulite is left as a marker adjacent to the melt migration path. New
modelling of mineral equilibria shows that a two-pyroxene hornblende assemblage is stable at
P < 11 kbar, whereas a garnet granulite assemblage is stable at P > 12 kbar (Fig. 4), suggesting
that garnet granulite may have formed with less than 5 km crustal loading of the batholith.
Though the garnet granulite assemblages signify that the Western Fiordland Orthogneiss
experienced high-P conditions, the very local nature of these textures indicates widespread
metastability (>90 %) of the two-pyroxene hornblende granulite assemblages. These results
indicate that metastable assemblages may be widespread in mafic lower arc crust during
deep burial and demonstrate that the degree of reaction in the case of Fiordland is related to
interaction with migrating melts.

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Funding: MQ Safety Net Grant

Figure 4. An H₂O-saturated combined P-T pseudosection calculated for the LG4051
host (S1) and GRZ bulk compositions. The inferred peak S1 assemblage field is
outlined in bold. The inferred peak GRZ quadrivariant assemblage field g-di-hb-
bi-pl-ru-q-H₂O, calculated with a fixed H₂O-content equivalent to the minimum
amount of H₂O required to calculated the peak S1 assemblage at 9 kbar, is also
outlined in bold. The arrow indicates a likely P-T path for the Lake Grave rocks.
Alloys in ophiolites wheel in new ideas on Earth evolution

Ophiolites are pieces of oceanic lithosphere that have been thrust onto the edges of continental plates; a complete ophiolite section consists of mantle-derived peridotites, overlain successively by mafic and ultramafic lavas and sedimentary rocks such as greywackes and cherts. The peridotitic members of the ophiolite sequences commonly contain bodies of massive chromite, in lenses, layers and veins, and the origins of these chromitites has been controversial for at least a century. The chromitites commonly contain scattered grains of Platinum-Group-Element (PGE) alloys, and these tiny grains are keys to the origins of the ophiolites. Rendeng Shi, one of GEMOC’s co-workers, has used a specially built separation plant to process tons of chromites from the Triassic-Jurassic Luobusa and Dongqiao ophiolites in Tibet, releasing several hundred grains of alloy minerals, and has used GEMOC’s facilities to analyse their elemental composition and their Os-isotope ratios. This has resulted in new insights into chromitite formation, the development of ocean basins, and the isotopic composition of the Earth’s convecting mantle (GEMOC publication #482).

170 grains of Ru-Os-Ir alloys were analysed; most are osmiridium or iridosmine (Fig. 1). Based on elemental and isotopic compositions, two populations can be identified. Group I, found in both ophiolite bodies, has fractionated PGE patterns typical of similar alloys from other ophiolites. In contrast, Group II alloys from the Dongqiao ophiolites show PGE patterns with a “stepped” pattern, similar to those commonly seen in sulfide minerals that are residual after melting events (see GEMOC Publication #290). Group I alloys from both ophiolites have very homogeneous $^{187}\text{Os}/^{188}\text{Os} = 0.12645 \pm 0.00004$ (2S; n=145), broadly consistent with the young age of the ophiolite. The Group II alloys from Dongqiao have more heterogeneous $^{187}\text{Os}/^{188}\text{Os}$ (0.12003 to 0.12194); referred to a typical Primitive Mantle evolution curve, these values yield Re-depletion ages from ca 950 to $\geq 1.1$ Ga.

The Group I alloys are interpreted as early cumulate phases, precipitated during the crystallisation of magmas derived from the asthenosphere. In contrast, Group II alloys are inferred to reflect the breakdown of residual sulfides from the mantle section of the ophiolite, retained since a Proterozoic melt-depletion event. The signatures of such events would probably be lost by homogenisation in the convecting asthenospheric mantle, so these ancient depletion ages suggest that the Dongqiao mantle section originated as a piece of subcontinental lithospheric mantle, trapped during the opening of the Neo-Tethyan ocean (see Research Highlight, p30). The coexistence of the two groups of alloys in Dongqiao samples
Figure 2. Models for the Re–Os evolution of the convecting mantle. Mantle evolution curves were defined as follows: CCR (Carbonaceous Chondrite reservoir) curve assumes that the Earth’s mantle has an Os isotopic composition and Re/Os similar to that of carbonaceous chondrites ($^{187}$Os/$^{188}$Os CC=0.1262 ± 0.0006, $^{187}$Re/$^{188}$Os CC=0.392 ± 0.015 (Walker et al., 2002b)); ECR (Enstatite Chondrite reservoir) curve is calculated using a present-day $^{187}$Os/$^{188}$Os value of 0.1281 ± 0.0004 and $^{187}$Re/$^{188}$Os=0.421 ± 0.013 as measured in enstatite chondrites (Walker et al., 2002b); PUM (Primitive Upper Mantle) curve has a present day $^{187}$Os/$^{188}$Os=1.296 ± 0.0008 and $^{187}$Re/$^{188}$Os=0.42. These estimates were obtained by linear regression through suites of mantle-derived peridotite xenoliths and orogenic-massif peridotites sampling mainly the Proterozoic to Phanerozoic sub-continental upper mantle (Meisel et al., 2001) (modified from GEMOC publication #482).
Where are the diamonds in the Congo?

Our knowledge of the nature and composition of the subcontinental lithospheric mantle (SCLM) is largely based on the study of xenoliths and xenocrysts brought to the Earth’s surface by volcanism (e.g. kimberlite). Ni and Cr in pyrope garnets can be used to estimate temperature (TNi) and pressure (PCr) of equilibration. The pressure-temperature (P-T) relationships may be used to construct the geotherm.

The depth of the lithosphere-asthenosphere boundary (LAB) can be estimated by Y and temperature relationship in garnet, the asthenosphere being characterised by absence of low-Y garnets (< 10 ppm). Zr, Y, Ga and Ti contents in garnets can be used in order to determine the types of metasomatism in the SCLM where the garnets were derived. The increase in Zr accompanied by increases in Y and Ti indicate melt metasomatism whereas an increase in Zr with low to moderate Ti, Y and Ga characterise phlogopite metasomatism (Griffin et al., 1992, CMP 110 and GEMOC publication #1). Garnets can be categorised into 5 groups based on their inter-element correlations: depleted harzburgites, depleted lherzolites, depleted/metamotaissed lherzolites, fertile lherzolites and melt-metasomatised peridotites (GEMOC publication #299).

Given the depth at which the garnets equilibrated and the geochemical process and rock type indicated by the composition of the garnets, the proportion of the garnets reflecting individual rock types and processes at particular depths can be calculated. This allows the construction of a section through the lithosphere showing the variation in the proportions of rock types or types of processes with depth. These sections have been described as “Chemical Tomography” (see GEMOC publication #409 for more information).

Garnets included in diamond are characterised by high XMg [Mg/(Mg+Fe)], and show sinuous rare-earth element (REE) patterns with enrichment in MREE and depletion in HREE. Malkovets et al. (2007, GEMOC publication #449) suggested that the presence of abundant chromite associated with garnets showing these characteristics indicate the presence of diamond.

This study applies this methodology to data from xenocrystic peridotitic pyrope garnets.
from Kundelungu, Mbuji Mayi and Luebo in the southern part of the Democratic Republic of the Congo (Fig. 1; GEMOC publication #565). Because the Mbuji Mayi and Luebo regions are located inside the Congo-Kasai Craton whereas Kundelungu is outside of the craton, this study provides an opportunity to compare the composition and structure of the lithospheric mantle and kimberlite peridotitic diamond potential in two different geological settings. The data allow the following conclusions:

1. Despite the location in two different tectonic settings, Kundelungu, Mbuji Mayi and Luebo are characterised by low, cratonic-type conductive geotherms (Fig. 2), but the deeper parts of the Kundelungu section have been thermally disturbed.

2. The lithospheric mantle beneath the Kundelungu area (off-craton) is relatively thin and fertile compared with that represented by garnets from Mbuji Mayi and Luebo (on-craton) (Fig. 3), and may represent refertilised Archean cratonic lithosphere as also shown by zircon data (GEMOC publication #464).

3. The disturbance of the initially low geotherm in Kundelungu is correlated with the upwelling of melts related to the opening of the East African Rift.

4. The mantle sections beneath the Kundelungu, Mbuji Mayi and Luebo regions were affected by melt-related and phlogopite-related metasomatism but these effects, and especially the melt-related metasomatism, were most pronounced in Kundelungu.

5. The Mbuji Mayi and Luebo areas have higher peridotitic diamond potential as shown by abundant harzburgitic garnets with characteristics similar to those of garnets included in diamond and abundance of chromite (Fig. 4 for Luebo).

6. The apparent scarcity of diamonds in the kimberlites of the Kundelungu Plateau as indicated by the scarcity of harzburgitic garnets and chromite is attributed to the heating and melt-related metasomatism that has affected the lithosphere in the region. Some of Kundelungu Iherzolitic garnets have characteristics similar to garnets included in diamond (Fig. 4).

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THE TEACHING HIGHLIGHTS 2008

- All of our units ran successfully in 2008 with student numbers up from 2007. In February 2009 we ran our field trip to New Zealand (GEOS373 Volcanic Geology). Students enjoy the amazing volcanic landscapes while learning skills in the identification of volcanic rocks, deposits and landforms. The students visit a range of deposits from the basaltic scoria cones of the Auckland region, to the andesitic cones of Ruapehu and Ngarauhoe to rhyolitic lavas and ignimbrites around Rotorua and Taupo. This attracted 40 students – a record number - and was very successful.

- Kelsie Dadd, Jenny George (Environment and Geography) and Mark Taylor (formerly with Environment and Geography) were awarded a Learning and Teaching grant of $15,000 to look at Work-Integrated Learning in Environmental and Life Sciences. Kelsie is exploring experiential learning and, in particular, boat trips in marine science courses.

- We were awarded $30,000 to replace laptop computers in our portable computer facility. These were used for a GIS exercise during GEOS226 Introduction to Field Geology, in December 2008.

- The Department established a presence on Facebook that is used to advertise events and to keep in contact with alumni.

- Craig O’Neill was a finalist for the Malcolm McIntosh Prize for Physical Scientist of the Year, to be awarded to an outstanding scientist born after 1/1/72.

- EPS successfully ran another field trip to Broken Hill together with the University of Sydney. Numbers were very high and a decision has been made to run the unit twice in 2009 but still in cooperation with the University of Sydney.
Kelsie Dadd participated in the UNESCO-funded University of the Sea program, supervising six final year undergraduate and postgraduate students from the Asia Pacific region during a 4-week Geoscience Australia research cruise on the RV Sonne in the Indian Ocean. The first leg of the cruise sailed from Singapore to Fremantle.

As in previous years, we continue to develop our “tailored problem-based learning” modules and to add new problems based on real industry issues or recent research. These prepare the students for employment by ensuring they master a range of generic skills such as problem-solving, team work and critical thinking as well as technical content. Where possible we integrate computers into the coursework using both our portable computer laboratory and more traditional computer labs. Students are introduced to a number of computer packages used in industry.

Simon George ran a new unit in 2008, GEOS204: Life, the Universe and Everything. This unit covers mainly astrobiology, so includes elements of astronomy, physics, chemistry, biology and geology. It also includes a module on organic geochemistry and our energy security. GEOS204 is taught assuming no prior knowledge in these sciences and has proved to be very popular, attracting over 70 students in 2009.

2008 was also a year of change around the University. The academic units in the University were reorganised from Divisions into larger Faculties. We are now within the Faculty of Science. We also began a University-wide process of curriculum renewal that will continue over the next few years.

Geophysics teaching progress 2008

The geophysics curriculum was assessed as part of the university-wide curriculum review and as a result, a new unit dealing with petroleum geophysics and geology will be introduced in 2011.

Use of an extensive pool of GPS units for undergraduate (and postgraduate) fieldwork continued. Extended use of seismic, gravity, GPS (including the ASHTECH Z-Xtreme Differential GPS system) and resistivity (DUALEM Frequency Domain EM System) and the new GPR equipment for student field projects in exploration, groundwater, environmental and engineering geophysics was implemented.

Equipment upgrades funded by Macquarie University over the last five years have resulted in an excellent array of new instrumentation.

- Software such as GEOSOFT, MODELVISION, EMVISION, ERMAPPER, SeisImager, Profile Analyst, Discover and Reflexw have been maintained, while teaching packages such as Maxwell, Quickmag, Noddy and Discover 3D were purchased to upgrade the software suite.
- A GEODE seismic system was purchased to replace an older system and was used successfully within the first week on a third year field excursion.
- The MALA Ground Penetrating Radar (GPR) system was expanded with the purchase of additional high frequency and rough terrain antennas.
The following honours projects in GEMOC were completed in 2008:

**Shelley Allchurch:** Petrographic, geochemical and geochronological characterisation of crustal xenoliths from Coliban Dam, Victoria with implications for the early evolution of the Lachlan Fold Belt.

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

**Sharlin Emami:** Petrogenesis and geochemical characterisation of ultramafic cumulates from the root of the Fiordland Magmatic Arc, New Zealand.

**Elizabeth Hoese:** The use of perovskites to examine the age and origins of kimberlites.

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

**Ben Wilkins:** Geophysical investigations of the structure of the Budawang Synclinorium.

The following honours projects are relevant to GEMOC in 2009:

**Eileen Dunkley:** Geochemical and isotopic evolution of the Median Batholithic magmatic arc, Fiordland, New Zealand.

**Andrew Frost:** Petrogenesis of the Prominent Hill deposit within the Mt Woods Inlier, Gawler Craton, South Australia.

**Jaime Lovell:** The usefulness of mASW in delineating soils.

**Danielle Mitchell:** Organic geochemistry of high latitude early Permian sediments exposed on the south coast of NSW.

**Rosanna Murphy:** The major and trace element composition and isotope geochemistry of the garnet in silicic volcanic and plutonic rocks.

**Sophie Ratcliff:** An investigation of the breccia of the Lower Wasp Head Formation, southern-most Sydney Basin.

**Elyse Schinella:** Convergence on Europa: Past and present?

**James Watton:** Petrographic and geochemical characterisation of the Western Fiordland Orthogneiss - Breaksea Orthogneiss boundary, Fiordland, New Zealand.
Teaching and training program - GEMOC postgraduate

**GEMOC’s Active International Exchange Program** continued, with three recipients of the new China Government (CSC) scholarships commencing in 2008 (Lijuan Wang, Jinxiang Huang and Yamei Wang). Yoann Gréau and Véronique le Roux continued PhD co-tutelle programs jointly with the University of Montpellier (France) and Anne Fonfrege commenced a co-tutelle with the University of Jean Monnet (St Etienne, France) in 2008.

**COMPLETED**

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

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

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

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

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

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

**Guillaume 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)

**Véronique Le Roux (PhD):** Refertilisation and isotopic variations (Sr, Nd, Hf) in the Lherz Massif (France); *Eurodoc and Co-tutelle with Montpellier University, France* (graduated 2009) *(see Research Highlights, p33)*

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

*See advertisement for GEMOC postgraduate opportunities, Appendix 6.*
Bertrand Moine (PhD): The role of fluids in the genesis, segregation and crystallisation of intraplate oceanic mantle magmas: implications for crustal accretion; Co-tutelle with University of Jean Monnet (graduated 2000)

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

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

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

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

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

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

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

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

CURRENT

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

Jacques Batumike (PhD): The origin of kimberlites from the Kundelungu region (D.R. Congo) and the nature of the underlying lithospheric mantle; IPRS, iMURS (commenced 2005) (see Research Highlights, p58)

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

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

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

David Child (PhD): Characterisation of Actinide particles in the environment for nuclear safeguards using mass spectrometric techniques (commenced part time 2007)
David Clark (PhD): Contributions to integrated magnetics - applications to the Earth Sciences (commenced 2006)

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

James Cowlyn (PhD): Growth of evolved continental crust in the primitive Tonga Arc: A study of the island of Fonualei; MQRES (EAPE CoRE) (commenced 2008)

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

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

Cara Danis (PhD): Geothermal structure of Eastern Australian Basins; APA (commenced 2008)

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

Anne Fonfrege (PhD): Geochemical and isotopic characterisation of magma mixing: comparative studies in volcanic and plutonic settings; Co-tutelle with Jean-Monnet University, France (commenced 2008)

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

Jinxiang Huang (PhD): Origin of eclogite and pyroxenite xenoliths in kimberlites and basalts; China Government Scholarship and co-tutelle with China University of Geosciences, Beijing (commenced 2008)

Alan Kobussen (PhD): Composition, structure, and evolution of the lithospheric mantle beneath Southern Africa; iMURS (commenced 2006) (see Research Highlights, p36)

Weiqiang Li (PhD): Stable metal isotope geochemistry of the Cadia and Northparkes porphyry Cu-Au deposits; iMURS (commenced 2006) (see Research Highlights, p50)

Marek Locmelis (PhD): Understanding nickel deposits using platinum group element geochemistry; iMURS (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)
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)

Lijuan Wang (PhD): Crustal evolution of the Yangtze Block using zircons in sediments; China Government Scholarship (commenced 2008)

Yamei Wang (PhD): Evolution of the subcontinental lithospheric mantle beneath the Western Block of the North China Craton: a mantle xenolith approach; China Government Scholarship (commenced 2008)

**COMMENCING 2009**

Fiona Foley (PhD): Generation of continental crust during subduction initiation

Felix Genske (PhD): Assessing the heterogeneous source of the Azores mantle plume

Melissa Murphy (PhD): A novel U-series isotopic approach for investigation of the Beverley U mine, South Australia

Matt Pankhurst (PhD): Geodynamic significance of shoshonitic magmatism within the Andean Altiplano

Suresh Puthiyaveetil Othayoth (PhD): Timescales of soil evolution and sediment transport in a small catchment in SE Australia

Claudio Marchesi, James Cowlyn, John Caulfield and Kelsie Dadd.

June Chevet.

Yoann Gréau, Alan Kobussen, Sue O’Reilly and Jinxiang Huang.

Technology development program

Background

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

In 2008 a new strand of Technology Development commenced with the acquisition of a nucleus of a computer cluster for computational analysis, part of the strategic plan to develop strong capabilities in geodynamic and geophysical modelling. This new development is detailed after the section on geochemical analytical instrumentation.

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)
  - a Thermo Finnigan Triton TIMS (installed March 2005)
  - a Spectro XLAB2000 energy-dispersive XRF with rocker-furnace sample preparation equipment
  - a LECO RC412 H₂O-CO₂ analyser (delivered September 2003)
  - an Ortec Alpha Particle counter
  - a New Wave MicroMill micro-sampling apparatus

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

The new ThermoFisher iN10 FTIR microscope.
a ThermoFisher iN10 FTIR microscope
- 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, Griggs apparatus and a multi-anvil apparatus for pressures to 27 GPa.
- The Centre for Isotope Studies has provided access to extraction lines and gas-source mass-spectrometers for stable-isotope analysis of fluids and minerals; it is planned that these facilities will be moved to GEMOC at Macquarie.

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

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

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

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 through AccessMQ.

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

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

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

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

**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 2008

1. Facility for Integrated Microanalysis

a. Electron Microprobe: During 2008 the SX50 developed a range of problems, which proved difficult to repair since service is now limited. Consideration is being given to replacement of the unit with an SEM. The SX100 serviced all projects including analysis of perovskite in kimberlites; analysis of platinum group minerals; minor and trace element analysis of metals.

b. Laser-ablation ICPMS microprobe (LAM): During 2008, the LAM laboratory produced large volumes of data for fourteen 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 developed to date kimberlite emplacement by in situ U-Pb analysis of groundmass perovskite, and to date kimberlitic rutile xenocrysts (see Research Highlights). As in the recent years more than 7000 U-Pb analyses of zircons were carried out, related to projects (including TerraneChron® applications) in Cameroon, Spain, Hungary, Norway, Indonesia, Chile, Argentina, Mongolia, China, Kazakhstan, Russia and Australia (NSW, SA, WA). 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 has allowed uninterrupted periods of time for method development without disrupting the productivity of the laboratory.

A significant proportion of time on one laser-probe was used for the analysis of trace elements in diamond, as part of an ARC Linkage project sponsored by Rio Tinto. The analysis of trace elements, FTIR spectra and carbon isotopes by SHRIMP ion probe (see Research Highlights) gave new insights into the processes of diamond crystallisation.

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, continued to produce severe competition for instrument time on the MC-ICPMS.

In 2005 significant advances were made in the analysis of ‘non-traditional’ stable isotopes (see Research Highlights) and included the development of separation techniques and analytical protocols for Ti, Fe and Ni isotopes. In 2008 an emphasis was placed on the refinement of separation techniques for Cu and Li in a wide range of rock compositions from ultramafic to granitic. Methods were developed for the separation and analysis of Li isotopes. Major applications during 2008 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. \textit{In situ} Hf isotopes were measured in zircons from Antarctica, Korea, New Zealand, Chile, Tibet, China, Mongolia, Russia, North America, Africa and Australia. We carried out Re-Os studies on xenoliths from the USA, South Africa, eastern China, and Siberia. Sr and Nd isotopes were measured \textit{in situ} in kimberlitic perovskites from South Africa.

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

e. Software: GLITTER (GEMOC Laser ICPMS Total Trace Element Reduction) software is our on-line interactive program for quantitative trace element and isotopic analysis and features dynamically linked graphics and analysis tables. This package provides the first real-time interactive data reduction for LAM-ICPMS analysis, allowing inspection and evaluation of each result before the next analysis spot is chosen. Its capabilities include the on-line reduction of U-Pb data. The use of GLITTER has greatly increased both the flexibility of analysis and the productivity of the laboratory. An arrangement by which New Wave Research marketed the software together with their laser microprobe equipment was terminated late in 2007. Sales are now handled by AccessMQ (formerly Macquarie Research Limited) and GEMOC provides customer service and backup. During 2008 a further 28 full licences, and 13 additional licences of GLITTER were sold bringing the total number in use to >160 worldwide, in forensics and materials science, as well as earth science applications. During 2005, Will Powell, Norm Pearson and Chris Ryan began updating GLITTER to version 4.4. Will Powell continued in his role in GLITTER technical support and software development through 2008, producing a new version (4.4.2) that was provided without charge to existing customers and accompanies all new orders.

2. Laser development

GEMOC continues to benefit from an industry partnership with New Wave Research (formerly Merchantek EO), a major US manufacturer of laser ablation systems. The mobility of the probes has allowed them to be used on the quadrupole ICPMS instruments as well, in a range of applications. A Merchantek/New Wave Research 193 nm excimer system based on a Lambda Physik OPTex laser, delivered in March 2002 was repaired and realigned late in 2005 for use in diamond analysis. Three more New Wave laser systems, acquired during 2004 (a UP-266 nm and two UP-213 nm), represented a major upgrading of the instrument park and giving redundancy to limit downtime. The 213 nm lasers are now used for most of the zircon analytical work including both U-Pb and Hf isotope analyses, especially where small grains are being analysed. The 266 nm systems have proven most useful for analysis of sulfides, and for other stable-isotope applications.

3. Energy dispersive XRF

A Spectro XLAB2000 energy-dispersive X-ray spectrometer, installed in November 2000 in a joint venture with Tasman Resources, produces high-quality major- and trace-element data. However, during 2007 productivity was severely reduced by recurring problems with the detector. These problems continued in 2008, forcing the use of other laboratories to obtain data for several projects.

A LECO RC412 H₂O-CO₂ analyser, installed in September 2003 to replace an outdated unit, is providing high-quality analyses to complete whole-rock analyses by XRF and solution-ICPMS.
4. Solution analysis

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

The in situ analysis of the Rb-Sr, Lu-Hf, Sm-Nd and Re-Os systems by laser ablation microprobe has required the development of corrections for isobaric overlaps (e.g. $^{87}$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 was developed for the dissolution of rocks and mineral separates, to enable the separation of Sr, Nd and Hf from the same sample digestion. Prior to the installation of the Triton TIMS the isotopic analyses were performed using the MC-ICPMS in solution mode. Subsequently the analysis of Sr and Nd has been moved on to the Triton but Hf continues to be run on the MC-ICPMS. An additional clean-up column has also been added to the Nd separation method to remove Ba and LREE from samples with LREE-enriched compositions. This step has been found to be necessary in order to run these samples on either the MC-ICPMS or TIMS.

During 2008 further developments were made in the separation of ‘non-traditional’ isotopes, with significant improvements in the separation of Cu from silicate rocks and sulfide minerals and Li from silicate rocks. 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. Diamond preparation and analysis

In 2008 Argyle diamonds donated to GEMOC a laser-cutting installation, which will allow us to cut thin plates of single diamond crystals, allowing detailed spatial analysis of trace elements, isotopic ratios and the abundance and aggregation state of nitrogen. GEMOC also took delivery of a new-generation FTIR microscope, the ThermoFisher iN10. This will allow the spatial mapping of whole diamond plates at high resolution with very short acquisition times.

6. SelFrag — a new approach to sample preparation

GEMOC ordered a SelFrag installation, the first in Australia, to be delivered early in 2009. This instrument uses high-powered electrical pulses to disaggregate rocks and other materials along the grain boundaries. It removes the need to crush rocks for mineral separation, and provides a high proportion of unbroken grains of trace minerals such as zircon. The installation will be used for zircon separation, the analysis of grain size and shape in complex rocks, and the liberation of trace minerals from a range of mantle-derived and crustal rocks.

7. Computer cluster

GEMOC has received funding to purchase a 24 node computer cluster to enhance its high-performance computing capabilities, and allow the development and maintenance of massively parallel geodynamics and geophysics computer codes. The machine will possess 3GHz Xeon quad core processors, and will enable full global 3D simulations of mantle convection and lithospheric deformation. The machine will be integrated with existing high-performance computing infrastructure within the geophysics group, and will run a Linux operating system (Ubuntu) allowing easy upgrades and maintenance by the geophysics group.
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 collaborative research on industry problems involving national and international partners
- provision of high quality geochemical analyses with value-added interpretations in collaboration with industry and government organisations, extending our industry interface
- use of AccessMQ consultancies and collaborative industry projects, which employ and disseminate the technological developments carried out by the Centre
- GLITTER, an on-line data-reduction program for Laser Ablation ICPMS analysis, developed by GEMOC and CSIRO GEMOC participants, has been successfully commercialised and is available from GEMOC through AccessMQ (http://www.es.mq.edu.au/GEMOC/); the software is continuously upgraded
- collaborative relationships with technology manufacturers (more detail in the section on Technology Development)
  - GEMOC (Macquarie) is the Australian demonstration site for Agilent Technologies LAM-ICPMS applications
  - GEMOC (Macquarie) is an international test site for New Wave Research Lasers

SUPPORT SOURCES

GEMOC industry support includes:

- direct funding of research programs
- “in kind” funding including field support (Australia and overseas), access to proprietary databases, sample collections, digital datasets and support for GIS platforms
- logistic support for fieldwork for postgraduate projects
- collaborative research programs through ARC Linkage Projects and the Macquarie University External Collaborative Grants (MUECRG) and PhD program support
- assistance in the implementation of GIS technology in postgraduate programs
- participation of industry colleagues as guest lecturers in undergraduate units
- extended visits to Macquarie by industry personnel for interaction and research
- ongoing informal provision of advice and formal input as members of the Advisory Board
ACTIVITIES IN 2008

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 (www.es.mq.edu.au/GEMOC/TerraneChron.html).

The ARC Linkage Project titled “Global Lithosphere Architecture Mapping” (GLAM) continued with full industry partner support following the takeover of WMC Resources by BHP Billiton. Planning and workshop sessions at Macquarie with participants from BHP Billiton and GEMOC, and visits by Macquarie researchers to Perth, were key activities in 2008, following a successful application for a new 3-year Linkage Project. Dr Graham Begg spent significant research time at GEMOC through 2008 as part of the close collaborative working pattern for this project. Sub-licensing agreement was executed with Minerals Targeting International to accommodate Dr Begg’s new role (in relationship to Macquarie, BHPB, and the GLAM project) as Director of this company.

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 continued to support an ARC Linkage Project on Diamond Fingerprinting. Dr Debora Araujo has been employed as a Research Associate on the project and has carried out an extensive program of method development and diamond analysis.

In 2007-2008 GEMOC developed a technique for dating the intrusion of kimberlites and lamproites using LAM-ICPMS U-Pb analysis of groundmass perovskite (see GEMOC Publication #505). This rapid, low-cost application has proven very attractive to the diamond exploration industry, and has led to several small collaborative projects; it also will be applied in the new ARC Linkage project sponsored by De Beers.

During 2008, GEMOC increased its collaboration with CERCAMS, the Centre for Russian and Central Eurasian Mineral Studies at the Natural History Museum, London, that serves the international mineral deposits community as a centre for research into the geodynamics and metallogenesis of the Former Soviet Union and neighbouring territories.

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, and the development of the Macquarie Arc.

Industry visitors spent varying periods at GEMOC in 2008 to discuss our research and technology development (see visitor list, Appendix 3). This face-to-face interaction has proved highly effective both for GEMOC researchers and industry colleagues.

DIATREEM continued to provide LAM-ICPMS analyses of garnets and chromites to the diamond-exploration industry on a collaborative basis.
GEMOC publications, preprints and non-proprietary reports are available on request for industry libraries.

GEMOC was prominent in delivering keynote and invited talks and workshop modules at national and international industry peak conferences in 2008. Sue O’Reilly has been a member of the organising committee for the SGA Conference in Townsville in 2009. See Appendix 4 for abstract titles and GEMOC Publications.

A new ARC Linkage project was awarded with de Beers as Industry Partner (see below).

A new collaborative research project aimed at developing an integrated approach to understanding the formation of the mineral sand deposits using Australian deposits as a world benchmark, and to improve exploration strategies employed in Australia and in Russia was initiated in collaboration with Professor Alexandr Kremenetsky from Institute of Mineralogy, Geochemistry and Crystal Chemistry of Rare Elements (IMGRE), PIRSA and Iluka Resources.

CURRENT INDUSTRY-FUNDED COLLABORATIVE RESEARCH PROJECTS

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

GEMOC’s industry collaborative projects are designed to develop the strategic and applied aspects of the basic research programs based on understanding the architecture of the lithosphere and the nature of Earth’s geodynamic processes that have controlled the evolution of the lithosphere and its important discontinuities. Most of the industry collaborative projects rely on geochemical information from the Geochemical Analysis Unit in GEMOC and especially on novel methodologies developed by (and some unique to) GEMOC.
Geochemical data on crustal and mantle rocks are being integrated with tectonic analyses and large-scale datasets (including geophysical data) to understand the relationship between lithosphere domains and large-scale mineralisation.

The use of mantle sulfides to date mantle events, and the characterisation of 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 an important tool for characterising the tectonic history and crustal evolution of terranes on the scale of 10 – 100 km and delivers a cost-effective exploration tool to the mineral (and potentially petroleum) exploration industry.

The recent breakthrough in developing a robust methodology to analyse the trace elements in diamonds quantitatively is another world-first for GEMOC. In addition to providing unique knowledge about the nature and compositions of deep mantle fluids that has led to a new hypothesis for how diamonds form in the Earth’s mantle (see Research Highlights 2007, p. 27, 30), it has potential practical applications to diamond fingerprinting for forensic applications and to better prediction of targets for diamond exploration.

Formal projects newly funded for 2009:

**Composition, structure and evolution of the lithospheric mantle beneath southern Africa: improving area selection criteria for diamond exploration**

*Supported by ARC Linkage*

*Industry Collaborator: De Beers*

*Summary:* Trace-element analyses of garnet and chromite grains from kimberlites distributed across the Kaapvaal craton and the adjacent mobile belts will be used to construct 2D and 3D models of compositional and thermal variation in the lithospheric mantle (to ~250km depth), in several time slices. Regional and high-resolution geophysical datasets (e.g. seismic, magnetotelluric, gravity) will be used to test and refine this model. Links between changes in the compositional structure of the lithospheric mantle and far-field tectonic events will be investigated using 4-D plate reconstructions. The results will identify factors that localise the timing and distribution of diamondiferous kimberlites, leading to new exploration targeting strategies.

Formal projects active in 2008:

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

*Supported by a matching Macquarie University External Collaborative grant*

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

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

**Supported by ARC Linkage**

**Industry Collaborator: BHP Billiton**

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

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

**Supported by ARC Linkage**

**Industry Collaborator: Rio Tinto**

**Summary:** As diamond crystals grow deep in the Earth’s mantle, they trap minute inclusions of the fluids from which they crystallise. We will use recently developed laser-ablation microprobe techniques to analyse the trace-element patterns of diamond crystals from the Argyle, Diavik and Murowa mines (Australia, Canada and Zimbabwe). The results will define the nature and evolution of the parental fluids of the diamonds, and thus shed new light on the processes of diamond formation and the nature of fluids in the deep Earth. The data will be used to test the potential for fingerprinting diamonds by source; such fingerprinting can be used as a tool in controlling the flow of stolen and illegally mined diamonds. The project will provide new insights into the processes by which diamond crystallises in the Earth’s mantle. A better understanding of these processes can lead to improved models and techniques for diamond exploration, enhancing the prospect of finding new deposits in Australia and abroad. 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.

Lithosphere evolution across a craton margin, southern Africa

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

**Industry Collaborator: De Beers**

**Summary:** The margins of cratonic blocks extend to 150-300 km depth, and exert a strong control on crustal tectonics. Kimberlite magmas intruded across the southern margin of the Kaapvaal Craton (S. Africa) provide detailed sampling of the lithospheric mantle. We will use these samples to map the composition and structure of the mantle in two time slices (120 Ma, 90 Ma), providing new information on how the craton margins channel fluids. Linkages between crustal tectonics and mantle events are being constrained by comparing TerraneChron® analyses of zircons from modern streams, and the kimberlites themselves, with existing Re-Os ages for mantle rocks.
Trace-element analysis of diamonds

Supported by Industry and a matching Macquarie University Collaborative Grant
Industry Collaborator: Rio Tinto

Summary: Diamonds contain minute amounts of trapped fluids, representing the medium from which the diamonds grew; these fluids are a unique source of information on processes in Earth’s mantle. New techniques for the trace-element analysis of these fluids, developed recently in GEMOC were further developed, and applied to selected populations of diamonds from the Argyle mine (WA). The data will provide new insights into the genesis of diamond, with applications both to exploration models and to test the feasibility of “fingerprinting” of diamonds for exploration and forensic purposes (tracing illegal diamond sources). This project led to the ARC Linkage Grant for 2007.

Global Lithosphere Architecture Mapping

Supported by ARC Linkage
Industry Collaborator: BHP Billiton

Summary: Compositional domains in the subcontinental lithospheric mantle reflect the processes of continental assembly and breakup through Earth’s history. Their boundaries may focus the fluid movements that produce giant ore deposits. Mapping these boundaries in this first-stage project is providing fundamental insights into Earth processes and a basis for the targeting of mineral exploration. We are integrating mantle petrology, tectonic synthesis and geophysical analysis to produce the first maps of the architecture of the continental lithosphere, to depths of ca 250 km (e.g. GEMOC Publication #423). These maps will provide a unique perspective on global dynamics and continental evolution, and on the relationships between lithosphere domains and large-scale mineralisation.

Mechanisms of PGE fractionation and concentration in mafic and ultramafic melts

Supported by AMIRA and MERIWA and an international postgraduate scholarship from Macquarie University
Industry Collaborators: BHP Billiton, Independence, LionOre
In collaboration with Dr Marco Fiorentini from UWA with shared PhD student Marek Locmelis

Summary: A long-standing goal of research on nickel-sulfide (NiS) deposits has been the development of reliable lithogeochemical indicators that can act as guides for exploration. In order to better constrain how platinum-group element (PGE) signatures may be utilised as pathfinders for those NiS deposits, this project focusses on the processes that control the fractionation and concentration of PGE in mafic and ultramafic magma types. The study looks into a range of variables controlling the PGE geochemistry, including the role of sulfides (i.e. pentlandite, millerite), oxides (i.e. chromite), silicate phases (i.e. olivine, pyroxene) and platinum-group minerals (i.e. alloys, antimonides, arsenides, tellurides) in the concentration and fractionation of PGE in mineralised and barren sequences. Furthermore, the study investigates the spatial relationship between the PGE signature of mafic and ultramafic rocks and the occurrence of various types of NiS mineralisation, thus optimising the use of the PGEs as vectors towards mineralised environments. See 2007 Research highlights p. 34.
GEMOC’s international links

BACKGROUND

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

FUNDED COLLABORATIVE PROJECTS COMMENCED OR ONGOING IN 2008 INCLUDE:

- Collaboration in the CERCAMS project (www.nhm.ac.uk/research-curation/projects/cercams/gallery.html) as part of the ARC Discovery project “Earth’s internal system: deep processes and crustal consequences” (see section on Funded Research Projects). The CERCAMS project is a major study of crustal evolution across the Altaides, led by the Centre for Russian and Central EurAsian Mineral Studies at the Natural History Museum, London (Dr Richard Herrington, PI on the Discovery Project, and Dr Reimar Seltman) and involving Russian research groups, a number of industry sponsors and GEMOC.

- Trace elements and fluids in diamonds and relevance to mantle fluids and processes with Professor Oded Navon (Hebrew University, Israel).

- Shear-induced metal segregation in ordinary chondrites, a collaborative project with Professor Joel Baker 2007-2009 (Victoria University, New Zealand).

- The first million years of our solar system – stellar nucleosynthetic inputs, solid formation and planet building with Professor N. Petford (Bournemouth University, UK).

- Core formation and degassing of the Earth, a collaborative project with Dr S. Nielsen and Professor A. Halliday (University of Oxford) and Dr M. Rehkamper (Imperial College, London).

- Partitioning of chalcophile elements between metal, sulfide and silicate, a collaborative project with Dr D. Frost and Professor D. Rubie (Bayreuth University, Germany).

- Detailed 2-D and 3-D structure of the Kaapvaal Craton in several time slices, using mantle-derived xenocrysts: a collaborative project with De Beers.

- Global Lithosphere Architecture Mapping, involving analysis of crustal evolution, the composition of the lithospheric mantle and the interpretation of seismic tomography: a collaborative project with BHP Billiton and Professor Steve Grand (University of Texas at Austin).

- Collaboration with Professor Massimo Coltorti and Dr Costanza Bonadiman from the University of Ferrara on the geochemistry of amphiboles, mantle metasomatism, and the age and origin of the lithospheric mantle beneath the Cape Verde Islands and Antarctica.

- A 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 (led by Professor Sun-Lin Chung), and has expanded to include collaboration with Nanjing University.

Refer to the Research Program and Postgraduate sections of this Report for details of other projects.
• The nature of the lithosphere in Mongolia, and lithosphere extension in the Taiwan region, with Dr Kuo-Lung Wang (Institute of Earth Sciences, Academia Sinica, Taiwan).

• Collaboration with colleagues at the University of Jean Monnet, St Etienne, including Professor Jean-Yves Cottin, Dr Bertrand Moine and Dr Marie-Christine Gerbe (with reciprocal funding from both sides) expanded. A formal agreement between the two universities includes PhD exchange, academic exchange and research collaboration relevant to the nature of the lithosphere in the Kerguelen Archipelago, Crozet Islands and the Hoggar region of Algeria. In addition, studies on magma mixing in granites commenced with a new co-tutelle agreement (Anne Fonfrege).

• Collaboration with colleagues at the University of Montpellier continued with two co-tutelle PhD projects (Véronique Le Roux and Yoann Gréau).

• Trace elements in mineral inclusions in lower mantle diamonds from Juina, Brazil with Dr Felix Kaminsky (KM Diamond Exploration, Vancouver, Canada, pictured right with Elena Belousova in Vancouver, Canada).

• Dr Farida Ait-Hamou from the Université des Sciences et de la Technologie Houari Boumediene (USTHB), Algeria, undertook fieldwork in Algeria to collect mantle xenoliths from the Hoggar region as part of the Hoggar strand of the Discovery Project “Earth’s Internal System: deep processes and crustal consequences”. Analyses of these xenoliths will be integrated with geophysical datasets to understand the origins of the Hoggar Swell, a major topographic feature of N. Africa.

• Igneous rocks, mineral deposits, lithosphere structure and tectonic setting: southeastern China and eastern Australia. This collaboration with Nanjing University has expanded from an AusAID grant under the ACILP scheme with Professor Xisheng Xu (Nanjing University).

• Collaboration with Professor Yuri Kostitsyn from the Vernadsky Institute of Geochemistry and Analytical Chemistry (GEOKHI), Russian Academy of Science includes studies on continental crust formation in the modern subduction zone: Kamchatka Peninsula. Professor Kostitsyn is also involved in the GEMOC project testing models for continental crustal growth using the TerraneChron® database.

• Studies with Professor Jianping Zheng (China University of Geosciences, Wuhan) on the evolution of the lithosphere beneath several parts of China, crustal evolution in the North China Block, the Yangtze Block and southeastern China, and the UHP metamorphism of Dabie-Sulu peridotites.

• Studies on Cathaysia’s place in Rodinia, crustal evolution of southeast China, and crustal evolution of the Yangtze Block with Professor Jinhai Yu and Ms Lijuan Wang (collaborative project with Nanjing University).

• Studies continued with Dr Rendeng Shi (University of Science and Technology, Hefei, China) on the age and origin of platinum group alloy phases in podiform chromitites in ophiolites from Tibet.

• TerraneChron® analysis of Proterozoic terrains in Africa, North America and Europe, with BHP Billiton and several other mineral-exploration companies.
Age and magma sources of Chilean Cu-porphyries, with Codelco (Chile) and the CSIRO Division of Exploration and Mining (Perth).

Several collaborative projects continued with Dr Kreshimir N. Malitch (Department of Geochemistry, All-Russia Geological Research Institute (VSEGEI), St Petersburg) including:

1. the nature and origin of zircons from the intra-continental paleorift-related ultramafic intrusions of the Noril'sk area (northern Siberia, Russia). The latter include world-class PGE (platinum-group element)-Cu-Ni sulfide deposits related to Noril'sk-1, Talnakh and Kharaelakh ultramafic-mafic intrusions, subeconomic PGE-Cu-Ni deposits related to Chremogorsk, Zub-Marksheider and Vologochan intrusions, prospective Mikchanga intrusion and non-economic Nizhny Talnakh, Zelyonaya Griva and Kruglogorsk intrusions;

2. analysis of Os-(Ir-Ru) alloy grains derived from two world-class Au-PGE placer deposits associated with the Guli clinopyroxenite-dunite massif (northern Siberia, Russia) and the Evander Goldfield within the Witwatersrand Basin (South Africa). The main aim of this study is to place further constraints on osmium-isotope signatures of the mantle sources for Os-rich alloy grains at Guli and Evander, which (along with Witwatersrand grains) represent the oldest terrestrial platinum-group minerals known so far.

Formal visits to three Chinese institutions strengthened or initiated collaborative research projects and agreements:

- Nanjing University
- China Academy of Sciences, Geophysical and Geochemical Institutes
- China University of Geosciences (Beijing)
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 Centre funding period that ended in 2001.

Key elements of funding continuation include:

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

Strategy for ongoing Geochemical Analysis Unit funding

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

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


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

**GEMOC INCOME 2008**

This is a summary of 2008 income. A full, audited statement of detailed expenditure and income is prepared by Macquarie University. *No in-kind support is included here.*

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<td><em>Discovery (including Fellowships), Linkage (Project and International), Federation Fellowships</em></td>
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Scientific innovation relevant to National Priority Areas

Research Priority 1: An Environmentally Sustainable Australia
- Goal 1: Water – a Critical Resource
- Goal 2: Water – Transforming existing industries and
- Goal 6: 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 2008/2009
MACQUARIE UNIVERSITY
Department of Earth and Planetary Sciences

Academic and GEMOC Managerial Staff
(Teaching and Research)
Dr Juan Carlos Afonso (Geodynamic modelling, CoRE)
Dr Nathan Daczko (Structural and metamorphic geology, tectonics, geodynamics)
Dr Kelsie Dadd (Physical volcanology, geochemistry, tectonics)
Dr Richard Flood (Volcanic geology, application of magnetic fabrics to reconstruction of volcanic terrains)
Professor W.L. Griffin, Program Leader (Technology development and industry liaison, CoRE)
Dr Simon Jackson (Trace element geochemistry, metallogeny)
Dr Mark Lackie (Rock magnetism, paleomagnetic reconstructions)
Dr Craig O’Neill (Geodynamic modelling, CoRE)
Professor Suzanne Y. O’Reilly, Director (Crust and mantle evolution, lithosphere modelling)
Dr Norman Pearson (Director, GAU)
Dr Tracy Rushmer (Experimental rock deformation and experimental petrology, CoRE)
Dr Bruce Schaefer (Geodynamics, isotope geochemistry, CoRE)
Professor Simon Turner (Isotopic geochemistry, CoRE)
Professor Bernard Wood (Experimental petrology)

Research Staff
Dr Debora Araujo
Dr Christoph Beier
Dr Elena Belousova
Dr Mei-Fei Chu
Dr Alex Corgne
Dr Anthony Dosseto
Dr Kevin Grant
Emeritus Professor Trevor Green
Dr Jacqueline Halpin
Dr Heather Handley
Dr Claudio Marchesi
Dr Laure Martin
Dr Lev Natapov
Emeritus Professor John Veevers
Emeritus Professor Ron Vernon
Dr Ming Zhang

Professional Staff
Miss Shelley Allchurch (Technical Assistant)
Ms Manal Bebbington (Rock preparation)
Mr James Bevis (Technical Assistant)
Mrs Nikki Bohan (Administrator)
Mr Steven Craven (Rock preparation)
Miss Cara Donnelly (Research Officer)
Ms Suzy Ehlhou (Geochemist)
Dr Oliver Gaul (Research Officer)
Mr Felix Genske (Research Officer)
Ms Sally-Ann Hodgkiss (Research Officer, Design consultant)
Mrs Emma Jago (Administrator)
Mrs Carol McMahon (Administrator)
Mr Luke Milan (Research Associate)
Miss Melissa Murphy (Research Officer)
Dr Justin Payne (Geochemist - ICPMS)
Dr William Powell (Research Officer)
Dr Ayesha Saeed (Geochemist)
Mr Peter Wieland (Geochemist)

Adjunct Professors
Dr Anita Andrew
Professor Bruce Chappell (Granite petrogenesis, geochemistry)
Professor Mike Etheridge
Dr Richard Glen
Dr Jingfeng Guo
Dr Jon Hronsky (BHP Billiton)
Professor Else-Ragnhild Neumann
Professor Xisheng Xu

Visiting Fellows
Associate Professor Ian Metcalfe
Professor Oded Navon
Dr Jin Hui Yang
Professor Jianping Zheng

Honorary Associates
Dr John Adam
Dr Farida Ait-Hamou
Dr Olivier Alard
Professor Tom Andersen
Dr Sonja Aulbach
Dr E.V.S.S.K. Babu
Dr Graham Begg
Dr Eloise Beyer
Dr Phillip L. Blevin
Dr Rosa Maria Bomparola
Professor Hannes Brueckner
Dr Robert Buldtude
Dr Gilles Chazot
Professor Massimo Coltorti
Professor Kent Condie
Dr Jean-Yves Cottin
Dr Karsten Gohl
Dr Michel Grégoire
Dr Bin Guo
Dr Xiumian Hu
Dr Bram Janse
Dr Mel Jones
Dr Felix Kaminsky
Dr Hans-Rudolf Kuhn
Dr Kreshimir Malich
Dr Vladimir Malkovets
Dr Bertrand Moine
Dr Valeria Murgulov
Dr Geoff Nichols
Dr Yvette Poudjom Djomani
Dr Sonal Rege
Dr Peter Robinson
Dr Chris Ryan
Dr Giovanna Sapienza
Dr Bruce Schaefer
Dr Stirling Shaw
Dr Simon Shee
Dr Zdislav Spetsius
Dr Nancy van Wagoner
Dr Kuo-Lung Wang
Professor Xiang Wang
Dr Xiao-Lei Wang
Mr Bruce Wyatt
Ms Chunmei Yu
Professor Jin-Hai Yu

FORMAL COLLABORATORS

University of Wollongong
Professor Allan Chivas (DEST Systemic Infrastructure partner)

Monash University
Dr Bruce Schaefer (LIEF and Research partner)

University of Newcastle

University of Sydney
Professor G. Clarke (DEST Systemic Infrastructure partner)

University of Western Sydney
Professor Peter Williams (DEST Systemic Infrastructure partner)

University of Western Australia
Dr Marco Fiorentini

Australian National University (Research School of Earth Sciences)
Professor Geoff Davies
Professor Brian Kennett
Professor Gordon Lister
Professor Hugh O’Neill
Professor Masahiko Honda

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

PIRSA (South Australian Geological Survey)
Dr Anthony Reid
Mr Martin Fairclough

OTHER COLLABORATORS ON PROJECT BASIS
Dr Farida Ait-Hamou (Université des Sciences et de la Technologie Houari Boumediene (USTHB), Algiers)
Professor Joel Baker (Victoria University, NZ)
Dr Bernard Bingen (Geological Survey of Norway, Trondheim)
Professor J.-L. Bodinier (Université Montpellier, France)
Dr Costanza Bonadiman (University of Ferrara)
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 Julie Dickinson (Sydney University)
Professor Steve Grand (University of Texas at Austin)
Dr Jeff Harris (University of Glasgow, Glasgow)

Dr Richard Herrington (Natural History Museum, London)
Professor Yuri Kostitsyn (Vernadsky Institute of Geochemistry and Analytical Chemistry and Geochemistry Department at Moscow State University, Moscow)
Dr J.-P. Lorand (Museum National d’Histoire Naturelle)
Professor Oded Navon (The Hebrew University, Jerusalem)
Dr Sune Nielsen (University of Oxford)
Professor Nick Petford (Bournemouth University, UK)
Professor Elisabetta Rampone (Genoa University, Genoa, Italy)
Associate Professor Mark Reagan (University of Iowa, USA)
Klaus Regenauer-Lieb (CSIRO Exploration and Mining and the University of Western Australia)
Dr Patrice Rey (University of Sydney)
Professor Marco Scambelluri (Genoa University, Genoa, Italy)
Dr Rendeng Shi (University of Science and Technology, Hefei, China)
Professor Thomas Stachel (University of Alberta, Edmonton)
Dr Csaba Szabo (Eotvos University, Budapest)
Dr Qin Wang (Nanjing University)

Technology Partners
Agilent Technologies (Hewlett Packard)
New Wave Research
Spectro Instruments
Nu Instruments

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


Appendix 2: Publications


Appendix 3:  
Visitors/GAU users

GEMOC VISITORS 2008  
(Excluding Participants in 
Conferences and Workshops)  
Macquarie

Dr Chris Adams (Institute of  
Geological and Nuclear Science, 
NZ)
Mr Robin Armit (Monash University)
Dr Steve Barnes (CSIRO Exploration  
and Mining)
Dr Graham Begg (Minerals Targeting 
International Pty Ltd)
Prof Paul Bierman (The University of 
Vermont, USA)
Prof Hannes Brueckner (Queens 
College, City University of New 
York, USA)
Dr Solomon Buckman (University of 
Wollongong)
Prof Douglas Burbank (University of 
California, Santa Barbara, USA)
Dr Michel Ballevere (Universite de 
Renee, France)
Dr Fabio Cammarano (Berkeley 
Seismological Laboratories, USA)
Dr Robert Craig Cook (Cambridge, 
NZ)
Dr Shane Cronin (Massey University, 
NZ)
Mr Sam Deed (Adelaide University)
Dr Graeme Eagles (Royal Holloway, 
University of London, UK)
Dr Martin Fairclough (Primary 
Industries and Resources South 
Australia)
Dr Marco Fiorentini (The University 
of Western Australia)
Mr Fred Fryer (Agilent Technologies)
Dr Bob Hayden (Predictive Mineral 
Discovery Cooperative Research 
Centre)
Dr Nick Haywood (BHP Billiton, WA)
Dr Jon Hronsky (Vertex Exploration 
Solutions Pty Ltd)
Dr David Kelsey (Adelaide University)
Prof Yuri A Kostitsyn (Russian 
Academy of Science)
Ms Kamonporn Kromkhun (Adelaide 
University)
Ms Lucy McGee (Auckland 
University, NZ)
Dr Claudio Marchesini (University of 
Granada, Spain)
Dr Chris Marjo (UNSW Analytical 
Centre)
Mr Massimiliano Melchiorre 
(Università di Ferrara, Italy)
Mr Greg Melton (University of 
Alberta, Canada)
Prof Oded Navon (Hebrew University 
of Jerusalem, Israel)
Dr Alison Ord (CSIRO Perth)
Dr Glen Phillips (University of 
Newcastle)
Prof Richard Price (The University of 
Waikato, NZ)
Ms Sureeporn Pumpeng (The Gem 
and Jewelry Institute of Thailand)
Dr Bruce Schaefer (School of 
Geosciences, Monash University)
Ms Ailsa Shwarz (Adelaide 
University)
A/Prof Ian Smith (The University of 
Auckland, NZ)
Dr Alex Song (Department of 
Terrestrial Magnetism, Carnegie 
Institution of Washington, UK)
Ms Chaniya Somboon (The Gem and 
Jewelry Institute of Thailand)
Mr John Sumpton (DeBeers)  
A/Prof Chakkaphan Sutthirat (The 
Gem and Jewelry Institute of 
Thailand)
Dr Kuo-Lung Wang (Institute of 
Earth Sciences, Academia Sinica, 
Taiwan)
Mr Dachochai Wilairat (Agilent 
Technologies, Thailand Ltd)  
Prof Kate Wright (Curtin University of 
Technology)
Mr Bruce Wyatt (Wyatt Geology 
Consulting Ltd - Consultant to De 
Beers)
Mr Anurak Yaemplai (The Gem and 
Jewelry Institute of Thailand)
Dr Jin-Hui Yang (Chinese Academy of 
Sciences, Beijing, China)
Prof Jianping Zheng (China 
University of Geosciences, 
Wuhan, China)
EXTERNAL USERS OF THE GEOCHEMICAL ANALYSIS UNIT FACILITIES IN 2008
(Note: this does not include contract work through AccessMQ)

Dr Chris Adams (Institute of Geological and Nuclear Science)
Mr Robin Armit (Monash University)
Prof Hannes Brueckner (Queens College, City University of New York, USA)
Dr Solomon Buckman (University of Wollongong)
Dr Robert Craig Cook (Waikato University, NZ)
Mr Sam Deed (Adelaide University)
A/Prof Damian Gore (Macquarie University)
Mr Duncan Keenan-Jones (Macquarie University)
Ms Kamonporn Kromkhun (Adelaide University)
Ms Lucy McGee (Auckland University, NZ)
Mr Massimiliano Melchiorre (Università di Ferrara, Italy)
Prof Oded Navon (Hebrew University of Jerusalem, Israel)
Dr Glen Phillips (University of Newcastle)
Ms Sureeporn Pumpeng (The Gem and Jewelry Institute of Thailand)
Dr Bruce Schaefer (School of Geosciences, Monash University)
Ms Ailsa Shwarz (Adelaide University)
Ms Chaniya Somboon (The Gem and Jewelry Institute of Thailand)
A/Prof Chakkaphan Sutthirat (The Gem and Jewelry Institute of Thailand)
Dr Kuo-Lung Wang (Institute of Earth Sciences, Academia Sinica, Taiwan)
Ms Tin Tin Win (private consultant)
Mr Anurak Yaemplai (The Gem and Jewelry Institute of Thailand)
Dr Jin-Hui Yang (Chinese Academy of Sciences, Beijing, China)
Appendix 4: Abstract titles

TITLES OF ABSTRACTS FOR CONFERENCE PRESENTATIONS IN 2008

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

THE 18th V.M. GOLDSCHMIDT CONFERENCE: FROM SEA TO SKY, VANCOUVER, CANADA, 13-18 JULY, 2008

How primitive is the “primitive” mantle?
O. Alard1,2, V. Le Roux1,2, J.L. Bodinier1, J.P. Lorand3, W.L. Griffin2 and S.Y. O’Reilly2
1. Géosciences Montpellier, U. Montpellier II, UMR 5243 CNRS, Montpellier, France, 2. GEMOC Macquarie

Sulfides, diamonds and eclogites: Their link to peridotites and Slave Craton tectonothermal evolution
S. Aulbach1, R.A. Creaser1, L.M. Heaman1, S.S. Simonetti1, W.L. Griffin2 and T. Stachel1
1. Earth and Atmospheric Sciences, University of Alberta, Edmonton, Canada, 2. GEMOC Macquarie

Core formation and the Pb and Tl isotope evolution of the silicate Earth
R.G.A. Baker1,2, B.J. Wood3, M. Rehkämper1, M. Schönbächler1,4 and S.G. Nielsen5

U-Th-Ra disequilibria along the EPR: Evidence for off-axis melting?
C. Beier1, S.P. Turner1 and Y. Niu2
1. GEMOC Macquarie, 2. Department of Earth Sciences, Durham University, Durham, UK

U-Pb age, Hf-isotope and trace-element composition of zircon megacrysts from the Juina kimberlites, Brazil
E.A. Belousova1, F.V. Kaminsky2 and W.L. Griffin1
1. GEMOC Macquarie, 2. KM Diamond Exploration Ltd., West Vancouver, Canada

THE GEOLOGICAL SOCIETY OF AMERICA, NORTHEASTERN SECTION, 43RD ANNUAL MEETING, NEW YORK, USA, 27-29 MARCH, 2008

Significance of detrital zircon ages from the Westboro Quartzite, Avalon Terrane, Eastern Massachusetts
J.C. Hepburn1, E.J. Fernández-Suárez2, G.A. Jenner3 and E.A. Belousova4
1. Department of Geology and Geophysics, Boston College, Chestnut Hill, MA, USA, 2. Departmento de Petrología y Geoquímica, Universidad Complutense, Madrid, Spain, 3. Department of Earth Sciences, Memorial University of Newfoundland, St. John’s, Canada, 4. GEMOC Macquarie

Plate tectonics or not: Lithospheric stress on terrestrial planets and super-earths
C.J. O’Neill1, A. Lenardic1 and A.M. Jellinek1
1. GEMOC Macquarie, 2. Department of Earth Science, Rice University, Houston, Texas, 3. Department of Earth and Ocean Science, University of British Columbia, Vancouver, Canada

U-Pb age, Hf-isotope and trace-element composition of zircon megacrysts from the Juina kimberlites, Brazil
E.A. Belousova1, F.V. Kaminsky2 and W.L. Griffin1
1. GEMOC Macquarie, 2. KM Diamond Exploration Ltd., West Vancouver, Canada

RST (RÉUNION DES SCIENCES DE LA TERRE), NANCY, FRANCE, 21-24 APRIL, 2008

Nouvelles données isotopiques (Sr-Nd-Hf-O) des roches gabbroïques de l’Archipel de Kerguelen (Océan Indien)
J. Chevet1, M.-C. Gerbe2, M. Grégoire3, J.Y. Cottin2, S.Y. O’Reilly1 and W.L. Griffin1
1. GEMOC Macquarie, 2. Magmas et Volcans, Université Jean Monnet, Saint-Étienne, France, 3. Observatoire Midi Pyrénées, Université Toulouse, Toulouse, France

5TH ANNUAL K-8 SCIENCE AND TECHNOLOGY CONFERENCE, SYDNEY, JUNE, 2008

A world apart: planet Earth in space and time
O’Neill, C. Keynote
GEMOC Macquarie
Appendix 4: Abstract titles

$^{210}$Pb-$^{226}$Ra disequilibria: Mantle melting or gas fractionation?
K. Berlo$^1$ and S. Turner$^2$
1. Department of Earth and Planetary Sciences, McGill University, Canada,
2. GEMOC Macquarie

An outline of juvenile crust formation and recycling history in the Archaean Western Dharwar craton, from zircon in situ U-Pb dating and Hf-isotopic compositions
Y.J. Bhaskar Rao$^1$, W.L. Griffin$^2$, J. Ketchum$^2$, N.J. Pearson$^2$, E. Beyer$^2$ and S.Y. O’Reilly$^2$
1. National Geophysical Research Institute, Hyderabad, India, 2. GEMOC Macquarie

Rate of spheroidal weathering determined by U-Series nuclides (Río Icacos basin, Puerto Rico)
F. Chabau$^1$, E. Blaes$^1$, E. Pelt$^1$, A. Dosseto$^1$, H. Buss$^1$, A. White$^1$ and S. Brantley$^4$
1. CGS-EOST, CNRS-University of Strasbourg, France, 2. GEMOC Macquarie, 3. USGS, CA, USA, 4. Penn State University, PA, USA

Element partitioning during core formation
A. Corgne and B.J. Wood Keynote
GEMOC Macquarie

How much heat and REE in calcium silicate perovskite?
A. Corgne and B.J. Wood invited
GEMOC Macquarie

Water storage and amphibole control in arc magma differentiation
J.P. Davidson$^1$, S.P. Turner$^1$ and C.G. Macpherson$^1$
1. Department of Earth Sciences, University of Durham, Durham, UK,
2. GEMOC Macquarie

Vegetation over hydrologic control of sediment transport over the past 100,000 yr
A. Dosseto$^1$, S.P. Turner$^1$, P. Hesse$^1$, K. Maher$^1$ and K. Fryirs$^2$
1. GEMOC Macquarie, 2. Department of Physical Geography, Macquarie University, Australia, 3. Department of Geological and Environmental Sciences, Stanford University, USA

Alkali activities in silicate melts
K.J. Grant and B.J. Wood
GEMOC Macquarie

Timescales of crustal assimilation at intra-oceanic arcs: U-series and geochemical constraints from Lopevi Volcano, Vanuatu, SW Pacific
H.K. Handley$^1$, S.P. Turner$^1$, I.E.M. Smith$^2$ and R.B. Stewart$^1$
1. GEMOC Macquarie, 2. Department of Geology, University of Auckland, Auckland, New Zealand, 3. Institute of Natural Resources, Massey University, Palmerston North, New Zealand

Cu isotopic anomalies around porphyry Cu deposits
W. Li, S.E. Jackson and N.J. Pearson
GEMOC Macquarie

Contrasting magma sources in ultramafic-mafic intrusions of the Noril’sk area (Russia): Hf-isotope evidence from zircon
K.N. Malitch$^1$, E.A. Belousova$^2$, W.L. Griffin$^2$, I.Y. Badanina$^1$, O.V. Petrov$^1$ and N.J. Pearson$^2$
1. All-Russia Geological Research Institute, St. Petersburg, Russia,
2. GEMOC Macquarie

Precision of in situ isotope ratio measurements by LAM-MC-ICPMS
N.J. Pearson, W.L. Griffin and S.Y. O’Reilly
GEMOC Macquarie

Distribution of Pt, Os, Ir during liquid metal segregation under extremely reducing conditions
T. Rushmer
GEMOC Macquarie

Genesis of high-Mg andesites at White Island, New Zealand
S. Turner and B. Wood
GEMOC Macquarie


Petrographic and geochemical characterisation of charnockitic and cumulate gabbro xenoliths from Coliban Dam, central Victoria, with implications for the evolution of the Lachlan Orogen
S. Allchurch$^1$, N. Daczko$^1$ and I. Graham$^2$
1. GEMOC Macquarie, 2. School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, Australia

Tectonics, plumes and supercontinents: the energy link
G. Begg
Minerals Targeting International PL, GEMOC Macquarie

TerraneChron® approach to the crustal evolution studies and implications for continental growth
E.A. Belousova, W.L. Griffin and S.Y O’Reilly Keynote
GEMOC Macquarie

The University of the Sea and the benefits to learning of active participation in a research cruise
K. Dadd$^1$ and E. Baker$^2$
1. GEMOC Macquarie, 2. UNEP Shelf Programme Regional Office, School of Geosciences, University of Sydney, Australia

Australian junior exploration floats, 2001-2006 and their implications for IPOs
P. Gu$^{1,3}$, O.P. Kruezer$^{2,3}$ and M.A. Etheridge$^{1,4}$
1. GEMOC Macquarie, 2. Centre for Exploration Targeting, The University of Western Australia, WA, 3. Western Australia School of Mines, Curtin University, WA, 4. Tectonex GeoConsultants, Balmain NSW,
The psychology of decision-making in mineral exploration – a key to improving return on investment in our business
M. Etheridge1, C. Wastell2, G. Lucas3, L. Hartley4 and M. McMahon
1. GEMOC Macquarie, 2. Department of Psychology, Macquarie University, 3. Macquarie Graduate School of Management, Macquarie University

The Uralla Magmatic Centre: preservation of plutonic and volcanic rocks representing an upper crustal section of some 8 km
R. Flood and S. Shaw
GEMOC Macquarie

U-Pb, Nd and Hf isotopic constraints on basin development and deformation in the Western Gawler Craton
K. Howard1, M. Hand1, K. Barovich1, B. Wade1, E. Belousova2 and B. Wade1
1. University of Adelaide, 2. GEMOC Macquarie

The Proterozoic: Hiding Archean in the basement
W.L. Griffin1, G. Begg1, S.Y. O’Reilly1 and L. Natapov1

The emergence of steady-state plate tectonics in dynamic mantle models
C. O’Neill
GEMOC Macquarie

A spectrum of Hadean geodynamics from diamond stability constraints
C. O’Neill
GEMOC Macquarie

Archean Lithospheric mantle: formation, composition and today’s refertilised remains
S.Y. O’Reilly1, W.L. Griffin1 and G. Begg1,2

Provenance of ophiolitic sand: comparison of ancient and modern sand
M. Murphy, R. Portner, N. Daczko, J. Dickinson and S. Allchurch
GEMOC Macquarie

The crustal evolution of the Musgrave Province
A. Schwarz1,2, M. Hand1, K. Barovich1, B. Wade1, E. Belousova1 and E. Jagodzinski1
1. PIRSA, SA, 2. Continental Evolution Research Group, University of Adelaide, SA, 3. GEMOC Macquarie

33rd INTERNATIONAL GEOLOGICAL CONGRESS (IGC), OSLO, 6-14 AUGUST, 2008
Juvenile and old components in Proterozoic crust; examples from Lu-Hf isotopes in zircon from magmatic Svecofennian and rapakivi rocks in Sweden
U.B. Andersson1, W.L. Griffin1, G. Begg1 and K. Högdahl1

Gondwana assembly: geochronological and Hf isotope constraints from the east African orogen in NE Mozambique
B. Bingen1, G. Viola1, W.L. Griffin1, J. Jacobs1, A.K. Engvik1, I.H.C. Henderson1, R. Boyde1, R.J. Thomas1, E. Daudi1, O. Skar1, R.M. Key1, A. Solli1, J.S. Sandstad1, M. Smethurst1 and T. Bjerkgerd1

Geochemo evidence for subcontinental lithospheric mantle in oceanic domain (Sal, Cape Verde Archipelago)
C. Bonadiman1, M. Coltorri1, L. Beccaluva1, W.L. Griffin1, S.Y. O’Reilly2 and N. Pearson2
1. University of Ferrara, Italy, 2. GEMOC Macquarie

Heterogeneity in the oceanic lithosphere as evidenced by mantle xenoliths from Sal Island (Cape Verde Archipelago)
M. Coltorri1, C. Bonadiman1, S.Y. O’Reilly2, W.L. Griffin2 and N. Pearson2
1. University of Ferrara, Italy, 2. GEMOC Macquarie

The continental LAB: Can we sample it?
W.L. Griffin and S.Y. O’Reilly
GEMOC Macquarie

U-Pb dating and Hf isotope analysis of zircon from very young magmatic rocks at the axial valley of the Mid-Atlantic Ridge
Y. Kostitsyn1, E. Belousova1, N. Bortnikov1, T. Zinger1 and E. Sharkov1
1. V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry (GEOKHI) Russian Federation, 2. GEMOC Macquarie, 3. Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry (IGEM) RAS, Russian Federation, 4. Institute of Precambrian Geology and Geochronology (IGGD) RAS, Russian Federation

Hf-isotope constraints on contrasting magma sources in economic and non-economic ultramafic-mafic intrusions of the Noril’sk area (Russia): Evidence from zircon
K. Malich1, E. Belousova1, W. Griffin1, N. Pearson1 and V. Khalenev1

Compositional variation in the lithospheric mantle and correlation with depth to the lithosphere-asthenosphere boundary
S.Y. O’Reilly
GEMOC Macquarie

Advances in mantle geochronology
N. Pearson1, S. O’Reilly1, W. Griffin1 and O. Alard1
1. GEMOC Macquarie, 2. CNRS, Université de Montpellier, France

Unusual plagioclase moat / pyroxene necklace structure around garnet in quartz-rich layers of the Averoya eclogite, Western Gneiss Region, Norway
P. Robinson1, N.R. Daczko2, T.E Krogh2 and K. Hollocher3
Appendix 4: Abstract titles

The Proterozoic Kibaran Belt in central Africa: intracratonic 1375 Ma emplacement of a LIP
L. Tack1, M.T.D. Wingate2, B. De Waele3, J. Meert4, E. Belousova4, W. Griffin4,
A. Tahon5, M. Fernandez-Alonso6, D. Baudet1, H.N.C. Cutton6 and S. Dewaele6
1. Royal Museum for Central Africa, Belgium, 2. TSRC, The University of Western Australia, Australia,
3. University of Florida, United States, 4. GEMOC Macquarie

9th INTERNATIONAL KIMBERLITE CONFERENCE, FRANKFURT, GERMANY,
10-15 AUGUST, 2008

Kimberlitic sources of super-deep diamonds in the Juina area, Mato Grosso State, Brazil
P. Andreazza1, F.V. Kaminsky2, S.M. Sablukov2, E.A. Belousova3, M. Tremblay4 and W.L. Griffin5
1. Diagem Inc., Montreal, Quebec, Canada, 2. KM Diamond Exploration Ltd., West Vancouver, Canada,
3. GEMOC Macquarie

Carbonatitic to silicic melt inclusions in lherzolite xenoliths from Lac de Gras, Slave Craton – Melt differentiation and mantle metasomatism
D.P. Araújo, W.L. Griffin and S.Y. O’Reilly
GEMOC Macquarie

Micro-inclusions in monocrystalline octahedral diamonds from Diavik, Slave Craton: Clues to diamond genesis
D.P. Araújo, W.L. Griffin and S.Y. O’Reilly
GEMOC Macquarie

Combined U-Pb and Lu-Hf analysis of megacrystic zircons from the Kalyandurg-4 kimberlite pipe, S. India: Implications for the emplacement age and Hf isotopic composition of the cratonic mantle
E.V.S.S.K. Babu1,2, W.L. Griffin1, A. Mukherjee3, S.Y. O’Reilly1 and E.A. Belousova1
1. GEMOC Macquarie, 2. National Geophysical Research Institute, Hyderabad, India, 3. NMDC Ltd., Khanij Bhavan, Masab Tank, Hyderabad, India

Eclogite xenoliths from the kimberlites of the Eastern Dharwar Craton, South India: Material representing ancient crust of the Western Dharwar Craton?
E.V.S.S.K. Babu1,2, W.L. Griffin1, S. Panda2, S.Y. O’Reilly1 and Y.J. Bhaskar Rao1
1. GEMOC Macquarie, 2. National Geophysical Research Institute, Hyderabad, India

Peridotic garnet geochemistry: key to the understanding of lithospheric structures and kimberlites diamond potential in Southern Congo
J.M. Batumike, S.Y. O’Reilly and W.L. Griffin
GEMOC Macquarie

Isotopic studies of minerals and their host kimberlites from Australia and Southern Africa
S.A. Cooper1-2, Y.A. Kostitsyn1, E.A. Belousova3 and W.L. Griffin1
1. GEMOC Macquarie, 2. Orogenic Exploration Pty Ltd, Burwood, Vic, Australia, 3. Laboratory of Isotopic Geochemistry and Geochronology,
GEOKHI RAS, Russia

Age of FS66 kimberlite beneath Murray Basin, South Australia: Laser ablation ICP-MS dating of kimberlitic zircon, perovskite, and rutile
S.A. Cooper1-2, E.A. Belousova1, W.L. Griffin1 and B.J. Morris3

Geology and exploration history of kimberlites and related rocks in South Australia
S.A. Cooper1-2 and B.J. Morris3

An evidence for the composition of the Ordovician upper mantle beneath West Sangilen (Southeast Tuva, Russia)
A. Gilshcher1, V. Malkovets1, Y. Litasov1, W. Griffin2 and S. O’Reilly3
1. Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia, 2. GEMOC Macquarie

Petrology and geochemistry of eclogitic sulfides: a new insight on the origin of mantle eclogites?
Y. Gréau1-2, W.L. Griffin1, O. Alard2 and S.Y. O’Reilly1
1. GEMOC Macquarie, 2. Geosciences Montpellier, CNRS UMR-5243, Equipe Manteau-Noyau, Universite Montpellier II, France

Diamonds and carbonatites in the deep lithosphere: Evidence of genetic links
W.L. Griffin1, D. Aráujo1, S.Y. O’Reilly1, S. Rege1 and E. van Achterbergh2
1. GEMOC Macquarie, 2. Rio Tinto Technology and Innovation, Bundoora, Vic, Australia

Contrasting lithospheric mantle across the suture between the Eastern and Western Dharwar Cratons, central India
W.L. Griffin1, A.F. Kobussen1, E.V.S.S.K. Babu1, S.Y. O’Reilly1, R. Norris1 and P. Sengupta1

Super-deep diamonds from kimberlites in the Juina area, Mato Grosso State, Brazil
F.V. Kaminsky1-3, G.K. Khachatryan1, P. Andreazza2, D. Araujo3 and W.L. Griffin3
1. KM Diamond Exploration Ltd., Brazil, 2. GEMOC Macquarie

The scale and scope of Cretaceous refertilisation of the Kaapvaal lithospheric mantle, Kaapvaal Craton, South Africa
A.F. Kobussen, W.L. Griffin and S.Y. O’Reilly
GEMOC Macquarie
Diamondiferous microxenoliths and xenocrysts from the Nyurbinskaya kimberlite pipe, Yakutia

V. Malkovets1,2, D. Zedgenizov1, W. Griffin2, A. Dak1, S. O’Reilly2, N. Pokhilenko1 and S. Mityukhin4
1. YaNIGP CNIGRI, ALROSA Co. Ltd., Mirny, Yakutia, Russia, 2. GEMOC Macquarie

Evolved carbonatitic kimberlites from the Batain Nappes, eastern Oman continental margin

S. Nasir1, S. Al-Khirbash1, H. Rollinson1, A. Al-Harthiy1, A. Al-Sayigh1, A. Al-Lazki1, E. Belousova2, F. Kaminsky3, T. They4, H.J. Massonne4 and S. Al-Busaidi5

Late Jurassic-Early Cretaceous kimberlite, carbonatite and ultramafic lamprophyric sill and dyke swarms from the Bomethra area, northeastern Oman

S. Nasir1, S. Al-Khirbash1, H. Rollinson1, A. Al-Harthiy1, A. Al-Sayigh1, A. Al-Lazki1, E. Belousova2, F. Kaminsky3, T. They4, H.J. Massonne4 and S. Al-Busaidi5

Archean lithospheric mantle: its formation, its composition and today’s refertilised remains

S.Y. O’Reilly1, W.L. Griffin2, M. Zhang1 and G. Begg1

In-situ isotope ratio measurement: a decade of development of applications for mantle peridotites and kimberlites

N.J. Pearson, W.L. Griffin and S.Y. O’Reilly
GEMOC Macquarie

Trace-element geochemistry of diamond

S. Rege1, W.L. Griffin1, S.E. Jackson1, N.J. Pearson1, S.Y. O’Reilly1, D. Zedgenizov2 and G. Kurat3
1. GEMOC Macquarie, 2. Institute of Mineralogy and Petrography, Novosibirsk, Russia, 3. Naturhistorisches Museum, Vienna, Austria

Natural silicon carbide from different geological settings: polytypes, trace elements, inclusions

A.A. Shiriyaev1, W.L. Griffin1, E. Stoyanov4,5 and H. Kagi3
1. Institute of Crystallography, Moscow, Russia, 2. GEMOC Macquarie, 3. Bayerisches GeoInstitute, Bayreuth, Germany, 4. Arizona State University, Tempe, USA, 5. Tokyo University, Japan

Late Jurassic-Early Cretaceous kimberlite, carbonatite and ultramafic lamprophyric sill and dyke swarms from the Bomethra area, northeastern Oman

S. Nasir1, S. Al-Khirbash1, H. Rollinson1, A. Al-Harthiy1, A. Al-Sayigh1, A. Al-Lazki1, E. Belousova2, F. Kaminsky3, T. They4, H.J. Massonne4 and S. Al-Busaidi5

Archean lithospheric mantle: its formation, its composition and today’s refertilised remains

S.Y. O’Reilly1, W.L. Griffin2, M. Zhang1 and G. Begg1

In-situ isotope ratio measurement: a decade of development of applications for mantle peridotites and kimberlites

N.J. Pearson, W.L. Griffin and S.Y. O’Reilly
GEMOC Macquarie

Trace-element geochemistry of diamond

S. Rege1, W.L. Griffin1, S.E. Jackson1, N.J. Pearson1, S.Y. O’Reilly1, D. Zedgenizov2 and G. Kurat3
1. GEMOC Macquarie, 2. Institute of Mineralogy and Petrography, Novosibirsk, Russia, 3. Naturhistorisches Museum, Vienna, Austria

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A.A. Shiriyaev1, W.L. Griffin1, E. Stoyanov4,5 and H. Kagi3
1. Institute of Crystallography, Moscow, Russia, 2. GEMOC Macquarie, 3. Bayerisches GeoInstitute, Bayreuth, Germany, 4. Arizona State University, Tempe, USA, 5. Tokyo University, Japan

Trace elements and oxygen isotopes in garnets from diamondiferous xenoliths, Nurbinskaya pipe, Yakutia: Implications for diamond genesis

1. YaNIGP CNIGRI, ALROSA Co. Ltd., Mirny, Yakutia, Russia, 2. GEMOC Macquarie, 3. Planetary Geosciences Institute, Dept. of Geological Sciences, Univ. of Tennessee, USA, 4. ALROSA Co. Ltd., Mirny, Yakutia, Russia, 5. Department of Geosciences and Geophysics, Univ. of Wisconsin, Madison, USA

Diamond-forming fluids and kimberlites: The trace element perspective

Y. Weiss1, R. Kessel1, W.L. Griffin2, I. Kiflawi1, D.R. Bell2, J.W. Harris4 and O. Navon1
1. Institute of Earth Sciences, The Hebrew University of Jerusalem, Israel, 2. GEMOC Macquarie, 3. School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA, 4. Division of Earth Sciences, University of Glasgow, Glasgow, Scotland

Carbonatic to hydrous-silicic growth medium of diamonds from Internationalnaya kimberlite pipe (Yakutia)

D.A. Zedgenizov1, D. Araujo2, A.L. Ragozin1, V.S. Shatsky1, H.Kagi3 and W.L. Griffin2
1. Institute of Geology and Mineralogy, Novosibirsk, Russia, 2. GEMOC Macquarie, 3. Geochemical Laboratory, Graduate School of Science, University of Tokyo, Tokyo, Japan

2008 IAVCEI GENERAL ASSEMBLY, REYKJAVIK, ICELAND, 18-25 AUGUST, 2008

Reconciling 226Ra excesses with “Old” U-Th ages requires a young mixing component at Rabaul, Papua New Guinea

H. Cunningham1, S. Turner1, A. Dosseto1, H. Patia2, S. Eggins3 and R. Arculus3
1. GEMOC Macquarie, 2. Rabaul Volcano Observatory, Rabaul, Papua New Guinea, 3. Australian National University, Canberra, Australia

Composition and facies characteristics of explosive and non-explosive volcanioclastic rocks from a Miocene slow spreading ridge, Macquarie Island

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

Diamond forming fluids from Kankan, Guinea: major and trace element study

Y. Weiss1, R. Kessel1, W.L. Griffin2, I. Kiflawi1, D.R. Bell2, J.W. Harris4 and O. Navon1
1. Institute of Earth Sciences, The Hebrew University of Jerusalem, Israel, 2. GEMOC Macquarie, 3. School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA, 4. Division of Earth Sciences, University of Glasgow, Glasgow, Scotland

Co-evolution of oceanic crust and mantle diapirs: implications for diamond genesis in the Papukulungu kimberlite pipe, Tanzania

N.J. Pearson1, S.Y. O’Reilly1, W.L. Griffin2, J.W. Valley3,4, G. Kurat3 and D.A. Zedgenizov1
1. GEMOC Macquarie, 2. Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia, 3. Naturhistorisches Museum, Vienna, Austria, 4. Arizona State University, Tempe, USA
Don’t blow your lid! Constraining volatile transfer in an active caldera, Rabaul, Papua New Guinea
H.S. Cunningham1, R.J. Wysockanzski2, S.P. Turner1, A. Nichols1, H. Patia4 and S. Eggs1
1. GEMOC Macquarie, 2. Victoria University of Wellington, Wellington, New Zealand, 3. JAMSTEC 2-15 Natsushima-cho, Yokosuka, Kanagawa, Japan, 4. Rabaul Volcano Observatory, Rabaul, Papua New Guinea, 5. RSES, Australian National University, Canberra, ACT, Australia

U-series isotope and experimental constraints on the Genesis of high-Mg andesites at White Island, New Zealand
S. Turner and B. Wood
GEMOC Macquarie

AGU FALL MEETING, SAN FANCISCO, USA, 15-19 DECEMBER, 2008
The effects of compositional and rheological stratifications on the evolution of oceanic lithosphere from geophysical-petrological-dynamic modeling
J.C. Afonso1,2, S. Zlotnik2, J. Fullea2 and M. Fernandez2
1. GDL, Instituto de Ciencias de la Tierra “Jaume Almera” (CSIC), Lluís Solé i Sabarís s/n, Barcelona, Spain

U-series constraints on mantle melting in the Manus back-arc basin
C. Beier1, S. Turner1, W. Bach2, D. Niedermeier2, J. Sinton1 and J.B. Gill4
1. GEMOC Macquarie, 2. Petrologie der Ozeankruste, Department of Geosciences, University of Bremen, Germany, 3. Department of Geology and Geophysics University of Hawaii, USA, 4. Earth and Planetary Sciences, University of California, Santa Cruz, USA

Geochemical heterogeneities in OIB and MORB sources: Implications for melting processes and mantle dynamics I-III
C. Beier1, S. Turner1, C. O’Neill1, C. Lee2 and V. Salters1
1. GEMOC Macquarie, 2. Rice University, 3. Florida State University

New constraints on fluid addition beneath the Tonga Arc: Reconciliation of U-Th-Ra disequilibria in a single-stage fluid addition model
J. Caulifed, S.P. Turner, A. Dosseto and C. Beier
GEMOC Macquarie

Exhumation and brittle to ductile deformation of the Suckling-Dayman core complex along an active microplate boundary, eastern Papua New Guinea
N.R. Daczko1, P. Caff1 and P. Mann2
1. GEMOC Macquarie, 2. The University of Texas at Austin, Institute for Geophysics, Jackson School of Geosciences, Austin, USA

Vegetation over hydrologic control of sediment transport over the past 100,000 yr
A. Dosseto1, K. Maher2, S.P. Turner1, P. Hesse3 and K. Fryirs3
1. GEMOC Macquarie, 2. Department of Geological and Environmental Sciences, Stanford University, CA, USA, 3. Department of Physical Geography, Macquarie University

Reappraisal of fluid and sediment contributions to Lesser Antilles magmas
S.A. DuFrane1, A. Dosseto2, S.P. Turner2 and M. van Soest3
1. School of Earth and Environmental Sciences, Washington State University, Pullman, USA, 2. GEMOC Macquarie, 3. School of Earth and Space Exploration, Arizona State University, Tempe, USA

Characterizing the lithospheric-sublithospheric upper mantle system: its thermal, compositional, seismological, and rheological structure in 3D
J. Fullea1, J.C. Afonso2, J.A. Connolly3, M. Fernandez1, D. Garcia-Castellanos1 and S. Zlotnik1
1. GDL, Institute of Earth Sciences “Jaume Almera”, CSIC, Lluís Solé i Sabarís s/n, Barcelona, Spain, 2. GEMOC Macquarie, 3. Earth Science Department, Swiss Federal Institute of Technology, Zurich, Switzerland
Fe-Mn geochemistry of OIB from the Azores
M. Humayun, S. Turner, C. Beier, J. Georgen, E. Widom and V.A. Fernandes
1. National High Magnetic Field Laboratory and Department of Geological Sciences, Florida State University, USA, 2. GEMOC Macquarie, 3. Department of Ocean, Earth and Atmospheric Sciences, Old Dominion University, Norfolk, United States, 4. Department of Geology, Miami University, Oxford, USA, 5. Berkeley Geochronology Center, Berkeley, USA

Inverted regional metamorphism in the coaxially refolded Tonga Formation: Evidence for Cretaceous accretional tectonics in the Cascades Crystalline Core
1. Department of Earth Sciences, University of Southern California, Los Angeles, USA, 2. Marathon Oil Company, Houston, TX, United States, 3. Geology Department, San Jose State University, San Jose, USA, 4. GEMOC Macquarie

Mantle episodicity from within and from above
A. Lenardic, C. O’Neill, A. Jellinek and L. Moresi
1. Rice University, Department of Earth Science, Houston, USA, 2. GEMOC Macquarie, 3. University of British Columbia, Department of Earth and Ocean Sciences, Vancouver, Canada, 4. Monash University, School of Mathematical Sciences, Victoria, Australia

Coupling the volcanic and atmospheric evolution of Earth and Venus to their long-term tectonic state
C. O’Neill and A. Lenardic
1. GEMOC Macquarie, 2. Rice University, Main St, Houston, USA

A Mesoproterozoic continental flood rhyolite province: The end member example of the large igneous province clan
1. Monash University, School of Geosciences, Clayton, Vic, Australia, 2. GEMOC Macquarie, 3. Adelaide University, School of Geology and Geophysics, Adelaide, SA, Australia

Deformation of ordinary chondrite under very reducing conditions: Implications for liquid metal compositions, HSE partitioning and enstatite chondrites
T. Rushmer and A. Corgne
GEMOC Macquarie

Source composition and melting dynamics across the Azores plume
S. Turner, C. Beier, T. Plank and W. White
1. GEMOC Macquarie, 2. Lamont-Doherty Earth Observatory, Columbia University, Palisades, USA, 3. Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, USA

Channelised melt flow in downwelling mantle: implications for $^{226}$Ra-$^{210}$Pb disequilibria in arc magmas
C. Koenders, N. Petford and S. Turner
1. Kingston University, CEESR, London, UK, 2. Bournemouth University, Fern Barrow, Poole, UK, 3. GEMOC Macquarie
## Appendix 5: Funded research projects

**GRANTS AND OTHER INCOME FOR 2008**

<table>
<thead>
<tr>
<th>2008 Funding Source</th>
<th>Investigators</th>
<th>Project Title</th>
<th>Amount</th>
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<tr>
<td>ARC Discovery</td>
<td>Daczko, Dickinson</td>
<td>Spreading ridge sedimentation processes: a novel approach using Macquarie Island as a natural laboratory</td>
<td>$65,000</td>
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<td>ARC Discovery</td>
<td>O’Reilly, Griffin, Pearson, Alard, et al.</td>
<td>Earth’s internal system: deep processes and crustal consequences</td>
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<td>ARC Discovery</td>
<td>Wood</td>
<td>The behaviour of geochemical traces during differentiation of the Earth</td>
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<td>ARC Discovery</td>
<td>O’Neill, Wood, Irifune (Administered by ANU)</td>
<td>Discovering the deep mantle: experimental petrology at very high pressures</td>
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<td>ARC Linkage Project with BHPB</td>
<td>O’Reilly, Griffin, O’Neill</td>
<td>Global lithosphere architecture mapping II (including Industry contribution)</td>
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<tr>
<td>ARC Linkage Project with Rio Tinto</td>
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<td>Trace-element analysis of diamonds: new applications to diamond fingerprinting and genesis (including Industry contribution)</td>
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<td>ARC Linkage Project with De Beers Group Services</td>
<td>O’Reilly, Griffin, Pearson</td>
<td>Composition, structure and evolution of the lithospheric mantle beneath Southern Africa: improving area selection criteria for diamond exploration (including Industry contribution)</td>
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<td>Origin and evolution of Earth’s chemical reservoirs</td>
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<td>De Beers</td>
<td>Griffin, Belousova</td>
<td>Kimberlite dating</td>
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<td>Department of Earth and Planetary Sciences</td>
<td>O’Reilly</td>
<td>GAU maintenance contribution</td>
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<td>MQRF Research Grant</td>
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<td>Episodicity in mantle convection: effects on continent formation and metallogenesis</td>
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<td>2008 Funding Source</td>
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<td>DVC (Research) Discretionary Fund</td>
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<td>Support for Fellow in Feodor Lynen Project (Christoph Beier)</td>
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<td>Dosseto</td>
<td>Impact of European settlement on soil loss in the Murray-Darling Basin: a novel quantitative geochemical approach</td>
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<td>MQ Research Fellowship</td>
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<td>MQECRG</td>
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<td>Basin Development in Proterozoic South Australia: developing a time-integrated, compositional framework to assist mineral exploration (including Industry contribution)</td>
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<td>MQNS</td>
<td>Rushmer</td>
<td>Formation of the Earth's first silicic crust</td>
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<td>RIBG</td>
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<td>Fourier Transform Infrared (FTIR) Microscope</td>
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<td>NCRIS (MQ contribution)</td>
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<td>AuScope (<a href="http://www.auscope.org.au">www.auscope.org.au</a>)</td>
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<td>RAACE</td>
<td>Carroll</td>
<td>The mechanisms and deep-crustal controls on continental rifting</td>
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<td>iMURS</td>
<td>Caulfield</td>
<td>Tofua Volcano, Tonga Arc, eruption history and timescales of magma chamber processes</td>
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<td>iMURS</td>
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<td>Gabbroic rocks from the Kerguelen Island (Indian Ocean): a petrologic, geochemical and isotopic investigation of their origin</td>
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<td>iMURS</td>
<td>Cunningham</td>
<td>A U-series isotope study of magma residence times, degassing and petrogenesis of Rabaul Caldera, Papua New Guinea</td>
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<td>iMQRES</td>
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<td>Mantle xenoliths, kimberlites and related rocks of the Kuruman Kimberlite Province, Kaapvaal Craton, South Africa</td>
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<td>iMURS</td>
<td>Gréau</td>
<td>Elemental and isotopic fractionation of siderophile and chalcophile elements: A new perspective on eclogite origin</td>
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<td>Funding Source</td>
<td>Investigators</td>
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<td>iMURS/IPRS Kobussen</td>
<td>Composition, structure and evolution of the lithospheric mantle beneath Southern Africa</td>
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<td>iMURS Li</td>
<td>Stable metal isotope geochemistry of the Cadia and Northparkes porphyry Cu-Au deposits</td>
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<td>iMURS Locmelis</td>
<td>Understanding nickel deposits using platinum group element geochemistry</td>
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<td>iMURS/IPRS Mwandulo Batumike</td>
<td>The origin of kimberlites from the Kundelungu region (D.R. Congo) and the nature of the underlying lithospheric mantle</td>
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<td>iMURS Nikolic</td>
<td>Evolution of crust-mantle systems near a young rift: NW Spitsbergen, Norway</td>
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<td>Spreading ridge sedimentation processes: a novel approach using Macquarie Island as a natural laboratory</td>
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<td>PGRF Cunningham</td>
<td>Using short-lived U-Series Isotope to understand the timescales of Magmatic processes: Rabaul Caldrea, Papua New Guinea</td>
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<td>PGRF Donnelly</td>
<td>The Kimberlites and related rocks of the Kuruman Kimberlite Province, Kaapvaal Craton, South Africa</td>
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<td>PGRF Gréau</td>
<td>Stable metal isotope geochemistry of the Northparkes porphyre Cu-Au deposits</td>
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<td>PGRF Kobussen</td>
<td>The lithospheric mantle beneath southern Africa: composition, structure and evolution</td>
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<td>PGRF Mwandulo Batumike</td>
<td>Origin and age of Kundelungu Kimberlites, and diamond potentiality, crustal evolution and lithospheric mapping in southern D.R. Congo</td>
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<td>PGRF Portner</td>
<td>Magmatism, Deformation and Sedimentation in Seafloor spreading environments</td>
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<td>The lithospheric mantle beneath southern Africa: composition, structure and evolution</td>
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### Funded Research Projects for 2009

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<tr>
<th>2008 Funding Source</th>
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<th>2009 Funding Source</th>
<th>Project Title</th>
<th>Amount</th>
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<tr>
<td>International Traveling Scholarship</td>
<td>Mwandulo Batumike</td>
<td>ARC Discovery</td>
<td>Diamond genesis: cracking the code for deep-Earth processes</td>
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<td>ARC Discovery</td>
<td>Earth’s internal system: deep processes and crustal consequences</td>
<td>$230,000</td>
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<td>Mantle melting dynamics and the influence of recycled component</td>
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<td>Composition, structure and evolution of the lithospheric mantle beneath Southern Africa: improving area selection criteria for diamond exploration</td>
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<td>CORE Start up grant</td>
<td>Research Grant</td>
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<td>CORE Start up grant</td>
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<td>Department of Earth and Planetary Sciences</td>
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<td>Australian Antarctic Division</td>
<td>The tectonic significance of regional flat-lying fabrics in rocks (logistic support)</td>
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<td></td>
<td>DVC (Research) Discretionary Fund</td>
<td>Support for Fellow in Feodor Lynen Project (Christoph Beier)</td>
<td>$20,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MQ Safety Net</td>
<td>Did obesity kill the arc? A model from the Fiordland Arc, New Zealand</td>
<td>$17,000</td>
</tr>
</tbody>
</table>
## Appendix 5: Funded research projects 2009

<table>
<thead>
<tr>
<th>2009 Funding Source</th>
<th>Investigators</th>
<th>Project Title</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>MQRF Research Grant</td>
<td>Dosseto</td>
<td>Impact of European settlement on soil loss in the Murray-Darling Basin: a novel quantitative geochemical approach</td>
<td>$17,335</td>
</tr>
<tr>
<td>MQ Research Fellowship</td>
<td>Dosseto</td>
<td>Impact of European settlement on soil loss in the Murray-Darling Basin: a novel quantitative geochemical approach</td>
<td>$13,000</td>
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<tr>
<td>MQECRG</td>
<td>Belousova</td>
<td>Basin Development in Proterozoic South Australia: developing a time-integrated, compositional framework to assist mineral exploration (including Industry contribution)</td>
<td>$30,000</td>
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<tr>
<td>ARC LIEF</td>
<td>O’Reilly CI (ANU Lead Institution)</td>
<td>IOPD</td>
<td>$1,200,000</td>
</tr>
<tr>
<td>ARC LIEF (MQ contribution)</td>
<td>O’Reilly CI (ANU Lead Institution)</td>
<td>IOPD</td>
<td>$40,000</td>
</tr>
<tr>
<td>NCRIS Auscope (<a href="http://www.auscope.org.au">www.auscope.org.au</a>)</td>
<td>O’Reilly</td>
<td>A4.45: Macquarie University Project - Earth Composition and Evolution</td>
<td>$100,000</td>
</tr>
<tr>
<td>NCRIS (MQ contribution)</td>
<td>O’Reilly</td>
<td>A4.45: Macquarie University Project - Earth Composition and Evolution</td>
<td>$50,000</td>
</tr>
<tr>
<td>RAACE</td>
<td>Bailey</td>
<td>Law Dome: Ice and crust mass balance studies</td>
<td>$20,427</td>
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<tr>
<td>iMURS</td>
<td>Caulfield</td>
<td>Tofua Volcano, Tonga Arc, eruption history and timescales of magma chamber processes</td>
<td>$46,677</td>
</tr>
<tr>
<td>iMURS</td>
<td>Chevet</td>
<td>Gabbroic rocks from the Kerguelen Island (Indian Ocean): a petrologic, geochemical and isotopic investigation of their origin</td>
<td>$46,677</td>
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<tr>
<td>iMQRES</td>
<td>Cowlyn</td>
<td>Growth of evolved continental crust in the primitive Tonga Arc: A study of the island of Fonualei</td>
<td>$46,677</td>
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<tr>
<td>iMURS</td>
<td>Cunningham</td>
<td>A U-series isotope study of magma residence times, degassing and petrogenesis of Rabaul Caldera, Papua New Guinea</td>
<td>$46,677</td>
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<tr>
<td>iMQRES</td>
<td>Donnelly</td>
<td>Mantle xenoliths, kimberlites and related rocks of the Kuruman Kimberlite Province, Kaapvaal Craton, South Africa</td>
<td>$46,677</td>
</tr>
<tr>
<td>iMQRES</td>
<td>Foley</td>
<td>Generation of continental crust during subduction initiation</td>
<td>$46,677</td>
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<tr>
<td>iMURS</td>
<td>Gréau</td>
<td>Elemental and isotopic fractionation of siderophile and chalcophile elements: A new perspective on eclogite origin</td>
<td>$46,677</td>
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<tr>
<td>iMQRES</td>
<td>Huang</td>
<td>Origin of eclogite and pyroxenite xenoliths in kimberlites and basalts</td>
<td>$46,677</td>
</tr>
<tr>
<td>iMURS/IPRS</td>
<td>Kobussen</td>
<td>Composition, structure and evolution of the lithospheric mantle beneath Southern Africa</td>
<td>$46,677</td>
</tr>
</tbody>
</table>
2009 Funding Source | Investigators | Project Title | Amount
--- | --- | --- | ---
iMURS | Li | Stable metal isotope geochemistry of the Cadia and Northparkes porphyry Cu-Au deposits | $46,677
iMURS | Locmelis | Understanding nickel deposits using platinum group element geochemistry | $46,677
iMQRES | Portner | Spreading ridge sedimentation processes: a novel approach using Macquarie Island as a natural laboratory | $46,677

ARC Research Projects initiated prior to 2008 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.
GEMOC has a flourishing postgraduate research environment with postgraduate students from many countries (including France, Germany, China, Russia, USA, Canada and Australia). Scholarships funding tuition fees and a living allowance are available for students with an excellent academic record or equivalent experience. These include:

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

ACILP Australia China Institutional Links Program
ANZGG Australian and New Zealand Geomorphology Group
AMIRA Australian Mineral Industry Research Association
ANU Australian National University
APA (I) Australian Postgraduate Award (Industry)
ARC Australian Research Council
ARC LIEF Australian Research Council Linkage Infrastructure Equipment and Facilities
BHPB BHP Billiton
BSE Backscattered Electrons
CERCAMS Centre for Russian and Central EurAsian Mineral Studies
CNRS French National Research Foundation
CoRE Concentrations of Research Excellence
CSIC Consejo Superior de Investigaciones Cientificas (Spanish National Research Council)
CSIRO (EM) Commonwealth Scientific Industrial Research Organisation (Exploration and Mining)
DEST Department of Education, Science and Training (from 2002)
DIATREEM Consulting company within AccessMQ
DP Discovery Project
EAPE CoRE Earth and Planetary Evolution Concentration of Research Excellence
EMP Electron Microprobe
EPS Earth and Planetary Sciences
ERA Excellence in Research for Australia
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
GLAM Global Lithospheric Architecture Mapping
GLITTER GEMOC Laser ICPMS Total Trace Element Reduction software
GPS Global Positioning System
HIAF Heavy Ion Analytical Facility
IAVCEI International Association of Volcanology and Chemistry of the Earth's Interior
ICPMS Inductively Coupled Plasma Mass Spectrometer
iMURS International Macquarie University Research Scheme
IPRS International Postgraduate Research Scholarship
LAM-ICPMS Laser Ablation Microprobe - ICPMS
LIEF Linkage Infrastructure, Equipment and Facilities
MC-ICPMS Multi-Collector - ICPMS
MERIWA The Minerals and Energy Research Institute of Western Australia
MQNS Macquarie University New Staff Research Grants Scheme (formerly MUNS)
(i)MQRES (International) Macquarie University Research Excellence Scholarships
MQRF Macquarie University Research Fellowship (formerly MURF)
MUIPRA Macquarie University International Postgraduate Research Award
MURAACE Macquarie University Research Award for Areas and Centres of Excellence
NCRIS National Collaborative Research Infrastructure Scheme
PGE Platinum Group Element
PIRSA Primary Industries and Resources, South Australia
RAACE Research Areas and Centres of Excellence Postgraduate Scholarships
RIBG Research Infrastructure Block Grant
RSES Research School of Earth Sciences at ANU
SEM Scanning Electron Microscope
UWA University of Western Australia
XRF X-Ray Fluorescence
ARC National
Key Centre for the
Geochemical Evolution and
Metallogeny of Continents