GEMOC
2010 Annual Report

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



MACQUARIE UNIVERSITY

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

The GEMOC Annual Report is available from our website http://www.gemoc.mq.edu.au/ 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 over 14 years.

Front Cover: A collage of images reflecting GEMOC's work over 15 years: from mantle petrology to lithosphere evolution, modern volcanology to the genesis of giant ore deposits, and on to the cutting-edge geochemical, geophysical and planetary studies – and from micron to global to planetary scales.

(Photo page 1 by Neon Creative)

Contents

Director's preface 1

GEMOC in 2010 4

GEMOC participants 8

GEMOC's organisation 10

GEMOC's research program 11

Funded basic research projects for 2010/2011 17

GEMOC's context in 2010 22

GEMOC's structure 23

GEMOC communications 2010 25

Research highlights 2010 30

Teaching and training program: undergraduate 58

GEMOC honours 60

GEMOC postgraduate 62

Technology development program 67

Industry interaction 75

Current industry-funded collaborative research projects 78

GEMOC's international links 81

GEMOC funding 86

Benefits to Australia 88

Appendices

1 Participants 89

2 Publications 2010/2011 91

3 Visitors/GAU users 98

4 Abstract titles 100

5 Funded research projects 108

6 GEMOC postgraduate opportunities 114

Contact details 115

Glossary 115

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



Director's preface

(Mission accomplished....)

THIS REPORT SUMMARISES GEMOC'S 2010 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 has acknowledged GEMOC as a continuing ARC National Key Centre while GEMOC attracts sufficient funds to maintain its high research activity and output, achieves its annual goals, and submits an Annual Report fulfilling ARC reporting requirements.

2010 was an exciting year of success and change for GEMOC.

Success was marked with top results in the national ARC Excellence in Research for Australia (ERA) outcomes. Macquarie University was the only institution nationwide to score the top rating of "5" for all assessed categories in Earth Sciences (http://www.arc.gov.au/era/outcomes_2010.htm). This encompasses the overarching category of "Earth Sciences" and the more specialised categories including Geology and Geochemistry, reflecting the impact and productivity of GEMOC researchers [http://www.theaustralian.com.au/higher-education/gem-of-a-centre-at-macquarie/story-e6frgcjx-1225998310865]. Three GEMOC researchers are in the top 200 cited geoscientists for the last decade as published in "Thomson Essential Science Indicators" (Griffin #12, O'Reilly #17 and Pearson #170).

Change came with an expression of interest (EOI) for a Centre of Excellence that was submitted to the ARC, with Macquarie University as the lead and Administering Organisation (and me as Director), with Curtin University and the University of Western Australia (UWA) as Collaborating Institutions and the Geological Survey of Western Australia as an Australian Partner Institution. Our EOI was one of about 40 selected for preparation of a full application, out of approximately 140 EOIs submitted nationally in all disciplines. We were then invited to an interview in Canberra, with the result that we were granted funding for the ARC Centre of Excellence for Core to Crust Fluid Systems (CCFS) for seven years.

This new development will shape the future of GEMOC over the next decade. It was clear that the ARC considered that CCFS should capitalise on the high level of international recognition that GEMOC has achieved, so GEMOC will maintain its identity as a research centre at Macquarie but will be integrated into the new ARC Centre of Excellence. This new CCFS "Supercentre" will bring together complementary knowledge, experience and analytical expertise from the Australian partners and will interface with the Centre for Exploration Targeting at UWA. Five overseas nodes led by Partner Investigators in France, China, Canada, Germany and the USA will contribute resources and provide access to a wide variety of complementary expertise and instrumental capabilities.

The research vision of CCFS is to integrate geochemistry, petrophysics, geophysics and numerical and thermodynamic modelling, to reach a new level of understanding of Earth's dynamics and the fluid cycle(s) through time. A preliminary introduction to CCFS is at http://www.ccfs.mq.edu.au. At the time of writing the process of contractual signing for the ARC is in progress with the Australian and international Collaborating and Partner Institutions (to be in place for a formal start on 1st July), and the process of appointing a Chief Operating Officer has been initiated.

Director's preface

The winning of an ARC Centre of Excellence fulfils part of the vision of Macquarie Vice-Chancellor Steven Schwarz for Macquarie @50 (in 2014) to be a leading research University. Professor Schwarz designated GEMOC as a Macquarie Concentration of Research Excellence in 2006 and provided 6 new academic staff positions across isotopic and trace-element geochemistry, lithosphere and Earth dynamics, geophysical imaging of Earth's interior, dynamic modelling of Earth's mantle and the rheology of rocks and minerals, as described in previous Annual Reports. Seismologist Yingjie Yang (a pioneer in the use of ambient noise seismology to investigate crustal structure) arrived in mid-2010. His arrival completed the first stage in our strategic plan to build a dynamic group of new-generation researchers (with Juan Carlos Afonso and Craig O'Neill), spanning a broad range of geophysical and geodynamic expertise relevant to understanding deep-Earth processes and planetary systems.

It is very timely for GEMOC to expand its horizons within the context of the new ARC Centre of Excellence. Our strategic vision has expanded over the years, from understanding the composition, structure and evolution of the lithosphere to the integration of geophysical, geochemical and petrological data with tectonic and geodynamic modelling to gain a better knowledge of the whole-Earth system from its accretion to the present day. A peak outcome of this has been the completion of the first stage of the large-scale Global Lithospheric Architecture Mapping program (GLAM), in collaboration with Western Mining, then BHP-Billiton and subsequently Minerals Targeting International, drawing on the results of specialised research strands over a decade. The first major outcomes are published in GEMOC Publications 423, 542, 547, 576, 664, 671 and 679 and have been presented at numerous invited and keynote talks at peak conferences and workshops. The results are impacting a broad spectrum of areas including Earth's tectonic history, lithosphere evolution and the Early Earth, interpretation of seismology datasets, and global mineral exploration strategies.

The 2010 cover reflects the continual expansion of GEMOC's research horizons and achievements, and symbolises the micron to planetary scales of the research contributing to a better understanding of "how the Earth works".

Technology development and advances in geochemical analytical and imaging strategies continued through 2010. A new Zeiss scanning electron microscope with cathodoluminescence imaging and energy-dispersive analytical capabilities has enabled a new direction incorporating more emphasis on mineral imaging linked to microstructure and compositional variations. Further refinement of the new-generation FTIR microscope (ThermoFisher iN10) enabling rapid whole-grain mapping of spectral data, coupled with the in-house development of a novel spectral deconvolution program (soon to be made available as an open-file resource) has allowed exploitation of the huge array of data embedded in the digital FTIR images, but not previously accessible.

The first instruments (latest generation inductively-coupled-plasma mass spectrometers (ICPMS)) were installed following our successful 2010 LIEF application based at Macquarie with partner support from Sydney, Wollongong, ANU and Victoria University of Wellington (New Zealand); assessment of the remaining instruments is almost complete. The combination of a femtosecond laser and sector ICPMS will allow exciting new developments in *in situ* analytical capabilities that will extend our trace-element and isotopic applications. We aim to deliver more *in situ* analytical breakthroughs following our world-first examples of *in situ* Hf isotope analysis of zircon, Re-Os isotope analysis of mantle sulfides and trace-element analysis in diamond, as well as a spectrum of stable metal-isotope methods.

A selFrag instrument was installed in 2010 in a purpose-designed new mineral-separation laboratory for multiple applications, but with a particular focus on extraction of zircons for the ongoing *TerraneChron®* program (see *Research Highlights*). High-power electrostatic pulses fragment rocks into individual mineral grains without crushing and breaking, enabling accurate assessment of grain morphologies.

GEMOC's success in linking interdisciplinary knowledge and data is also evident in many of the 128 articles published or accepted for publication since January 2010 in high-impact journals including *Nature Geoscience, Geology, Earth and Planetary Science Letters, Journal of Petrology, Geochimica et Cosmochimica Acta, G-cubed, Lithos, Precambrian Research, Bulletin of the Geological Society of America, Contributions to Mineralogy and Petrology, Tectonophysics and Chemical Geology*, and to journals targeted at endusers including *Economic Geology*. The publication by current and recent PhD students of nineteen first-authored papers in high-impact journals is evidence of the outstanding quality of GEMOC's postgraduate environment.

GEMOC's conference presence again included a range of plenary, keynote and invited talks at peak and specialist international Conferences and Workshops (see *GEMOC Communications*). Over 40 international visitors came to GEMOC in 2010, highlighting our global profile and providing leverage of expertise, intellectual capital and resources.

GEMOC's original mission has been accomplished: our concepts and methodologies revealing the nature of the lithosphere have traction in mainstream geoscience and with industry stakeholders. The establishment of the ARC Centre of Excellence for Core to Crust Fluid Systems will expand our horizons even further and will bring another level of challenging scientific endeavours, with new goals and pathways to better understand the structure, composition and dynamics of our home planet Earth and its geological evolution "from core to crust" over 4.5 billion years.



Rehearsal for the Centre of Research Excellence interview, July 2010. (L-R) Jon Hronsky, Sue O'Reilly, Cam McCuaig and Simon Wilde.



GEMOC in 2010

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.

"...research foci on the different levels of the deep Earth and on planetary origins are complementary, and pivot on the continuing effective functioning of its unique, internationally recognised Geochemical Analysis Unit..."

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 *page 5*) 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), a 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 appointment over the past 3 years of three new academic staff (early-career at appointment time: Craig O'Neill, Juan Carlos Afonso and Yingjie Yang (arrived mid 2010)) has significantly expanded GEMOC's in-house research expertise and capabilities to undertake geodynamic and geophysical modelling, and computational Earth simulations. This has created powerful synergy with existing GEMOC programs related to the geochemical and petrologic studies of the deep Earth. A new computer cluster that can be successively upgraded by modular addition was established to support this initiative.

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.

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 enhance 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 has allowed 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 is also enabling continuing development of world-leading methodologies and applications in geochemistry (including isotopic) and especially for *in situ* (laser-ablation) analysis.

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.

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, Associate Professor 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. Dr Yingjie Yang arrived in 2010.

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 the 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.



Juan Carlos Afonso (right) with Javier Fullea visiting from the Dublin Institute for Advanced Studies, Dublin, Ireland.

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.

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 geochemical datasets**
- **strategic and collaborative alliances with technology manufacturers in design and application innovation**

This report documents the achievement of these goals in 2010 and aims for 2011.

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 geodynamic modelling

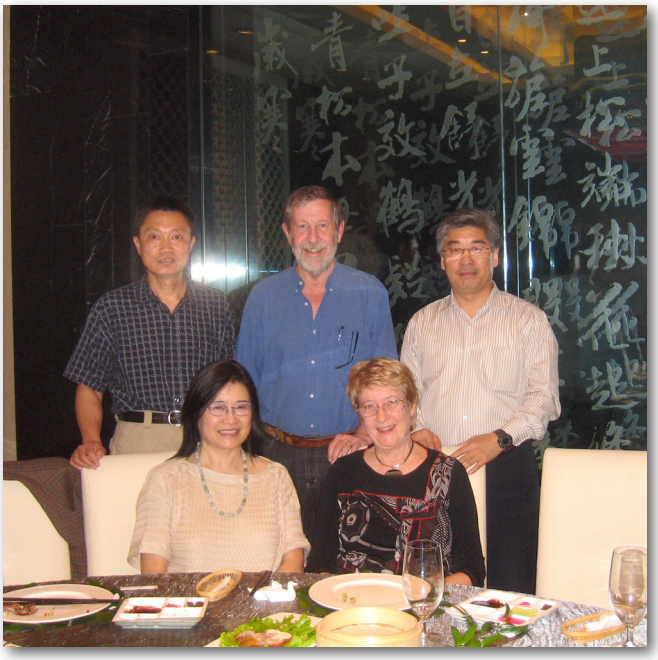
within the important contexts of...

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.



Ming Zhang, Bill Griffin, Jingfeng Guo (our first Chinese PhD) and his wife Nancy with Sue O'Reilly at a reunion in Beijing.



GEMOC participants

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.

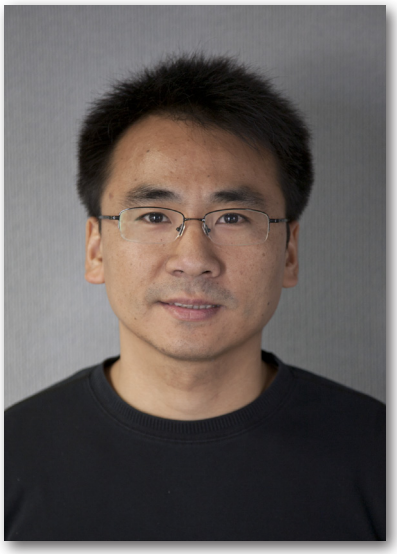
A full list of GEMOC participants and their affiliations is given in Appendices 1 and 3 and at http://www.gemoc.mq.edu.au/

CHANGES IN 2010

2010 arrivals in GEMOC

Dr Yingjie Yang

Dr Yingjie Yang commenced his employment at GEMOC in the Department of Earth and Planetary Sciences in August 2010. Dr Yang graduated with a PhD in geophysics from Brown University (USA) in 2005. He then worked as a research associate and senior research associate at the University of Colorado at Boulder on the development and application of new seismological methods to imaging and studying structures of the lithosphere and asthenosphere, including ambient noise seismology.

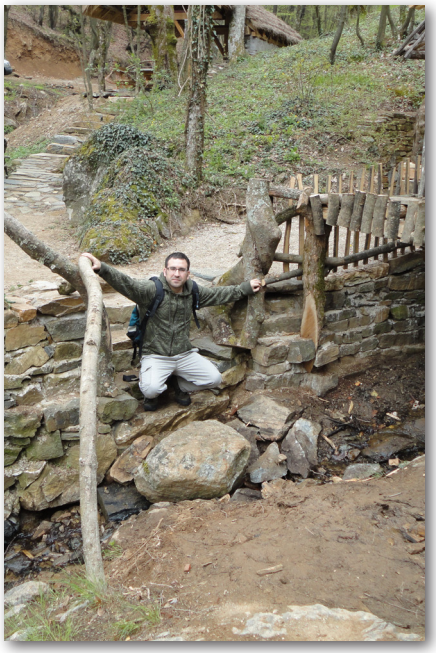


His research background is in theoretical and observational seismology. His primary research interests lie in understanding the structure, dynamics and deformation of the Earth's lithosphere and upper mantle by studying seismic velocity, anisotropy, and attenuation using seismological techniques. His current research focuses on the lithospheric structures of the Tibetan Plateau to understand the growth mechanism of the broadest and highest plateau in the world. He is also working on the development of new seismological methods to detect and understand the motion and deformation of rocks in the crust and upper mantle relevant to tectonic processes.

Dr Sandra Piazolo



Dr Sandra Piazolo arrived at GEMOC in mid 2010. After graduating with a PhD from the University of Mainz (Germany), she took up a project researcher position at the Geological Survey of Denmark and Greenland focusing on the metamorphic and structural evolution of West Greenland. She then moved to the University of Liverpool (UK) to develop a quantitative understanding of microstructural processes occuring in metamorphic rocks both experimentally and numerically. From 2004-2010 she was a Lecturer in Structural Geology and Tectonics at Stockholm University (Sweden). Her research focuses on the quantitative understanding of small scale processes and their influence on large scale processes. In her research she integrates different complementary techniques such as numerical modelling, field analysis, in-depth chemical and crystallographic analysis and physical experiments. Current interests are the influence of deformation on chemical reactions, and deformation and annealing phenomena in natural and experimental geomaterials.



Dr José María González-Jiménez

Dr José María González-Jiménez joined GEMOC in February 2010 as a post-doctoral Research Associate. He graduated from University of Granada (Spain) with a PhD based on an investigation into the mechanism of concentration and remobilisation of platinum-group elements in ore deposits from ophiolite complexes. He is currently working on tracking the Re-Os signatures of platinum-group minerals in chromite deposits from ophiolite complexes worldwide, which have undergone a range of types of alteration and/or metamorphism. Combining classical micro-mineralogy with innovative micro-analytical tools, he is creating a new approach to studying platinum-group element mineralisation in mantle-derived rocks. This project involves collaboration with overseas researchers from Spain, Bulgaria, France, Canada, Mexico, Argentina, Chile and Japan.

Dr Heather Handley

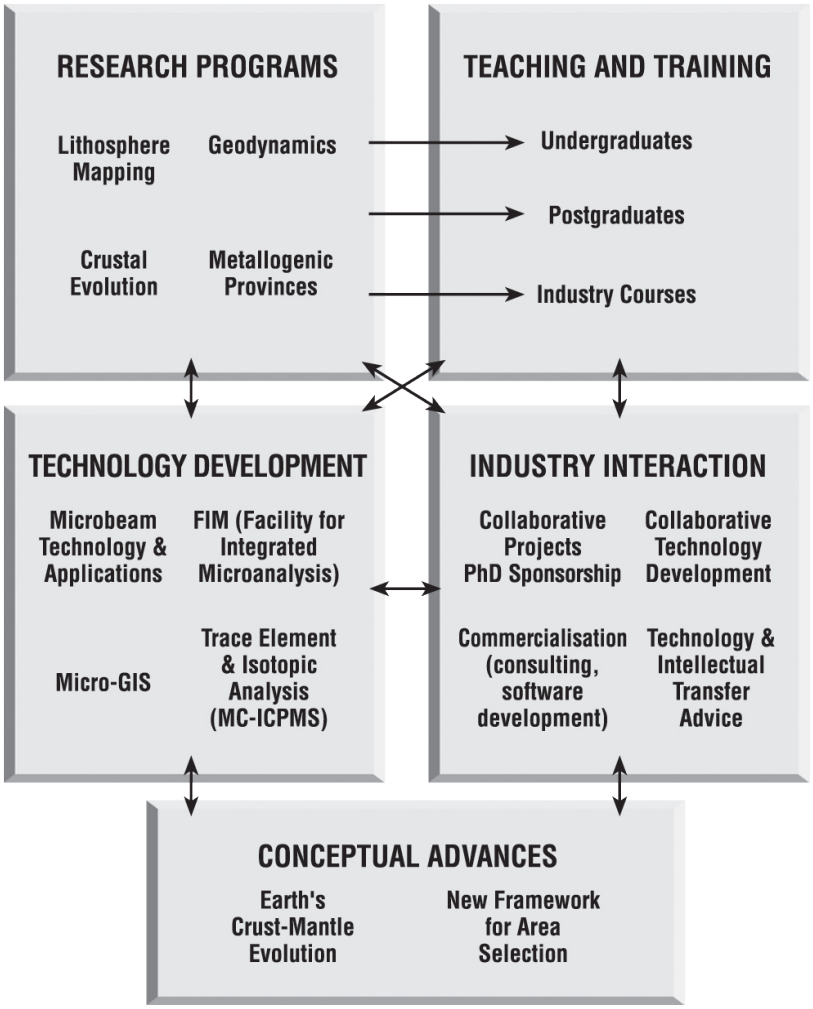


Dr Heather Handley is a Research Associate on an ARC Linkage Grant project at GEMOC. She graduated with a PhD from Durham University (UK) in 2006. Her PhD research placed geochemical and Sr-Nd-Hf-O isotopic constraints on volcanic petrogenesis at the Sunda arc, Indonesia. Since 2007 Heather's research has been focused upon the application of Uranium-series isotopes to magmatic and geomorphic systems and she presently oversees the Uranium-Series Laboratory within GEMOC. Recent studies are centred on using ^{210}Pb isotopes to further our understanding of magmatic degassing and using the fractionation of Uranium isotopes in fine-grained sediments to quantify timescales of sediment residence (i.e. storage in soils and associated transport in fluvial and/or aeolian systems). These investigations will provide better constraints on both the timescales of magmatic processes for volcanic hazard mitigation and soil production rates for landscape erosion studies.



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). Teaching and training benefit directly from these new advances. Technology development has been transferred to relevant end-users, applied in postgraduate research programs, and is the essential core that provides the data underpinning the conceptual advances about lithosphere architecture and evolution, core formation and planetary origins in GEMOC.





GEMOC's research program

The research aims

- to understand how Earth's core-mantle system controls crustal tectonics, and the assembly and destruction of continents through time
- to map the spatial and temporal distribution of elements, rock types and physical and chemical conditions within this system
- to understand the processes responsible for the evolution of Earth's chemical reservoirs
- to use quantitative modelling to simulate and understand Earth's geodynamic evolution
- to define the systematics of element redistribution in the mantle and crust
- to define timescales of magmatic and erosional cycles
- to understand mantle melting dynamics, the influence of recycled components and their ultimate contribution to plumes and the subcontinental lithosphere
- to constrain models of the crust and lithospheric mantle from geophysical datasets, through integration of geophysical, petrological and geochemical information
- to define the tectonic and geochemical processes that have created distinct crustal and mantle domains through time
- to produce and interpret maps of lithosphere thickness and lithospheric mantle type at the present day and for selected time (and location) slices through Earth's geological evolution
- to provide a new framework for area selection for a wide spectrum of economic deposits, by linking deep Earth models and processes to the formation of metallogenic provinces
- to define the timing of events and processes in the crust and mantle to understand crust-mantle linkages
- to develop collaborative links with international institutions and researchers relevant to GEMOC's goals

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

SCIENTIFIC CONTEXT

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

"Major changes will flow from the establishment from mid-2011 of the new ARC Centre of Excellence for Core to Crust Fluid Systems which will incorporate much of the research in GEMOC."

RESEARCH STRATEGY

The Research Program for 2010 - 2011 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 focused 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.

Major changes will flow from the establishment from mid-2011 of the new ARC Centre of Excellence for Core to Crust Fluid Systems which will incorporate much of the research of GEMOC.

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. 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

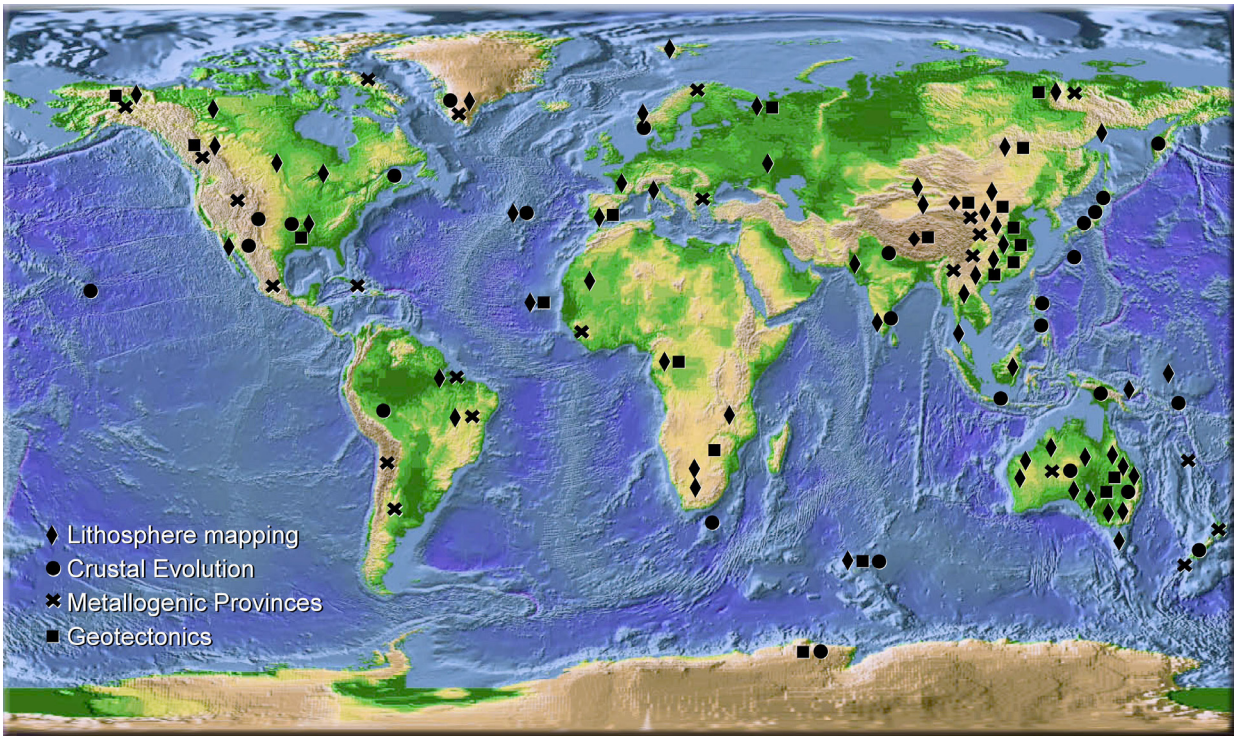
uses stratigraphic, tectonic, and geophysical data to interpret the history and causes of continental assembly and disruption, with a special focus on Australia, East Asia and major cratons (Siberia, Africa, Canada, South America, India). It provides the fundamental framework to link the research on 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 and understand deep Earth processes. Planetary structure within the solar system and comparisons with Earth parameters are being explored with geophysical datsets and integrated geodynamic modelling.

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.

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.



WHERE IN THE WORLD IS GEMOC?

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*)

Origin(s) of mantle eclogites

The composition of Earth's core and timing of core formation; core-mantle interaction (see *Research Highlights*)

Interpretation of deep seismic tomography (see *Research Highlights*)

Evolution of oceanic lithosphere: Kerguelen Plateau, Hawaii, Crozet Islands, abyssal peridotites (see *Research Highlights*)

Diamonds: origin and clues to deep mantle and lithosphere evolution and structure (see *Research Highlights*)

Basalts as lithosphere/asthenosphere probes

Plume compositions, sources and origins

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

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

Metal isotopes as tracers of lithosphere processes and Earth evolution

Planetary Analogues (see *Research Highlights*)

Crustal Evolution and Crustal Processes

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

U-series analysis of weathering and erosion processes (see *Research Highlights*)

Dating lower-crustal domains and tracking the 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

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

Integrated *in situ* analysis of U-Pb ages, Hf-isotopes and trace-elements in detrital zircons to characterise the magmatic history of major crustal terrains ("Event Signatures"): applications of *TerraneChron*® in 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

Metallogenesis

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 (see *Research Highlights*)

Identification of plume types fertile for Ni and PGE mineralisation

Crust-mantle interaction, granites and metallogenesis through time

In situ Re-Os dating of mantle sulfides and timing of mantle processes

Application of ^{186}Os to geochemistry and cosmochemistry

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

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

Trace elements in diamonds - source fingerprinting and genetic indicators

Geodynamics

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

Tasman Fold Belt: terrane analysis

Paleomagnetic studies of the northern New England Orogen

Subsurface pluton shape: Gravity studies

The role of east Antarctica in supercontinent assembly

Antarctic seismic studies

Nature of the lower continental crust, Fiordland New Zealand

The role of the Bering Sea in climate change over the last five million years

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

Crustal heat flow

Planetary Analogues (see *Research Highlights*)

Funded basic research projects for 2010/2011

FUNDED RESEARCH PROJECTS WITHIN GEMOC are formulated to contribute to the long-term, large-scale strategic goals and determine the short-term research plan. Research goals for each year are linked to the aims of funded projects. In addition to these projects, funding for the ARC Centre of Excellence for Core to Crust Fluid Systems (http://www.ccfs.mq.edu.au) will commence in 2011. Summaries of funded GEMOC projects are given here.

The effective strength of oceanic plate bounding faults

Craig O'Neill, Juan-Carlos Afonso: Supported by ARC Discovery Project Grant and MQ (commencing 2011)

***Summary*: The strength of the ocean faults surrounding the Australian plate controls the long-term fault motions, stress partitioning across the plate boundary and, ultimately, the seismicity of such fault systems. Numerous lines of evidence suggest such faults are far weaker than previous models predict, possibly due to the alteration of crustal and lithospheric rocks into hydrous phases. This is a critical gap in our understanding of such fault systems, and this project will ultimately constrain the weakening mechanisms acting on such faults, and produce a geodynamic-scale model for their effective strength. This project addresses the anomalously weak behaviour of the seismically active faults on the boundary of the Australian plate, in three key geodynamic areas. This will constrain the mechanisms which weaken such faults, and produce a model for their effective strength and evolution over geological timescales.**

Origin of silicic magmas in a primitive island arc: the first integrated experimental and short-lived-isotope study of the Tongan Kermadec system

Tracy Rushmer, Simon Turner: Supported by ARC Discovery Project Grant (commencing 2011)

***Summary:* Silicic magmas are the building blocks of the continental crust and constitute the most hazardous of volcanic eruptions. Silica-rich magmas are found in the Tonga-Kermadec arc, which extends for several thousand km north of New Zealand. Application of a novel combination of experiments and short-lived isotopes to selected magma samples from the primitive Tonga arc will explain the origin of these magmas. The combined technique will also allow us to estimate water content, rates of melting and magma migration at depth, which are critical factors for understanding volcanic hazards. This approach can then be expanded to other parental magma types here and to other arc systems. The Tongan arc forms a large portion of the Australian plate boundary and is one of the most chemically primitive systems known. Oddly, it produces volumes of more evolved, dangerous silicic magmas. The results of this project will establish the source of these magmas and rates of migration, which are fundamental for understanding volcanic hazards.**

Lithospheric Architecture Mapping in Phanerozoic Orogens

Bill Griffin, Sue O'Reilly, Norman Pearson, Elena Belousova: Supported by MQ Enterprise Partnerships Pilot Research Grant (commencing 2011)

***Summary:* The GEMOC Key Centre has developed the conceptual and technological tools required to map the architecture and evolution of the upper lithosphere (0-250 km depth) of cratons (the ancient nuclei of continents). Through two industry-funded programmes we have mapped most of the world's cratons, making up ca 70% of Earth's surface. The remaining 30% consists of younger mobile belts, which hold many major ore deposits, but are much more complex and difficult to map. This pilot project will develop the additional tools required to map the mobile belts, and will lead to an application for an ARC Linkage Project.**

Nature of the lower continental crust

Nathan Dazcko: Supported by MQSN grant (commencing 2011)

Summary: **Despite its importance to the study of crustal evolution and geodynamics, the composition of the lower part of the Earth's crust remains poorly known. This project utilises rare exposures of omphacite granulite in the natural laboratories of Fiordland, New Zealand and Hengshan Mountains, China to explore its influence on the composition, mineralogy and physical properties of the lower crust. The outcomes include characterisation of the rock types formed, their history and depth-temperature field of stability, and the determination of how omphacite granulite affects the strength of the crust and provides a fertile lower crustal source for magma.**

Strength and resistance along oceanic megathrust faults: implications for subduction initiation

Craig O'Neill: Supported by ARC Future Fellowship and MQ (commencing 2010)

Summary: **Plate tectonics is enabled by the sinking of dense oceanic lithosphere at ocean trenches - a process known as subduction, but how this process initiates is poorly understood. The development of an incipient subduction zone involves a major evolution of the plate boundary, into an oceanic megathrust fault system, capable of generating devastating earthquakes. An example is the Hjorta Trench, at the Australian-Pacific plate boundary south of Macquarie Island. This project will explore the evolution of this plate-boundary fault system during subduction initiation. Recent advances in our understanding of physical processes along plate-bounding faults will be incorporated into regional geodynamic simulations of this evolving fault system.**

Probing the composition of the early Solar System and planetary evolution processes

Sue O'Reilly, Bill Griffin, Norman Pearson, Olivier Alard, Benoît Ildefonse, Sylvie Demouchy: Supported by ARC DIISR French-Australian Science and Technology Program (commenced 2010)

Summary: **The aim of this project is to understand the origins and history of chondritic meteorites, the most primitive rocks in the solar system, and the stuff from which planets are made. An ongoing controversy about the relative ages and relationships between the different components of these primitive meteorites goes to the heart of models for the evolution of the Solar nebula and the generation of planets, including Earth. This controversy turns on the question of whether the various components of chrondritic meteorites have been formed separately in space and time, or have shared a common high-temperature history. To provide new constraints on this problem, we will focus on the chemical and micro-structural relationships between the chondrules and the very fine-grained matrix in which they are embedded. We will use both established and recently developed *in situ* microanalytical techniques, to measure the abundances and isotopic compositions of critical elements in the fine-grained minerals of chondrules and their matrix, and to determine the degree of structural alignment between the minerals in the two components. The data will be used to evaluate the degree of high-temperature interaction between chondrules and their matrix, and to assess different models for the formation of chondrites. The results will be compared with equivalent information on samples of the Earth's deep interior brought to the surface in volcanoes or tectonic uplift; such samples can provide analogues for the differentiation of meteoritic parent materials. The project will use complementary equipment in France and Australia: (laser-ablation (LA) inductively coupled mass spectrometry (ICPMS) at GEMOC (Macquarie University); ion microprobe and electron backscatter diffraction (EBSD) at GM (Geosciences Montpellier, UMR 5342)).**

Planetary differentiation of early solar system materials: an integrated isotopic and experimental approach

Bruce Schaefer: Supported by MQSN grant (commenced 2010)

Summary: **This project aims to use meteorites of a variety of compositions to investigate how, and how rapidly, planetesimals differentiate and start to form planetary bodies. Physical processes, such as the formation of**

metallic cores at the centres of small planets (<100 km diameter) and their corresponding rocky exteriors, can be simulated by conducting experiments on specific types of meteorites, which were the starting material for solar system formation. Sophisticated isotopic techniques, such as Os isotopes, will be used, allowing a time dimension on the rate of differentiation to be measured. Such processes can then be applied to the formation of the Earth.

The evolution of the oceanic lithosphere and upper mantle: a novel petrological-geophysical approach

Juan Carlos Afonso: Supported by MQNS grant (commenced 2010)

Summary: Understanding the evolution of the oceanic mantle, from the creation of oceanic lithosphere at mid-ocean ridges to its destruction at subduction zones, is a cornerstone in Earth Sciences. However, a complete model capable of reconciling all its geophysical and geochemical characteristics is still lacking. The proposed research program will combine novel interdisciplinary methods and powerful computer software to obtain a robust thermo-chemical-mechanical model for the evolution of the Earth's mantle beneath the oceans. This project will advance our knowledge of the evolution of ocean basins and continental margins, and thus it is directly translatable into predictive exploration methodologies for Australia's energy sector.

Nature, antiquity and length scales of compositional anomalies in the convecting Earth

Bruce Schaefer: Supported by MQNS (commenced 2010)

Summary: The convecting Earth is sampled by volcanic rocks and some ocean island basalts, such as those erupted in the Azores, preserve evidence of anomalously ancient material which is chemically and possibly also mineralogically distinct from the rest of the mantle. This project aims to evaluate the nature and role of heterogeneities in the mantle beneath the Azores and how these may influence melting dynamics. Through application of novel isotopic techniques we aim to further constrain geodynamic models for the Azores and inform the current vigorous debate surrounding the age, origin and indeed fundamental nature of the Earth's convecting interior.

Resurrecting Rodinia? The role of east Antarctica in supercontinent assembly

Nathan Daczko: Supported by ARC MQRDG (commenced 2010)

Summary: This project will determine the role of east Antarctica in the Rodinian supercontinent that assembled 1300-900 million years ago. Controversy exists regarding the timing of geological events in east Antarctica and how these relate to the architecture of the Rodinian supercontinent. This project will characterise the age and geochemical signature of key Precambrian rocks in Kemp and MacRobertson lands, which outcrop as islands, isolated nunataks and mountain ranges, and compare their evolution with proposed conjugate regions in India, Australia and broader Antarctica. These rocks will provide a missing link between disparate terranes in recent tectonic reconstructions of Rodinia.

Developing permeability in the Earth's crust: A coupled experimental and numerical study of geologically important fluids in a dynamic environment

Tracy Rushmer: Supported by MQRDG (commenced 2009)

Summary: The development of permeability in host rocks is key to understanding fluid flow and ore formation. However, we have yet to build into fluid transport models realistic evolutionary paths of porosity and permeability with time. While the controls on fluid flow and focusing in the Earth's crust are conceptually understood, we still need a quantitative approach to their evolution. This project uses a coupled approach between numerical modelling and dynamic experiments on natural crustal rocks to gain quantitative information on the physical and chemical mechanisms of generating enriched mineral zones. The results will seed a CSIRO MDU Collaboration Cluster application.

A novel approach for economic uranium deposit exploration and environmental studies

Simon Turner, Bruce Schaefer, Geoffrey McConachy: Supported by ARC Linkage and Quasar Resources (commenced 2009)

Summary: **The project proposes the use of a novel approach to prospect for economic uranium ore deposits. The measurement of radioactive decay products of Uranium in waters (streams and aquifers) and sediments will allow us to (i) identify and locate economic uranium ore deposits, and (ii) quantify the rate of release of uranium and decay products during weathering and hence the evolution of the landscape over time. In addition, this project will improve our knowledge on the mobility of radioactive elements during rock-water interaction, which can be used to assess the safety of radioactive waste disposal. Outcomes of this project will be: (i) the discovery of new economic uranium deposits; (ii) development of a new exploration technology allowing for improved ore deposit targeting. Information gained on the behaviour of radioactive elements at the Earth's surface will be critical for the study of safety issues related to radioactive waste storage and obtaining reliable time constraints on the evolution of the Australian landscape.**

Did obesity kill the arc? A model from the Fiordland Arc, New Zealand

Nathan Dazcko: Supported by MQSN grant (commenced 2009)

Summary: **This project explores crustal growth in a magmatic arc flare-up event, immediately before rapid crustal growth (obesity) and death of the arc. Rare exposures of deep arc crust (>60 km), in the natural laboratory of Fiordland, New Zealand, offer unique insight into crustal growth mechanisms. Our approach is to incorporate field-, petrographic- and isotope-based analysis for a fully integrated model of the evolution-extinction of this arc. We will quantify mantle versus crustal recycling sources and variations in magmatic flux rates, and document the rock types formed at the base of the thickest exposed continental arc, and their petrogenesis.**

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.**

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

Bill Griffin, Sue O'Reilly, Norman Pearson: Supported by ARC Linkage and De Beers Group Services (commenced 2008)

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.**

The role of supercontinents in Earth's dynamic evolution

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, 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.**

GEMOC's context in 2010

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.

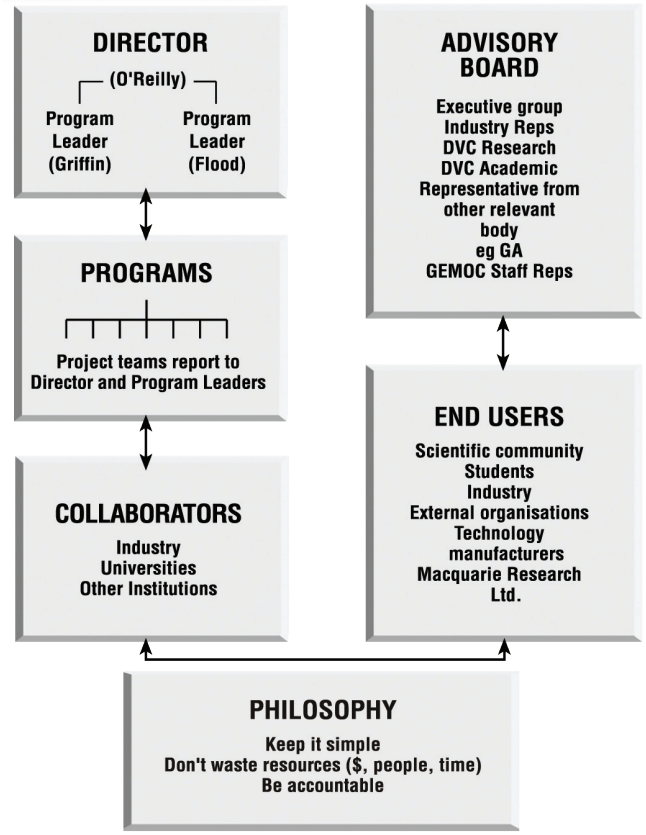


Bill Griffin with some very old rocks in South Africa, on a field trip sponsored by our Chinese collaborators.

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 Access MQ Limited 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.



MANAGEMENT STRUCTURE

MANAGEMENT ROLES

Professor Suzanne O'Reilly: Director of GEMOC.

Mrs Carol McMahon: GEMOC Administrator.

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

Associate Professor Kelsie Dadd: Head of the Department of Earth and Planetary Sciences and coordinates the Teaching Programs (Dr Mark Lackie wil be Acting Head for 2011 while Professor Dadd is Acting Associate Dean of teaching for the Faculty of Science).

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.

Dr Craig O'Neill: Manager of the GEMOC computing cluster.

Ms Sally-Ann Hodgekiss: GEMOC graphics and design consultant at Macquarie; NCRIS administrator.

ADVISORY BOARD MEMBERS (2010)

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*

Associate Professor Kelsie Dadd – *EPS Macquarie*

Professor Simon Turner *and* **GAU Manager Dr Norman Pearson** are ex officio members

External Board Members

Adjunct Professor Michael Etheridge – *Company Director*

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

Dr Paul Heitherseay – *representative of PIRSA*

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

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

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



GEMOC communications 2010

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. Undergraduate teaching is also 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 2010 ranged from presentations to specific industry groups in their offices to numerous formal and informal workshops at GEMOC, and invited and plenary presentations at peak industry symposia, workshops and conferences nationally and internationally.

GEMOC PUBLICATIONS FOR 2010 ARE GIVEN IN *APPENDIX 2*

The 64 GEMOC Publications that were published in 2010 (and another 60+ already accepted for 2011) 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 2010 (AND BEYOND)

GEMOC staff, postdoctoral researchers and postgraduates again had a high profile at peak metallogenic, geodynamic and geochemical conferences as convenors, invited speakers, or presenters, with 105 presentations including:

- 29th Nordic Geological Winter Meeting (Oslo, Norway)
- SGTSG 2010 Specialist Group in Tectonics and Structural Geology Conference 2010 (Port Macquarie, NSW)
- The Geological Society of North America Joint Section Meeting GSA North-Central and South-Central Sections both Celebrating their 44th Annual Meeting. GSA North-Central/ South-Central 2010 (Branson, Missouri, USA)
- 13th Quadrennial IAGOD Symposium 2010 'Giant Ore Deposits Down-Under' (Adelaide, Australia)
- International Field Conference and Workshop on Tephrochronology, Volcanism and Human Activity, Active Tephra (Kyushu, Japan)
- Cordilleran Section – 106th Annual Meeting and Pacific Section, American Association of Petroleum Geologists (Anaheim, CA, USA)
- European Geosciences Union General Assembly 2010 (Vienna, Austria)
- Goldschmidt 2010, Earth, Energy and the environment (Knoxville, Tennessee, USA)
- 11th International Platinum Symposium (Sudbury, Ontario, Canada)



Sue O'Reilly surrounded by students at the International Zircon Course, Beijing, October 2010.

- 2010 Western Pacific Geophysics Meeting (Taipei, Taiwan)
- Australian Earth Sciences Convention 2010 (Canberra, Australia)
- The 20th General Meeting of the International Mineralogical Association - IMA2010 Bonds and Bridges: Mineral Sciences and their Applications (Budapest, Hungary)
- Australian Society of Exploration Geophysicists (ASEG) and Petroleum Exploration Society of Australia (PESA), 21st International Geophysical Conference and Exhibition (Sydney, Australia)
- 14th International Symposium on Deep Seismic Profiling of the Continents and their Margins (Seismix2010) (Cairns, Australia)
- Evolving Early Earth, 5th International Archean Symposium (5IAS) (Perth, WA)
- International Conference 'Geochemistry of Magmatic Rocks' as a Part of the School 'Geochemistry of Alkaline rocks' (Crimean Peninsula, Ukraine)
- XXX Reunión de la Sociedad Española de Mineralogía SEM (Madrid, Spain)
- State of the Arc Conference (SOTA 2010): Subduction to Eruption (Syros and Santorini, Greece)
- Australian Space Science Conference 2010 (Brisbane, Queensland, Australia)
- Society of Economic Geologists, SEG 2010 Conference (Keystone Resort, Colorado, USA)
- 5th SHRIMP Workshop and International Workshop on Advances in High Resolution Secondary Ion Mass Spectrometry (HR-SIMS) and LA-ICPMS Geochronology: Application to Geological Processes (Beijing, China)



Bill Griffin at the International Zircon Geochronology Training Course (Beijing, China).

- International Zircon Geochronology Training Course (Beijing, China)
- 2010 Chinese National Symposium of Petrology and Geodynamics (Peking University, Beijing, China)
- Groundwater 2010: The Challenge of Sustainable Management (Canberra, Australia)
- Australian Geothermal Energy Conference (Adelaide, Australia)
- New England Geology Symposium (UNE, Armidale, Australia)
- AGU 2010 Fall Meeting (San Francisco, California, USA)

Plenary Talks in 2010 included Bill Griffin (IMA, Hungary)

Keynote talks in 2010 included Sue O'Reilly, Yingjie Yang (Western Pacific Geophysics meeting, Taiwan), Graham Begg (AESC, Canberra), Sue O'Reilly, Yakov Weiss (IMA, Hungary), Bill Griffin, Graham Begg (5th International Archean Symposium, Perth)

Invited talks in 2010 included Simon Turner (AESC, Canberra), Bill Griffin (Western Pacific Geophysics Meeting, Taiwan) Sue O'Reilly (5th Shrimp Workshop, Beijing), Bill Griffin (Int. Zircon Geochronology Training Course, Beijing), Craig O'Neill (AGU, San Francisco), Sue O'Reilly, Elena Belousova, Norman Pearson (5th International Archean Symposium, Perth)

A full list of abstract titles and authors 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.

OTHER CONFERENCE ROLES

Bill Griffin was co-convenor for session "*Diamond crystallisation under natural and experimental conditions*" at the IMA in Budapest August, 2010.

Norman Pearson co-convened Session V09 "*Recent Advances in High Precision Trace Element and Isotopic Analysis*" at the Western Pacific AGU meeting, held in Taipei, Taiwan, in June.

Simon Turner and Tracy Rushmer co-convened the 5th "State of the Arc" meeting on Santorini in September 2010.

Simon Turner presented a U-series isotope short course in Geneva.

Elena Belousova wass co-convener of session "*Russia and Central Asia*" at the 13st IAGOD Quadrennial Symposium, Adelaide, South Australia, April 2010.



Sue O'Reilly with Vice-Chancellor Steven Schwartz after receiving the award for Distinguished Professor (Photo: Paul Wright).

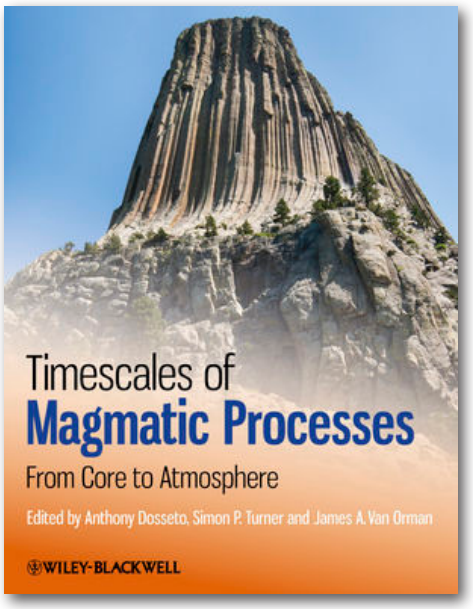
Mark Lackie co-convened the ASEG 21st International Geophysical Conference and Exhibition, Sydney.

Craig O'Neill convened sessions "*Geophysics and Geothermal Applications I and II*" at the ASEG/PESA 21st International Geophysical Conference and Exhibition held in Sydney.

ESTEEM FACTORS AND OUTREACH

Sue O'Reilly was awarded the title of Distinguished Professor, reflecting "exceptional distinction and an outstanding contribution to her discipline" and "outstanding, internationally recognised performance and continuing achievement in the three elements of academic endeavour: teaching, research and community engagement". Vice-Chancellor Steven Schwartz made the formal presentation at the Macquarie Research Excellence Awards in October 2010.

Sue O'Reilly and Bill Griffin were invited visitors of the Taiwan Academy of Sciences for 2 weeks in June 2010.



Simon Turner was co-editor of the Wiley-Blackwell book "*Timescales of Magmatic Processes*". Authors of chapters included Bill Griffin, Craig O'Neill, Sue O'Reilly, Tracy Rushmer and Simon Turner.

Nathan Daczko was awarded the E.S. Hills medal at Australian Earth Sciences Conventions 2010 held in July in Canberra. This new medal recognised his outstanding contribution to the geological sciences. See http://www.gsa.org.au/recognition/eshills.html

Juan Carlos Afonso was selected 2010 "Most Outstanding Young Scientist" by the Tectonics Division of the European Geosciences Union.

In June 2010 Norman Pearson was a visiting scientist at the Institute for Earth Sciences, Academia Sinica where he assisted in the development of their facilities for *in situ* isotopic analysis. During this visit he gave an invited lecture at the pre-AGU Workshop "*Frontiers in Geochemical Research*".

Juan Carlos Afonso was the 2010 Honorary Collins Lecturer at the Department of Earth Sciences, Carleton University, Ottawa.

Nathan Daczko continued as chair of the Geological Society of Australia Specialist Group in Tectonics and Structural Geology (SGTSG), and chaired the organising committee for the 2010 Field Conference.

Sue O'Reilly was Chief Guest Editor of the special Lithos Volume 120 "*The Lithosphere - Asthenosphere boundary: nature, formation and evolution from Hadean to now*" and Juan Carlos Afonso and Bill Griffin were co-guest editors.

Sue O'Reilly was the Geoscience Panel Member for ICREA (Catalan Institute for Advanced Research), Barcelona, Spain in 2010.

Tracy Rushmer is a NSF (National Science Foundation) panel member for Geochemistry and Petrology (2010-2012).

Juan Carlos Afonso was appointed Division Officer of the European Geosciences Union (Geodynamics Division).

Simon Turner continued as Director of the Geochemical Society.

Bill Griffin continued as an invited founding core member of the new International Precambrian Research Centre of China (IPRCC) at Beijing SHRIMP Centre and the Department of Geology, Chinese Academy of Geological Sciences.

Bruce Schaefer was the AuScope Earth Composition and Evolution Component Leader and coordinated the National Geochemistry Program for the AuScope NCRIS capability; http://www.auscope.org.au.

Simon Turner served on the AuScope II steering committee.

Tracy Rushmer was the Science faculty representative for the LH Martin Institute shortcourse on Women in Research Leadership.

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

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

Norman Pearson continued as 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*".

Bruce Schaefer was an Expert Examiner in cultural heritage for the Federal Government in extraterrestrial materials.

Juan Carlos Afonso continued as a Topical Editor of the EGU journal Solid Earth.

Representation on editorial boards included: Lithos (Griffin, O'Reilly, Rushmer); Geological Society of America Bulletin (Griffin); Journal of Petrology (Turner); Solid Earth (Schaefer); Acta Geologica Sinica (Griffin); Journal of Exploration Geophysics, Managing Editor (Lackie).

MEDIA

An interview with Sue O'Reilly was published in "The Australian" (http://www.theaustralian.com.au/higher-education/gem-of-a-centre-at-macquarie/story-e6frgcjx-1225998310865) highlighting the outstanding ERA (Excellence in Research for Australia) results for the Earth Sciences, Geology and Geochemistry categories (top rating of 5 for each of these assessed categories at Macquarie). The full ERA results can be seen at http://www.arc.gov.au/era/outcomes_2010.htm.

Sue O'Reilly was invited to contribute two articles to the Mantle Plumes website:
http://www.mantleplumes.org/LithosphereRemnants.html
http://www.mantleplumes.org/CapeVerde.html

Bruce Schaefer commented on a News article in Cosmos "Solar System now two million years older", August 2010, http://www.cosmosmagazine.com/node/3660/full.

Craig O'Neill was active in media outlets including:
Enceladus episodic overturn, Scientific American, January, 2010, http://www.scientificamerican.com/article.cfm?id=saturn-enceladus-episodic-overturn;
Saturn's ice moon shows signs of life, The Australian, 11 Janurary, 2010 (Page 5), http://www.theaustralian.com.au/news/health-science/saturns-ice-moon-shows-signs-of-life/story-e6frg8y6-1225817874008.

Craig O'Neill also published a commentary about the Japan Earthquake in Cosmos "The Anatomy of a Megathrust Earthquake" http://www.cosmosmagazine.com/features/online/4203/the-anatomy-a-megathrust-earthquake?

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 partnerships in 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

PUBLICATION SPOTLIGHT

GEMOC Publication #671, "The growth of the continental crust: Constraints from zircon Hf-isotope data" by Belousova et al. was the hottest article in Lithos from June to October 2010 and remains 2nd on the most-downloaded list to June 2011.

GEMOC Publication #650, "The continental lithosphere-asthenosphere boundary: Can we sample it?" by O'Reilly and Griffin was the hottest article in Lithos from October to December 2010 and remains the most downloaded paper in Lithos from November 2010 to June 2011.

GEMOC Publication #625 "Buoyant ancient continental mantle embedded in oceanic lithosphere (Sal Island, Cape Verde Archipelago) by Coltorti et al. and #635 "The mechanics of continental lithosphere-asthenopshere coupling" by O'Neill et al., were also in the top 25 list of hottest articles in in Lithos from October to December 2010.

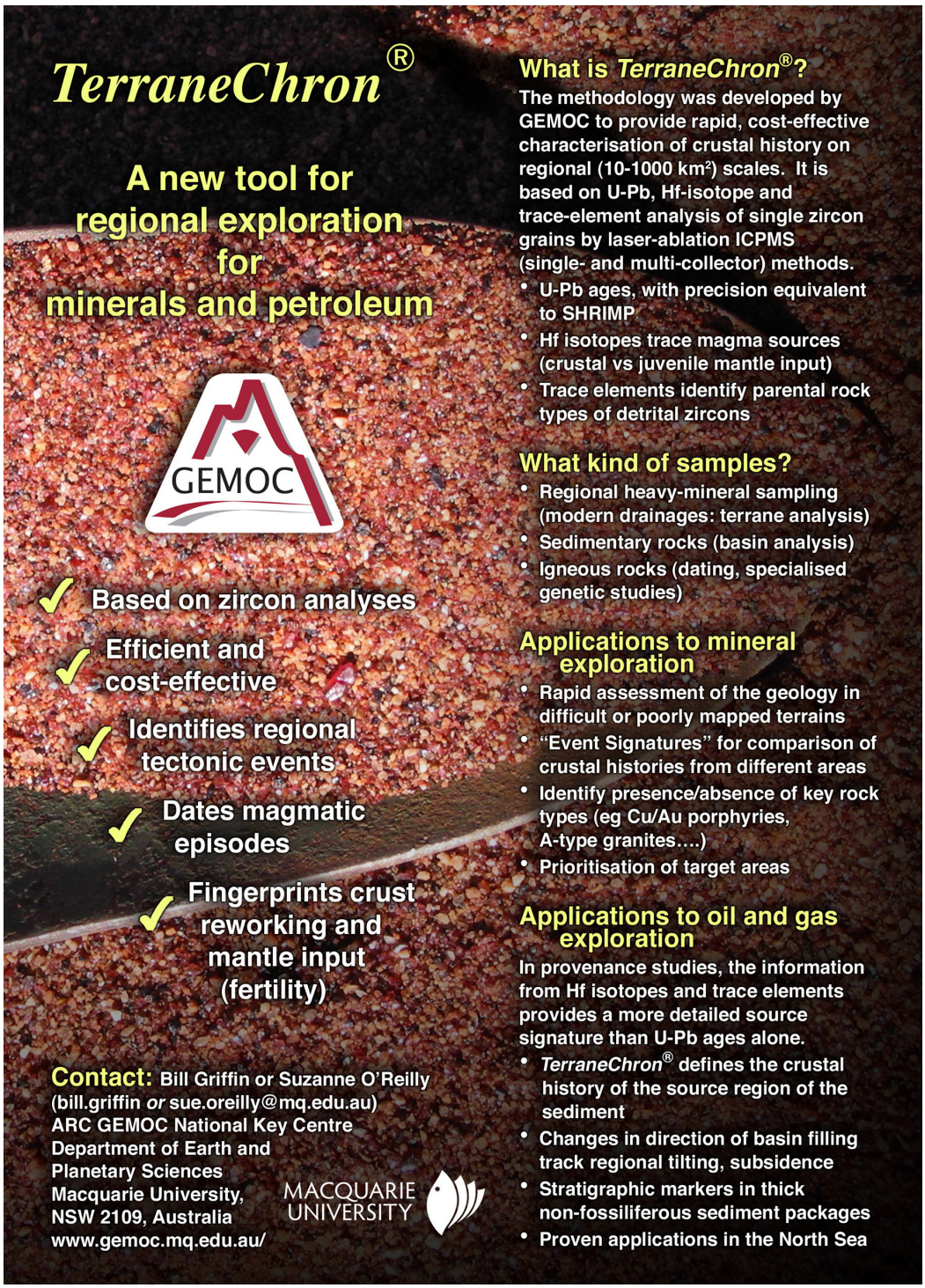
GEMOC Publication #409 "Imaging chemical and thermal heterogeneity in the sub-continental lithospheric mantle with garnets and xenoliths: Geophysical implications" by O'Reilly and Griffin received an award for the most cited paper in Tectonophysics since 2005.

GEMOC Publication #428 "Comment: Hf-isotope heterogeneity in standard zircon 91500" by Griffin, Pearson, Belousova and Saeed received an award for the most cited paper in Chemical Geology since 2005.

Research highlights 2010

TERRANECHRON® IS GEMOC'S UNIQUE METHODOLOGY FOR TERRANE EVALUATION. During 2010 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.

Visit the TerraneChron® web page at http:// www.gemoc.mq.edu.au/TerraneChron.html



When the Earth moves: Applications to geothermal exploration (Western USA)

Seismic waves are the main tool used to reveal information about the underground structure of the Earth, because they can penetrate into the deep interior and be received by seismographs. Seismic tomography is a technique for constructing three dimensional structure of the Earth's interior using these waves. It is analgous to the CT scanning used in medicine to look inside our bodies. Traditional seismic tomography uses natural earthquakes as sources to image internal structure. However, earthquakes are mainly located at tectonic plate boundaries, and this makes it difficult to image the shallow structure of the crust, especially in the top 10 km of the Earth, in aseismic regions such as the Australian continent. The advent of ambient noise tomography in 2005 revolutionised seismic tomography. This new method uses the microseismic noise produced by ubiquitous minor ground motions, the so-called

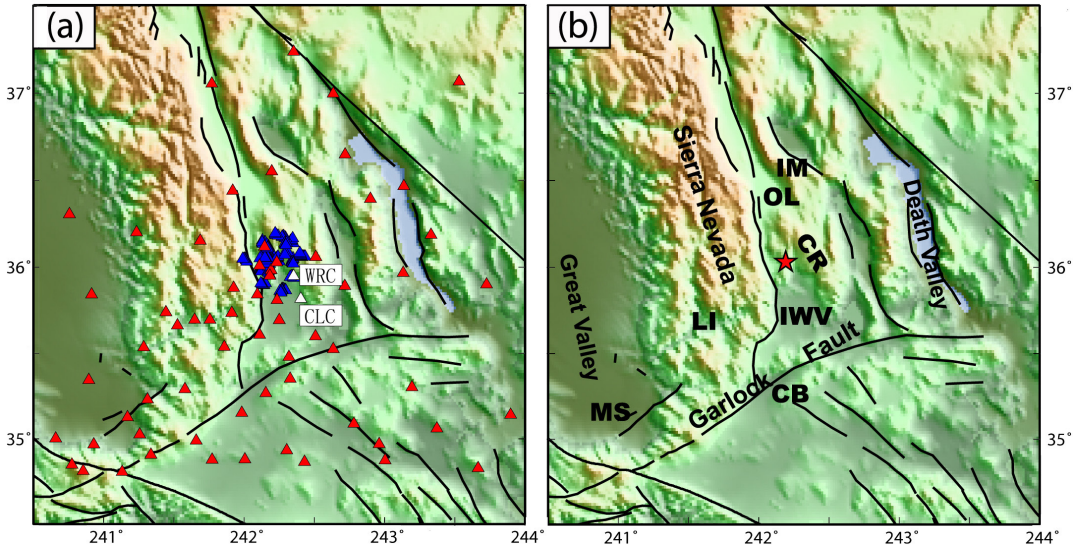


Figure 1. (a) Distribution of seismic stations (triangles) in the Coso Geothermal Area and surrounding areas used in this study. Black lines denote faults. (b) Place names mentioned in text: CB: Cantil Basin; CR: Coso Range; IM: Inyo Mountains; IWV: Indian Wells Valley; LI: Lake Isabella; MS: Maricopa sub-basin; OL: Owens Lake.

ambient noise, to map seismic velocity along the path between any two seismic stations, independently of earthquakes. It is especially useful for imaging the shallow levels of the crust, where the most abundant natural resources are located, such as mineral deposits, oil and gas reservoirs, and geothermal fields.

The Coso Geothermal Area lies at the southwestern corner of the actively deforming part of the Basin and Range Province of North America; it is within the Eastern California Shear Zone (Fig. 1). It also lies in the part of the Basin and Range that has experienced the most recent significant volcanism. The Coso Range contains one of the young magmatic centres along the western margin of the Basin and Range; its activity started about 4 Ma ago but entered a phase of bimodal volcanism about 1 Ma ago. The recent magmatic activity produced high temperatures beneath the Coso Geothermal Area, and commercial power development began there in the 1980s. The power plants are currently producing 270 MW from four geothermal power plants. To characterise the geothermal resource and generate electricity more efficiently in the future, numerous geophysical studies have been carried out over the geothermal field. However, two main questions still remain: the depth of the magma chamber acting as the heat source and the relationship of magmatism to faulting or shearing at depth.

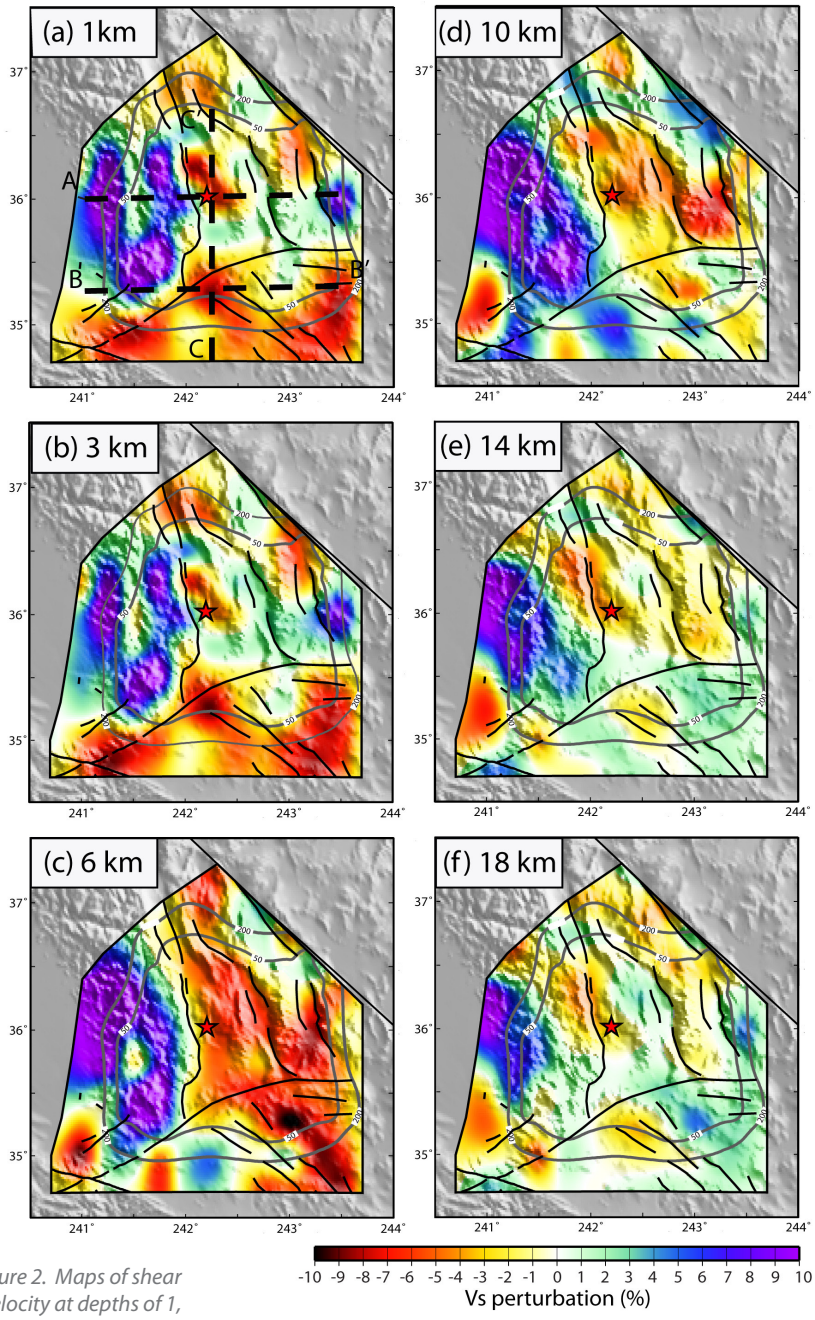


Figure 2. Maps of shear velocity at depths of 1, 3, 6, 10, 14 and 18 km, plotted as perturbations to averages at each depth: 1 km (2.867 km/s), 3 km (3.174 km/s), 6 km (3.319 km/s), 10 km (3.452 km/s), 14 km (3.524 km/s), 18 km (3.574 km/s). Two grey contours of resolution at scales of 50 and 200 km are plotted in each map. The three dashed lines in Fig. 2a show the surface locations of the three vertical transects shown in Fig. 3.

In this study, ambient noise tomography was adopted to image shallow structures beneath the Coso Geothermal Area and surrounding areas using all the stations nearby (Fig. 1; see *GEMOC Publication #702*). The purpose was to constrain the depth of any magma chambers underlying the area. The resulting 3D shear-velocity structure from this study is shown as maps of shear velocities at depths of 1, 3, 6, 10, 14 and 18 km (Fig. 2) and three vertical shear-velocity transects whose surficial positions are indicated in Figure 2a. Warm colors in these figures represent lower seismic velocities, indicating either high temperature or the presence of magma; cold colors represent higher seismic velocities indicating lower temperature.

Low velocities in the entire depth column beneath the Coso Range are quite close to the position of the Coso Geothermal Field (Fig. 3). In particular, a feature with very low velocity is imaged in the top 2 km. The appearance of this anomaly, even though the dominant surface exposures are granite, suggests profound alteration of the crust in the area and/or significant influence from shallow magmatic or hydrothermal fluids. Although the entire crustal column beneath the Coso Geothermal Area appears to have depressed Vs speeds (Fig. 3), there is an indication of a stronger low-velocity zone between depths of 6 and 8 km. This may reflect a deeper magmatic anomaly underlying the shallow geothermally-induced anomaly in the top 2 km. The absence of really low velocities below ~14 km (Fig. 2e) tends to support a shallow-magma interpretation.

An intriguing feature that emerges in this study is the low velocities between about 6 and 8 km depth under much, but not all, of the Basin and Range Province (Fig. 2c, 3). This feature correlates well with the extent of sizeable exposures of Neogene and Quaternary volcanic rocks (Fig. 4), strongly suggesting a magmatic origin. Within the area well-resolved by this study, only the older Miocene volcanic centre in the southern Sierra Nevada and some small centres in the eastern Sierra Nevada remain outside this zone. It is implausible that this entire feature represents uniformly distributed melt at these depths, but local accumulations of melt seem consistent with very low electrical resistivity found near these depths north of Coso. This anomaly probably represents crust profoundly reworked by igneous processes over the

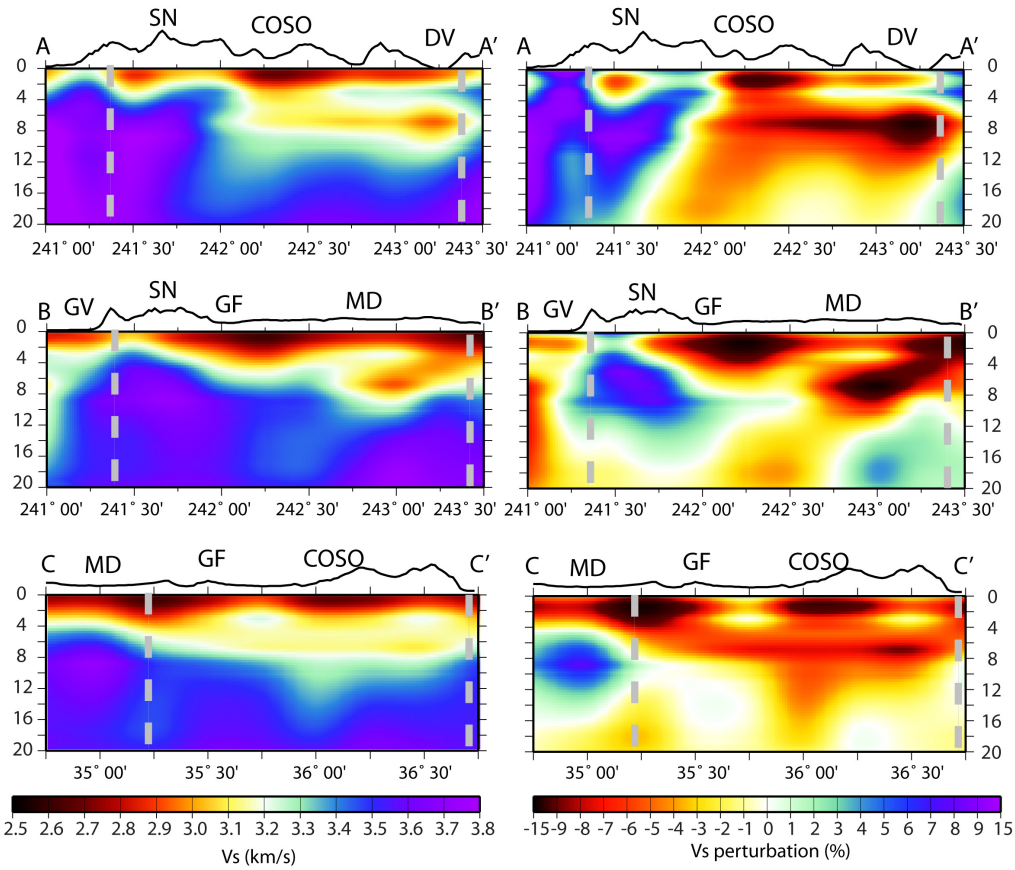


Figure 3. Vertical transects of shear velocities plotted both as absolute values (left) and as perturbations relative to the 1D Vs averages (right). The two dashed gray lines in each plot enclose an area where the imaging has a lateral resolution of 50 km. The locations of the cross-sections are shown in Fig. 2a. Abbreviations: COSO: the Coso Geothermal Area; SN: the Sierra Nevada Mountains; DV: Death Valley; MD: the Mojave Desert; GV: California's Great Valley; GF: the Garlock Fault.

past few million years. The modern low velocities may represent some combination of melt, alteration, magmatic fluids and high temperatures.

In summary, beneath the Coso Geothermal Area, shear velocities are generally depressed. A prominent low-velocity anomaly is resolved clearly within the top 2 km, probably resulting from geothermal alteration at shallow depths. The low-velocity anomaly between 6 and 12 km indicates the location of a magmatic body. No magmatic body is imaged below 14 km depth. Low velocities in the broad regions surrounding Coso at depths near 7 km underlie areas with Miocene to recent volcanism. This project has proven the usefulness of ambient-noise tomography for geothermal exploration; the method can be also applied anywhere in Australia in the future to investigate the underground structures relevant to geothermal energy exploration.

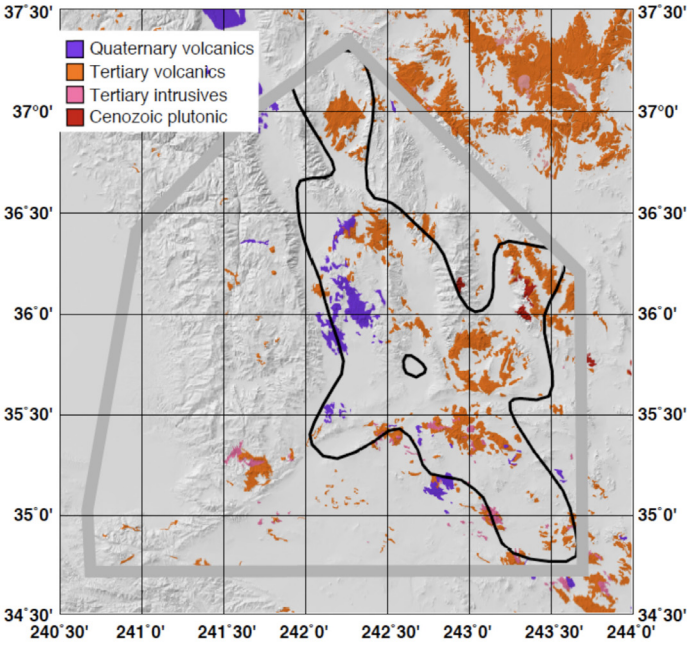


Figure 4. Exposures of Cenozoic igneous rocks in eastern California compared with outline (black) of low Vs (<~3% at 6 km depth, Fig. 2c). The extent of the inverted region is shown by the grey outline.

Contact: Yingjie Yang
Funded by: Macquarie CoRE funding

Continents can't subduct!...or can they?

We commonly assume that continental crust cannot be subducted to significant depths, due to its high relative buoyancy. However, clear field and petrological evidence shows that relatively large sections of continental crust have been subducted to depths >100 km and then exhumed, at numerous locations worldwide. The discovery of metamorphic diamonds (Kokchetav massif, Russia; Western Norway…) and especially of pyroxene exsolution in garnets (e.g. Western Norway, Sulu metamorphic belt (China)) further demonstrated the possibility of ultra-deep subduction of continental crust to depths >250 km. The possibility of continental material being subducted to depths of the transition zone, and perhaps even into the lower mantle, is supported by geochemical and isotopic signatures in magmas erupted in island arcs, presumably from source regions at depths >300 km, and by experimental data at extremely high pressures. These studies indicate there may be a "depth of no return" for continentally-derived materials at around 8.5–9 GPa (270 km), where dense silicates start to form. However, the actual amount of continental material that can be subducted below the point of no return, and its final fate, have never been assessed with coupled thermomechanical-thermodynamic numerical models. This is the objective of an ongoing GEMOC research project (for more details see *GEMOC Publication #659*).

To allow direct comparisons with geological, geochemical and geophysical evidence, numerical simulations need to include realistic thermophysical properties for all the materials involved in the model. Therefore we couple our thermo-mechanical solvers with thermodynamic datasets that account for all expected metamorphic reactions and phase changes. Earlier models made use of thermodynamic databases strictly suitable only at pressures <3 GPa, while we use an in-house database valid up to ~25 GPa that includes

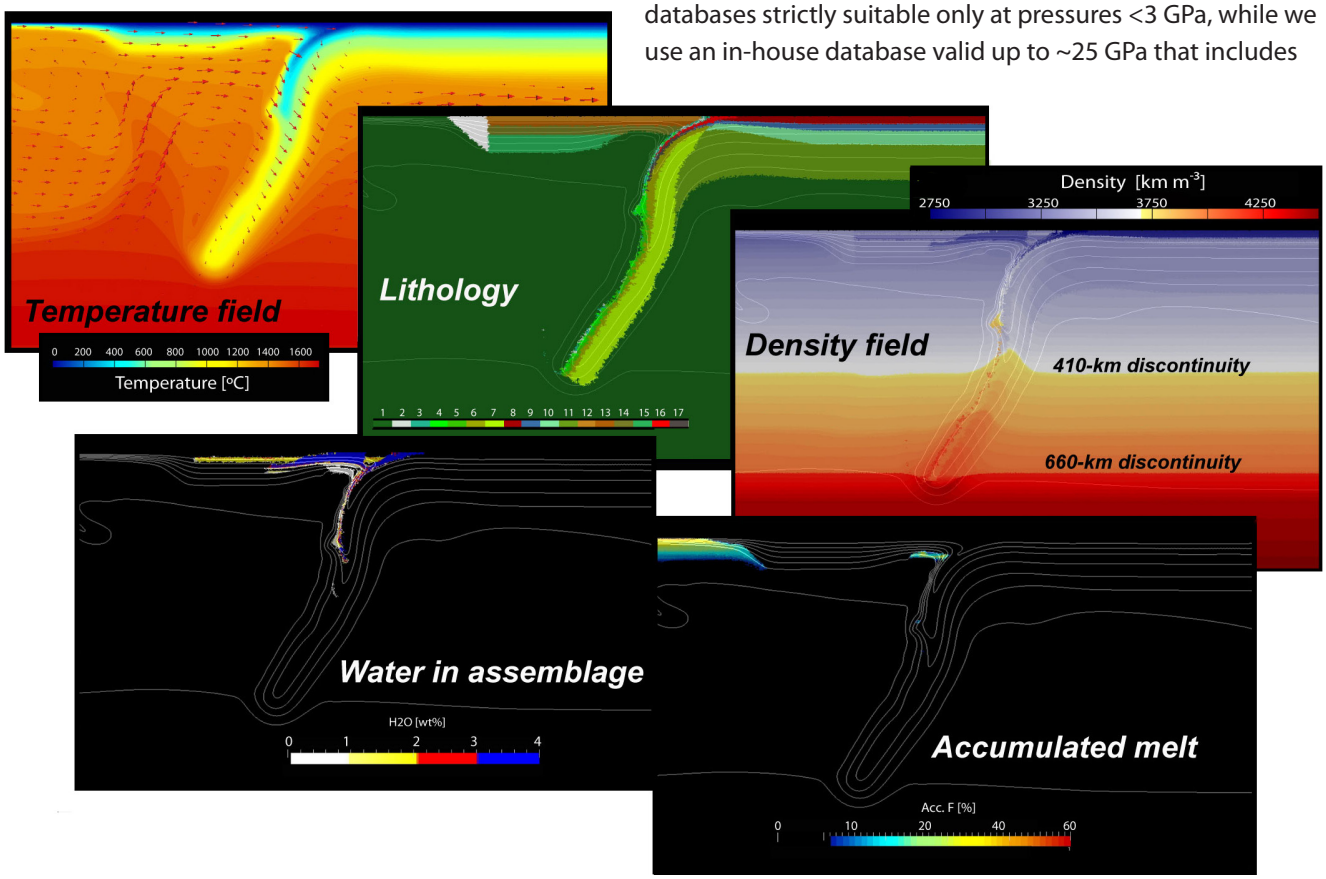


Figure 1. Snapshot from one of our simulations showing the thermal, density and compositional fields. The amount of bound water in the assemblages and accumulated melting in the mantle are also shown. The simulations were carried out with a modified version of the Underworld platform (http://www.underworldproject.org).

all major phases obtained in UHP experiments on compositions relevant to the continental crust. Importantly, we have not imposed velocity boundary conditions to either force or stop continental subduction, so the velocities obtained in our simulations emerge self-consistently from the balance between internal forces in our numerical domain.

We have run a total of 80 simulations (Fig. 1) to test different aspects of the problem (effects of compositional variations in the mantle, passive-margin geometries, types of continental sediments, etc.). The main results can be summarised as follows:

(1) The buoyancy increase due to subduction of continental material may not be the only explanation for the typical decrease in convergence velocity observed in collisional settings after the continental crust arrives at the trench. Delamination of the lithospheric mantle at lower crust levels after a period of continental subduction can result in a similar pattern of convergence velocities. This scenario is favoured in settings dominated by slab rollback.

(2) The thermal structures of the continental plate and passive margin play important roles in the evolution and final configuration of the collision. The colder temperatures in a thick continental plate give it an extra strength, which overcomes the effects of its negative buoyancy. Thus, the overall effect of increasing the thermal thickness of the continental plate is to reduce convergence velocities, stalling subduction and impeding deep recycling of continental material.

(3) When both the arc and the continental plate are free to move (e.g. bounded by mid-ocean ridges), the system evolves as forward subduction rather than as slab rollback. Although the circulation patterns in the sublithospheric mantle and in the mantle wedge are significantly different in these two cases, the general pattern and absolute values of the resulting convergence velocities are similar. Replenishment of fertile mantle in the mantle wedge and enhanced partial melting are favoured in forward-subduction scenarios.

(4) The composition of the continental lithospheric mantle exerts a moderate influence on the overall evolution of the collision system. Since the highly depleted part of the continental mantle seems to be restricted to shallow depths (<60–80 km), the thermal effect is usually more important and the overall buoyancy of the lithospheric mantle at the beginning of the collision is negative.

(5) The rheology of the continental crust is a major factor controlling both the duration of continental subduction and the volume of continental material that can be subducted. Strong crusts favour deep subduction of continental materials while soft crusts tend to accumulate at shallow depths. In the latter case, the decoupling between the upper crust and the rest of the lithosphere effectively restricts the increase in the positive buoyancy of the slab, which remains negatively buoyant at all conditions.

(6) Subducted continental crust remains buoyant with respect to the surrounding mantle down to depths of ~250–300 km. Potential detachments from the slab will therefore result in upwelling of these continental portions. However, the characteristic cold temperatures in the uppermost part of the slab result in a strong mechanical coupling between the crustal and mantle components, making detachment more difficult.

(7) Subducted continental crust that reaches depths >250–300 km becomes significantly denser than the surrounding mantle, due to the appearance of high-density phases. This provides extra negative buoyancy to the slab and inhibits the return of subducted crust to the surface (the point of no return).

“The rheology of the continental crust is a major factor controlling both the duration of continental subduction and the volume of continental material that can be subducted.”

Contact: Juan Carlos Afonso
Funded by: Macquarie CoRE Funding

The Lithosphere-Asthenosphere boundary: Can we sample it?

THE LITHOSPHERE-ASTHENOSPHERE BOUNDARY (LAB) represents the base of the Earth's lithosphere, the rigid and relatively cool outer shell characterised by a conductive thermal regime, and isolated from the convecting asthenosphere. Chemically, the LAB should divide a

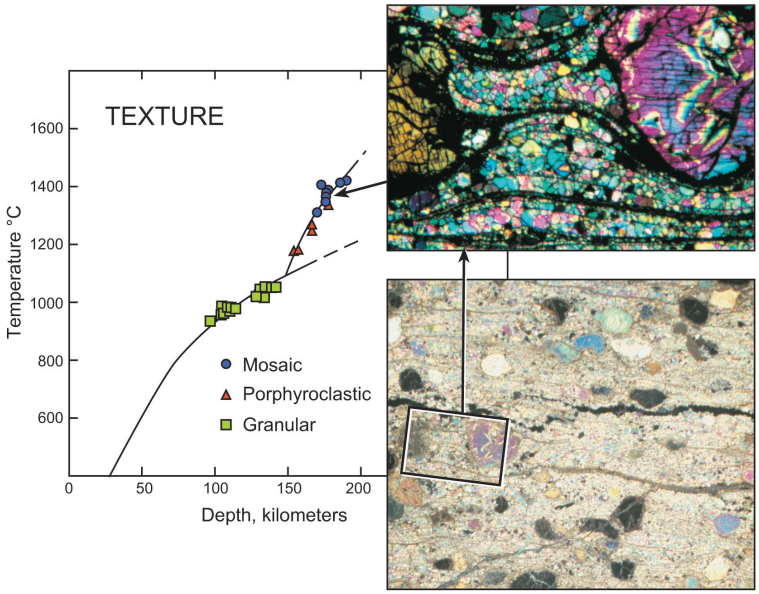


Figure 1. The original Lesotho xenolith geotherm of Boyd and Nixon (1975) showing the conductive low-T limb defined by granular-structured garnet lherzolites and the "kinked" limb defined by high-T sheared peridotites such as PHN1611 (photomicrographs). Base of upper photomicrograph is 0.5 mm.

lithospheric mantle that is variably depleted in basaltic components from a more fertile asthenosphere. In xenolith suites from cratonic areas, the bottom of the depleted lithosphere is marked by a rapid downward increase in elements such as Fe, Ca, Al, Ti, Zr and Y, and a rapid decrease in the median Mg# of olivine (Figs. 1,2), reflecting the infiltration of mafic melts and related fluids (*GEMOC Publication #650*). Eclogites and related mafic and carbonatitic crystallisation products are concentrated at the same depths as the maximum degrees of metasomatism (Fig. 3), and may represent the melts responsible for the refertilisation of the basal lithosphere. This refertilised zone, which lies at depths of ca 170-220 km beneath Archean and Proterozoic cratons, is unlikely to represent a true LAB (*GEMOC Publication #576*; http:// www.mantleplumes.org/LithosphereRemnants.html).

Re-Os isotopic studies of the deepest fertile peridotite xenoliths show that they retain evidence of ancient depletion events; seismic tomography data show high-velocity material extending to much greater depths beneath cratons. The cratonic "LAB" probably represents a level where asthenospheric melts have ponded and refertilised the lithosphere, rather than marking a transition to the convecting asthenosphere. Our only deeper samples are rare diamond inclusions and some xenoliths inverted from majoritic garnet, which are

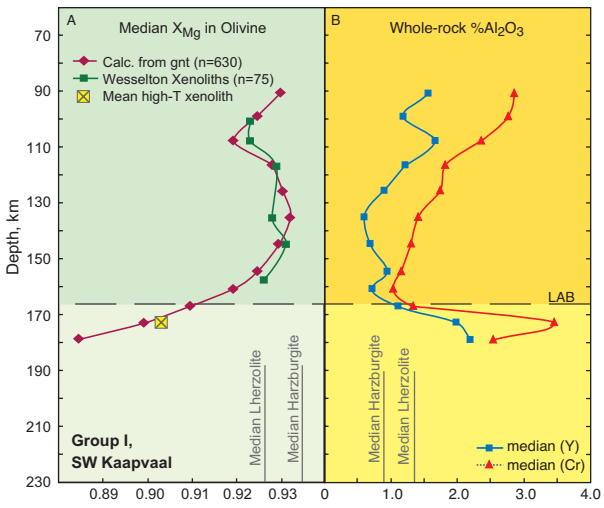


Figure 2. Geochemical parameters that can be derived from the compositions of xenocrystic peridotitic garnets. (A) X_{Mg} of coexisting olivine vs depth (GEMOC Publication #222) (B) Median whole-rock Al_2O_3 contents vs depth in the same kimberlites (GEMOC Publication #132).

unlikely to represent the bulk composition of the asthenosphere.

In younger continental regions the lithosphere-asthenosphere boundary is shallower (commonly at about 80–100 km) and more clearly marked. In regions of extension and lithosphere thinning (e.g. eastern China, eastern Australia, Mongolia), upwelling asthenosphere may cool to form the lowermost lithosphere, and may be represented by xenoliths of fertile garnet peridotites in alkali basalts worldwide. It has also been shown experimentally that the LAB beneath cratons is coincident with the depth where the mantle solidus is exceeded for some compositions, and this is the level where segregation of carbonate-rich fluids can occur (e.g. *Wyllie, JGR 85, 1988; Gudfinnsson and Presnall, JGR 101, 1996*). The presence of carbonate-rich fluids, in addition to mafic melts, at this level provides a possible explanation for the magnetotelluric signals that suggest the LAB may be detected by lower resistivity (*Jones et al., Lithos 120, 2010*). Gaillard et al. (*Science 322, 2008*) demonstrated that carbonate melts are much more highly conductive than silicate melts, and that small amounts of carbonate melt will wet grain boundaries, providing a physical-chemical basis for the magnetotelluric signals at these depths.

The increased conductivity commonly observed at about 90 km in young tectonic lithospheric regions and from about 180 to 220 km in cratonic regions also may coincide with the level at which fluids may segregate because there is a sharp drop in the water-storage capacity of mantle wall rocks, coupled with the onset of small degrees of partial melting in the presence of water (e.g. *Green et al., Nature 467, 2010*).

The LAB is a movable boundary. It may become shallower due to thermal and chemical erosion of the lithosphere, assisted by extension (Fig. 4). Refertilised lithospheric sections, especially where peridotites are intermixed with eclogite, may be subject to gravitational delamination. The lithosphere-asthenosphere boundary may also be deepened by subcretion of upwelling hot mantle (e.g. plumes). This process may be recorded in the strongly layered lithospheric mantle sections seen in the Slave Craton (Canada), northern Michigan (USA) and the Gawler Craton (Australia).

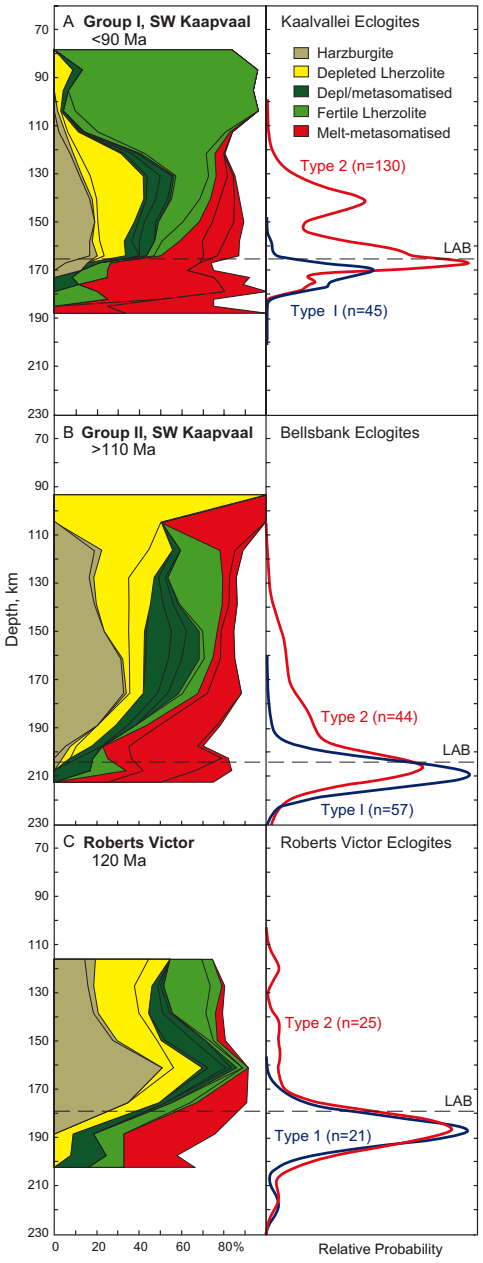


Figure 3. Distribution of eclogites in representative mantle sections. (Data from GEMOC Publication #461)

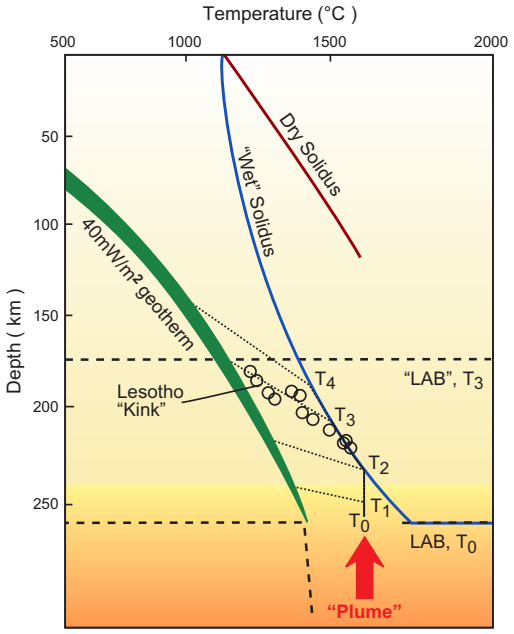


Figure 4. Development of a kinked geotherm by impingement of a thermal pulse on the base of the lithosphere; the accompanying refertilisation front moves up through the lithosphere to establish a new "LAB" and a (temporarily) kinked geotherm.

Contacts: Sue O'Reilly and Bill Griffin
Funded by: ARC Discovery Project and Linkage Grants, BHP-Billiton, MQ PhD Scholarships

Out of Africa: Garnets reveal insights into Earth's oldest mantle

MOST OF OUR KNOWLEDGE ABOUT THE COMPOSITION, STRUCTURE, THERMAL STATE and processes in the subcontinental lithospheric mantle (SCLM) has been obtained by analysing mantle-derived xenoliths and xenocrysts, brought to the Earth's surface in volcanic rocks such as kimberlites. Xenolith studies are often costly and time consuming, and it is often difficult to obtain enough samples for a statistically representative xenolith suite. A more accessible source of information is the xenocrysts derived from the disaggregation of mantle xenoliths. As xenocrysts are far more abundant than xenoliths, they are useful in characterising the SCLM sampled by kimberlites that lack mantle xenoliths.

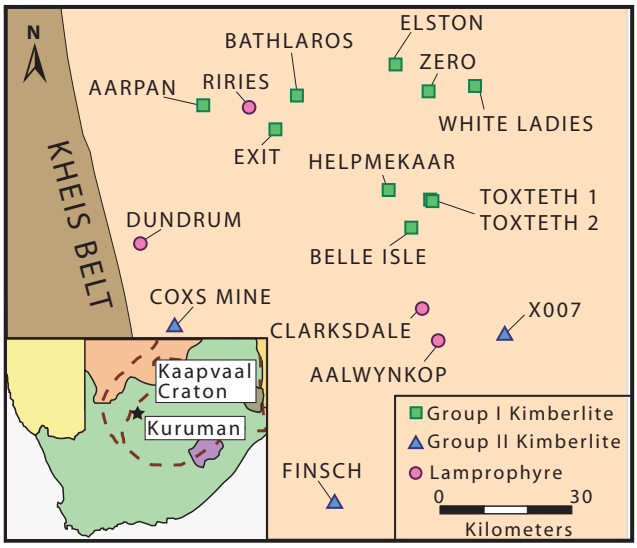


Figure 1. Location and classification of intrusions in the Kuruman Province of South Africa.

Pyrope garnet xenocrysts are particularly useful, because the Ni and Cr contents in some garnets can be used to estimate equilibrium temperature (T_{Ni}) and pressure (P_{Cr}) conditions and these P-T data can be used to construct a geotherm. With this framework, the Ni contents of other garnets can give a T, and projection of the T to the geotherm gives a depth estimate for the individual grains. The Y content of garnets can be used to estimate the depth of the lithosphere-asthenosphere boundary (LAB), as low-Y garnets (< 10 ppm) are restricted to the lithosphere. Furthermore, the trace-element (i.e. Zr, Y, Ga and Ti) contents in garnets can be used to identify different types of metasomatism that affected the SCLM where the garnets were derived. Garnets can be subdivided, based on inter-element correlations, into five groups: depleted harzburgites, depleted lherzolites, depleted/metasomatised lherzolites, fertile lherzolites and melt-metasomatised peridotites (*GEMOC Publication #299*). The proportion of garnets from these five categories can then be mapped as a function of depth, to construct "chemical tomography" sections that show geochemical variation with depth in the lithospheric section.

The Kuruman Kimberlite Province (Fig. 1) lies on the western margin of the Kaapvaal Craton and contains some of the oldest known kimberlites (~1.6 to 1.8 Ga; *Shee et al., 1989, Proc. 4th Int. Kimb. Conf. p 60-82; GEMOC Publication #662*). While most kimberlites intrude through SCLM that has undergone many episodes of metasomatism (*GEMOC Publication #449*; *Foley, 2008, Nature Geoscience, 1, 503-510*), the Kuruman Province may provide a unique opportunity to examine a relatively undisturbed section of the SCLM. This study utilised the major- and trace-element compositions of mantle-derived garnets from Kuruman intrusions, which represent two distinct geochronological and petrogenetic groups, namely Proterozoic kimberlites and Cretaceous orangeite. The data provided several key observations:

(1) The Proterozoic kimberlites sampled SCLM with low conductive geotherms (~40 mW/m^2; Fig. 2a,b), but these were thermally disturbed at shallow depths, consistent with the lack of diamonds in these kimberlites.

(2) The Proterozoic kimberlites sampled a lithospheric thickness of ~170 km, while the X007 Cretaceous orangeite sampled a thinner (~145 km) SCLM that had a lower conductive geotherm (~37.5 mW/m^2; Fig. 2c).

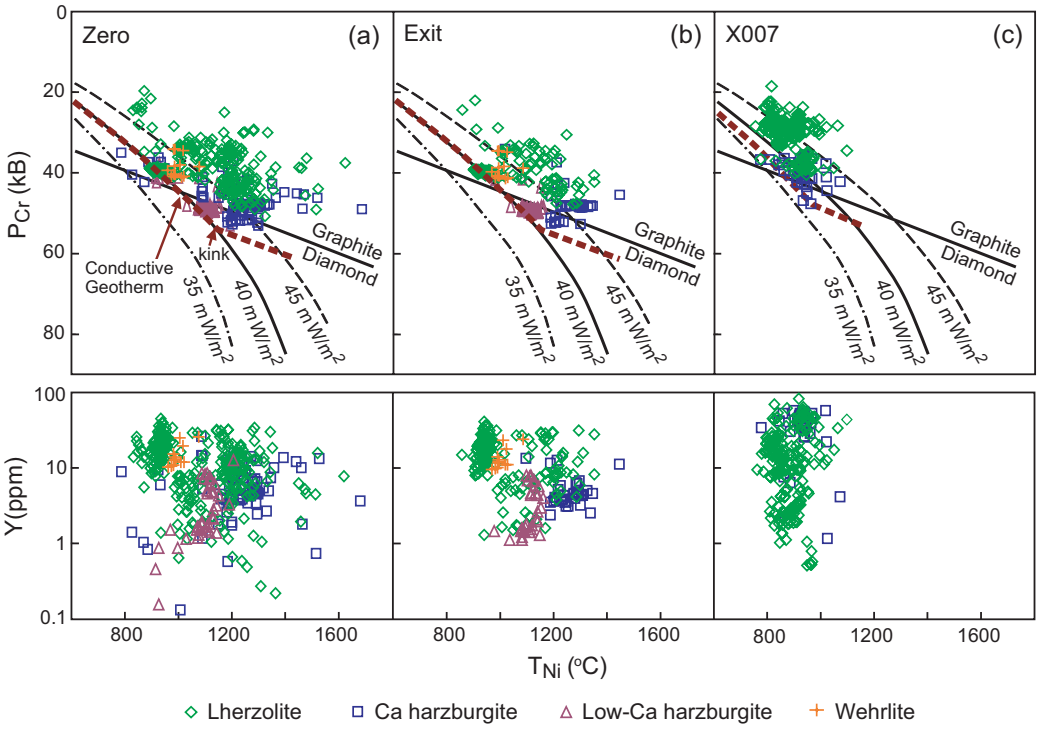


Figure 2. Conductive geotherms from the (a) Proterozoic Zero kimberlite, (b) Proterozoic Exit kimberlite, and (c) Cretaceous X007 orangeite. Note the higher 40mW/m² geotherm for the kimberlites relative to the younger orangeite intrusion.

(3) Chemical tomography (Fig. 3) reveals that the SCLM sampled by the Proterozoic kimberlites (i) was highly depleted; (ii) had experienced extensive phlogopite-related metasomatism; and (iii) had not experienced significant melt-related metasomatism, even at great depths.

(4) The SCLM sampled by the Cretaceous X007 orangeite contained much less harzburgite and had experienced more extensive metasomatic modification, producing more abundant lherzolites.

These observations are consistent with the concept of the secular chemical evolution of the SCLM, whereby older depleted lithosphere is progressively refertilised by asthenospheric-derived melts over time (*GEMOC Publication #303*). As such, the Proterozoic Kuruman kimberlites provide an excellent example of relatively unmodified ancient SCLM and represent an important, rarely observed, point of reference for the chemical evolution of the SCLM.

Contacts: Cara Donnelly, Bill Griffin
Funded by: ARC Discovery Project Grant and Linkage, iMURS, PGRF

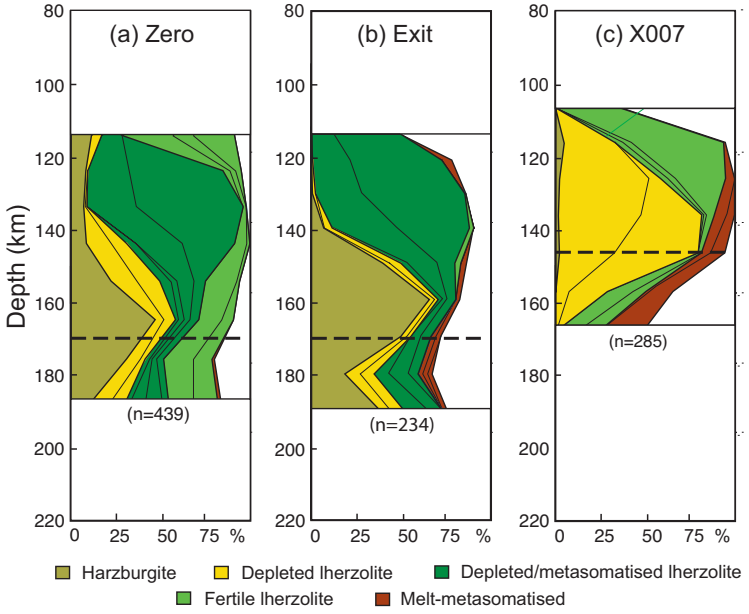


Figure 3. SCLM chemical tomography for the (a) Proterozoic Zero kimberlite, (b) Proterozoic Exit kimberlite, and (c) Cretaceous X007 orangeite. Note the more fertile compositions and shallower LAB (derived from Y contents in garnet) of the younger X007 orangeite, relative to the kimberlites.

What's new? - *TerraneChron*® pinpoints when and where continental crust really grew

THE CONTINENTAL CRUST IS AN "END PRODUCT" OF THE CHEMICAL DIFFERENTIATION of the Earth's primitive mantle through time; the question of crustal growth rate thus bears directly on the nature and timing of this differentiation process. It is not enough to just measure the relative volumes of crust with known ages, because some of the crust may be juvenile (i.e. derived from the convecting mantle), while other parts may be derived by recycling older crust. To understand the growth of the crust through time, we need to determine the sources of the magmatic rocks that went into making the crust: do these represent juvenile additions, or recycling, or perhaps the mixing of juvenile and recycled material? The U-Pb and Lu-Hf isotope systems in zircon give us a powerful tool for answering questions like this. *In situ* microanalysis of the U-Pb system can give us the age of a single zircon grain, while the isotopic composition of its Hf tells us whether its parent magma was generated in the mantle, or by remelting of older crust.

GEMOC's *TerraneChron*® program (integrated U-Pb, Hf-isotope and trace-element analysis of zircon) has built up a worldwide database of about 14,000 analyses of zircon, derived largely from detrital sources. This has been used to examine processes of crustal evolution on a global scale, and to test existing models for the growth of continental crust through time (Fig. 1; *GEMOC Publication #671*). In this study we introduced a new approach to quantitatively estimating the proportion of juvenile material added to the crust at any given time during its evolution. However, no zircon database, even our very large one, can be completely representative of the upper crust, because the samples have not been taken randomly. To overcome this sampling bias, we have normalised our data to the relative areas of Archean, Proterozoic and Phanerozoic crust that have been mapped in GEMOC's GLAM project

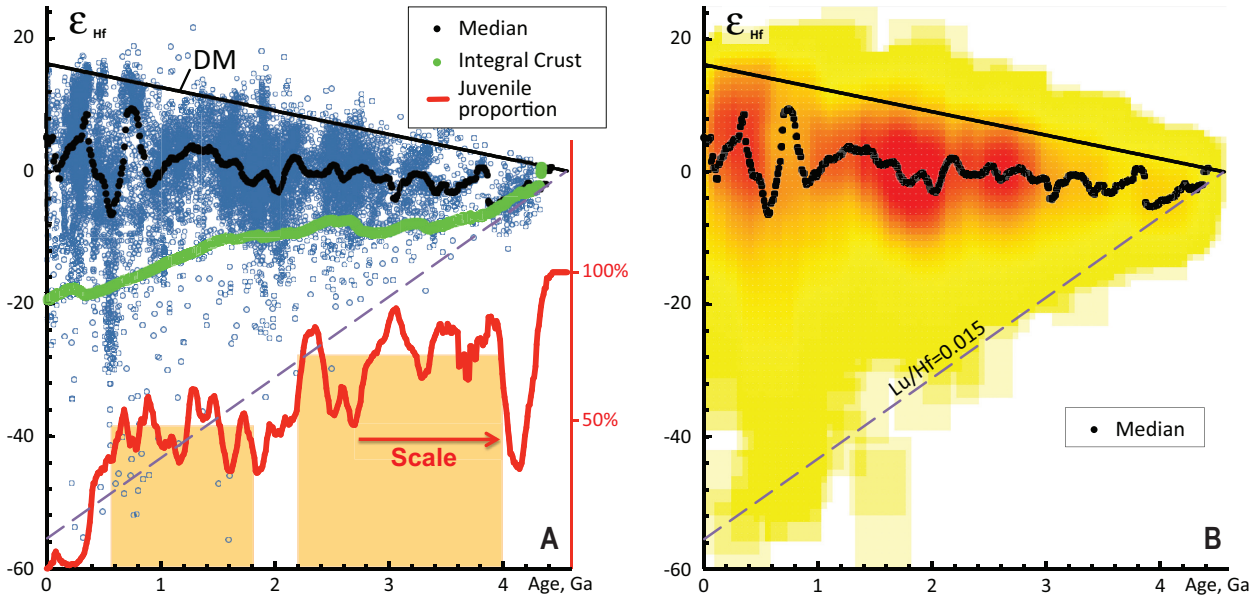


Figure 1. ε_{Hf} versus zircon U-Pb age for all zircons in the database (N=13,844): (A) the green line is the calculated integral ε_{Hf} of the crust and the red line is the calculated juvenile proportion (right-hand scale); (B) data are illustrated by a two-dimensional histogram with each element/cell representing 50Ma × 1 ε_{Hf} unit and the window of smoothing is 250 Ma × 5 ε_{Hf}, where the full dataset is taken as 100%. More intense colours (into red) indicate higher density of the data. Dashed line shows the evolution of "average crust" from 4.56 Ga.

(see *GEMOC Publication #547*). This estimate has then been used to model the crustal growth rate over the 4.56 Ga of Earth's history. The model suggests that there was little episodicity in the production of new crust, even though plots of the magmatic ages of rocks show marked peaks at some time intervals (Fig. 2).

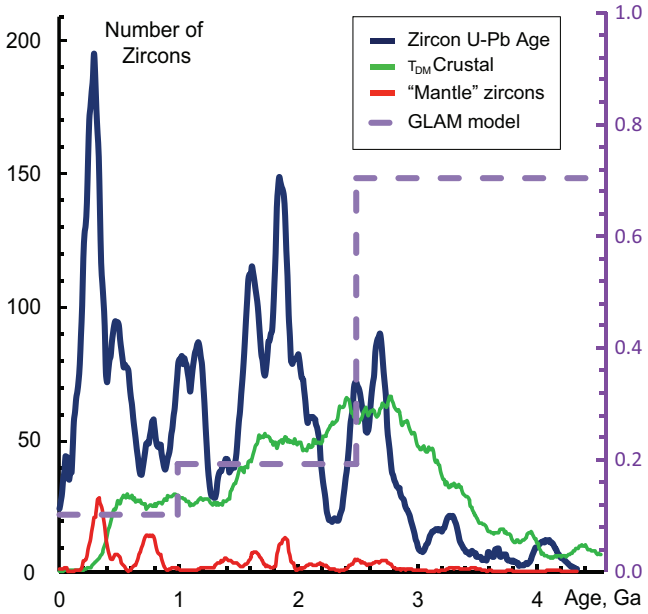


Figure 2. Relative probability curves (left scale) of U–Pb zircon ages (blue line), T_{DM} C model ages (green line) and number of zircons with juvenile Hf-isotope compositions (red line; defined as grains with εHf=0.75×εHf DM). Proportions of the continental lithosphere formed during three major time intervals derived from GLAM mapping are shown by the dashed line (right axis).

The distribution of age-Hf isotope data from zircons worldwide implies that at least 60% of the existing continental crust separated from the mantle before 2.5 Ga (Fig. 3). However, taking into consideration new evidence coming from geophysical data, the formation of most continental crust early in Earth's history (at least 70% before 2.5 Ga) is even more probable. Thus, crustal reworking has dominated over net juvenile additions to the continental crust, at least since the end of the Archean. This explains the increasing number of zircons with non-radiogenic Hf-isotope compositions (with ε_{Hf} lower than -20) found throughout post-Archean time. Moreover, the proportion of juvenile material in newly formed crust decreases stepwise through time: it is about 70% in the 4.0 – 2.2 Ga time interval, about 50% from 1.8 – 0.6 Ga, and possibly less than 50% since 0.6 Ga (Fig. 1A). These changes maybe related to the formation and breakup of supercontinents. This study thus represents a major advance in our understanding of the genesis of the continental crust through time.

Contacts: Elena Belousova, Bill Griffin

Funded by: ARC Linkage Project Grant and industry projects

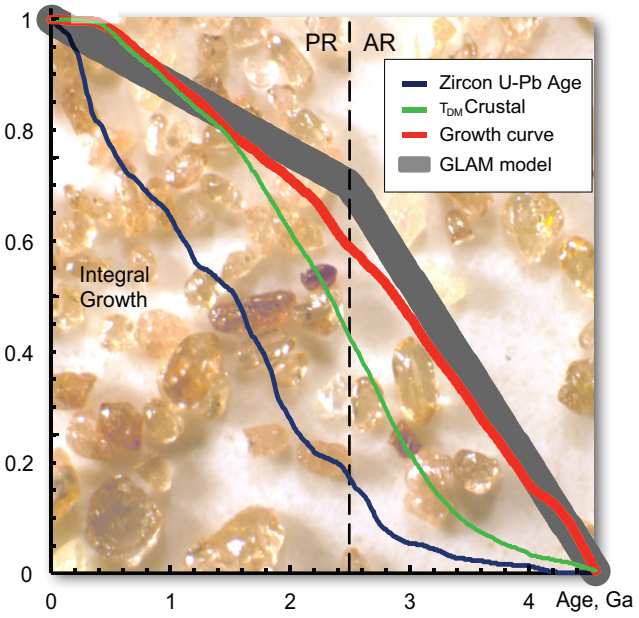


Figure 3. The integrated crustal growth curve (red line) derived in this study, compared with the GLAM (Global Lithospheric Architecture Mapping) model shown as a grey band. Integrated curves for the zircon U-Pb age data and crustal model age are shown for comparison.

The Earth's first continental crust

THE EARTH'S OLDEST CONTINENTAL CRUST IS COMPOSED PRIMARILY OF FELSIC ROCKS of the tonalite-trondhjemite-granodiorite series (commonly known as TTGs). These granitoids typically occur as plutons that are encompassed by belts of metamorphosed mafic volcanics (known as greenstones). In spite of their close association, the exact relationship between the TTG granitoids and surrounding greenstones is problematic. This is partially because original stratigraphic contacts are rarely preserved in such old rocks. Another problem is that, although it is generally believed that TTG magmas were produced by the partial melting of an older basaltic crust, the tectonic environment in which this occurred is unknown and appears not to have any modern analogues. We have approached these difficulties by obtaining specifically relevant experimental and geochemical data for greenstones from one of the oldest known greenstone belts (the Nuvvuagittuq belt of northern Quebec, dated at 4.28 billion years). Our objective is to test for a direct genetic link between the greenstones and a closely associated but younger (3.66 billion years) tonalite (PC-103) of the TTG series.

A significant characteristic of the Nuvvuagittuq greenstones is their resemblance to much younger volcanic rocks called boninites, which are now exclusively associated with subduction zones (and hence with plate tectonics). Two samples of Nuvvuagittuq greenstone were used as starting materials for the experiments. These included PC-227 and PC-162 which are among the most mafic and least altered of the Nuvvuagittuq greenstones. For comparison, experiments were also conducted on a modern boninite from northern Tonga. The experiments were undertaken at GEMOC using powdered samples of natural rock. They were conducted in end-loaded piston-cylinder apparatus using conventional techniques. Analyses of the run products and starting materials were done by electron microprobe and ICP-MS at the GEMOC Geochemical Analysis Unit.

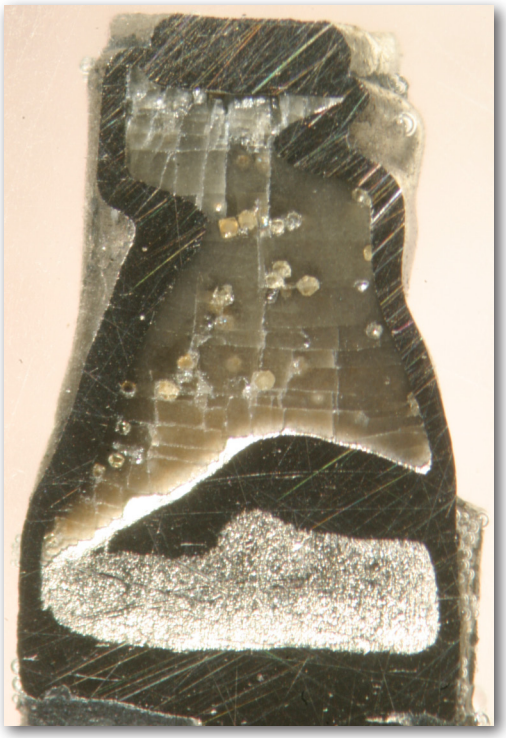


Figure 1. A longitudinal section through an experimental capsule showing the outer metal capsule (made of silver-palladium alloy) and rounded crystals of yellow garnet in a tonalitic glass.

At temperatures of 950 °C to 1050 °C and pressures of 1.5 GPa to 2.0 GPa, the greenstones and boninite undergo between 30 % and 45 % partial melting and produce residual garnet ± clinopyroxene ± orthopyroxene (Fig. 1). The partial melts have tonalitic compositions and are similar in many respects to the natural tonalite PC-103. They have similar concentrations of most major elements and also produce similarly shaped patterns on mantle-normalised plots of incompatible element concentrations (Figs. 2 and 3). The latter may reflect a familial connection between the original greenstones and associated tonalite. This is because the comparatively high degrees of partial-melting needed to form the tonalitic melts have relatively little effect on the relative concentrations of most incompatible elements. It is only the influence of residual garnet that is needed to produce the distinctively inclined heavy Rare Earth patterns that characterise both the experimental and natural tonalite compositions.

Although the overall concentrations of incompatible elements in the experimentally-produced melts are lower than those of the natural tonalite, this is due to our use of the most mafic and incompatible-element-poor greenstones as starting materials. On average, the Nuvvuagittuq greenstones are considerably more enriched in incompatible species than our starting materials, although the relative concentrations of most elements are similar. If this factor is taken into account (compare Figs. 2 and 3), it seems likely that the TTG PC-103 inherited many of its primary geochemical characteristics from an earlier fractionation event that also produced the basaltic Nuvvuagittuq lavas (now represented by the greenstones).

Although modern magmas compositionally similar to the Nuvvuagittuq greenstones are associated only with subduction zones, our experiments do not provide additional support for the existence of plate tectonics on Earth during the Hadean. Instead, they are consistent with continental crust formation that involved some kind of crustal re-cycling process during the Hadean. Regardless of whether this process was plate tectonics (or something else) it must have replicated many of the magmatic consequences of modern plate tectonics, including arc-like basaltic magmas. It must also have occurred on a sufficiently large scale that it was able to exert a major compositional influence on the first continental crust.

Contacts: John Adam, Tracy Rushmer
Funded by: ARC Discovery Project Grant

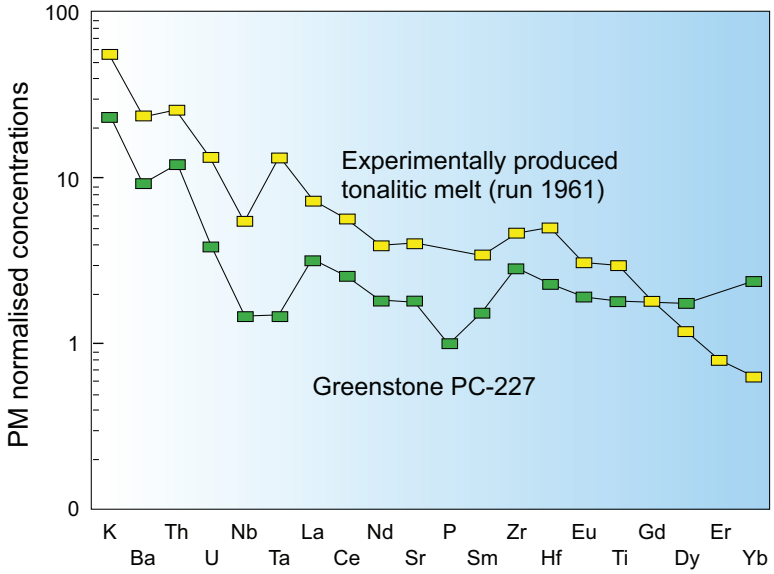


Figure 2. Mantle-normalised concentrations of incompatible elements in the greenstone PC-227 and an experimentally produced tonalitic melt that resulted from partial melting of PC-227.

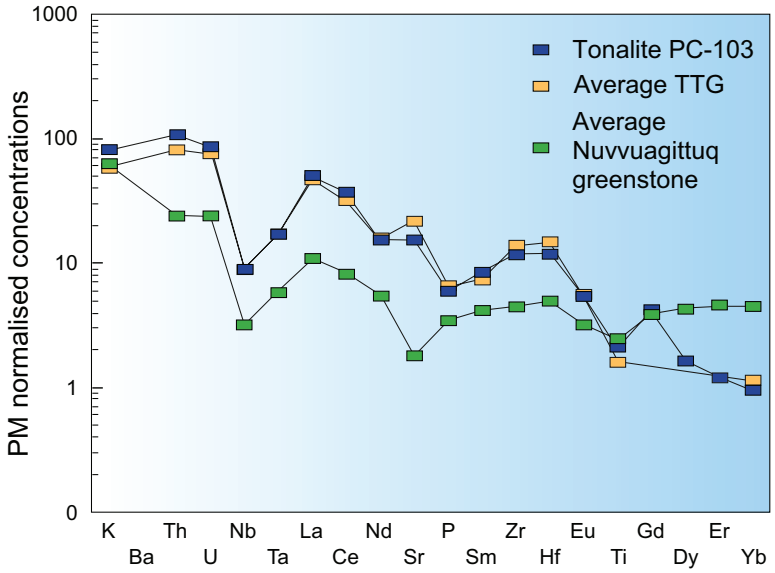


Figure 3. Mantle-normalised incompatible element concentrations in the tonalite PC-103, an estimated average TTG, and in an average Nuvvuagittuq greenstone.

On the edge: Continent roots and giant Nickel deposits

THE LOCATION OF MAGMATIC NI-CU-PGE SULFIDE DEPOSITS is closely related to lithospheric architecture, particularly the deep roots of sub-continental lithospheric mantle (SCLM). Giant deposits are found close to the margins of cratons, the large (100s to 1000s of km across) stable blocks

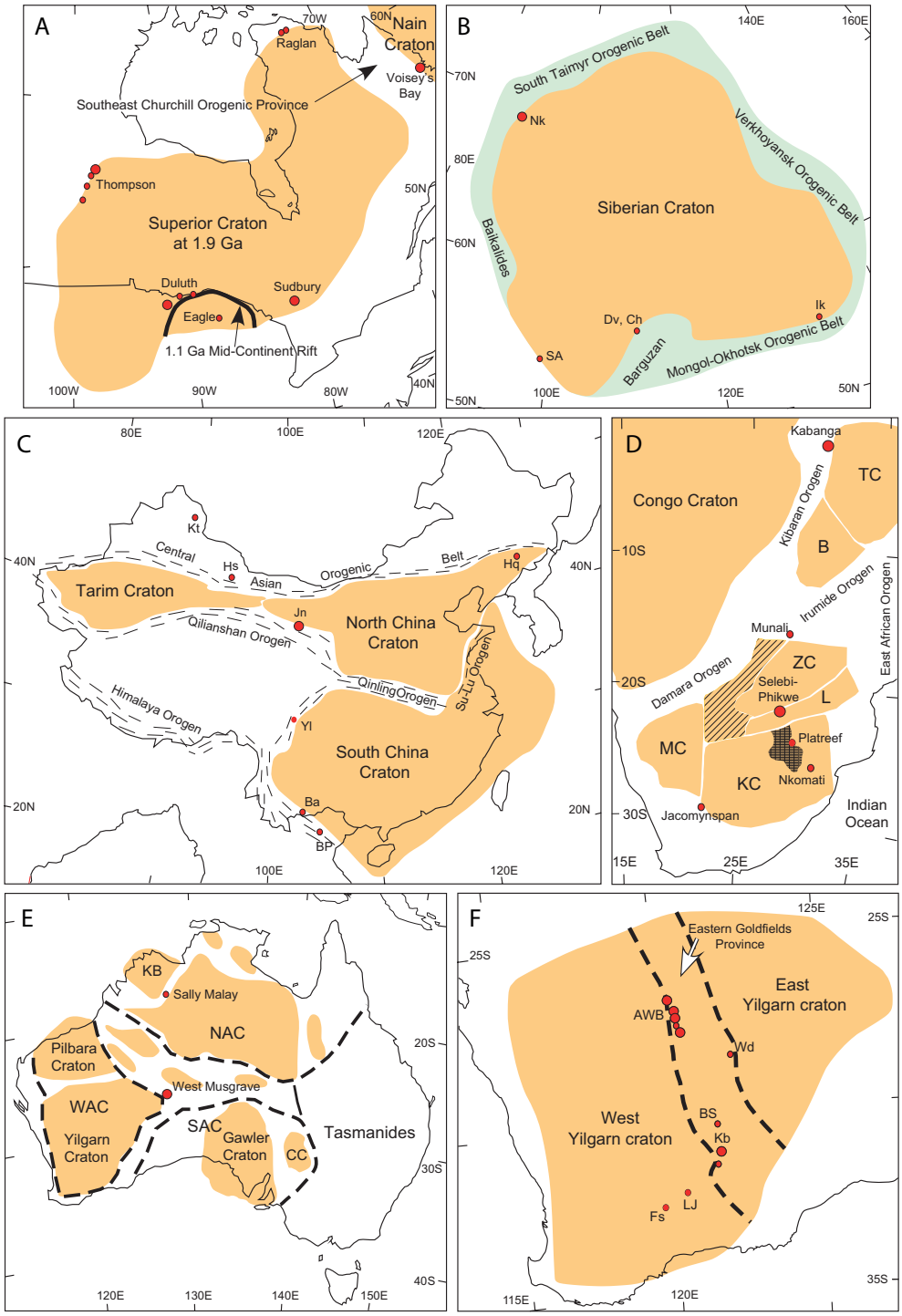


Figure 1. Examples of cratonic/lithospheric architecture (orange polygons and dashed polygons) and the location of nickel sulfide deposits (red dots; size reflects relative deposit size for each region). See GEMOC Publication #664. A) Proterozoic deposits of North America at ca 1.9 Ga. B) Siberian craton. Lighter grey is area of Middle to Late Proterozoic and/or Phanerozoic orogenic reworking and possible terrane accretion. C) Cratons of China; flanking Phanerozoic orogens are patterned. D) Cratonic architecture of southern Africa. E) Proterozoic deposits of Australia. F) Neoarchean deposits of the Yilgarn craton, Australia .

produced by the amalgamation of smaller chunks of thick lithosphere (mantle root plus overlying crust) during Precambrian tectonic collisions (Fig. 1). These deposits are associated with mafic-ultramafic rocks, especially the massive outpourings of magma known as Large Igneous Provinces. The metal quantities and grades observed in such deposits require segregation of a magmatic sulfide melt from a very large volume of parental ultramafic melt. This requires a high degree of melting at depths of 100 km or less; this and the large melt volumes involved are consistent with a mantle-plume origin. Some small- to medium-sized deposits may be associated with melting of upwelling asthenosphere following delamination of the lithospheric mantle. Segregation of the sulfide liquid from the melt may be triggered by interaction with crustal rocks. This liquid eventually forms disseminated or massive sulfide accumulations in the host mafic or ultramafic rocks.

All deposits formed during periods of active regional tectonism, most commonly under mildly compressional to transpressional conditions. The timing and tectonic setting of the deposits are consistent with a plume impact (craton margin) model involving 5 stages (Fig. 2):

1. Mantle plume impact and upward flow towards areas of thinner lithosphere
2. Plume decompression melting at shallower levels
3. Melt transfer into the (upper) crustal environment via active trans-lithospheric faults and an interconnected intrusion (sills) network
4. Variable interaction of melts with crust
5. Nickel sulfide precipitation and accumulation

Most large deposits formed in intracontinental settings, or with (former) passive margins at the edge of small marginal basins. The rarity of large deposits associated with the margins of large oceans or with subduction-zone environments reflects either poor preservation or (with the latter) limitations on plume interaction with continental lithosphere. The model provides a coherent predictive framework for mineral exploration.

Contacts: Graham Begg, Jon Hronsky, Bill Griffin and Sue O'Reilly
Funded by: BHP Billiton (and previously by WMC Resources), and Discovery, SPIRT, and Linkage grants from the Australian Research Council

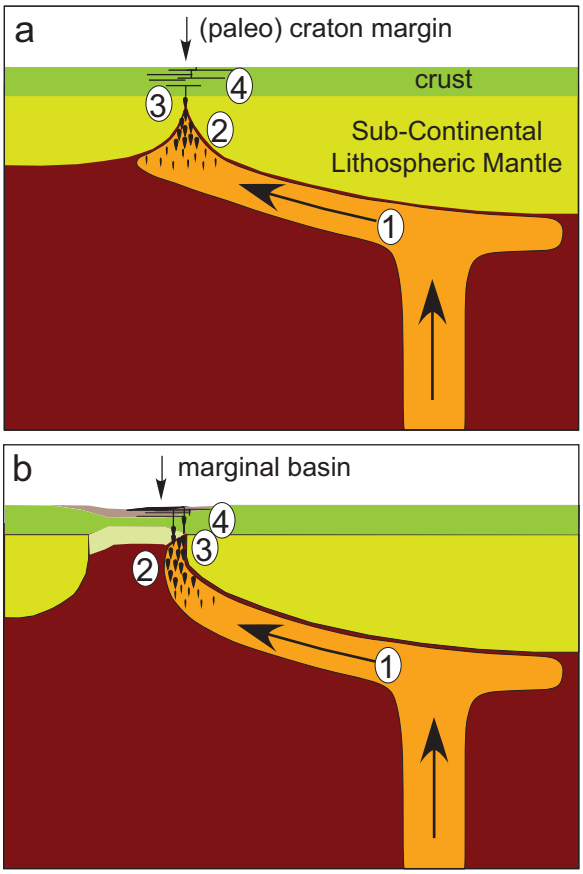


Figure 2. Generalised model showing formation of nickel sulfide deposits at tectonically active margins of thick (>150 km) lithospheric blocks (mostly cratons; after GEMOC Publication #664). In scenario a) the blocks are contiguous, whilst b) depicts a small, intervening marginal basin. The former encourages evolution of the melt via ponding and wallrock interaction at all crustal levels, with resultant deposits found mostly within mafic host rocks. The latter (b) favors shallower melting of the plume, direct melt access to the upper crust, and therefore typically ultramafic host rocks.

Noble method updates the Ni exploration toolkit

KOMATIITES CONTAIN SOME OF THE WORLD'S LARGEST NICKEL-SULFIDE DEPOSITS and the development of reliable lithogeochemical indicators to guide exploration has been a long-standing goal. A common lithogeochemical approach is to identify whole-rock signatures that record sulfide segregation, and use these to predict if a system has reached sulfide saturation and therefore is worth exploring for nickel sulfide deposits. For this purpose the platinum-group elements (PGE: Os, Ir, Ru, Rh, Pt, Pd) are of great interest. The PGE are chalcophile and partition very strongly into segregating sulfides, which produces a PGE depletion in the remaining silicate melt. However, PGE abundances in ultramafic melts and/or rocks reflect a complex range of factors including magmatic processes and emplacement dynamics, alteration, metamorphism, and weathering. As a consequence, whole-rock signatures depleted in PGE may not reflect the segregation of sulfides. Moreover, the changes in whole-rock PGE geochemistry are mostly too subtle and too ambiguous to be used in exploration, because their low concentrations (a few parts per billion) are a challenge to the analyst.

Rather than working with whole-rock signatures, GEMOC is using its state-of-the-art micro-analytical facilities to probe minerals that record the geochemical evolution of ultramafic systems. *In situ* mineral analysis by laser ablation ICP-MS enables measurement of PGE concentrations down to the low ppb level in spots a few microns across. The research focuses on the role of chromite in the fractionation and concentration of ruthenium (Ru) because chromite can host Ru in solid solution (see *Research Highlights 2009*). The Ru content of chromite should therefore reflect if the chromite crystallised in a sulfide-undersaturated (barren) or sulfide-saturated (potentially mineralised) system.

To test this idea, we have analysed chromite in a wide range of komatiites from the Eastern Goldfield's Superterrane (EGST) in the Yilgarn Craton of Western Australia. The EGST contains some of the world's largest komatiite-hosted nickel deposits. Numerous previous studies and an intense mineral exploration history make this an excellent natural laboratory for the investigation of komatiite geochemistry. Laser ablation ICP-MS data show that chromites from barren komatiites (Agnew, Kurrajong, Murphy Well and Sullivans) have Ru concentrations between 120 and 420 ppb (Fig. 1). In contrast, the Ru contents of chromites from the world-class nickel deposits at Mount Keith (Fig. 2), Kambalda, Black Swan, and Betheno are below the detection limit of the laser ablation ICP-MS (down to

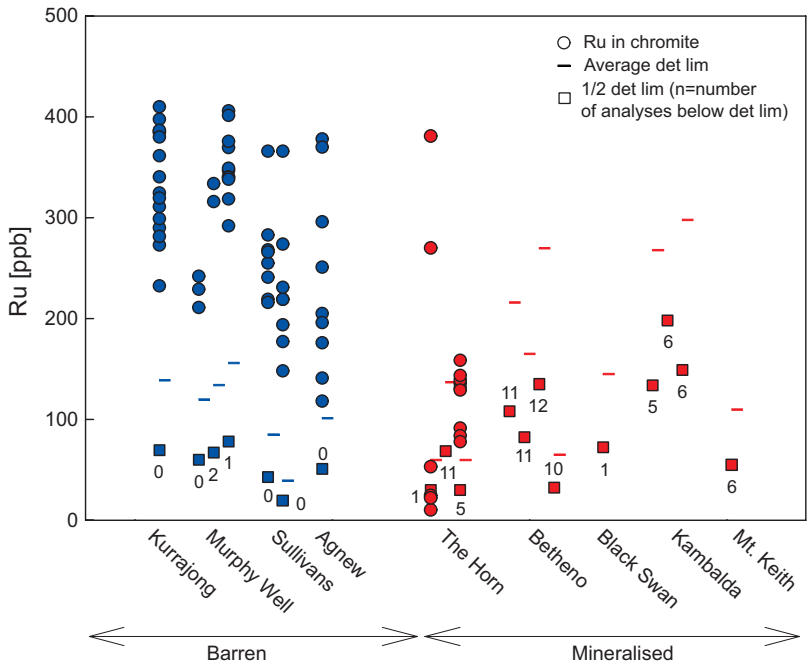


Figure 1. Ruthenium variation in chromite as observed in barren (blue symbols) and mineralised (red symbols) komatiites from Western Australia.

5 ppb, depending on grain size and measurement conditions). The one exception found so far is a nickel deposit at The Horn, where the chromites have Ru concentrations mostly between 10 and 150 ppb; this is still distinctly lower than the mean concentrations observed in chromites from the barren komatiites.

The results suggest that the partitioning of ruthenium into chromite is dominantly controlled by the sulfide content of the system. In sulfide-saturated systems, the chalcophile Ru will dominantly partition into sulfides, whereas in the absence of sulfides, Ru partitions into chromite. Therefore, Ru concentrations in chromite can be used in the exploration for nickel-sulfide deposits, based on the empirical evidence that Ru-enriched chromites are associated with barren systems. This method can be applied directly to polished sections and/or grain mounts and therefore provides a rapid and cost-effective tool in the hunt for nickel-sulfide deposits.

Contacts: Marek Locmelis, Norman Pearson
Funded by: ARC Discovery Project Grant (O'Reilly, Griffin and Pearson), MQRES, EPS Postgraduate Fund

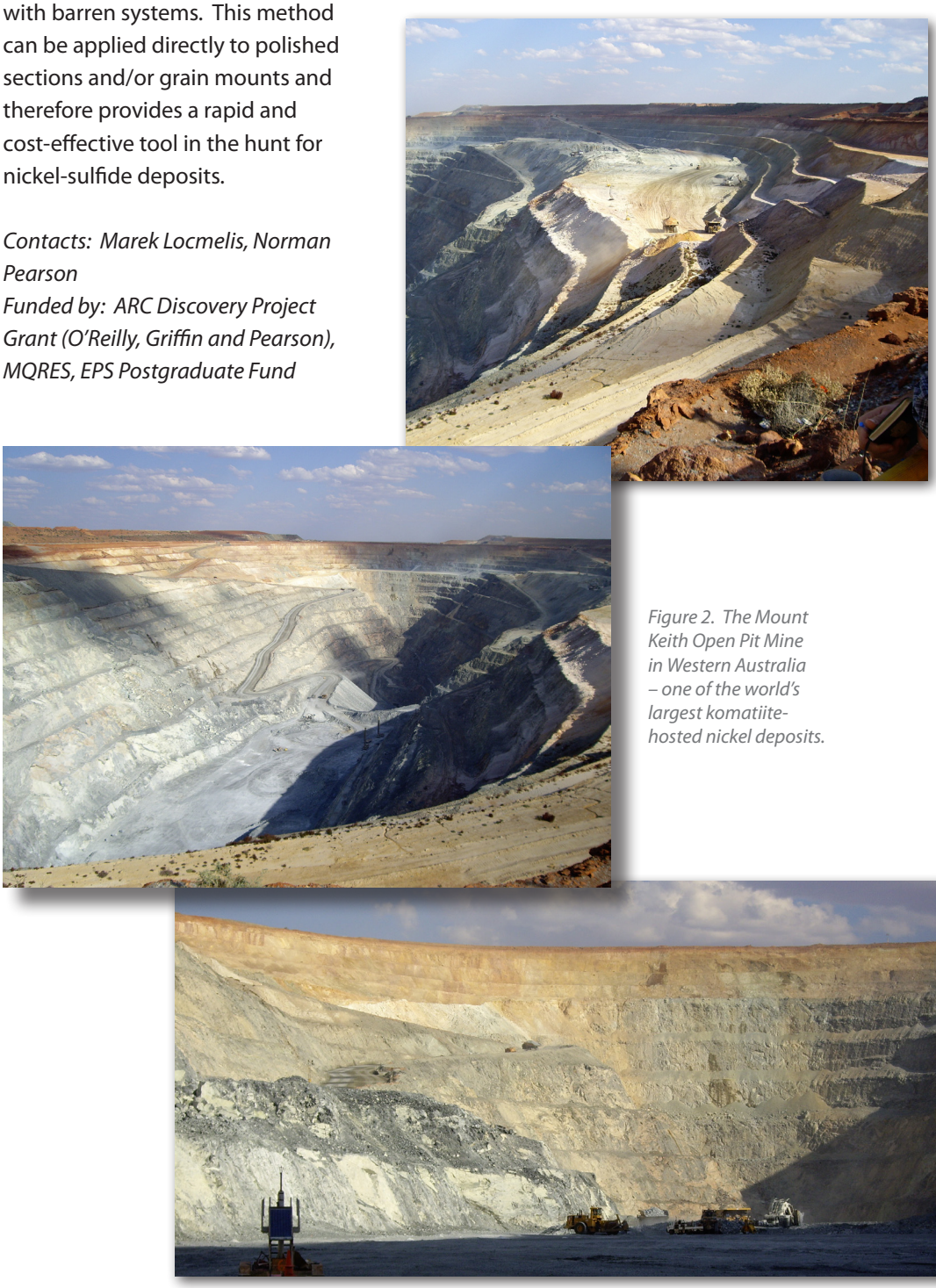


Figure 2. The Mount Keith Open Pit Mine in Western Australia – one of the world's largest komatiite-hosted nickel deposits.

Zircons from the roof of the world unearth Himalayan evolution



THE TIBETAN PLATEAU, one of the most remarkable places to visit in Asia for travellers, is known as the roof of the world. The formation of such a high broad uplift naturally attracts geologists' curiosity. Following decades of investigations, we know that it formed during the collision between the Indian and Eurasian plates. However, some details remain controversial, for instance: when did these two plates collide, (from Late Cretaceous to Oligocene), and what mechanisms support the immense relief? Now, *in situ* analysis of Hafnium isotopes in zircon, commonly a trace mineral, combined with the isotopic analysis of Hafnium and Neodymium in its host rocks in the southern part of the Lhasa terrane, offer us new answers to these questions.

In this study, we analysed rocks from the south Transhimalayan batholiths, including Gangdese granitoids and Oligo-Miocene adakites. Our integrated Hf and U-Pb isotope analyses of zircon crystals, together with Hf and Nd isotopes of their host rocks, show a secular change in the magma sources that can be related specifically to the encroachment of the Indian plate into the southern part of the Tibetan orogen during the continental collision.

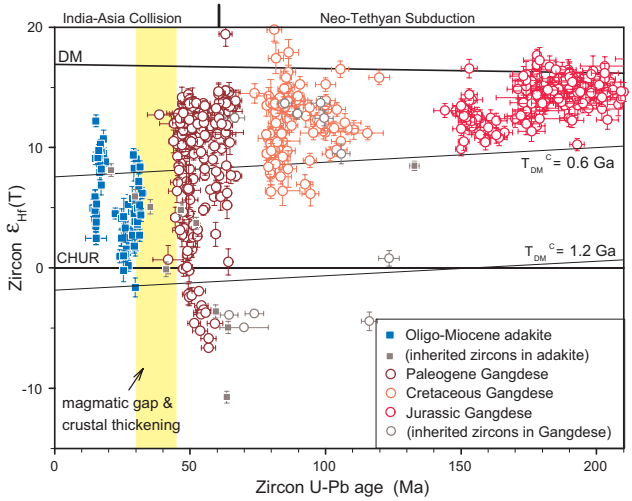


Figure 1. In situ Hf and U-Pb isotopic data for zircons from Gangdese granitoids and Oligo-Miocene adakites in the southern part of the Lhasa terrane.

The magmatic zircons, crystallised between ca 200 Ma and 50 Ma, mainly show depleted mantle-type Hf-isotope characteristics but this changes markedly in the Paleogene (Fig. 1). The Hf-isotope shift is interpreted as reflecting the subduction of the Himalayan sediments, driven by the approach of the Indian plate, and thus signals the initiation of the India-Asia collision by 55 Ma.

Our data also indicate that the crust of southern Tibet thickened significantly between ca 45 - 30 Ma, before emplacement of the post-collisional adakites (Mg-rich silicic igneous rocks). These adakites exhibit Hf-Nd isotopic systematics different from the previous Gangdese magmatism, suggesting mixing of melts from (a) the juvenile Gangdese mafic crust and (b) incorporated Himalayan sediments, with zircon residues fractionating Nd and Hf abundances during crystallisation (Fig. 2). See *GEMOC Publication #730.*

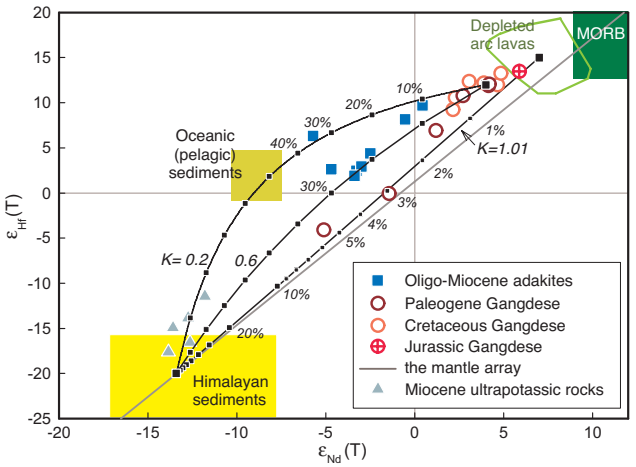


Figure 2. Whole-rock ε_{Hf}(T) vs ε_{Nd}(T) plots of the Transhimalayan rocks, showing how the adakites fall along mixing curves between the older Gangdese magmas and Himalayan sediments.

Contacts: Mei-Fei Chu, Norman Pearson, Sue O'Reilly
Funded by: ARC Discovery Project Grant

The Big Bang - New insights into the 1912 eruption of Katmai volcano

In June 1912, the biggest and one of the most compositionally diverse eruptions of the last century took place in the Katmai group of volcanoes on the Alaska Peninsula. In the space of 60 hours, 13 km^3 of rhyolite, dacite and andesite magma were explosively ejected, producing an ash cloud covering 77,000 km^2 that extended as far east as Greece and filled the Valley of Ten Thousand Smokes. The eruption started with a crystal-poor rhyolite followed by a gradual increase in the proportions of dacitic and andesitic material. The eruption took place from a vent at the site of the present-day Novarupta dome, but the magma came from beneath the summit of Mount Katmai 10 km to the east. As the magma moved out, the summit started to collapse some 11 hours after the onset of the eruption, finally forming a 5.5 km^3 caldera. New geochemical data are now giving a very detailed picture of the lead-up to this massive volcanic eruption.



View along the Valley of Ten Thousand Smokes towards Mount Katmai.

The entire major- and trace-element range in the successive magmas can be modeled by 80-90% closed-system crystal fractionation over a temperature interval from 1279 to 719 °C at 100 MPa, starting with about 65 km^3 of parental basaltic magma. Numerical thermal models suggest that, for wall rock temperatures appropriate to this depth, this volume of magma would cool and crystallise by 90% over this temperature interval within a few tens of thousands of years. However, a significant range in $^{87}Sr/^{86}Sr$, ($^{230}Th/^{238}U$) and ($^{226}Ra/^{230}Th$) in the magmas requires open-system processes. The U-series isotopes indicate that crustal residence times for some dacites were close to 8000 years, whereas the rhyolites appear to be significantly older (50-200 kyr). Thus, magmas that erupted within only 60 hours of one another in 1912 had resided in their crustal magma chambers for quite different time spans. Nevertheless, because they were emplaced in the same thermal regime, they all evolved along similar liquid lines of descent from parental magmas with similar overall compositions. The system was built up progressively with multiple injections of mafic magmas, which provided both mass and heat; some of the heat led to melting of older silicic material that provided much of the magma mass for the rhyolite. Although this scenario is increasingly recognised as a common one, it cannot be deduced from field observations or major- and trace-element compositional variations. Only the data from short-lived radioactive isotopes are sensitive to processes such as protracted magma build-up, differentiation, assimilation and eruption.

Aerial view of Mount Katmai showing the caldera that formed during the 1912 eruption (Captain Budd Christman, NOAA Corps).



Contact: Simon Turner
Funded by: National Environment Research Council, UK

Journey from the centre of the Earth: xenoliths reveal the velocity of magmas

THE RATES AT WHICH MAGMAS RISE THROUGH THE CRUST AND UPPER MANTLE cannot be measured directly, but can be estimated by several indirect means, based on observations from mantle-derived xenoliths in alkali basalts, kimberlites and related rocks (*GEMOC Publication #666*). These magmas are generated in the convecting mantle at depths from about 90 to 200 km, commonly are not fractionated during their ascent and may incorporate fragments of the lithospheric mantle as they travel through it.



Figure 1. Angular xenoliths of spinel peridotite in alkali basalt from Batchelor Crater, Queensland, Australia.

At upper mantle temperatures and pressures (depths of 50-250 km and temperatures of 1000-1300 °C), mantle rocks have been shown to deform plastically, at least in response to long-term stresses. However, the entrainment of xenoliths in an ascending magma requires that fragments of rock be broken off the walls of magma chambers or conduits, a process that implies brittle fracture in response to short-term stresses. This brittle response is evidenced by the typically angular to subangular shapes (Figs. 1,2), resulting in polygonal and facetted xenoliths (Fig. 3), and the common linear contact surfaces of veins in xenoliths (Fig. 4). Significant rounding is restricted to xenoliths from breccias or those associated with the more explosive eruptions such as maars, diatremes, and some cinder cones. Xenoliths in kimberlites are typically more rounded than those in basalts, but many display planar faces (Fig. 3). This rounding appears to reflect tumbling of xenoliths during turbulent ascent and eruption. However, we infer that at the time of their entrainment, most xenoliths are angular, and originated by brittle fracture.

The mineral assemblages and mineral chemistry of many xenoliths can be compared with experimental studies to derive the depth and temperature at which they were picked up by the ascending magma. These xenoliths therefore can provide constraints on the shallowest depths of magma generation and segregation, and on how rapidly magmas get to the surface.



Figure 2. A composite xenolith showing spinel peridotite veined by basaltic magma that crystallised in the mantle, within a volcanic bomb from Mt Shadwell, Victoria, Australia. Note the originally straight sides (emphasised by white dashed lines) and the rounded edges of the xenolith due to abrasion in the magma. The spinel peridotite areas appear rounded due to reaction with the invading basaltic magma.

The rates of ascent of magmas are equivalent to the residence times of xenoliths in the magma after their entrainment. These rates can be estimated by a variety of methods using the physical and compositional parameters of the xenoliths. Mantle-derived peridotite, eclogite and pyroxenite xenoliths are relatively dense, and the magma must be ascending more rapidly than the xenoliths can sink through it. These calculations suggest an average ascent rate through the whole lithosphere (mantle and crust) in the range of 0.2 to 0.5 metres per second (about 0.5 to 2 km/hour). The ascent rates through

the shallow crust may be much higher; >20 metres per second and up to supersonic speeds (≥300 metres per second) in the uppermost crust.

Residence times of xenoliths in the magma also can be estimated using calculations based on temperature-related diffusion phenomena (chemical zoning, grain-boundary adjustment) observed in xenoliths; all of these approaches suggest ascent rates in the range of 0.2 to 0.4 metres per second.



Figure 3. Xenolith from kimberlite showing polygonal shape with planar surfaces.

It has been suggested that high contents of CO_2 in magmas provide a significant "propellant effect" to assist xenolith transport. This is not correct, because the density and viscosity of the mixed magma-fluid system are lower than those of unmixed magmas. However, the exsolution of CO_2 both provides heat that helps to prevent the magma from cooling during ascent, and enhances crack propagation. Magmas representing significant proportions of partial melting, such as tholeiitic basalts, rarely carry mantle-derived xenoliths; this probably reflects ascent rates that are too slow to hold (or possibly incorporate) high-density xenoliths entrained in the magma.

In summary, magmas carrying mantle xenoliths must reach the surface within a maximum of about 8 to 60 hours after picking up these dense fragments from depths of about 200 to 80 km depth. See *GEMOC Publication #666.*

Contacts: Sue O'Reilly, Bill Griffin
Funded by: ARC Discovery Project Grants

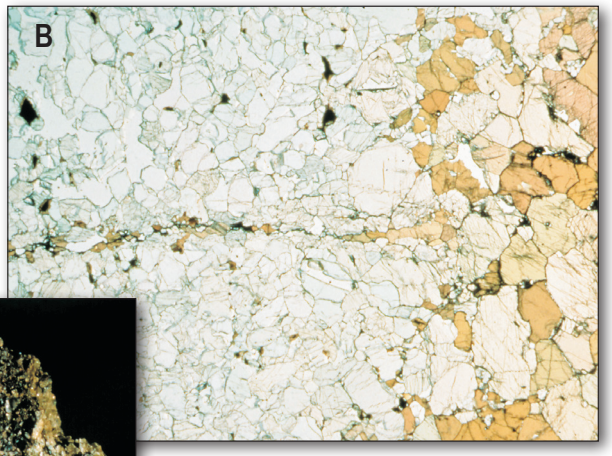




Figure 4. A: Spinel peridotite xenolith showing straight-sided vein of garnet pyroxenite (basaltic magma crystallised within the mantle). B: Photomicrograph of thin section of a peridotite showing an amphibole-rich vein with thin offshoot. Note the straight sides on both the large and small veins. Field of view is 2.5 cm across.

Core formation in partially molten planetesimals: A complex network analysis

THE SEGREGATION OF METALLIC CORES FROM SILICATE MANTLES is one of the earliest, and most important, differentiation processes in the evolution of terrestrial planetary bodies. Although a magma-ocean model is commonly used for efficient core formation, more recent scenarios using calculations from extinct radionuclides (e.g. ^{26}Al, ^{60}Fe) call for segregation of the core from partially molten silicate – a silicate "mush matrix". This segregation scenario requires growth of molten core material into blebs large enough to overcome the strength of the mush matrix so that separation can occur. The geochemical ramifications can be significant because bleb size will control the degree of equilibration. In collaboration with colleagues from the Mathematics Department at the University of Melbourne (A. Tordesillas and D. Walker), we have developed an innovative approach that combines partial-melting experiments on natural materials with complex-network analysis to quantify the growth of metallic melt regions in a silicate mush matrix. The presence of silicate melt is a significant transition point in the segregation of liquid metal and we are characterising this by using graph-theoretic techniques from Complex Networks. Properties of the networks have been constructed from the experimental data to determine whether the molten metal and silicate zones are tending to mix or separate, as manifested in the liquid metal blebs growing during melting and deformation of the rock sample (Fig. 1).

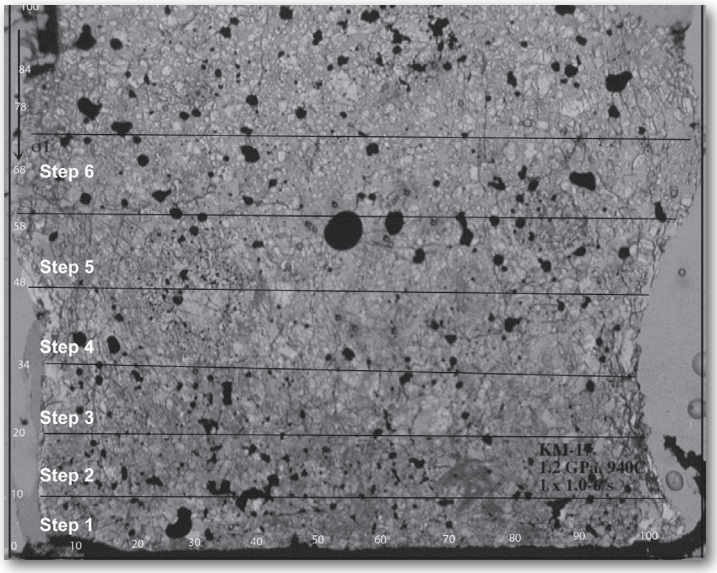


Figure 1. A backscattered-electron image of experiment KM-17, deformed at 940°C, 1.2 GPa and at 1.0 x 10^{-6}/s. Metal-sulfide eutectic quench liquid is most common and forms blebs in the silicate glass in the middle of the sample. The grid is placed on top of the sample and data collected at every point (100 data points per line by approximately 10 lines per step). Steps were chosen by the changes in the modes of melt and liquid vs unmelted material and go from step 1, where no melt or liquid metal is present, to step 6 where silicate melt fraction is the highest.

Complex Network Analyses: A basic network or graph consists of nodes, with some pairs of nodes connected by a link. Here, the networks are constructed from textural information collected at distinct sampling sites located at the intersection points of a near-regular sampling grid placed on the experimental sample. The sampling sites are then assigned to the nodes of a complex network. The topological structure of such a network is uninteresting. However, if we then label each node as a "type" according to the sampled data, i.e., node type indicates silicate melt, liquid metal, etc. then there are useful network measures to summarise the patterns of connections between node types (Fig. 2). One such measure is the assortativity, which quantifies a node's 'preference' to attach to other nodes of the same type. In complex networks, the statistics that are most associated with assortativity arise from the question of whether network nodes of the same degree (number of links attached to a node) are typically connected to each other. A random network where there is no discernable pattern of mixing has an assortativity measure of zero. We performed this analysis on the experimental data to establish whether separation of liquid metal from silicate melt (positive assortativity) or mixed (negative or zero assortativity) has occurred in the silicate mush matrix under deformation.

Results: For the assortativity coefficient, we found that the sample subnetworks evolve to a highly disassortative network due to the early dominance and residual presence of type 1 (solid silicate) within the sample. This is expected as it is a mush, so that solid silicate remains even in the

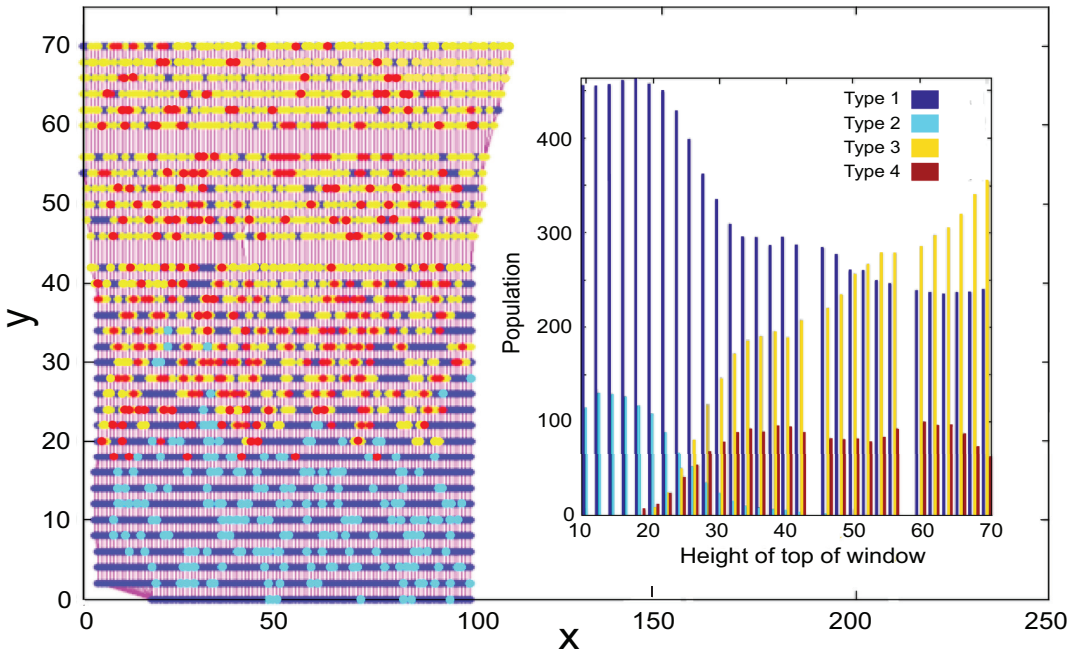


Figure 2. Full sample grid showing spatial distributions of type 1 (solid silicate), type 2 (solid metal), type 3 (liquid silicate) and type 4 (liquid metal). 29 windows "slide up" the sample, starting from the bottom of the sample (step 1) and ending at the hot spot with the highest melt fraction of both metal and silicate (step 6). The change in the population of each type as the window moves up is shown in the inset: in step 1, type 1 is dominant with some type 2, but by step 6, type 3 is dominant with some types 1 and 4.

highest temperature zone. For the subnetwork of liquid metal and silicate melt, we observed an assortativity coefficient around zero for heights above *y*=20 (types 3, silicate melt, and 4, liquid metal, are absent from the sample below this height) which is indistinguishable from a random mixing pattern. A simple randomisation test of the assortativities of surrogate random networks, each constructed by assigning node types 3 and 4 randomly, confirmed this. At heights beyond *y*=60, we find that the experimental sample with respect to node types 3 and 4 had evolved to a pattern with a significant positive assortativity coefficient (Fig. 3). In this area of the sample, there is significant "clumping" of the silicate melt and the liquid metal in the sample with respect to height (i.e. with increasing temperature and deformation). At *y*=60 and above, the zone of the highest strain and concentrated deformation, we find the highest fraction of silicate melt.

This novel approach has allowed us to quantify the texture by treating the four-phase system as a complex network. We see a "clumping" of metallic liquid and of silicate liquid as the proportion of silicate melt increases (from steps 1 to 6 in the sample) and deformation is concentrated in this weaker partially molten zone (step 6). The clumping processes may be driven by a combination of low pressure (dilational sites) in the mush zone, developed during deformation, and contrasts in surface energy and viscosity between the silicate melt and metallic liquid. The analysis of the textural data in step 6 shows that the network is assortative; the nodes of the same type are more likely to be connected together. This analysis can allow us to extract unambiguous network trends that can then predict the growth of blebs in the presence of silicate melt. This can then be used in calculations that include a modified Stokes Law to predict sinking rates for core formation in partially molten planetesimals.

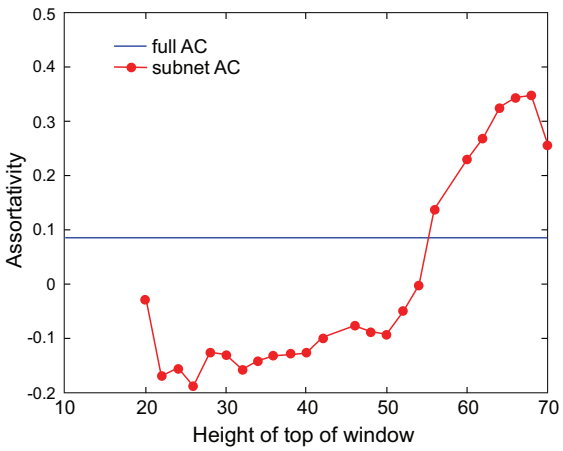


Figure 3. Assortativity coefficient of the 29 sliding window subnetworks consisting of nodes of types 3 and 4 only (from Fig. 2, nodes of types 3 and 4 do not exist below y=20). The blue line shows the equivalent value of the assortativity coefficient for the global network comprising all types for the entire sample (window size is the full sample).

Contact: Tracy Rushmer
Funded by: ARC Discovery Project Grant

Catastrophic overturn on Enceladus

NEW RESEARCH AT GEMOC HAS EXPLAINED THE ENIGMATIC BEHAVIOUR OF ENCELADUS, Saturn's sixth-largest moon. This tiny ball of ice and rock is only 500 km across—and yet it hosts a level of geologic activity comparable to Earth.

Enceladus's south pole erupts water-rich geysers into Saturn's ring system, from a region carved up by unusually warm fractures known as 'tiger stripes'. Thermal imaging of the moon's surface by the Cassini space-probe indicates that Enceladus is losing far more heat than it should be generating - a fundamental disparity in the thermal balance of the body. What's more, the south pole terrane is geologically young - cratering statistics indicate that it is less than 100 Myrs old, and perhaps much younger. In contrast, heavily cratered plains on Enceladus yield ages of up to 4.2 Ga - as old as any surface in the outer solar system, while the moderately cratered plains of Sarandib Planitia and Samarkand Sulcus yield ages of 170–3,750 Myrs and 10–980 Myrs, respectively. The episodic distribution of ages of different terranes on Enceladus implies that Enceladus has experienced localised periods of surface activity, interspersed with periods of relative inactivity.

In a paper published in Nature Geoscience in 2010 (*GEMOC Publication #621*), we proposed a model to resolve the discrepancy between Enceladus's heat production and heat loss. In this model, the massive heat loss at the moon's south pole can be explained by a periodic tectonic regime, resulting in geologic eruptions - such as those now visible on Enceladus - occurring every billion years or so.

As Enceladus orbits Saturn, the massive planet's gravitational pull causes the icy moon to flex, generating tidal heat on the satellite. Enceladus's orbit is not circular, so as it goes around Saturn its orbital distance changes, and the gravitational force that it feels changes slightly. As a result Enceladus is constantly squeezed and stretched, generating a lot of heat, like a squash-ball being squeezed in a hand. Radioactive decay - which powers most of Earth's tectonism, is only marginally important on Enceladus.

Despite its high range of tidal heating, Enceladus is still losing many times more heat than tidal sources can account for. Either something is unaccounted for, or the heat being released today is not matching the steady-state production rate. Instead, Enceladus may be in the middle of a 'pulse' of transiently enhanced heat loss well above its background average.

The new research suggests what we are seeing on Enceladus now is a transient period of active lid behaviour—a brief episode of



Figure 1. Cassini photograph of Enceladus, showing the relatively young South Pole Terrane, exhibiting a sub-linear 'Tiger-stripe' fracture system, and much older heavily cratered plains to the north. (Credits: NASA)

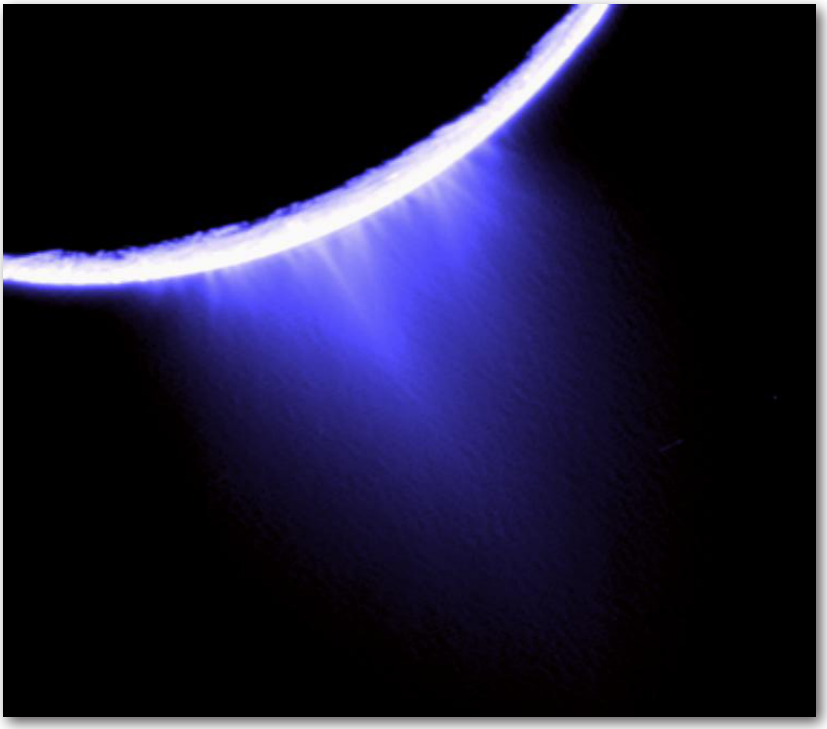


Figure 2. Water-rich geysers emanating from the 'Tiger-stripe' fractures in the South Pole Terrane. Image from UV Camera. (Credits: NASA)

tectonic activity that resurfaces a limited area of the moon. In the new model, heat is pent up inside the interior over billions of years, building up to a critical level and then escaping in one big pulse of activity. The models show that episodic partial-lid recycling occurs for plausible lid strengths and Enceladus's estimated supply of tidal energy. The localised nature of such overturn episodes, their periodicity of 0.1–1 billion years and an anomalous heat flow during these episodes are consistent with Enceladus's geology and modelled heat supply.

The models suggest that the pulses of activity would last for around 10 million years - a blink of an eye, geologically. Outside these active episodes, Enceladus would exhibit a more dormant, stagnant-lid mode of convection - not unlike many other icy moons. But if this periodic tectonic behaviour is endemic to icy satellites with evidence of partial resurfacing throughout the solar system, the other satellites also should show signs of episodic resurfacing. Indeed, Ganymede, Rhea and Miranda all show signs of episodic resurfacing deep in their geological past, and so transient tectonics in the outer solar system may be more common than previously thought.

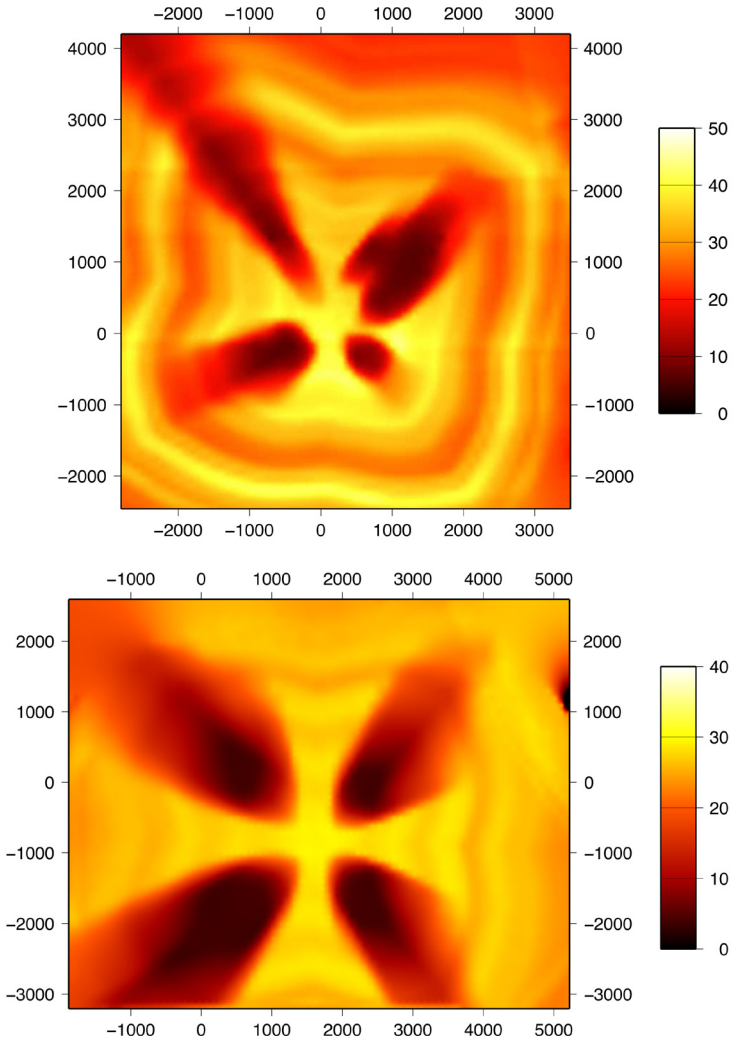
Contact: Craig O'Neill
Funded by: Macquarie CoRE funding

Brilliant imaging: new facets of diamonds' deep inner secrets

DIAMONDS, ALONG WITH THE MINERAL AND FLUID INCLUSIONS they can contain, represent the deepest direct samples from the Earth's mantle. Studying these diamond "capsules" as well as their contents has shed light on the chemistry of mantle fluids. A principal technique in the world of diamond research is infrared (IR) spectroscopy. This is a very simple technique for observing and quantifying the impurities that commonly occur in the diamond lattice, including both nitrogen and hydrogen. It is now the main technique used for diamond classification, which is based upon the abundance and nature of the nitrogen impurities.

Developments in IR analytical capabilities have made the mapping of these impurities far easier and quicker than ever before. The most modern equipment, as used in GEMOC, can collect thousands of point spectra across a single diamond in a single working day. However, for quantitative anaysis, the raw FTIR spectra must be deconvoluted. This has produced a requirement for an automated method that can accurately deconvolute thousands of spectra and quantify the most common impurities. We have developed an open-source (i.e. free to access) software routine (DiaMap) that automatically deconvolutes the spectra and quantifies the main nitrogen and hydrogen impurity features of a diamond. This includes the nitrogen concentration and aggregation state, the size of the platelet peak (interstitial carbon aggregates formed as a by-product of nitrogen aggregation) and the relative abundance represented by the main hydrogen peak.

Application of this technique has already shown some interesting results with respect to diamonds of mixed-habit growth. These are diamonds that show periods of smooth faceted octahedral growth and rough, hummocky cuboid growth, occurring at the same time. This often results in a center cross feature, which may or may not be obvious to

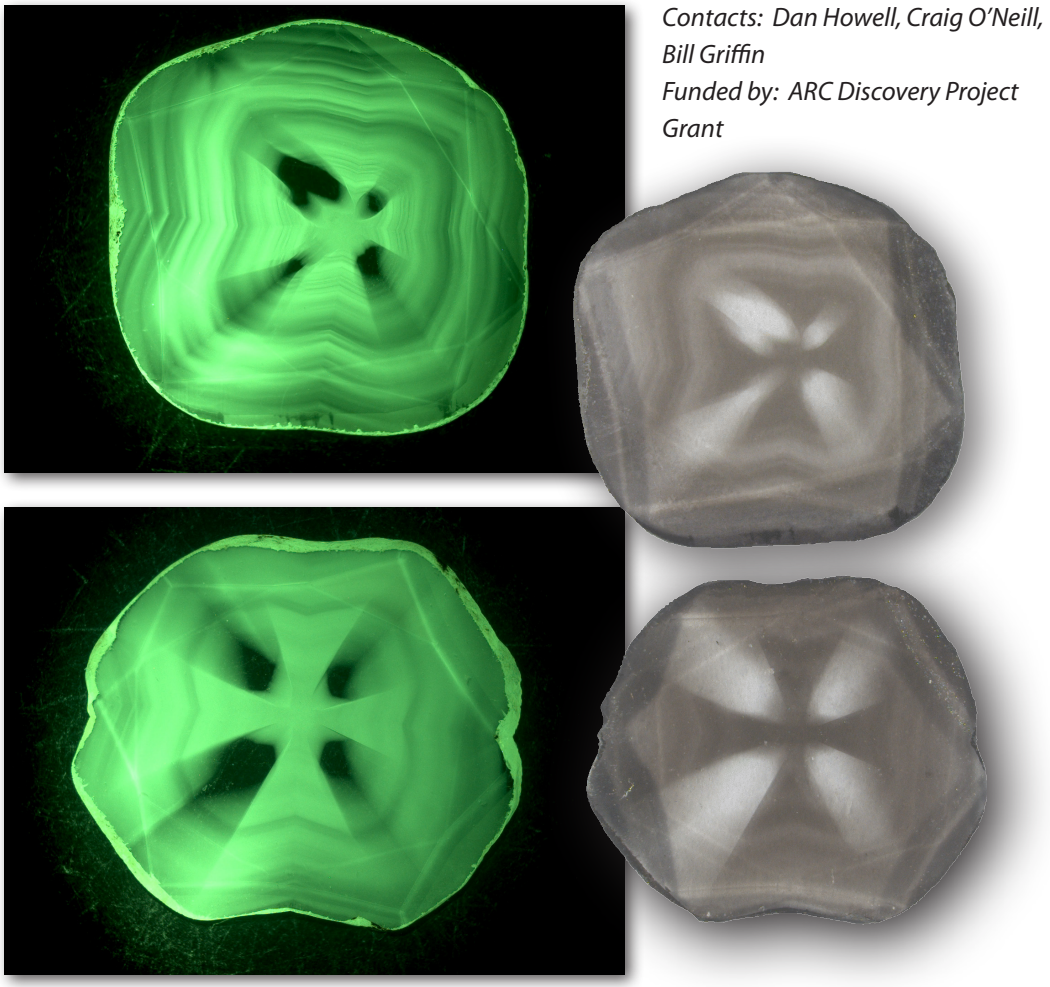


Maps of diamond MC06 (top) and MC12 (bottom), made up of thousands of infrared spectra, showing the relative intensity of the dominant hydrogen band (3107 cm^-1) in diamond. The hydrogen concentration correlates with cuboid growth, which is a different growth mechanism to that which produces perfect, octahedral gem quality diamonds.

the naked eye. A common feature observed in these types of diamonds is that platelet concentrations are much lower in cuboid sectors relative to contemporary octahedral sectors. No satisfactory reason for this has ever been given, but the most recent idea suggests that the high concentrations of hydrogen in cuboid sectors inhibit nitrogen aggregation, resulting in reduced platelet production. However, our new IR mapping shows that aggregation state of N can be the same in contemporary sectors, while platelet concentrations are lower in the cuboid sectors. This leads to the more logical conclusion that other defects (disc-like cracks), which are only found in cuboid sectors, are responsible for reducing the quantity of interstitial carbon atoms and therefore lowering the platelet concentrations. This has serious implications for another commonly utilised diamond classification method, based on platelet concentrations.

The application of this IR mapping method, in combination with other techniques like laser ablation mass spectrometry (LA-ICP-MS) to measure trace elements, cathodoluminescence imaging to reveal growth stratigraphy, and secondary ion mass spectrometry (SIMS) to measure carbon isotopic ratios, will reveal further information about the role of fluids in the mantle.

Contacts: Dan Howell, Craig O'Neill, Bill Griffin
Funded by: ARC Discovery Project Grant



Images of sample MC06 (top) and MC12 (bottom) taken under UV light. The luminescence comes only from the cuboid sectors (shown to be hydrogen-rich by the IR maps) while the octahedral sectors appear black. The cross feature that appears by luminescence is the reason these mixed-habits diamonds are commonly referred to as "star" or "centre-cross" diamonds.

Teaching and training program - GEMOC undergraduate

GEMOC's teaching program aims to:

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

ALL OF OUR UNITS RAN SUCCESSFULLY IN 2010 with student numbers up again from 2009. Our retention of students from first year also increased. GEOS226 Introduction to Field Geology, which runs in December each year, attracted 60 students.



Students on the field trip for GEOS206 Marine Depositional Environments.

This year continued with implementation of the university-wide curriculum change with our first and second year units changing from 4 credit points to 3 credit points. We are also introducing two new units that will be ready for 2011: GEOS272 Geology of Australia - Global Perspectives that will investigate interdisciplinary perspectives on the origin and geological evolution of Australia and its plate margins; and GEOS309 Liquid Fuels and Energy Security that will combine geological and geophysical approaches to investigate exploration and production methods for crude oil, natural gas and coal bed methane.



EPS successfully ran a new GEOS307 field course based in Alice Springs together with the University of Sydney. With combined enrolments of over 60 students this year, the unit was run twice. It lasted one month with Nathan Daczko, Bruce Schaefer, Sandra Piazolo, Tracy Rushmer, and Ryan Portner leading field groups. The students enjoyed mapping two locations in the red centre at Ormiston Gorge and Aileron. The mapping skills required ramped

up during the field campaign and culminatedin mapping very complex and difficult granulites at Mt Boothby (Aileron). Student feedback was excellent and the course will run again in 2011.

In line with the University's review of postgraduate units and programs, we are currently revising our Masters degree by coursework. This will be known as a Master of Science with a specialisation in Geoscience from 2013.



The GEOS307 field work moved from Broken Hill/ Olary to Alice Springs where they mapped two locations at Ormiston Gorge (pictured here) and Aileron.

Geophysics teaching progress 2010

The geophysics curriculum of the 300-level units was updated throughout the year in readiness for the new curriculum, which will take effect in 2011. A new unit dealing with petroleum geophysics and geology was developed and will be introduced in 2011.

Student numbers had increased from the previous year in both 200- and 300-level subjects.

Extended use of seismic, gravity, GPS (including the ASHTECH Z-Xtreme Differential GPS system) and resistivity (DUALEM Frequency Domain EM System) electrical (TerraTEM em equipment) 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, Discover3D, Maxwell, Quickmag and Reflexw have been maintained, while teaching packages such as SurfSeis and SeisImagerSW were upgraded.
- A set of small netbooks was purchased to enhance the teaching of linux-based software.



Teaching and training program - GEMOC honours

The following honours projects in GEMOC were completed in 2010:

Mid year submission

Andrew Buchel: Geophysical delineation of impact structures: an investigation of impact origin of the Borealis Basin, Mars

Eileen Dunkley: Geochemical evolution of the Median Batholith magmatic arc, Fiordland, New Zealand

Elizabeth Teague: The application of *in-situ* zircon and monazite geochronology to understanding the tectonic evolution of the Wongwibinda Complex, Southern New England Fold Belt

End of year submission

Will Abbott: Crater Mt, Papua New Guinea; A Diatreme Hosted Low Sulphidation Carbonate-Base Metal Gold Deposit

Trent Bowman: Salinity and depth of groundwater in various vineyards in the southern Hunter region, NSW

Glen Cathers: A combined geological and geochemical approach to determine the petrogenesis and geochronology of the Mount Hawker and Pluto packages, Gawler Craton, South Australia

Chris Firth: Understanding the magmatic history of Ambrym and Yasur Volcanoes, Vanuatu

Tom Harris: Gravity constraints on the subsurface geometry of the elongate S-Type Bundarra Plutonic Suite, Eastern Australia

Troy Hewitt: 3-D structure and lithosperic evolution of the Myall Syncline, NSW: Application of magnetic and gravity modelling

Tim Jones: The Effects of Thermochemical Piles and the Post-Perovskite Phase Transition on Plume Dynamics

Jaime Lovell: Multichannel analysis of surface waves: Evaluating the effects of acquistion parameters in distinguishing shallow subsurface structure

Matthew Robertson: Characterisation of the source for Solander Island volcanics using *in-situ* REE, U-Pb and Hf-isotope analysis of zircon

Max Milz: Thermo-tectonic history of the Carnarvon Basin

Susie Schartz: Controls on the chemistry and petrography of IOCG mineralisation in the Eastern Gawler Craton, SA

Commenced Mid year

Katherine Farrow: Parallel isotopic studies of turbidite mud-sand pairs and application of the *TerraneChron*® method to a low-pressure high-temperature regional aureole: Mt Stafford, Central Australia

Nicholas Tefay: Petrographic characterisation and zircon geochronology of the Cobungra Granite low-P high-T regional aureole in the Omeo Metamorphic Complex, Lachlan Fold Belt

The following honours projects are relevant to GEMOC in 2011

Cam Adams: The interaction of the Thomson and Lachlan Fold Belts, NW NSW: Sedimentary basin analysis of the Eromanga and Cobar Basins with emphasis on geothermal prospects and economic mineralisation occurance at Ordovician basement features

Patt Carr: Geodynamic setting of the eastern Gawler Craton: an insight from the Proterozoic mafic components

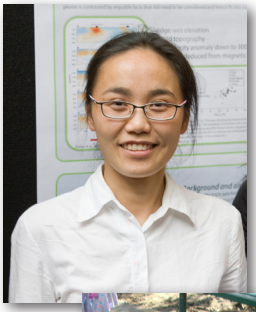
Maricar Damayo: The influence of pre-existing fabric on the progression of reactions, mineral replacement and element mobility: Examples from the Olary Domain, South Australia

Amanda Pearse: The subcontinental lithospheric mantle of easternmost Zealandia: A mantle xenolith study of the Chatham islands

Allyson Tanner: An experimental study of primitive arc magmas in the Tonga-Kermadec Arc



Teaching and training program - GEMOC postgraduate





GEMOC POSTGRADUATE STUDENTS had 18 papers published or accepted in high-profile international journals in 2010, including in Precambrian Research, Lithos and Contributions to Mineralogy and Petrology, and 18 presentations at international conferences. Particular highlights were:

- Jinxiang Huang (pictured left) was awarded the prize for "Excellent Student Presentation" at the 2010 Annual Chinese National Symposium of Petrology and Geodynamics at Peking University in Beijing.
- Ekaterina Rubanova (pictured left) was awarded the Russian Academy of Science Young Scientist Medal in "Geology, Geophysics, Geochemistry and Mining Sciences."

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)

Jacques Batumike (PhD): Origin of kimberlites from the Kundelungu region: Lithospheric mapping, diamond potential and crustal evolution in southern Democratic Republic of the Congo; (graduated 2009)

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)

John Caulfield (PhD): Nature and timing of magma genesis at Tofua volcano, Tonga; *iMURS* (graduated 2010)

June Chevet (PhD): Basaltic intrusives and mafic/ultramafic cumulates, Kerguelen Archipelago; *iMURS* (graduated 2010)

Heather Cunningham (PhD): Using short-lived U-series isotopes to constrain the time scales of magmatic processes in an active caldera, Rabaul, Papua New Guinea; *iMURS* (graduated 2009)

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)

Cara Donnelly (PhD): Kimberlites, related rocks and the subcontinental lithospheric mantle of the Kuruman Province, Kaapvaal Craton, South Africa; *iMURS* (Graduated 2010. Awarded Vice-Chancellor's commendation, see *Research Highlights p. 38*)

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)

Alan Kobussen (PhD): The composition, structure and evolution of the subcontinental lithospheric mantle in Southern Africa; *iMURS* (graduated 2010)

Véronique Le Roux (PhD): Melt-rock interactions and melt-assisted deformation in the Lherz peridotite: Implications for the structural, chemical and isotopic evolution of the lithospheric mantle; (graduated 2009)

Weiqiang Li (PhD): Copper isotope geochemistry of the Northparkes porphyry Cu-Au deposit; *iMURS* (graduated 2010)

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

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

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)

Ryan Portner (PhD): Sedimentary and volcaniclastic record of a mid-ocean spreading ridge: Macquarie Island, Southern Ocean; *iMURS* (graduated 2010)

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)

See advertisement for GEMOC postgraduate opportunities, *Appendix 6*.

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): An ice and crust mass balance study of the Law Dome ice cap, East Antarctica, using geophysical techniques; *RAACE* (commenced 2004)

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)



Steve Craven presenting his work at SGTSG 2010 Conference held in Port Macquarie in February 2010.

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)

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

Eileen Dunkley (PhD): Hf isotopic behaviour in turbidites, migmatites and granites at Mount Stafford, Central Australia; *MQRES* (commenced 2010)

Fiona Foley (PhD): Generation of continental crust during subduction initiation; *iMQRES* (commenced 2009)

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)

Felix Genske (PhD): Assessing the heterogeneous source of the Azores mantle plume; *iMQRES* (commenced 2009)

Yoann Gréau (PhD): Siderophile and chalcophile elements in Roberts Victor Eclogites: Insights on the generation of mantle heterogeneity; *iMURS and Co-tutelle with Montpellier University, France* (commenced 2007, completed 2010)

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)

Marek Locmelis (PhD): Mechanisms of platinum-group element fractionation in ultramafic melts and implications for the exploration for magmatic nickel sulphide deposits; *iMURS* (commenced 2006, completed 2010) (see *Research Highlights, p.46*)

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

Daniel Miescher (MSc): Petrographic and geochemical characterisation of a layered garnetite-pyroxenite xenolith and of garnet in the Breaksea Orthogneiss, Fiordland New Zealand

Luke Milan (PhD): Cordillera Zealandia, Fiordland, New Zealand: A Mesozoic arc flare-up on the palaeo-Pacific Gondwana margin; (commenced 2004, completed 2010)



Nathan Daczko, Daniel Miescher, and Prof Geoffrey Clarke (Univ. of Sydney) on field work in Fiordland, New Zealand for Daniel's MSc research project.

Melissa Murphy (PhD): A novel U-series isotopic approach for investigation of the Beverley U mine, South Australia; *APA* (commenced 2009)

Matt Pankhurst (PhD): Geodynamic significance of shoshonitic magmatism within the Andean Altiplano; *MQRES* (commenced 2009)

Suresh Puthiyaveetil Othayoth (PhD): Timescales of soil evolution and sediment transport in a small catchment in SE Australia; (commenced 2009)

Ekaterina Rubanova (PhD): Fluid processes in the deep mantle: Geochemical studies of diamonds and related minerals; *IMQRES* (commenced 2010)

Edward Saunders (PhD): Gold distribution and mobility within the mantle and its significance to mineralised provinces; *APA* (commenced 2010)

Elyse Schinella (PhD): Processes shaping the Venusian landscape; *APA* (commenced 2010)

Rajat Taneja (PhD): Origin of intraplate volcanism in the east Indian Ocean; *IMQRES* (commenced 2010)

Lijuan Wang (PhD): Crustal evolution of the Yangtze Block using zircons in sediments; *China Government Scholarship* (commenced 2008, submitted 2010)

Yao Yu (PhD): The evolution and tectonic dynamics of the subcontinental lithospheric mantle, SE China; *China Government Scholarship and co-tutelle with Nanjing University* (commenced 2010)





Rajat Taneja in his beautiful research area, the Cocos Islands.

COMMENCING 2011

Clement Gaildry (PhD): Island arc processes as seen through Vanuatu volcanism and geochemistry; *iMQRES*

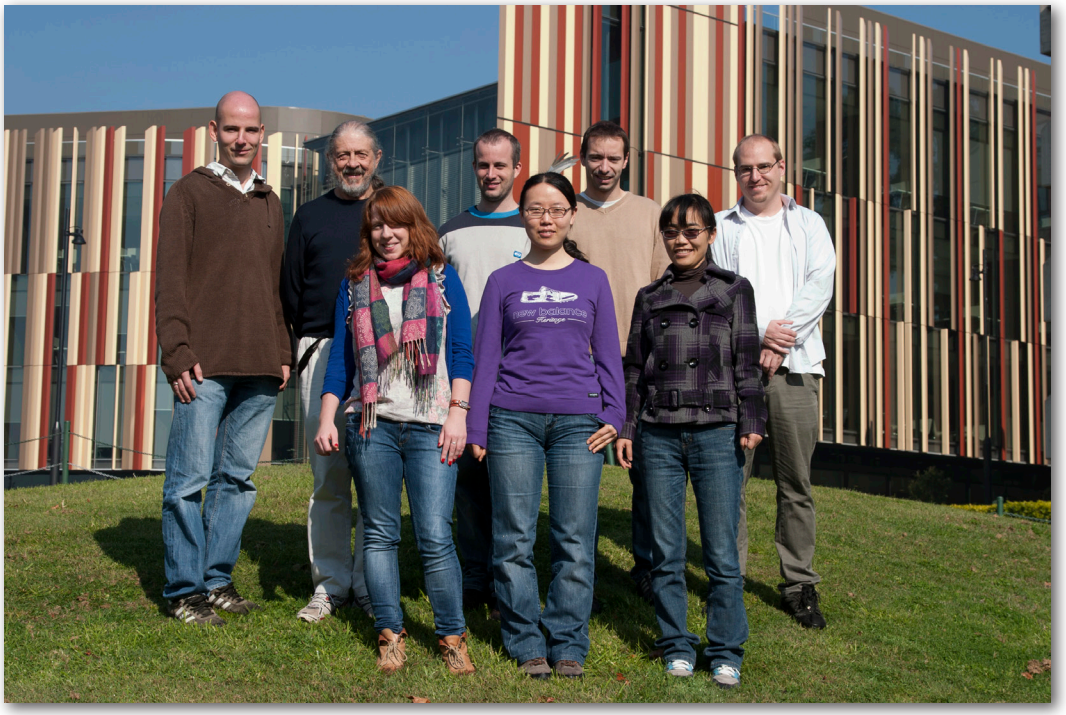
Chris Firth (PhD): Integrating the volcanological and magmatic record of a young Arc volcano: Yasur Vanuatu; *APA*

Kim Jessop (MSc): Petrology and Geochemistry of Buckland Province Flows, Dykes and Intrusions

Rosanna Murphy (PhD): Stabilising a craton: origin and emplacement of the 3.1 Ga Mpuluzi batholith (Swaziland/RSA); *MQRES*

Kathleen Murray (MSc): Zircon U-Pb-Hf trace elelment analysis from metapelites on the Mawson Coast, Antarctica

Pablo Lara (PhD): Late Noeproterozoic granitoid magmatism of the Southernmost section of the Don Feliciano Belt in Uruguay: Regional geology, geochemistry, geochronology and its significance for the geotectonic evolution of the region



Some of GEMOC's 2010 postgraduate students in front of the new Library: (top) Felix Genske, Steve Craven, Ed Saunders, Yoann Gréau, Marek Locmelis (bottom) Fiona Foley, Yao Yu 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 2009 a new strand of Technology Development commenced with acquisition of the 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 on p.74.

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-100 electron microprobe
  - a Zeiss EVO MA15 Scanning electron microscope (installed January 2010)
  - four Agilent 7500 ICPMS (industry collaboration; two installed October 2004; two installed May 2010)
  - 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 Nu Plasma multi-collector ICPMS
  - a Nu Plasma high resolution multi-collector ICPMS
  - a Thermo Finnigan Triton TIMS (installed March 2005)
  - a Spectro XLAB2000 energy-dispersive XRF with rocker-furnace sample preparation equipment
  - a LECO RC412 H_2O-CO_2 analyser
  - an Ortec Alpha Particle counter
  - a New Wave MicroMill micro-sampling apparatus
  - a ThermoFisher iN10 FTIR microscope
  - selFrag electrostatic rock disaggregation facility (installed 2010)
  - clean labs and sampling facilities provide infrastructure for ICPMS, XRF and isotopic analyses of small and/or low-level samples

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

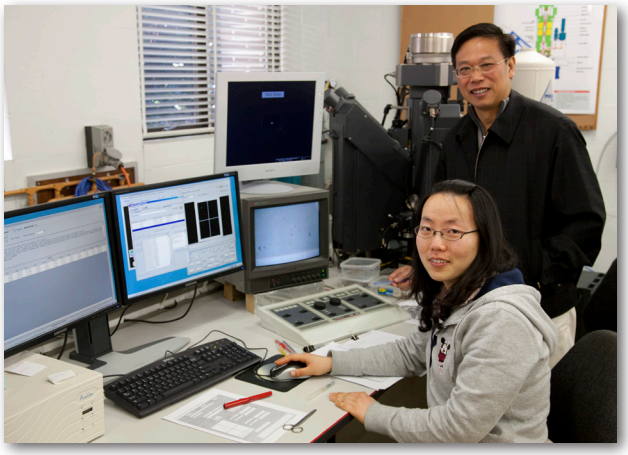
- Experimental petrology laboratories include four piston-cylinder presses (pressures to 4 GPa), hydrothermal apparatus, controlled atmosphere furnaces, Griggs apparatus and a multi-anvil apparatus for pressures to 27 GPa.
- The Centre for Isotope Studies has provided access to extraction lines and gas-source 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. In late 2009 GEMOC was awarded an ARC LIEF grant to integrate the two existing multi-collector inductively-coupled-plasma mass spectrometers (MC-ICPMS) with 3 new instruments: a femtosecond laser-ablation microprobe (LAM); a high-sensitivity magnetic-sector ICPMS; a quadrupole ICPMS. The quadrupole ICP-MS was purchased in 2010 and the other new equipment will be purchased and installed in 2011.

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 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



Co-tutelle PhD student Yao Yu at the EMP with her supervisor from Nanjing University, Xisheng Xu (a former GEMOC PhD).

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

Scanning Electron Microscope: for high-resolution imaging

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.



TerraneChron® Team - Elena Belousova, Ayesha Saeed and Norman Pearson.

CURRENT STATUS

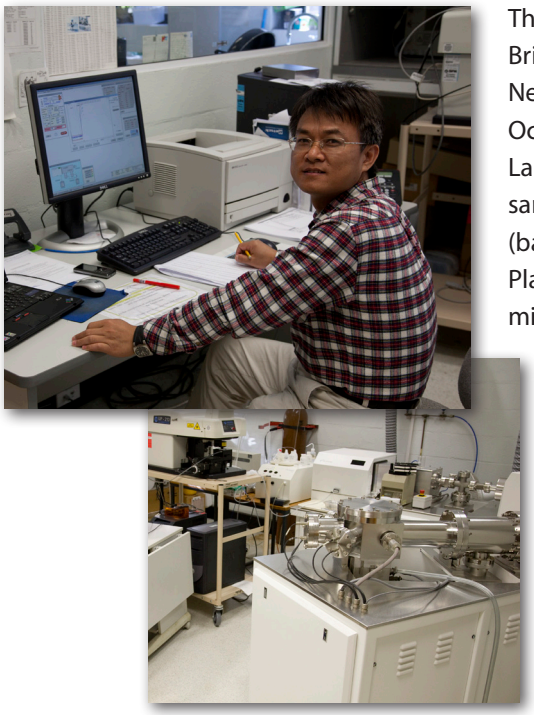
Electron microprobe (EMP): In January 2010 the original EMP, a Cameca SX50 installed in 1993, was decommissioned and replaced with a Zeiss EVO MA15 Scanning Electron Microprobe. Prior to this the SX50 had been used mainly for the imaging and analysis of zircons, in connection with *TerraneChron*® applications and basic research. The Zeiss is configured with a cathodoluminescence detector and Bruker Energy Dispersive System. In early 2003 a new CAMECA SX100, with five crystal spectrometers and a PGT Energy Dispersive System, was installed. It is fitted with large-area diffracting crystals for improved sensitivity and lower limits of detection. The CAMECA SX100 carries the workload of the routine major and minor element analyses for the majority of GEMOC's research projects.

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.

Installation of the new 7700CX ICP-MS.



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. In 2010 two new Agilent 7700CX ICP-MS were purchased and one of them replaced the 7500S. This instrument is dedicated to *in situ* U-Pb analysis and joins one of the 7500CS instruments as part of the LAM-ICPMS stable. The 7500CS routinely provides quantitative analyses of > 30 elements at sub-ppm levels in minerals, glasses and metals, as well as precise U-Pb dating of zircons.



Our Long time collaborator Prof Jianping Zheng from China University of Geosciences (Wuhan), running Hf isotopes on the LAM-MC-ICPMS.

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 October 2010 one of the UP-213 systems was upgraded with a New Wave Large Format sample cell, which has improved signal sensitivity and sample washout. 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. This has subsequently been decommissioned.

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" (http://www.glitter-gemoc.com/) software enhances laboratory productivity and data interpretation; the software is marketed internationally through Access MQ.

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 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.

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 (then at Monash University), and was installed in March 2005. Following an intensive period of testing the Triton quickly became the primary source of solution Sr, Nd and Os isotope analyses in the Facility, relieving the MC-ICPMS of this aspect of the 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.

Felix Genske gowned-up in the clean labs.



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 2010

1. Facility for Integrated Microanalysis

a. Electron Microprobe: During 2008 the SX50 developed a range of problems and a decision was made in 2009 to decommission it. An order was placed for a Zeiss EVO MA15 SEM to carry the electron imaging workload and the installation of this instrument took place in January 2010. The Zeiss is configured with a cathodoluminescence detector and Bruker Energy Dispersive System, and since its installation it has provided high-resolution BSE and CL images for *TerraneChron*® (http://www.gemoc.mq.edu.au/TerraneChron.html) and all other research projects. The SX100 serviced all projects including analysis of perovskite in kimberlites; analysis of platinum group minerals; minor and trace element analysis of metals.



Dan Howell imaging his diamonds on the Zeiss EVO MA15 SEM.

b. Laser-ablation ICPMS microprobe (LAM): During 2010, 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 collaborations. 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. As in recent years more than 7000 U-Pb analyses of zircons were carried out, related to projects (including *TerraneChron*® applications: http://www.gemoc.mq.edu.au/TerraneChron.html) from Congo, Russia, Norway, Burkina Faso, Mongolia, China, Papua New Guinea, Indonesia, New Zealand, France, Ghana 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*).

Until May, U-Pb dating of zircons was carried out on the Agilent 7500S and then on the new Agilent 7700CX. One of the two Agilent 7500CS instruments was dedicated to laser-probe applications, and the other set up for solution analysis. The continued operation of three ICP-MS has allowed uninterrupted periods of time for method development without disrupting the productivity of the laboratory.

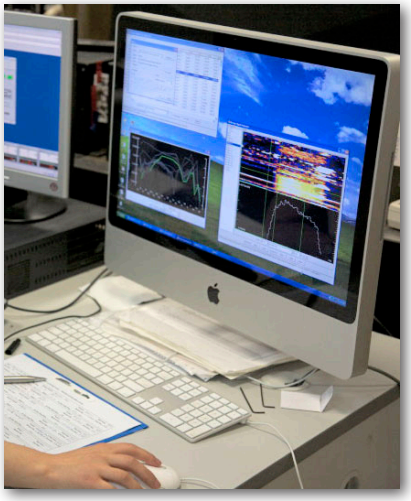
c. MC-ICPMS: The rapid growth in the use of the *TerraneChron*® application (see *Research Highlights* and: http://www.gemoc.mq.edu.au/TerraneChron.html), coupled with the demand for *in situ* Re-Os analysis and stable isotope analysis, continued to produce severe competition for instrument time on the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

"During 2010 a further 22 full licences of GLITTER were sold bringing the total number in use to 171 worldwide, in forensics and materials science, as well as earth science applications."

In 2005 significant advances were made in the analysis of 'non-traditional' stable isotopes and included the development of separation techniques and analytical protocols for Tl, Fe and Ni isotopes. In 2010 there was further development for the separation and analysis of Li isotopes and improvements in the analysis of U-series isotopes in rocks and groundwaters. Major applications during 2010 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 and alloys in mantle-derived rocks. *In situ* Hf isotopes were measured in zircons from Australia, Congo, Russia, Norway, Burkina Faso, Mongolia, China, Papua New Guinea, Indonesia, New Zealand, Brazil, Columbia, Chile, Sweden, France and Ghana. We carried out Re-Os studies on xenoliths from the USA, South Africa, northern Africa, eastern China and Siberia. Sr and Nd isotopes were measured *in situ* in kimberlitic perovskites from South Africa.

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

http://www.glitter-gemoc.com/



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 Access MQ (formerly Macquarie Research Limited) and GEMOC provides customer service and backup. During 2010 a further 22 full licences of GLITTER were sold bringing the total number in use to 171 worldwide, in forensics and materials science, as well as earth science applications. During 2005, Will Powell, Norm Pearson and Chris Ryan began updating GLITTER to version 4.4 and version 4.4.3 is currently available without charge to existing customers and accompanies all new orders. Will Powell continued in his role in GLITTER technical support and software development through 2010.

2. Laser development

For more than a decade GEMOC benefited 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 both the quadrupole ICPMS and MC-ICPMS instruments, 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 decommissioned in 2009. 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.



Olivier Alard of the University of Montpellier (a former GEMOC PhD) showing his PhD student Jennifer Chaufard the ropes in the LAM-ICPMS lab.

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. Following resolution of a series of problems in 2008, the XLAB2000 returned to full operation in 2009.

A LECO RC412 H_2O-CO_2 analyser, installed in September 2003 to replace an outdated unit, is providing high-quality analyses to complete whole-rock analyses by XRF and solution-ICPMS.

4. Solution analysis

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

The *in situ* analysis of the Rb-Sr, Lu-Hf, Sm-Nd and Re-Os systems by laser ablation microprobe has required the development of corrections for isobaric overlaps (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 2010 further developments were made in the separation of 'non-traditional' isotopes, with significant improvements in the separation of Li and Mg 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 allows 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. Refurbishment of the laboratory to house the laser cutter was completed in late 2009 and installation of the equipment took place in early 2010. GEMOC also took delivery of a new-generation FTIR microscope, the ThermoFisher iN10. This allows the spatial mapping of whole diamond plates at high resolution with very short acquisition times (see *Research Highlights*).

6. SelFrag – a new approach to sample preparation

The first selFrag instrument in Australia was installed in GEMOC in May 2010. 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 higher proportion of unbroken grains of trace minerals such as zircon. Since its installation selFrag has been used for a range of applications including 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.



GEMOC's new selFrag installation was finally in place in 2010 - and Elena Belousova clearly was pleased with its behaviour.

7. Computer cluster

A new 64-core computer cluster (Enki) came online in 2010, with the capability to run massively parallel high-resolution geodynamics simulations in 3D at a global scale. The cluster is running some of the most cutting-edge simulation software packages, including CitcomS – enabling 3D spherical mantle simulations, and Underworld – a lithosphere and mantle deformation computational framework designed for massively parallel simulations. It has supported two Honours student projects, as well as two ongoing PhD projects, and underpins at least two successful ARC Discovery projects. Further funding obtained in 2010 will be used to expand the cluster into a 96+ core machine within the next year.



Industry interaction

INDUSTRY INTERACTION, TECHNOLOGY TRANSFER AND COMMERCIALISATION PROGRAM

GEMOC RELIES ON A VIGOROUS INTERACTION WITH THE MINERAL EXPLORATION INDUSTRY at both the research and the teaching/training levels. The research results of the Centre's work are transferred to the industry and to the scientific community in several ways:

- 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 Access MQ 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 Access MQ (http://www.gemoc.mq.edu.au/); the software is continually 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

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
- logistical 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 2010

Ten major 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 (http://www.gemoc.mq.edu.au/TerraneChron.html).

During 2010, GEMOC increased its collaboration with Barrick Gold of Australia, applying the *TerraneChron*® method to their copper-gold exploration programs in Papua New Guinea and South America.

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. A successful bid for an ARC Linkage grant in 2008 ensured the continuation of the project despite key players leaving BHP Billiton. A sub-licencing agreement was executed with Minerals Targeting International to accommodate Dr Graham Begg's new role (in relationship to Macquarie, BHP Billiton and the GLAM project) as Director of this company. Planning and workshop sessions at Macquarie with participants from BHP Billiton and GEMOC were key activities in 2010. Dr Begg spent significant research time at GEMOC through 2010 as part of the close collaborative working pattern for this project.

GEMOC's development of a methodology for analysis of 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. This work is continuing, with a focus on understanding the growth and chemical history of individual diamonds and diamond populations; it was supported in 2010 by an ARC Discovery Project, on which Dr Dan Howell is employed as a Research Associate.

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 is being applied in an ARC Linkage project sponsored by De Beers.

A new initiative in 2009, continued in 2010, was the application of U-series isotopes to groundwater studies for both exploration and investigation of palaeoclimate. Collaboration with Heathgate Resources at the Beverley Uranium mine in South Australia is investigating these processes using a well-constrained aquifer system in both a mining and exploration context (Melissa Murphy's PhD project).

Modelling capabilities have now been extended to industry related projects. An ongoing collaboration with Granite Power Ltd continues, which has led to important data exchange and ongoing consulting projects through Access MQ. A successful Honours project was carried out in collaboration with Chevron Australia Ltd., developing gravity and thermal models for the Northwest Shelf. An ongoing collaboration between GEMOC, Granite Power Hydrolex Ltd. has led to several upcoming or submitted publications on the thermal structure of the Sydney Basin.

Studies on the controls of fractionation and concentration of platinum-group elements (PGE) in ultramafic magmas continued in 2010 as part of the PhD project of Marek Locmelis, funded by AMIRA Project P710a; Marek submitted his thesis in 2010, and is continuing with the research

as a Research Associate. The research goal is to develop reliable geochemical indicators that can guide the exploration for magmatic nickel-sulfide deposits with a particular focus on the role of chromite and olivine in the concentration and fractionation of PGE in komatiites. Industry partners are BHP Billiton, Independence Group NL, Norilsk Nickel, MERIWA and ARC. The project is in collaboration with the Centre for Exploration Targeting / University of Western Australia, CSIRO Exploration and Mining and the Australian National University.

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.

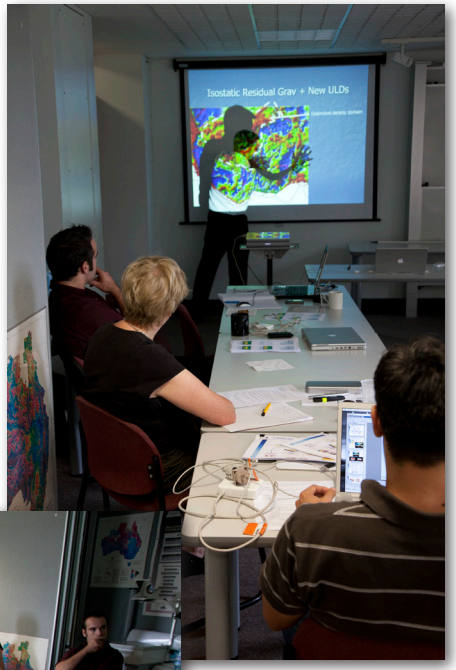
A collaborative research project continued in 2010 with the Geological Survey of Western Australia, in which GEMOC is carrying out *in situ* Hf-isotope analyses of previously SHRIMP-dated zircon grains from across the state. This is a part of the WA government's Exploration Incentive Scheme.

Industry visitors spent varying periods at GEMOC in 2010 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 2010. See *Appendix 4* for abstract titles and *Appendix 2* for GEMOC Publications.





The annual review meeting for the Global Lithospheric Architecture Mapping (GLAM) project gathered geologists, geophysicists, geochemists and industry representatives.

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 Access MQ Limited, 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 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 breakthrough in developing a robust methodology to quantitatively analyse the trace elements in diamonds 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.

Funded projects

Lithospheric Architecture Mapping in Phanerozoic Orogens

Supported by MQ Enterprise Partnership Scheme Pilot Research Grant (MQPSPRG)

Industry Collaborator: Minerals Targeting International

Summary: **The GEMOC Key Centre has developed the conceptual and technological tools required to map the architecture and evolution of the upper lithosphere (0-250 km depth) of cratons (the ancient nuclei of continents). Through two industry-funded programmes we have mapped most of the world's cratons, making up ca 70 % of Earth's surface. The remaining 30% consists of younger mobile belts, which hold many major ore deposits, but are much more complex and difficult to map. This pilot project is developing the additional tools required to map the mobile belts.**

A novel approach to economic uranium deposit exploration and environmental studies

Supported by ARC Linkage Project

Industry Collaborator: Heathgate Resources

Summary: **The project proposes the use of a novel approach to prospecting for economic uranium ore deposits. The measurement of radioactive decay products of uranium in waters (streams and aquifers) and sediments will allow us to (i) identify and locate economic uranium ore deposits and (ii) quantify the rate of release of uranium and decay products during weathering and hence the evolution of the landscape over time. In addition, this project will improve our knowledge of the mobility of radioactive elements during rock-water interaction, which can be used to assess the safety of radioactive waste disposal. Outcomes of this project will be: (i) the discovery of new economic uranium deposits; (ii) development of a new exploration technology allowing for improved ore deposit targeting. Information gained on the behaviour of radioactive elements at the Earth's surface will be critical for the study of safety issues related to radioactive waste storage and obtaining reliable time constraints on the evolution of the Australian landscape.**

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

Supported by ARC Linkage Project

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 ~250 km 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.**

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 generated 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 were obtained from the mineral zircon (collected from river sands and rocks), which acts as a time capsule allowing us to determine the nature and sources of individual magmatic rocks and also sedimentary sequences. This has provided an integrated understanding of the geological history of the region to aid mineral exploration, and added to knowledge of the composition, metallogeny and assembly of this region of the Australian continent. The outcomes of this project were summarised in journal publications (e.g. Belousova et al., 2009 in Lithos; Howard et al., 2009 in Chemical Geology; see *Appendix 2* for GEMOC Publications) and reported to the Macquarie University Research Office in January, 2009.**

Global Lithosphere Architecture Mapping II

Supported by ARC Linkage Project

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.

Mechanisms of PGE fractionation and concentration in mafic and ultramafic melts

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

Industry Collaborators: BHP Billiton, Independence, LionOre

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

Summary: A long-standing goal of research on nickel-sulfide (NiS) deposits has been the development of reliable lithogeochemical indicators that can act as guides for exploration. In order to better constrain how platinum-group element (PGE) signatures may be utilised as pathfinders for those NiS deposits, this project focuses on the processes that control the fractionation and concentration of PGE in mafic and ultramafic magma types. The study looks into a range of variables controlling the PGE geochemistry, including the role of sulfides (i.e. pentlandite, millerite), oxides (i.e. chromite), silicate phases (i.e. olivine, pyroxene) and platinum-group minerals (i.e. alloys, antimonides, arsenides, tellurides) in the concentration and fractionation of PGE in mineralised and barren sequences. Furthermore, the study investigates the spatial relationship between the PGE signature of mafic and ultramafic rocks and the occurrence of various types of NiS mineralisation, thus optimising the use of the PGEs as vectors towards mineralised environments. See *Research highlights p. 46.*



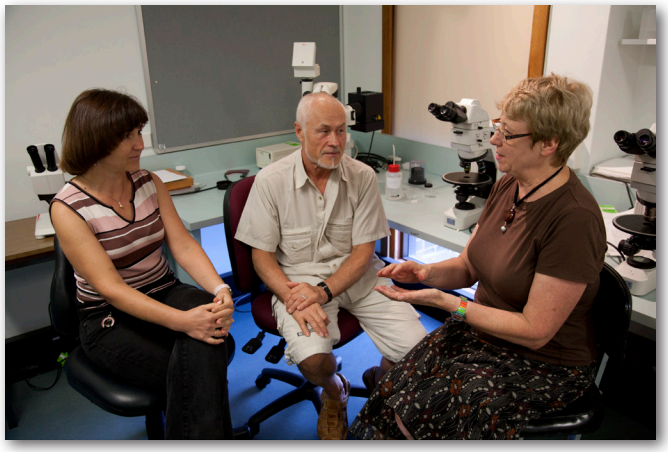
GEMOC's international links

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, South America, China, Brazil, Japan, Thailand and Russia.

FUNDED COLLABORATIVE PROJECTS COMMENCED OR ONGOING IN 2010 INCLUDE:

- An MOU was signed with the China Academy of Science, (Beijing) involving the Institutes of Geochemistry and Geophysics. This will allow for exchange of personnel, co-tutelle PhD projects, and joint access to the complementary analytical equipment at each institution. In the first exchange, Dr Chuanzhou Liu arrived at GEMOC for a 6-month stay aimed at transfer of GEMOC's technology for *in situ* analysis of Os isotopes.
- Trace elements and fluids in diamonds and relevance to mantle fluids and processes with Professor Oded Navon (Hebrew University, Israel), Professor Thomas Stachel (Edmonton, Canada) and Dr Jeff Harris (University of Glasgow, UK). Funded by an ARC Discovery Project, including the PhD project of Ms Ekaterina Rubanova. Dr Zdislav Spetsius (Mirny, Siberia) visited GEMOC for analytical work connected with the project.



Dr Zdislav Spetsius (Mirny, Siberia) visited GEMOC for analytical work connected with the diamond project; here in a discussion with Elena Belousova and Sue O'Reilly.

- Shear-induced metal segregation in ordinary chondrites, a collaborative project with Professor N. Petford 2007-2009 (Bournemouth University, UK).
- The first million years of our solar system – stellar nucleosynthetic inputs, solid formation and planet building with Professor Joel Baker (Victoria University, New Zealand).
- Core formation and degassing of the Earth, a collaborative project with Dr S. Nielsen, 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).

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

- Dr Kelsie Dadd was one of a team of 50 international scientists who participated in a nine-week Integrated Ocean Drilling Program (IODP) expedition in the Bering Sea in 2009. Kelsie sampled ice-rafted debris and ash layers in the recovered sediment cores. Ash shards are currently being separated from the sediment for analysis. The sampled ice-rafted debris consisted of 148 pebble-sized clasts. The physical properties (including rounding and sphericity) of over 100 clasts were analysed. Low roundness at some sites indicates the presence of glaciers or perennial sea ice in those locations, while most of the other pebbles are likely to have originated from fluvial environments and beaches with low wave action due to the presence of seasonal sea ice.
- Collaboration continued 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.



Bill Griffin and Professor Sun-Lin Chung in a lively and liquified discussion of a TerraneChron® study to unravel the timing and tectonic history of regions in Tibet.

- A *TerraneChron*® study to unravel the timing and tectonic history of regions in Tibet continued 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 and the Tibet Institute, Beijing.
- 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). The institute sponsored a workshop on "Frontiers in Geochemical Research" in conjunction with the 2010 Western Pacific AGU meeting in Taipei, in which Bill Griffin, Sue O'Reilly, Norman Pearson and Mei-Fei Chu from GEMOC participated.
- 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 continued under a co-tutelle agreement (Anne Fonfrege).
- Collaboration with colleagues at the University of Montpellier continued with the co-tutelle PhD project of Yoann Gréau (submitted late 2010) and projects on the mantle budget of platinum group elements, microstructures of meteorites and mantle rocks, and ophiolites. A new collaboration commenced funded by the DIISR Grant "Probing the composition of the early Solar System and planetary evolution processes". Exchange visits of Dr Olivier Alard and two postgraduate students from Montpellier (Jennifer Chaufard and Valerie Migeon) to GEMOC and Dr Norman Pearson to Montpellier, advanced the research on this project.



Norman Person with collaborators from the University of Montpellier, France, Dr Olivier Alard and Professor J.-L. Bodinier while on field work on the famous Lherz massif in the Pyrenees.

- 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). Co-tutelle PhD student Yao Yu arrived at GEMOC from Nanjing, to carry out further FTIR studies of water in mantle-derived xenoliths.

- 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-mafic intrusions of the Noril'sk area (northern Siberia, Russia). The latter include world-class PGE (platinum-group element)-Cu-Ni sulfide deposits related to Noril'sk-1, Talnakh and Kharaelakh ultramafic-mafic intrusions, subeconomic PGE-Cu-Ni deposits related to Chernogorsk, Zub-Marksheider and Vologochan intrusions, the prospective Mikchanga intrusion and non-economic Nizhny Talnakh, Zelyonaya Griva and Kruglogorsk intrusions; (2) analysis of Os-(Ir-Ru) alloy grains in 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.



Kreshimir Malitch and Elena Belousova disecting the history of NiS deposits related to the Siberian Traps.

- Professor Jerry Friedman (Stanford University) and his Australian colleague Dr Nick Fisher visited GEMOC for a week to renew a collaboration with Bill Griffin and Elena Belousova on the development of new statistical approaches for recognising structure and populations in GEMOC's large geochemical databases. In this case the week was spent testing some new ideas, using Elena's zircon database (see *GEMOC Publications 93, 139, 209, 265, 269, 299*).



Jerry Friedman, Nick Fisher, Elena Belousova and Bill Griffin examining Elena's Zircon database to test new statistical approaches for recognising structure and population.

- 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.

GEMOC's international links



Elena Belousova and Alexander Kremenetsky in the field in South Australia.

- A collaborative project with Alexander Kremenetsky, Director of the Institute of Mineralogy, Geochemistry and Crystal Chemistry of Rare Elements (IMGRE), Moscow, Russia, utilised our *TerraneChron*® approach to look at giant provinces of heavy-mineral placer deposits in Australia and Russia.
- 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. A co-tutelle Phd student from Wuhan will arrive in 2011 to work on one of these projects.
- 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 and cotutelle program; Lijuan submitted her PhD thesis in late 2010).
- Studies continued with Dr Rendeng Shi (Institute of Tibet Plateau Research, China Academy of Sciences, Beijing) 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 several mineral-exploration companies.
- On-going collaboration with BHP Billiton (Dr Kathy Ehrig) and University of Tasmania (Prof Vadim Kamenetsky) looking for the evidence of younger magmatic events (e.g. Grenville-age event) in the magmatic evolution of the Gawler Craton, with a particular focus in the region around the giant Olympic Dam deposit.





Bill Griffin and participants in an international field trip to the Barberton Greenstone Belt, sponsored by the IPRCC.

- GEMOC established relationships with the newly established International Precambrian Research Centre of China (IPRCC), with Bill Griffin joining the Board. He also participated in an international field trip to the oldest rocks in southern Africa (the Barberton Greenstone Belt and surrounding areas of Swaziland, and the Limpopo Belt), led by Prof Alfred Kroener, and taught part of a Geochronology Workshop in Beijing, sponsored by the IPRCC.
- Formal visits to 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, Wuhan).

- A new collaborative research project was initiated with the Royal Holloway University of London, to look at the crustal evolution and geodynamic history of Southeast Asia. The preliminary results and new constraints on basement ages, granitic magmatism, and sediment provenance in the Malay Peninsula were presented at the European Geosciences Union General Assembly 2010, Vienna, Austria, 2–7 May, 2010 and accepted for publication in Gondwana Research. Another milestone was the submission of Inga Sevastjanova's PhD thesis; other students will begin in 2011.
- A new collaborative research project was started with Dr Sevetlana Bogdanova (Department of Earth and Ecosystems, Lund University, Sweden) looking at the Volgo-Uralia crustal segment, which is the least-known part of the East European Craton. Its crystalline crust is hidden beneath a thick Neoproterozoic to Phanerozoic cover but disclosed by thousands of drillings. In conjunction with the recent reflection seismic profile, this collaboration provided the first isotopic study of the Bakaly granitoid block in eastern Volgo-Uralia, which represents a subsurface section of the layered upper-middle crust. The outcomes of this project were presented at the 5th International Archaean Symposium (Perth) in September, 2010 and published in American Journal of Science (December, 2010).
- A field trip to the Balkan ophiolites of Serbia (Bill Griffin and Sue O'Reilly) has started a collaboration with Dr Nada Vaskovic, of Belgrade University, on the geochronology of these and related rocks.



Sue O'Reilly has started a collaboration with Dr Nada Vaskovic of Belgrade University, on the geochronology of Balkan granites - here with one of their samples.

GEMOC funding

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 Access MQ Limited
- 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 (http://www.auscope.org.au) award in the NCRIS round in 2007 and receives 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

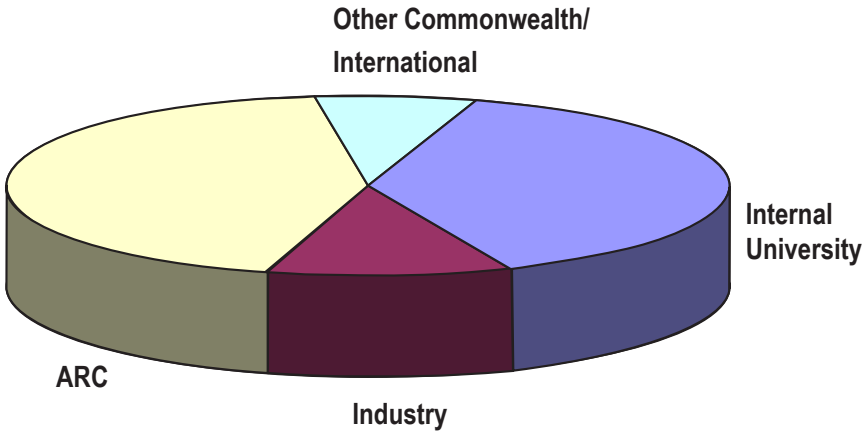
- Delivery of new exploration tools to industry through novel analytical methodologies
- Research and Development ventures with manufacturers leading to equipment replacement
- Applications to funding schemes for matching funds for new purchases and with partner co-investment
- Industry capital investment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

GEMOC INCOME 2010

This is a summary of 2010 income. A full, audited statement of detailed expenditure and income is prepared by Macquarie University. *No in-kind support is included here.*

	$K
ARC	
Discovery (including Fellowships), Linkage (Project and International), Federation Fellowships	1,466.0
OTHER COMMONWEALTH	
Postgraduate awards	75.0
NCRIS	188.2
INDUSTRY	
Collaborative Research grants (MUECRG industry components and direct industry)	45.0
External collaborative research projects and GLITTER through Access MQ	346.8
INTERNAL UNIVERSITY	
GAU maintenance (Department)	30.0
Internal competitive schemes	
Macquarie Fellowships	0
Matching to Other Commonwealth	50.0
Matching to ARC schemes	455.0
Research grants	171.1
Postgraduate awards	537.7
Postgraduate research grants	4.0
Capital Equipment	40.0
TOTAL	**3,408.7**

PIE-CHART OF INCOME SOURCES 2010



BENEFITS TO AUSTRALIA

- 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 2010/2011

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 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 Sandra Piazolo (Rock deformation and microstructures)

Dr Tracy Rushmer (Experimental rock deformation and experimental petrology, CoRE)

Dr Bruce Schaefer (Geodynamics, isotope geochemistry, CoRE)

Professor Simon Turner (Isotopic geochemistry, CoRE)

Dr Yingjie Yang (Geophysics/ seismology, CoRE)

Research Staff

Dr John Adam

Dr Jaques Batumike

Dr Elena Belousova

Dr Mei-Fei Chu

Dr John Caulfield

Dr Beverley Coldwell

Dr José María González-Jiménez

Emeritus Professor Trevor Green

Dr Heather Handley

Dr Daniel Howell

Dr Lev Natapov

Dr Michael Turner

Emeritus Professor John Veevers

Emeritus Professor Ron Vernon

Professional Staff

Ms Manal Bebbington (Rock preparation)

Mr Stephen Craven (Rock preparation)

Miss Cara Donnelly (Research Officer)

Dr Oliver Gaul (Research Officer)

Mr Felix Genske (Research Officer)

Dr Kevin Grant (Geochemist)

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

Dr Alan Kobussen (Research Associate)

Ms Jennie Linehan (Research Officer)

Dr Marek Locmelis (Research Officer)

Mrs Carol McMahon (Administrator)

Mr Luke Milan (Research Associate)

Miss Rosanna Murphy (Research Assistant)

Dr William Powell (Research Officer)

Dr Ayesha Saeed (Geochemist)

Mr Peter Wieland (Geochemist)

Adjunct Professors

Professor Bruce Chappell

Professor Mike Etheridge

Dr Richard Glen

Dr Jingfeng Guo

Dr Jon Hronsky

Professor Else-Ragnhild Neumann

Professor Xisheng Xu

Visiting Fellows

Associate Professor Ian Metcalfe

Dr Svetlana Tessalina

Dr Jianping Zheng

Honorary Associates

Dr Farida Ait-Hamou

Dr Olivier Alard

Professor Tom Andersen

Dr Debora Araujo

Dr Sonja Aulbach

Dr Graham Begg

Dr Christoph Beier

Dr Eloise Beyer

Dr Phillip L. Blevin

Professor Hannes Brueckner

Dr Robert Bultitude

Dr Gilles Chazot

Dr June Chevet

Professor Massimo Coltorti

Professor Kent Condie

Professor Jean-Yves Cottin

Dr Cara Donnelly

Dr Yoann Greau

Dr Michel Grégoire

Dr Bin Guo

Dr Jeff Harris

Dr Simon Jackson

Dr Bram Janse

Dr Mel Jones

Dr Felix Kaminsky

Dr Alan Kobussen

Dr Oliver Kreuzer

Dr Hans-Rudolf Kuhn

Dr Marek Locmelis

Dr Kreshimir Malitch

Dr Vlad Malkovets

Dr Claudio Marchesi

Dr Bertrand Moine

Dr Oded Navon

Dr Valeria Murgulov

Dr Geoff Nichols

Dr Yvette Poudjom Djomani

Dr Peter Robinson

Dr Chris Ryan

Dr Ayesh Saeed

Dr Giovanna Sapienza

Dr Stirling Shaw

Dr Simon Shee

Professor Thomas Stachel

Nancy van Wagoner

Dr Kuo-Lung Wang

Professor Xiang Wang

Dr Xiao-Lei Wang

Mr Yakov Weiss

Mr Bruce Wyatt

Dr Jin-Hui Yang

Dr Chunmei Yu

Professor Jin-Hai Yu

Dr Ming Zhang

FORMAL COLLABORATORS

University of Wollongong

Associate Professor Paul Carr (LIEF partner)

Professor Allan Chivas (DEST Systemic Infrastructure partner)

Victoria University of Wellington, New Zealand

Professor Joel Baker (LIEF partner)

University of Sydney

Professor G. Clarke (DEST Systemic Infrastructure partner; 2010 LIEF)

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

Dr Masahiko Honda (LIEF partner)

Professor Brian Kennett

Professor Gordon Lister

Professor Hugh O'Neill

PIRSA (South Australian Geological Survey)

Dr Anthony Reid

Mr Martin Fairclough

OTHER COLLABORATORS ON PROJECT BASIS

Professor Joel Baker (Victoria University, NZ)

Dr Christoph Beier (Erlangen, Germany)

Kim Berlo (McGill University, Canada)

Dr Bernard Bingen (Geological Survey of Norway, Trondheim)

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

Dr Costanza Bonadiman (University of Ferrara)

Professor Sun-Lin Chung (National Taiwan University)

Dr Yuriy Erinchek (VSEGEI)

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

Dr Julie Dickinson (Sydney University)

Professor Steve Grand (University of Texas at Austin)

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)

Dr Sune Nielsen (University of Oxford)

Professor Nick Petford (Bournemouth University, UK)

Professor Richard Price (Waikato University, NZ)

Professor Elisabetta Rampone (Genoa University, Genoa, Italy)

Professor Mark Reagan (University of Iowa, USA)

Dr Patrice Rey (University of Sydney)

Professor Marco Scambelluri (Genoa University, Genoa, Italy)

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

Dr Reimar Seltmann (Natural History Museum, London)

Professor Ian Smith (University of Auckland)

Dr Csaba Szabo (Eotvos University, Budapest)

Dr Qin Wang (Nanjing University)

Technology Partners

Agilent Technologies

Nu Instruments

Appendix 2: Publications 2010/2011

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

510. **Grant, K.J. and Wood, B.J.** 2010. Experimental study of the incorporation of Li, Sc, Al and other trace elements into olivine. *Geochimica et Cosmochimica Acta, 74, 2412-2428.*

581. **Portner, R.A., Daczko, N.R. and Dickinson, J.A.** 2010. Vitriclastic lithofacies from Macquarie Island (Southern Ocean): compositional influence on abyssal eruption explosivity in a dying Miocene spreading ridge. *Bulletin of Volcanology, 72, 165-183.*

601. **Kaminsky, F.V., Sablukov, S.M., Belousova, E.A., Andreazza, P., Tremblay, M. and Griffin, W.L.** 2010. Kimberlitic sources of super-deep diamonds in the Juina area, Mato Grosso State, Brazil. *Lithos, 114, 16-29.*

602. **Wang, K.L., O'Reilly, S.Y., Honda, M., Matsumoto, T., Griffin, W.L., Pearson, N.J. and Zhang, M.** 2010. Co-rich sulfides in mantle peridotites from Penghu Islands, Taiwan: footprints of Proterozoic mantle plumes under the Cathaysia Block. *Journal of Asian Earth Sciences, 37, 229-245.*

603. **Marchesi, C., Griffin, W.L., Garrido, C.J., Bodinier, J.-L., O'Reilly, S.Y. and Pearson, N.J.** 2010. Persistence of mantle lithospheric Re–Os signature during asthenospherization of the subcontinental lithospheric mantle: insights from *in situ* isotopic analysis of sulfides from the Ronda peridotite (Southern Spain). *Contributions to Mineralogy and Petrology, 159, 315-330.*

607. **Locmelis, M., Melcher, F. and Oberthuer, O.** 2010. Platinum-group element distribution in the oxidized Main Sulfide Zone, Great Dyke, Zimbabwe. *Mineralium Deposita, 45, 93-109.*

617. **Zheng, J.P., Griffin, W.L., Sun, M., O'Reilly, S.Y., Zhang, H.F., Zhou, H.W., Xiao, L., Tang, H.Y. and Zhang, Z.H.** 2010. Tectonic affinity of the West Qinling terrane (central China): North China or Yangtze? *Tectonics, 29, TC2009 doi:10.1029/2008TC002428.*

618. **Deckart, K., Godoy, E., Bertens, A., Jerez, D. and Saeed, A.** 2010. Barren Miocene granitoids in the Central Andean metallogenic belt, Chile: Geochemistry and Nd-Hf and U-Pb isotope systematics. *Andean Geology, 37, 1-31.*

619. **Wang, L., Griffin, W.L., Yu, J.-H. and O'Reilly, S.Y.** 2010. Precambrian crustal evolution of the Yangtze Block tracked by detrital zircons from Neoproterozoic sedimentary rocks. *Precambrian Research, 177, 131-144.*

620. **Malitch, K.N., Belousova, E.A., Griffin, W.L., Badanina, I.Y., Pearson, N.J., Presnyakov, S.L. and Tuganova, E.V.** 2010. Magmatic evolution of the ultramafic-mafic Kharaelakh intrusion (Siberian Craton, Russia): insights from trace-element, U-Pb and Hf-isotope data on zircon. *Contributions to Mineralogy and Petrology, 159, 753-768.*

621. **O'Neill, C. and Nimmo, F.** 2010. The role of episodic overturn in generating the surface geology and heat flow on Enceladus. *Nature Geoscience, 3, 88-91.*

622. **Afonso, J.C., Ranalli, G., Fernàndez, M., Griffin, W.L., O'Reilly, S.Y. and Faul, U.** 2010. On the Vp/Vs - Mg# correlation in mantle peridotites: implications for the identification of thermal and compositional anomalies in the upper mantle. *Earth and Planetary Science Letters, 289, 606-618.*

623. **Beier, C., Turner, S., Plank, T. and White, W.** 2010. A preliminary assessment of the symmetry of source composition and melting dynamics across the Azores plume. *Geochemistry, Geophysics, Geosystems, 11, Q02004, doi:10.1029/2009GC002833.*

624. **Jiménez-Munt, I., Fernàndez, M., Vergés, J., Afonso, J.C., Garcia-Castellanos, D. and Fullea, J.** 2010. The lithospheric structure of the Gorringe Bank: insights into its origin and tectonic evolution. *Tectonics, 29, TC5019, 16pp. doi:10.1029/2009TC002458.*

625. **Coltorti, M., Bonadiman, C., O'Reilly, S.Y., Griffin, W.L. and Pearson, N.J.** 2010. Buoyant ancient continental mantle embedded in oceanic lithosphere (Sal Island, Cape Verde Archipelago). *Lithos, 120, 23-233.*

626. **Hu, X., Jansa, L., Chen, L., Griffin, W.L., O'Reilly, S.Y. and Wang, J.** 2010. Provenance of Lower Cretaceous Wölong Volcaniclastics in the Tibetan Tethyan Himalaya: Implications for the final breakup of Eastern Gondwana. *Sedimentary Geology, 223, 193-205.*

627. **Fullea, J., Fernàndez, M., Afonso, J.C., Vergés, J. and Zeyen, H.** 2010. The structure and evolution of the lithosphere - asthenosphere boundarybeneath the Atlantic-Mediterranean Transition Region. *Lithos, 120, 74-95.*

628. **Howell, D., Wood, I.G., Dobson, D.P., Jones, A.P., Nasdala, L. and Harris, J.W.** 2010. Quantifying Strain Birefringence Halos Around Inclusions in Diamond. *Contributions to Mineralogy and Petrology, 160, 705-717.*

629. **Danis, C., Daczko, N., Lackie M. and Craven, S.** 2010. Retrograde metamorphism of the Wongwibinda Complex, New England Fold Belt and the implications of 2.5D subsurface geophysical structure for the metamorphic history. *Australian Journal of Earth Sciences, 57, 357-375.*

630. **Portner, R.A., Murphy, M.J. and Daczko, N.R.** 2011. A detrital record of lower oceanic crust exhumation within a Miocene slow-spreading ridge: Macquarie Island, Southern Ocean. *Geological Society of America Bulletin, 123, 255-273.*

631. **Li, W., Jackson, S.E., Pearson, N.J. and Graham, S.** 2010. Copper isotopic zonation in the Northparkes Porphyry Cu-Au deposit, SE Australia. *Geochimica et Cosmochimica Acta, 74, 4078-4096.*

632. **Brueckner, H.K., Carswell, D.A, Griffin, W.L, Medaris, Jr. L.G., Van Roermund, H.M.L. and Cuthbert, S.J.** 2010. The mantle and crustal evolution of two garnet peridotite suites from the Western Gneiss Region, Norwegian Caledonides: An isotopic investigation. *Lithos, 117, 1-9.*

633. **Danis, C., O'Neill, C. and Lackie, M.** 2010. Gunnedah basin 3D architechture and upper crustal temperatures. *Australian Journal of Earth Sciences, 57, 1-23.*

634. **Yang, J.-H., O'Reilly, S.Y., Walker, R.J., Griffin,W.L., Wu, F.-Y., Zhang, M. and Pearson, N.** 2010. Diachronous Decratonization of the Sino-Korean Craton: Geochemistry of Mantle Xenoliths from North Korea. *Geology, 38, 799-802.*

635. **O'Neill, C.J., Kobussen, A. and Lenardic, A.** 2010. The mechanics of continental lithosphere – asthenoshere coupling. *Lithos, 120, 55-62.*

636. **Shi, R.D., Griffin, W.L., O'Reilly, S.Y., Zhao, C.G., Huang, Q.S., Li, J. and Xu, J.F.** 2010. Evolution of the Lüliangshan garnet peridotites in the North Qaidam UHP belt, Northern Tibetan Plateau: Constraints from Re-Os isotopes. *Lithos, 117, 307-321.*

650. **O'Reilly, S.Y. and Griffin, W.L.** 2010. The continental lithosphere-asthenosphere boundary: Can we sample it? *Lithos, 120, 1-13.*

652. **Mints, M.V., Belousova, E.A., Konilov, A.N., Natapov, L.M., Shchipansky, A.A., Griffin, W.L., O'Reilly, S.Y., Dokukina, K.A. and Kaulina, T.V.** 2010. Mesoarchean Subduction Processes: 2.87 Ga eclogites from the Kola Peninsula, Russia. *Geology, 38, 739-742.*

653. **Beier, C., Turner, S.P., Sinton, J.M. and Gill, J.B.** 2010. Influence of subducted components on back-arc melting dynamics in the Manus Basin. *Geochemistry, Geophysics, Geosystems, 11, Q0AC03, doi:10.1029/2010GC003037*

654. **Kuznetsov, N.B., Natapov, L.M., Belousova, E.A., O'Reilly, S.Y. and Griffin, W.** 2010. Geochronological, geochemical and isotopic study of detrital zircon suites from late Neoproterozoic clastic strata along the NE margin of the East European Craton: Implications for plate tectonic models. *Gondwana Research, 17, 583-601.*

655. **Rege, S., Griffin, W.L., Pearson, N.J., Araujo, D., Zedgenizov, D. and O'Reilly, S.Y.** 2010. Trace-element patterns of fibrous and monocrystalline diamonds: insights into mantle fluids. *Lithos, 118, 313-337.*

656. **Turner, S., Sandiford, M., Reagan, M., Hawkesworth, C. and Hildreth, W.** 2010. Origins of large-volume, compositionally-zoned volcanic eruptions: new constraints from U-series isotopes and numerical thermal modeling for the 1912 Katmai-Novarupta eruption. *Journal of Geophysical Research, Solid Earth, 115, B12201, doi:10.1029/2009JB007195.*

657. **Tulloch, A.J., Ireland, T.R., Kimbrough, D.L., Griffin, W.L. and Ramezani, J.** 2011. Autochthonous inheritance of zircon through Cretaceous partial melting of Carboniferous plutons: the Arthur River Complex, Fiordland, New Zealand. *Contributions to Mineralogy and Petrology, 161, 401-421.*

658. **Ayarza, P., Palomeras, I., Carbonell, R., Afonso, J.C. and Simancas, F.** 2010. Wide-Angle Upper Mantle Reflector in SW Iberia: Some Constraints on its Nature. *Physics of the Earth and Planetary Interiors, 181, 88-102.*

659. **Afonso, J.C. and Zlotnik, S.** 2011. The subductability of continental lithosphere: the before and after story. In *Brown, D. and Ryan, P.D. (eds). Arc-Continental collision. Series: Frontiers in Earth Sciences 1st Edition., 2011, XII, 988 p. 200 illus. in color., Hardcover Springer, ISBN: 978-3-540-88557-3. (due June 2011)*

660. **Yu, J.-H., O'Reilly, S.Y., Wang, L., Griffin, W.L., Zhou, M.-F., Zhang, M. and Shu, L.** 2010. Components and Episodic growth of Precambrian crust in the Cathaysia Block, South China: evidence from U-Pb ages and Hf isotopes of zircons in Neoproterozoic sediments. *Precambrian Research, 181, 97-114.*

661. **Schaefer, B.F., Pearson, D.G., Rogers, N.W. and Barnicoat, A.C.** 2010. Re-Os isotope and PGE constraints on the timing and origin of gold mineralisation in the Witwatersrand Basin. *Chemical Geology, 276, 88-94.*

662. **Donnelly, C.L., Griffin, W.L., O'Reilly, S.Y., Pearson, N.J. and Shee, S.R.** 2011. The Kimberlites and related rocks of the Kuruman Kimberlite Province, Kaapvaal Craton, South Africa. *Contributions to Mineralogy and Petrology, 161, 351-371.*

663. **Porwal, A.K. and Kreuzer, O.P.** 2010. Introduction to the Special Issue: Mineral Prospectivity Analysis and Quantitative Resource Estimation. *Ore Geology Reviews, 38, 121-127.*

664. **Begg, G.C., Hronsky, J.A.M., Arndt, N.T., Griffin, W.L., O'Reilly, S.Y. and Hayward, N.** 2010. Lithospheric, cratonic, and geodynamic setting of Ni-Cu-PGE sulfide deposits. *Economic Geology, 105, 1057-1070.*

665. **Sevastjanova, I., Clements, B., Hall, R., Belousova, E.A., Griffin, W.L. and Pearson, N.** 2011. Granitic magmatism, basement ages, and provenance indicators in the Malay Peninsula: Insights from detrital zircon U-Pb and Hf-isotope data. *Gondwana Research, 19, 1024-1039.*

666. **O'Reilly, S.Y. and Griffin, W.L.** 2010. Rates of magma ascent: Constraints from mantle-derived xenoliths. In *Dosseto, A., Turner, S.P. and Van Orman, J.A. (eds) Timescales of Magmatic Processes: From Core to Atmosphere. Blackwell Publishing Ltd. SBN: 9781444332605, ISBN 10: 1444332600, Ch6, p116-124.*

667. **O'Neill, C. and Spiegelman, M.** 2010. Formulations for Simulating the Multiscale Physics of Magma Ascent. In *Dosseto, A., Turner, S.P. and Van Orman, J.A. (eds) Timescales of Magmatic Processes: From Core to Atmosphere. Blackwell Publishing Ltd. SBN: 9781444332605, ISBN 10: 1444332600, Ch 4 pgs 87-101.*

668. **Veevers, J.J. and Saeed, A.S.** 2011. Age and composition of Antarctic bedrock reflected by detrital zircons, erratics, and recycled microfossils in the Wilkes Land-Ross Sea-Marie Byrd Land sector (100° - 240° E). *Gondwana research.* (in press, corr. proof online)

669. **Turner, S.P. and Bourdon, B.** 2010. Melt transport from the mantle to the crust - Uranium-series isotopes. In, *Dosseto, A., Turner, S.P. and Van Orman, J.A. (eds), Timescales of magmatic processes: from core to atmosphere. Blackwell Publishing Ltd. SBN: 9781444332605, ISBN 10: 1444332600, Ch5, p102.*

670. **Dosseto, A. and Turner, S.P.** 2010. Magma cooling and differentiation - Uranium-series isotopes. In, *Dosseto, A., Turner, S.P. and Van Orman, J.A. (eds), Timescales of magmatic processes: from core to atmosphere. Blackwell Publishing Ltd SBN: 9781444332605, ISBN 10: 1444332600, Ch8, p160.*

671. **Belousova, E.A., Kostitsyn, Y.A., Griffin, W.L., Begg, G.C., O'Reilly, S.Y. and Pearson, N.J.** 2010. The growth of the continental crust: Constraints from zircon Hf-isotope data. *Lithos, 119, 457-466.*

672. **Wang, Q., Wyman, D.A., Lic, Z.-X., Sun, W., Chung, S.-L., Vasconcelos, P.M., Zhang, Q., Dong, H., Yu, Y., Pearson, N., Qiua, H., Zhu, T. and Feng, X.** 2010. Eocene north–south trending dikes in central Tibet: New constraints on the timing of east–west extension with implications for early plateau uplift? *Earth and Planetary Science Letters, 298, 205-216.*

673. **Adam, J. and Green, T.** 2011. Trace element partitioning between mica- and amphibole-bearing garnet lherzolite and hydrous basanitic melt: 2. Tasmanian Cainozoic basalts and the origins of intraplate basaltic magmas. *Contributions to Mineralogy and Petrology. DOI: 10.1007/s00410-010-0570-7* (online)

674. **Rushmer, T. and Knesel, K.** 2010. Defining Geochemical Signatures and Timescales of Melting Processes in the Crust: An Experimental Tale of Melt Segregation, Migration and Emplacement. In, *Dosseto, A., Turner, S.P. and Van Orman, J.A. (eds), Timescales of magmatic processes: from core to atmosphere. Blackwell Publishing Ltd. SBN: 9781444332605, ISBN 10: 1444332600, Published 29 Nov 2010 (USA), 19 Nov 2010 (ROW), Ch9, p181.*

675. **Daczko, N.R., Caffi, P. and Mann, P.** 2011. Structural evolution of the Dayman dome metamorphic core complex, eastern Papua New Guinea. *Geological Society of America Bulletin.* (in press)

676. **Marchesi, C., González-Jiménez, J.M., Gervilla, F., Garrido, C.J., Griffin, W.L., O'Reilly, S.Y., Proenza, J.A. and Pearson, N.J.** 2011. *In situ* Re-Os isotopic analysis of platinum-group minerals from the Mayarí-Cristal ophiolitic massif (Mayarí-Baracoa Ophiolitic Belt, eastern Cuba): implications for the origin of Os-isotope heterogeneities in podiform chromitites. *Contributions to Mineralogy and Petrology, 161, 977-990.*

677. **Alard, O., Lorand, J.-P., Laurie Reisberg, L., Bodinier, J.-L., Dautria, J.-M. and O'Reilly, S.Y.** 2011. Volatile-rich metasomatism in Montferrier xenoliths (southern France): consequences for Chalcophile and highly Siderophile element abundances in the sub-continental mantle. *Journal of Petrology.* (in press)

678. **Dadd, K.A.** 2011. Extension-related volcanism in the Middle to Late Devonian of the Lachlan Orogen: geochemistry of mafic rocks in the Comerong Volcanics. *Australian Journal of Earth Sciences, 59, 209-222.*

679. **Griffin, W.L., Begg, G.C., Dunn, D., O'Reilly, S.Y., Natapov, L.M. and Karlstrom, K.** 2011. Archean lithospheric mantle beneath Arkansas: continental growth by microcontinent accretion. *GSA Bulletin, doi: 10.1130/B30253.1* (in press, online)

680. **Zheng, J.P., Griffin, W.L., Li, L.S., O'Reilly, S.Y., Pearson, N.J., Tang, H.Y., Liu, G.L., Zhao, J.H., Yu, C.M. and Su, Y.P.** 2011. Highly evolved Archean basement beneath the western Cathaysia block, South China. *Geochimica et Cosmochimica Acta, 75, 242-255.*

681. **Konilov, A.N., Shchipansky, A.A., Mints, M.V., Dokukina, K.A., Kaulina, T.V., Bayanova, T.B., Natapov, L.N., Belousova, E.A., Griffin, W.L. and O'Reilly, S.Y.** 2011. UHPM: The Salma eclogites from the Belomorian Province, Russia: evidence for HP/UH metamorphism through the subduction of the Mesoarchean oceanic crust. In *(eds) L. Dobrzhinetskaya, S.W. Faryad, S. Wallis and S. Cuthbert. 25 years after the discovery of Coesite and Diamond, 696pp Elsevier ISBN: 0123851440, p.623-670.*

682. **Adams, C.J., Mortimer, N., Campbell, H.J. and Griffin, W.L.** 2011. Continuation of the Kaweka terrane into northern South Island, New Zealand: preliminary evidence from Rb-Sr metamorphic and U-Pb detrital zircon ages. *New Zealand Journal of Geology and Geophysics.* (in press)

683. **Martin, L.A.J., Ballèvre, M., Boulvais, P., Halfpenny, A., Vanderhaeghe, O., Duchêne, S. and Deloule, E.** 2011. Garnet re-equilibration by coupled dissolution-reprecipitation: Evidence from textural, major element and oxygen isotope zoning of "cloudy" garnet. *Journal of Metamorphic Geology, 29, 213-231.*

684. **Martin, L.A.J., Wood, B., Turner, S. and Rushmer, T.** 2011. Experimental measurements of trace element partitioning between lawsonite, zoisite and fluid and their implication for the composition of arc magmas. *Journal of Petrology.* (in press)

685. **Heimann, A., Spry, P.G., Teale, G.S., Conor, C.H.H. and Pearson, N.J.** 2011. The composition of garnet in garnet-rich rocks in the southern Proterozoic Curnamona Province, Australia: an indicator of the premetamorphic physicochemical conditions of formation. *Mineralogy and Petrology, 101, 49-74.*

686. **O'Reilly, S.Y., Afonso, J.C., Griffin, W.L. and van der Lee, S.** 2010. Preface. *Lithos, 120, vii-viii.*

687. **Bonadiman, C., Coltorti, M., Beccaluva, L., Griffin, W.L., O'Reilly, S.Y. and Siena, F.** 2011. Metasomatism vs host magma infiltration: a case study of Sal mantle xenoliths, Cape Verde Archipelago. *GSA Special Volume "Volcanism and Evolution of the African Lithosphere".* (in press)

688. **Melchiorre, M., Coltorti, M., Bonadiman, C., Faccini, B., O'Reilly, S.Y. and Pearson, N.J.** 2011. The role of eclogite in the rift-related metasomatism and Cenozoic magmatism of Northern Victoria Land, Antarctica. *Lithos. DOI: 10.1016/j.lithos.2010.11.012* (in press, corr. proof online)

689. **Portner, R.A., Dickinson, J.A. and Daczko, N.R.** 2011. Gravity flow interaction with a rugged mid-ocean ridge seafloor: an outcrop example from Macquarie Island. *Journal of Sedimentary Research, 81, 355-375.*

690. **Danis, C.** 2011. Deep 3D structure of the Sydney Basin using geophysical modeling. *Australian Journal of Earth Sciences.* (in press)

691. **Pankhurst, M.J., Schaefer, B F., Betts, P.G.** 2011. Geodynamics of rapid voluminous felsic magmatism through time. *Lithos. doi:10.1016/j.lithos.2010.11.014.* (online corr proof)

692. **Kirkland, C.L., Bingen, B., Whitehouse, M.J., Beyer, E. and Griffin, W.L.** 2011. Neoproterozoic palaeogeography in the North Atlantic Region: inferences from the Akkajaure and Seve Nappes of the Scandinavian Caledonides. *Precambrian Research, 186, 127-146.*

693. **Glen, R.A., Saeed, A., Quinn, C.D. and Griffin, W.L.** 2011. U–Pb and Hf isotope data from zircons in the Macquarie Arc, Lachlan Orogen: Implications for arc evolution and Ordovician palaeogeography along part of the east Gondwana margin. *Gondwana Research, 19, 670-685.*

694. **Schinella, E., O'Neill, C. and Afonso, J.C.** 2011. Processes forming volcanic topography at Atla Regio, Venus. *Reviewed conference proceedings of the 10th Australian Space Science Conference 2010.* (in press)

695. **Dadd, K.A., Locmelis, M., Higgins, K., Hashimoto, R. and Daniell, J.** 2011. Cenozoic volcanism of the Capel-Faust Basins, Lord Howe Rise, SW Pacific Ocean. *Deep-Sea Research Part II, 58, 922-932.*

696. **Andersen, T., Saeed, A., Gabrielsen, R.H. and Olaussen, S.** 2011. Provenance characteristics of the Brumunddal sandstone in the Oslo Rift derived from U-Pb, Lu-Hf and trace element analyses of detrital zircons by laser ablation ICMPS. *Norwegian Journal of Geology.* (in press)

697. **Shiryaev, A.A., Griffin, W.L. and Stoyanov, E.** 2011. Moissanite (SiC) from kimberlites: polytypes, tracelements, inclusions and speculations on origin. *Lithos, 122, 152-164.*

698. **Brown, D., Ryan, P., Afonso, J.C., Boutelier, D., Burg, J.P., Byrne, T., Calvert, A., Cook, F., DeBari, S., Dewey, J.F., Gerya, T.V., Harris, R., Herrington, R., Konstantinovskaya, E., Reston, T. and Zagorevski, A.** 2011. Arc-continent collision: The making of an orogeny. In: *Brown, D. and Ryan, P. (eds), Arc-continent collision, Springer's series Frontiers in Earth Sciences, Berlin.* (in press)

699. **Turner, S., Beier, C., Niu, Y. and Cook, C.** 2011. U-Th-Ra disequilibria and the extent of off-axis volcanism across the East Pacific Rise at 9°30'N, 10°30'N and 11°20'N. *Geochemistry, Geophysics, Geosystems. doi:10.1029/2010GC003403* (in press)

700. **Rushmer, T. and Petford, N.** 2011. Microsegregation rates of liquid Fe-Ni-S metal in natural silicate-metal systems: A combined experimental and numerical study. *Geochemistry, Geophysics, Geosystems, 12, Q03014, 17pp. doi:10.1029/2010GC003413.*

701. **Yang, Y., Shen, W. and Ritzwoller, M.H.** 2011. Surface wave tomography on a large-scale seismic array combining ambient noise and teleseismic earthquake data. *Earthquake Science 24, 55-64.*

702. **Yang, Y., Ritzwoller, M. H. and Jones, C.H.** 2011. Subsurface Characterization of the Coso Geothermal Field and Surroundings by Ambient Noise Tomography. *Geochemistry, Geophysics, Geosystems, doi:10.1029/2010GC003362, 2011.* (in press)

703. **Handley, H.K., Turner, S., Macpherson, C.G., Gertisser, R. and Davidson, J.P.** 2011. Hf-Nd isotope and trace element constraints on subduction inputs at island arcs: limitations of Hf anomalies as sediment input indicators. *Earth and Planetary Science Letters, 304, 212-223.*

704. **Zack, T., Stockli, D., Luvizotto, G.L., Barth, M.G., Belousova, E., Wolfe, M.R. and Hinton, R.W.** 2011. *In situ* U–Pb rutile dating by LA-ICP-MS: ^{208}Pb correction and prospects for geological applications. *Contributions to Mineralogy and Petrology. (in press)*

705. **González-Jiménez, J.M., Proenza, J.A., Gervilla, F., Melgarejo, J.C., Blanco-Moreno, J.A. and Ruiz-Sánchez, R.** 2011. High-Cr and high-Al chromitites from the Sagua de Tánamo district, Mayarí-Cristal Ophiolitic Massif (eastern Cuba): constraints on their origin from mineralogy and geochemistry of chromian spinel and platinum-group elements. *Lithos, 125, 101-121.*

706. **McGee, L.E., Beier, C., Smith, I.E.M. and Turner, S.P.** 2011. Dynamics of melting beneath a small-scale basaltic system: a U-Th–Ra study from Rangitoto volcano, Auckland volcanic field, New Zealand. *Contributions to Mineralogy and Petrology.* (in press, online)

707. **Barnes, S.J., Godel, B.M., Locmelis, M., Fiorentini, M.L. and Ryan, C.G.** 2011. Extremely Ni-rich Fe-Ni sulphide assemblages in komatiitic dunite at Betheno, Western Australia: results from synchrotron X-ray fluorescence mapping. *Australian Journal of Earth Sciences.* (in press, online)

708. **Coldwell, B., Adam, J., Rushmer, T. and Macpherson, C.** 2011. Evolution of the East Philippine Arc: Experimental constraints on magmatic phase relations and adakitic melt formation. *Contributions to Mineraology and Petrology.* (in press, online)

709. **Johnson, S.P., Sheppard, S., Rasmussen, B., Wingate, M.T.D., Kirkland, C.L., Muhling, J.R., Fletcher, I.R. and Belousova, E.** 2010. The Glenburgh Orogeny as a record of Paleoproterozoic continent–continent collision. *Geological Survey of Western Australia, Record 2010/5, 54p. (available online at http://www.dmp.wa.gov.au/GSWApublications)/.*

710. **Nasir, S., Al-Khirbash, S., Rollinson, H., Al-Harthy, A., Al-Sayigh, A., Al-Lazki, A., Theye, T., Massonne, H.-J., Belousova, E.** 2011. Petrogenesis of early cretaceous carbonatite and ultramafic lamprophyres in a diatreme in the Batain Nappes, Eastern Oman continental margin. *Contributions to Mineralogy and Petrology, 161, 47–74.*

711. **Wang, X., Chen, J. Griffin, W.L., O'Reilly, S.Y., Huang, P.Y. and Li, X.** 2011. Two stage zircon crystallization in the Jingshan monzogranite, Bengbu Uplift: Implications for the syn-collisional granites of the Dabie-Sulu UHP orogenic belt and the climax of movement on the Tan-Lu fault. *Lithos, 122, 201-213.*

712. **Bogdanova, S., De Waele, B., Bibikova, E.V., Belousova, E.A., Postnikov, A.V., Fedotova, A.A. and Popov, L.P.** 2011. The first U-Pb, Lu-Hf and Sm-Nd isotopic evidence of preserved Paleoarchean crust. *American Journal of Science.* (in press)

713. **Phillips, G., Landenberger, B., Belousova, E.A.** 2011. Building the New England Batholith, eastern Australia—Linking granite petrogenesis with geodynamic setting using Hf isotopes in zircon. *Lithos.* (in press)

714. **Howard, K.E., Hand, M., Barovich, K.M., Payne, J. and Belousova, E.A.** 2011. U-Pb, Lu-Hf and Sm-Nd isotopic constraints on provenance and depositional timing of metasedimentary rocks in the western Gawler Craton: Implications for Proterozoic reconstruction models. *Precambrian Research, 184, 43-62.*

715. **Villaseca, C., Orejana, D., Belousova, E.A., Armstrong, R.A., Pérez-Soba, C. and Jeffries, T.E.** 2011. U–Pb isotopic ages and Hf isotope composition of zircons in Variscan gabbros from central Spain: evidence of variable crustal contamination. *Mineralogy and Petrology, 101, 151-167.*

716. **Murgulov, V., Griffin, W.L. and O'Reilly, S.Y.** 2011. Lithospheric mantle evolution beneath northeast Australia. *Lithos, 125, 405-422.*

717. **Xiong, Q., Zheng, J., Griffin, W.L., O'Reilly, S.Y. and Zhao, J.** 2011. Zircons in the Shenglikou ultrahigh-pressure garnet peridotite massif and its country rocks from the North Qaidam terrane (western China): Meso-Neoproterozoic crust-mantle coupling events and early Paleozoic convergent plate-margin processes. *Precambrian Research*. (in press)

718. **Szpunar, M., Hand, M., Barovich, K., Belousova, E. and Jagodzinski, E.** 2011. Isotopic and geochemical constraints on the Paleoproterozoic Hutchison Group, southern Australia: implications for Paleoproterozoic continental reconstructions. *Precambrian Research*. (in press)

719. **Caulfield, J.T., Cronin, S.J., Turner, S.P. and Cooper, L.B.** 2011. Mafic Plinian Volcanism and Ignimbrite Emplacement at Tofua Volcano, Tonga. *Bulletin of Volcanology*. (in press)

720. **Malitch, K.N., Badanina, I.Yu., Belousova, E.A. and Tuganova, E.V.** 2011. Results of U-Pb dating of zircon and baddeleyite from the Norolsk-1 ultramafic-mafic intrusion (Russia). *Geology and Geophysics (in Russian)*. (in press)

721. **Villaseca, C. Belousova, E., Orejana, D., Castiñeiras, P. and Pérez-Soba, C.** 2011. Presence of Palaeoproterozoic and Archean components in the granulite-facies rocks of central Iberia: The Hf isotopic evidence. *Precambrian Research, 187, 143-154*.

722. **Locmelis, M., Pearson, N.J., Barnes, S.J. and Fiorentini, M.L.** 2011. Ruthenium in komatiitic chromite. *Geochimica and Cosmochimica Acta*. (in press)

723. **Pankhurst, M.J., Schaefer, B.F., Betts, P.G., Phillips, N. and Hand, M.** 2011. A Mesoproterozoic continental floor rhyolite province: An end member example of the Large Igneous Province clan. *Solid Earth*. (in press)

724. **González-Jiménez, J.M., Augé, T., Gervilla, F., Bailly, L., Proenza, J.A. and Griffin, W.L.** 2011. Mineralogy and geochemistry of platinum-rich chromitites from the mantle-crust transition zone at Ouen Island, New Caledonia Ophiolite. *The Canadian Mineralogist*. (in press)

725. **Collins, W.J., Belousova, E.A., Kemp, A.I.S. and Murphy, J.B.** 2011. Two contrasting Phanerozoic orogenic systems revealed by hafnium isotope data. *Nature Geoscience, 4, 333-337*.

726. **Konilov, A.N., Shchipansky, A.A., Mints, M.V., Dokukina, K.A., Kaulina, T.V., Bayanova, T.B., Natapov, L.M., Belousova, E.A., Griffin, W.L. and O'Reilly, S.Y.** 2011. The Salma eclogites of the Belomorian Province, Russia: HP/UHP metamorphism through the subduction of Mesoarchean oceanic Crust. In *Dobrzhinetskaya, L. E., Faryad, S.W., Wallis, S. and Cuthbert, S. (eds.) Ultrahigh-Pressure Metamorphism. Elsevier, Amsterdam, pp. 623-664*.

727. **Aulbach, S., O'Reilly, S.Y. and Pearson, N.J.** 2011. Eclogite and MARID xenoliths: origins of mantle Zr/Hf–Nb/Ta variability. *Contributions to Mineralogy and Petrology*. (in press)

728. **Wang, L.-J., Yu, J.-H., Griffin, W.L. and O'Reilly, S.Y.** 2011. Early crustal evolution in the western Yangtze Block: Evidence from U-Pb and Lu-Hf isotopes on detrital zircons from sedimentary rocks. *Precambrian Research*. (in press)

729. **Craven, S.J., Daczko, N.R. and Halpin, J.A.** 2011. Thermal gradient and timing of high-T—low-P metamorphism in the Wongwibinda Metamorphic Complex, southern New England Orogen, Australia. *Journal of Metamorphic Geology*. (in press)

730. **Chu, M.-F., Chung, S.-L., O'Reilly, S.Y., Pearson, N.J., Wu, F.-Y., Li, X.-H., Liu, D., Ji, J., Chu, C-H and Lee, H.-Y.** 2011. India's hidden inputs to Tibetan Orogeny revealed by Hf Isotopes of Transhimalayan zircons and host rocks. *Earth and Planetry Science Letters*. 10.1016/j.epsl.2011.05.020

731. **Morag, N., Avigad, D., Gerdes, A., Belousova, E. and Harlavan, Y.** 2011. Detrital zircon Hf isotopic composition indicates long-distance transport of north Gondwana Cambro-Ordovician sandstones. *Geology*. (in press)

732. **Maher, K.C., Jackson, S. and Mountain, B.** 2011. Experimental evaluation of the fluid-mineral fractionation of Cu isotopes at 250° and 300° C. *Chemical Geology*. (in press)

733. **Armit, R.A., Betts, P.G. and Schaefer, B.F.** 2010. Lu-Hf isotopic characteristics of the marginal terranes of the northern Gawler Craton. In: *Korsch, R.J. and Kotiscin, N., editors, GOMA Seismic and MT workshop 2010. Geoscience Australia, Record, 2010/39, 118-127*.

734. **Dosseto, A., Turner, S.P., Costa, F. and Van Orman, J.** 2010. Introduction to the Timescales of Magmatic Processes in the Crust: An Experimental Tale of Melt Segregation, Migration and Emplacement. In, *Dosseto, A., Turner, S.P. and Van Orman, J.A. (eds), Timescales of magmatic processes: from core to atmosphere. Blackwell Publishing Ltd. , p 1-8*.

735. **Wood, B.J. and Halliday, A.N.** 2010. The lead isotopic age of the Earth can be explained by core formation alone. *Nature, 465, 767–770*.

736. **Betts, P.G., Armit, R., Baines, G., Giles, D. and Schaefer, B.F.** 2010. Crustal boundaries of the marginal terranes of the northern Gawler Craton. In: *Korsch, R.J. and Kotiscin, N., editors, GOMA Seismic and MT workshop 2010. Geoscience Australia, Record, 2010/39, 128-137*.

737. **Bielik, M., Alasonati-Tasarova, Z., Zeyen, H., Dererova, J., Afonso, J.C. and Csicsay, K.** 2010. Improved Geophysical Image of the Carpathian-Pannonian Basin Region. *Acta Geodaetica et Geophysica Hungarica, 45, 284-298.*

738. **Berlo, K. and Turner, S.P.** 2010. ^{210}Pb- ^{226}Ra disequilibria in volcanic rocks. *Earth and Planetary Science Letters, 296, 155-164.*

739. **Chernicoff, C.C., Zappettini, E.O., Santos, J.O.S., Allchurch, S. and McNaughton, N.J.** 2010. The southern segment of the Famatinian magmatic arc, La Pampa Province, Argentina. *Gondwana Research, 17, 662-675.*

740. **Chevet, J., Grégoire, M. and Maaloe, S.** 2010. Composite xenoliths from Spitsbergen: Evidence of the circulation of MORB-related melts within the upper mantle. *Geological Society Special Publication, 337, 71-86.*

741. **Wang, X., Griffin, W.L. and Chen, J.** 2010. Hf contents and Zr/Hf ratios in granitic zircons. *Geochemical Journal, 44, 65-72.*

742. **Clarke, G.L., Fitzherbert, J.A., Milan, L.A., Daczko, N.R. and Degeling, H.S.** 2010. Anti-clockwise P-T paths in the lower crust: An example from a kyanite-bearing regional aureole, George Sound, New Zealand. *Journal Of Metamorphic Geology 28, 77-96.*

743. **Condie, K. and O'Neill, C.** 2010. The Archean-Proterozoic boundary: 500 My of Tectonic transition in Earth history. *American Journal of Science 310, 775-790.*

744. **Mints, M., Konilov, A., Dokukina, K., Kaulina, T., Belousova, E., Natapov, L., Griffin, W. and O'Reilly, S.** 2010. The Belomorian eclogite province: Unique evidence of Meso-Neoarchaean subduction and collision. *Doklady Earth Sciences, 434, 1311-1316.*

745. **Dosseto, A., Hesse, P.P., Maher, K., Fryirs, K. and Turner, S.** 2010. Climate and vegetation control on sediment dynamics during the last glacial cycle. *Geology, 38, 395-398.*

746. **Fernàndez, M., Afonso, J.C. and Ranalli, G.** 2010. The deep lithospheric structure of the Namibian volcanic margin. *Tectonophysics, 481, 68-81.*

747. **Kuznetsov, N.B., Natapov, L.M., Belousova, E.A., O'Reilly, S.Y. and Griffin, W.** 2010. Geochronological, geochemical and isotopic study of detrital zircon suites from late Neoproterozoic clastic strata along the NE margin of the East European Craton: Implications for plate tectonic models. *Gondwana Research, 17, 583-601.*

748. **Tack, L., Wingate, M.T.D., De Waele, B., Meert, B.J., Belousova, E., Griffin, W.L., Tahon, A. and Fernandez-Alonso, M.** 2010. The 1375 Ma "Kibaran event" in Central Africa: Prominent emplacement of bimodal magmatism under extensional regime. *Precambrian Research, 180, 63-84.*

749. **Metcalf, I. and Riley, N.J.** 2010. Conodont colour and alteration patterns in the Carbiniferous of the Craven Basin and adjacent areas, northern England. *Proceedings of the Yorkshire Geological Society, 58, 1-8.*

750. **Price, R., Turner, S., Cook, C., Hobden, B., Smith, I., Gamble, J., Handley, H., Maas, R. and Mobis, A.** 2010. Crustal and mantle influences and U-Th-Ra disequilibrium in andesitic lavas of Ngauruhoe volcano, New Zealand. *Chemical Geology, 277, 355-373.*

751. **Su, Y., Zheng, J., Griffin, W.L., Tang, H., O'Reilly, S. and Lin, X.** 2010. Zircon U-Pb and Hf isotopes of volcanic rocks from the Batamayineishan Formation in the eastern Junggar Basin. *Chinese Science Bulletin, 55, 4150-4161.*

753. **Heimann, A., Spry, P., Teale, G., Conor, C. and Pearson, N.** 2011. The composition of garnet in garnet-rich rocks in the southern Proterozoic Curnamona Province, Australia: an indicator of the premetamorphic physicochemical conditions of formation. *Mineralogy and Petrology, 1-26.* (online)

Appendix 3: Visitors/GAU users

GEMOC VISITORS 2010
(Excluding Participants in Conferences and Workshops)
Macquarie

Dr Ahmadjan Abduriyium (Chief Research Scientist, GAAJ-ZENHOKYO Research Laboratory, Tokyo, Japan)

Dr Olivier Alard (Geosciences, UMR 5243-CC60, of Montpellier 2, Montpellier, France)

Dr Graham Begg (Minerals Targeting International Pty Ltd, West Perth)

Dr Phillip Blevin (Department of Primary Industries NSW Government)

Prof Nikolay S Bortnikov (Russian Academy of Sciences, Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry, Moscow, Russia)

Mr Rex Brommecker (Barrick Gold of Australia)

Ms Chia-Ju Chieh (Department of Geosciences, National Taiwan University)

Dr Shane Cronin (Massey University, New Zealand)

Assoc Prof Ulrich Faul (Department Earth Sciences, Boston University MA, USA)

Dr Nick Fisher (ValueMetrics Australia, North Sydney, Australia)

Dr Nicolas Flament (School of Geosciences, University of Sydney)

Prof Jerome Friedman (Stanford, CA, USA)

Mr Fred Fryer (Agilent Technologies Australia)

Dr Javier Fullea Urchulutegui (Geophysics section, School of Cosmic Physics, Dublin Institute for Advanced Studies, Dublin, Ireland)

Dr Carmen Gaina (Geological Survey of Norway (NGU), Norway)

Ms Sarah Gilbert (CODES CoE, University of Tasmania, Hobart)

Dr Richard Glen (Department of Primary Industries, NSW Government)

Dr Jeff Harris (School of Geographical and Earth Sciences, University of Glasgow, UK)

Dr Michael Hotchkis (Australian Nuclear Science and Technology Organisation)

Dr Tsuyoshi Iizuka (Research School of Earth Sciences, Australian National University)

Prof Trevor Ireland (Research School of Earth Sciences, Australian National University)

Dr Dorrit Jacob (Department of Geosciences and Earth System, Science Research Centre, Johannes Gutenberg-Universität, Mainz, Germany)

Prof Vadim Kamenetsky (CODES CoE in Ore Deposits, University of Tasmania, Hobart)

Dr Thomas Landgrebe (University of Sydney)

Dr James Lee (Department of Geological Sciences and Geological Engineering, Queen's University, Ontario, Canada)

Dr Chuan-Zhou Liu (CAS)

Mr Yongjun Lu (Centre for Exploration Targeting, University of Western Australia, Crawley, WA)

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

Dr Guilherme Malmann (Research School of Earth Sciences, Australian National University)

Mr Toshifumi Matsuzaki (ICP-MS Business Manager, Agilent Technologies International Japan Ltd., Tokyo)

Prof Hugh O'Neill (Research School of Earth Sciences, Australian National University)

Prof Andrew Putnis (Institut für Mineralogie, Universtität Münster, Germany)

Dr Christine Putnis (Institut für Mineralogie, Universtität Münster, Germany)

Prof Mark Reagan (University of Iowa, USA)

Mr Cameron Ricketts (Department of Primary Industries, NSW Government)

Dr David Robson (Department of Primary Industries, NSW Government)

Dr Nic Rosengren (Minerals Exploration, BHP Billiton, Singapore)

Assoc Prof Claire Samson (Department of Earth Sciences, Carleton University)

Prof Ian Smith (University of Auckland, New Zealand)

Dr Zdislav Spetsius (NIGP, Alrosa Co Ltd, Yakutia, Russia)

Dr Carlos Villaseca Gonzalez (Dpto. Petrologia y Geioquimica. Faultad CC Geologicas, Centro Mixto U.C.M. – C.S.I.C., Universidad Complutense de Madrid, Spain)

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

Mr John Watkins (Department of Primary Industries, NSW Government)

Prof Xisheng Xu (Nanjing University, Nanjing, PR China)

Prof Jinhai Yu (Nanjing University, Nanjing, PR China)

Prof Jianping Zheng (State Key Lab of Geological Process and Mineral, Resources, Faculty of Earth Sciences, China University of Geosciences, Wuhan, PR China)

Dr Horst Zwingmann (CSIRO Earth Science and Resource Engineering, and University of Western Australia, Perth)

EXTERNAL USERS OF THE GEOCHEMICAL ANALYSIS UNIT FACILITIES IN 2010

(Note: this does not include contract work through Access MQ)

Dr Ahmadjan Abduriyium (Chief Research Scientist, GAAJ-ZENHOKYO Research Laboratory, Tokyo, Japan)

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

Mr Sarmad Ali (The School of Earth and Environmental Sciences, University of Wollongong)

Mr Robin Armit (School of Geosciences, Monash University)

Dr Christoph Beier (GeoZentrum Nordbayern, Universität Erlangen-Nürnberg, Erlangen, Germany)

Ms Chia-Ju Chieh (Department of Geosciences, National Taiwan University)

Dr Anthony Dosseto (School of Earth and Environmental Sciences, University of Wollongong)

Ms Sarah Gilbert (CODES CoE, University of Tasmania, Hobart)

Ms Carissa Isaacs (Centre for Exploration Targeting, School of Earth and Geographical Sciences, University of Western Australia)

Dr Chuan-Zhou Liu (CAS)

Mr Yongjun Lu (Centre for Exploration Targeting, School of Earth and Geographical Sciences, University of Western Australia)

Ms Lucy Magee (School of Environment, The University of Auckland, NZ)

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

Prof Neal McNaughton (Department of Imaging and Applied Physics, Faculty of Science and Engineering, School of Science, Curtin University)

David Mole (Centre for Exploration Targeting, School of Earth and Geographical Sciences, University of Western Australia)

Dr Zdislav Spetsius (Chief of Laboratory, Geology of Diamond Deposits, NIGP, Alrosa Co Ltd, Yakutia, Russia)

Ms Sonja Storm (School of Environment, The University of Auckland, NZ)

Dr Carlos Villaseca Gonzalez (Dpto. Petrologia y Geioquimica. Faultad CC Geologicas, Centro Mixto U.C.M. – C.S.I.C., Universidad Complutense de Madrid, Spain)

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

Ms Tin Tin Win

Ms Ailsa Woodhouse (University of Adelaide and PIRSA)

Prof Jinhai Yu (Nanjing University, PR China)

Prof Jianping Zheng (Faculty of Earth Sciences, China University of Geosciences, PR China)

Appendix 4: Abstract titles

TITLES OF ABSTRACTS FOR CONFERENCE PRESENTATIONS IN 2010

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

29TH NORDIC GEOLOGICAL WINTER MEETING, OSLO, 11-13 JANUARY 2010

Provenance characteristics of the Brumunddal sandstone in the Oslo Rift derived from U-Pb, Lu-Hf and trace element analyses of detrital zircons by laser ablation ICPMS
T. Andersen[1], A. Saeed[2], R.H. Gabrielsen[1] and S. Olaussen[3]
1. Department of Geosciences, University of Oslo, Norway, 2. GEMOC Macquarie, 3. Eni Norge AS. Stavanger, Norway

SGTSG 2010 SPECIALIST GROUP IN TECTONICS AND STRUCTURAL GEOLOGY CONFERENCE 2010, PORT MACQUARIE, NSW, 1-5 FEBRUARY 2010

Structural evolution of the Dayman Dome Metamorphic Core Complex, eastern Papua New Guinea
N.R. Daczko[1], P. Caffi[1], J.A. Halpin[1,2] and P. Mann[3]
1. GEMOC, Macquarie, 2. ARC Centre of Excellence in Ore Deposits, University of Tasmania, 3. Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, USA

The Mesoproterozoic transition in Australia: Arcs, plumes, and continental break-up?
P.G. Betts[1], D. Giles[2], J.R Stewart[1], B.F. Schaefer[3] and N. Chalmers[4,1]
1. School of Geosciences, Monash University, VIC, Australia, 2. Tectonics, Resources and Exploration (TRaX), School of Earth and Environmental Sciences, University of Adelaide, Australia, 3. GEMOC, Macquarie, 4. Marmot Resources, SA, Australia

The Wongwibinda Complex: A HTLP metamorphic terrain
S.J. Craven and N.R. Daczko
GEMOC, Macquarie

Unraveling a protracted history in the hot seat: Charnockitic magmatism in the Proterozoic Rayner Orogen, East Antarctica
J.A. Halpin[1,2], L.A. Milan[1], N.R. Daczko[1] and G.L. Clarke[3]
1. GEMOC, Macquarie, 2. ARC Centre of Excellence in Ore Deposits, University of Tasmania, Australia, 3. School of Geosciences, The University of Sydney, Australia

Provenance of metasedimentary rocks in the western Gawler Craton: Geochemical, zircon U-Pb, Lu-Hf and whole-rock Sm-Nd isotopic constraints
K.E. Howard[1], M. Hand[1], K. Barovich[1] and E. Belousova[2]
1. Centre for Tectonics, Resources and Mineral Exploration, University of Adelaide, Australia, 2. GEMOC, Macquarie

Provenance of Late Palaeoproterozoic cover sequences in the central eastern Gawler Craton: Exploring stratigraphic correlations with Curnamona and Mt Isa using detrital zircon, zircon Hf and Nd isotopic data
K.E. Howard[1], M. Hand[1], K. Barovich[1], A. Lambeck[2] and E. Belousova[3]
1. Centre for Tectonics, Resources and Mineral Exploration, University of Adelaide, Australia, 2. Geoscience Australia, ACT, 3. GEMOC, Macquarie

U-Pb zircon, zircon Hf and whole-rock Sm-Nd isotopic constraints on the evolution of Palaeoproterozoic rocks in the northern Gawler Craton
K.E. Howard[1], M. Hand[1], K. Barovich[1], J. Payne[1,2] and E. Belousova[3]
1. Centre for Tectonics, Resources and Mineral Exploration, University of Adelaide, Australia, 2. GEMOC, Macquarie

The old and the new - A cryptic record of contrasting lithospheric evolutions in central Australia
A.J. Woodhouse[1,2], M. Hand[1], K. Barovich[1], E. Belousova[3], E. Jagodzinski[2] and M. Wingate[4]
1. Centre for Tectonics, Resources and Exploration (TRaX), University of Adelaide, Australia, 2. Department of Primary Industries and Resources of South Australia (PIRSA), Geological Survey Branch, Adelaide, Australia, 3. GEMOC, Macquarie, 4. Department of Mines and Petroleum, Geological Survey of Western Australia, Perth, Australia

THE GEOLOGICAL SOCIETY OF NORTH AMERICA JOINT SECTION MEETING GSA NORTH-CENTRAL AND SOUTH-CENTRAL SECTIONS BOTH CELEBRATING THEIR 44TH ANNUAL MEETING. GSA NORTH-CENTRAL/ SOUTH-CENTRAL, BRANSON, MISSOURI, 11-13 APRIL 2010

Early Mesoproterozoic (1.5-1.3 ga) magmatic and tectonic evolution of the SE Laurentian Cratonic Margin: implications of U-Pb, Sm-Nd, and Lu-Hf data
M.E. Bickford[1], K.E. Karlstrom[2], W.R. Van Schmus[3], P.A. Mueller[4], W.L. Griffin[5], G.D. Kamenov[4], G.C. Begg[5] and E. Belousova[5]
1. Earth Sciences, Syracuse University, NY, USA, 2. Earth and Planetary Science, University of New Mexico, USA, 3. Department of Geology, Univ of Kansas, USA, 4. Department of Geological Sciences, University of Florida, Gainesville, USA, 5. GEMOC, Macquarie

13TH QUADRENNIAL IAGOD SYMPOSIUM 2010 'GIANT ORE DEPOSITS DOWN-UNDER', ADELAIDE, AUSTRALIA, 6-9 APRIL 2010

***TerraneChron*® as exploration tool for regional terrane-scale evaluation**
E.A. Belousova, W.L. Griffin, G.C. Begg and S.Y. O'Reilly **Invited**
GEMOC, Macquarie

Heavy mineral sands in the Eucla Basin, southern Australia: Deposition and province-scale prospectivity
B. Hou[1], J. Keeling[1], A. Reid[1], I. Warland[2], E. Belousova[3] and L. Frakes[4]
1. Minerals and Energy Division, Primary Industries and Resources SA, Australia, 2. Iluka Resources Limited, Kent Town, SA, Australia, 3. GEMOC, Macquarie, 4. Geology and Geophysics, The University of Adelaide, SA, Australia

INTERNATIONAL FIELD CONFERENCE AND WORKSHOP ON TEPHROCHRONOLOGY, VOLCANISM AND HUMAN ACTIVITY, ACTIVE TEPHRA IN KYUSHU, JAPAN, 9-17 MAY 2010

Merging eruption datasets: Building integrated eruptive records and realistic eruption forecasts
M. Turner[1,2], S. Cronin[2] and M. Bebbington[2]
1. GEMOC, Macquarie, 2. Volcanic Risk Solutions, Institute of Natural Resources, Massey University, Palmerston North, New Zealand

CORDILLERAN SECTION – 106TH ANNUAL MEETING AND PACIFIC SECTION, AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, ANAHEIM, CA, USA, 27-29 MAY 2010

A reconnaissance study of granite suites across San Diego County using $^{176}Hf/^{177}Hf$ from single zircon grains: evidence of magma mixing between mantle-derived and crustal-derived melts
S.E. Shaw[1] and V.R. Todd[2]
1. GEMOC, Macquarie, 2. Williamsport, PA

EUROPEAN GEOSCIENCES UNION GENERAL ASSEMBLY 2010, VIENNA, AUSTRIA, 2-7 MAY 2010

The fate of subducted continental material: Results from coupled thermodynamic-thermomechanical numerical modelling
J.C. Afonso[1] and S. Zlotnik[2]
1. GEMOC, Macquarie, 2. School of Geosciences/School of mathematics, Monash University, Melbourne, Australia

Mantle xenolith-bearing volcanics from the Cainozoic Adrar N'ajjer Massif (North Central-oriental Hoggar, South Algeria): Petrological evidences
F. Aït-Hamou[1], M. Grégoire[2], S. O'Reilly[3], W.L. Griffin[3] and M. Coltorti[4]
1. Faculté des Sciences de la Terre, dela Géographie et Aménagement du Territoire, Université des Sciences et Technologies Houari Boumedienne, USTHB, Algiers, Algeria, 2. DDTP-UMR5562, Observatoire Midi Pyrénées, Université Toulouse III, Toulouse, France, 3. GEMOC, Macquarie, 4. Dipartimento di Scienze della Terra, Università di Ferrara, Ferrara, Italy

The deep lithospheric structure of the Namibian volcanic margin
M. Fernandez[1], J.C. Afonso[2] and G. Ranalli[3]
1. Institute of Earth Sciences "Jaume Almera", CSIC, Group of Dynamics of the Lithosphere GDL, Barcelona, Spain, 2. GEMOC, Macquarie, 3. Department. of Earth Sciences and Ottawa-Carleton Geoscience Centre, Carleton University, Ottawa, Canada

The structure and evolution of the lithosphere - asthenosphere boundary beneath the Atlantic-Mediterranean Transition Region
J. Fullea[1], M. Fernàndez[2], J.C. Afonso[3], J. Vergés[2] and H. Zeyen[4]
1. Dublin Institute for Advanced Studies, Geophysics Section, Dublin, Ireland, 2. Group Dynamics of the Lithosphere (GDL), Institute of Earth Sciences Jaume Almera, Barcelona, Spain, 3. GEMOC, Macquarie, 4. Université de Paris-Sud, Département des Sciences de la Terre, Orsay Cedex, France

Petrogenesis and differentiation of potassic rear-arc magmas at Tambora Volcano, Eastern Sunda Arc, Indonesia
R. Gertisser[1], S. Self[2], L. Thomas[2], H. Handley[3] and P. van Calsteren[2]
1. Keele University, Earth Sciences and Geography, Keele, UK, 2. The Open University Department of Earth Sciences, Milton Keys, UK, 3. GEMOC, Macquarie

U-series constraints on sediment residence timescales in semi-arid Australia
H. Handley[1], A. Dosseto[2], P.O. Suresh[3], T. Cohen[3] and S. Turner[1]
1. GEMOC, Macquarie, 2. GeoQuEST Centre, School of Earth and Environmental Science, University of Wollongong, NSW, Australia, 3. Department of Environment and Geography, Macquarie University, NSW, Australia

An automated technique for detailed μ-FTIR mapping of diamond and spectral deconvolution
D. Howell, W.L. Griffin, C. O'Neill, S.Y. O'Reilly, N. Pearson and H. Handley
GEMOC, Macquarie

Mantle unrooting beneath the Alpine-Himalayan belt: evidences from Atlas, Zagros and Tibet
I. Jiménez-Munt[1], M. Fernàndez[1], A. Villaseñor[1], J. Vergés[1], D. Garcia-Castellanos[1], E. Saura[1] and J.C. Afonso[2]
1. Institute of Earth Sciences 'Jaume Almera', CSIC, Barcelona, Spain, 2. GEMOC, Macquarie

Major and trace element chemistry of pyrope garnets from the El Kseibat area (Algeria): Implications for lithosphere features in the north-eastern part of the West African Craton
M. Kahoui[1], W.L. Griffin[2], Y. Mahdjoub[1], E.A. Belousova[2], M. Chabane[3] and F.V. Kaminsky[4]
1. FSTGAT-USTHB, Algiers, Algeria, 2. GEMOC, Macquarie, 3. ORGM, Direction régionale Sud, Tamanrasset, Algeria, 4. KM Diamond Exploration Ltd, West Vancouver, Canada

Proterozoic Os model ages of sulfides in mantle peridotites from the Ronda massif (southern Spain): insights into the evolution of the W European subcontinental lithospheric mantle
C. Marchesi[1,2], W.L. Griffin[2], C.J. Garrido[3], J.-L. Bodinier[1], S.Y. O'Reilly[2] and N.J. Pearson[2]
1. Géosciences Montpellier, UMR5243, CNRS-Université Montpellier II, France, 2. GEMOC, Macquarie, 3. Instituto Andaluz de Ciencias de la Tierra, CSIC-Universidad de Granada, Granada, Spain

Upper mantle discontinuity beneath the SW-Iberia peninsula: A multidisciplinary view
I. Palomeras[1], F. Mancilla[2], P. Ayarza[3], J. C. Afonso[4], J. Diaz[1], J. Morales[2], R. Carbonell[1] and TopoIberia Working Group[1]
1. Instute of Earth Sciences, Structure and dynamics of the Earth, Barcelona, Spain, 2. Instituto Andaluz de Geofisica, Granada, Spain, 3. Departamento de Geologia, Universidad de Salamanca, Salamanca, Spain, 4. GEMOC, Macquarie

Detrital zircon U-Pb and Hf-isotope constrains on basement ages, granitic magmatism, and sediment provenance in the Malay Peninsula
I. Sevastjanova[1], B. Clements[1], R. Hall[1], E. Belousova[2], N. Pearson[2] and W. Griffin[2]
1. SE Asia Research Group, Department of Earth Sciences, Royal Holloway University of London, Egham Hill, UK, 2. GEMOC, Macquarie

New large-scale lithospheric model of the Western Carpathian-Pannonian Basin region based on the 3-D gravity modelling
Z.A. Tasarova[1], M. Bielik[2,3], H.-J. Götze[1], J.C. Afonso[4] and J. Fullea[5]
1. Christian-Albrechts-Universität zu Kiel, Institut für Geowissenschaften, Geophysics, Kiel, Germany, 2. Department of Applied and Environmental Geophysics, Faculty of Natural Sciences, Comenius University, Bratislava, Slovakia, 3. Geophysical Institute of the Slovak Academy of Sciences, Bratislava, Slovakia, 4. GEMOC, Macquarie, 5. Dublin Institute for Advanced Studies, Geophysics Section, Dublin, Ireland

GOLDSCHMIDT 2010, EARTH, ENERGY AND THE ENVIRONMENT, KNOXVILLE, TENNESSEE, USA, 13-18 JUNE 2010

Archean detrital zircon's age at the active East-Volcanic Zone of Kamchatka
Y. Kostitsyn[1] and E. Belousova[2]
1. GEOKHI RAS, Moscow, Russia, 2. GEMOC, Macquarie

The development of a nickel sulphide standard for the *in situ* analysis of platinum group elements and gold by Laser Ablation ICP-MS
S.E. Gilbert[1], L. Danyushevsky[1], P. Robinson[1], C. Wohlgemuth-Ueberwasser[2], M. Norman[3], J. Hanley[4] and N. Pearson[5]
1. CODES, University of Tasmania, Hobart, Australia, 2. University of Bonn, Germany, 3. ANU, Canberra, ACT, Australia, 4. St. Mary's University, Halifax, NS, Canada, 5. GEMOC, Macquarie

EPMA, FTIR and LA-ICP-MS determination of the composition of fluid microinclusions in diamonds
I. Kiflawi[1], Y. Weiss[1], W.L. Griffin[2] and O. Navon[1]
1. The Fredy and Nadine Herrmann Institute of Earth Sciences, the Hebrew University of Jerusalem, Israel, 2. GEMOC, Macquarie

Thickness of diamond-bearing metasomatic aureoles in the cratonic SCLM
V.G. Malkovets[1], W.L. Griffin[2], N.P. Pokhilenko[1], S.Y. O'Reilly[2] and S.G. Mishenin[1]
1. V.S. Sobolev Institute of Geology and Mineralogy, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia, 2. GEMOC, Macquarie

Sources of diamond-forming fluids
O. Navon[1], Y. Weiss[1] and W.L. Griffin[2]
1. The Fredy and Nadine Herrmann Institute of Earth Sciences, the Hebrew University of Jerusalem, Israel , 2. GEMOC, Macquarie

Melt/mantle mixing processes form podiform chromite deposits: Implications from Re-Os systematics of the Dongqiao Neo-Tethyan ophiolite, northern Tibet
R.D. Shi[1,2], W.L. Griffin[2], S.Y. O'Reilly[2], X.C. Zhi[3], Q.X. Xia[3], Q.S. Huang[1], X.R. Zhang[1] and D.L. Liu[1]
1. LCPU, Institute of Tibet Plateau Research, CAS, Beijing, China, 2. GEMOC, Macquarie, 3. School of Earth and Space Sciences, University of Science and Technology of China, Hefei, China

Early crustal evolution in the western Yangtze Block: Evidence from U-Pb and Lu-Hf isotopes on detrital zircons
L.J. Wang[1,2], S.Y. O'Reilly[2], W.L. Griffin[2] and J.H. Yu[1,2]
1. State Key Laboratory for Mineral Deposits Research, School of Earth Sciences and Engineering, Nanjing University, Nanjing, P.R. China, 2. GEMOC, Macquarie

Looking for the keys under the lamppost: Trace elements in fibrous diamonds
Y. Weiss[1], W.L. Griffin[2] and O. Navon[1]
1. The Fredy and Nadine Herrmann Institute of Earth Sciences, the Hebrew University of Jerusalem, Israel, 2. GEMOC, Macquarie

Metamorphic conditions controlling the trace element characteristics of metamorphic zircons
J.-H. Yu[1,2], L.-J. Wang[1,2] and S.Y. O'Reilly[2]
1. State Key Laboratory for Mineral Deposits Research, School of Earth Sciences and Engineering, Nanjing University, Nanjing, P.R. China, 2. GEMOC, Macquarie

11TH INTERNATIONAL PLATINUM SYMPOSIUM. SUDBURY, ONTARIO, CANADA, 18-29 JUNE 2010

Contemporaneous segregation of PGE- and BM-rich sulfide melts and chromite crystallization: the Caridad chromite deposit, Mayarí-Baracoa Ophiolitic Belt (eastern Cuba)
J.M. González-Jiménez[1], F. Gervilla[2], J.A. Proenza[3], T. Augé[4], W.L. Griffin[1], S.Y. O'Reilly[1] and N.J. Pearson[1]
1. GEMOC, Macquarie, 2. Departamento de Mineralogía y Petrología and Instituto Andaluz de Ciencias de la Tierra, University of Granada, Spain, 3. Departament of Mineralogia, Cristal·lografia i Diposits Minerals, University of Barcelona, 4. BRGM (Bureau de Rerecherches Geológiques et Miniéres), France

2010 WESTERN PACIFIC GEOPHYSICS MEETING TAIPEI, TAIWAN 2010 TAIPEI, TAIWAN, 22–25 JUNE 2010

Exploring Tibet by decoding the source components of Transhimalayan magmatism: An integrated Hf-O isotopic approach
M.F. Chu[1], S.-L. Chung[2], X-H. Li[3], H.-Y. Lee[2] and S. O'Reilly[1]
1. GEMOC Macquarie, 2. Department of Geosciences, National Taiwan University, Taipei, Taiwan, 3. Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China

Composition, age and extent of Archean continental lithosphere: an integrated seismic and geochemical approach
W.L. Griffin, S.Y. O'Reilly, G. Begg and J.C. Afonso **Invited**
1. GEMOC Macquarie, 2. Minerals Targeting International PL

Diverse lithosphere evolution regimes in Eastern China reveal multiple geodynamic processes
S.Y. O'Reilly[1], W.L. Griffin[1], N.J. Pearson[1], J. Zheng[2], J. Yu[3], X. Xu[3], K. Wang[4], L. Wang[1] and J. Yang[5] **Keynote**
1. GEMOC, Macquarie, 2. Earth Sciences, China University Geosciences, Wuhan, China, 3. Earth Sciences, Nanjing University, Nanjing, China, 4. Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, 5. Inst. Geology and Geophysics, Chinese Academy of Sciences, Beijing, China

Precision and contribution of uncertainties in isotope ratio measurements by LAM-ICPMS
N.J. Pearson, J.L. Payne, W.J. Powell, W.L. Griffin, E. Belousova and S.Y. O'Reilly
GEMOC, Macquarie

***In situ* sulfide studies in mantle peridotites from Penghu Islands, Taiwan: Insight to melt percolation, HSE fractionation and lithospheric evolution**
K.L. Wang[1], S. O'Reilly[2], W.L. Griffin[2] and N. Pearson[2]
1. Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, 2. GEMOC Macquarie

Triassic decratonization of the North China Block: Zircon in-situ Hf isotopic evidence
J. Yang[1], J. Sun[1], F. Wu[1], S.Y. O'Reilly[2], S. Wilde[3], W.L. Griffin[2] and E. Belousova[2]
1. State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China, 2. GEMOC Macquarie, 3. The Institute for Geoscience Research, Curtin University of Technology, Perth, WA, Australia

AUSTRALIAN EARTH SCIENCES CONVENTION 2010, CANBERRA, AUSTRALIA, 4-8 JULY 2010

Origin of nickel-rich sulphide assemblages in the Betheno deposit, Yakabindie, WA: evidence from synchrotron X-ray fluorescence mapping
S.J. Barnes[1], M.L. Fiorentini[2], B.M. Godel[1], C.G. Ryan[1] and M. Locmelis[3]
1. CSIRO Earth Sciences and Resource Engineering, 2. Centre for Exploration Targeting, University of WA, 3. GEMOC, Macquarie

Minerals and energy resources: outcomes of lithosphere–mantle geodynamic coupling
G.C. Begg[1,2], W.L. Griffin[1] and S.Y. O'Reilly[1] **Keynote**
1. GEMOC, Macquarie, 2. Minerals Targeting International PL

The Wongwibinda Complex: a HTLP metamorphic terrain
S.J. Craven
GEMOC, Macquarie

The benefits to student learning of participation in marine research cruises
K. Dadd
EPS and GEMOC, Macquarie

Cenozoic volcanism in the Capel-Faust Basins, northern Lord Howe Rise
K.A. Dadd[1], M. Locmelis[1], K. Higgins[2], R. Hashimoto[2], J. Daniell[2]
1. EPS and GEMOC Macquarie, 2. Geoscience Australia

IODP Expedition 323 in the Bering Sea: environmental change over 5 million years recorded in deep-sea sediment
K.A. Dadd[1], I. Aiello[2], H. Asahi[3], G. Bartoli[4], B. Caissie[5], M. Cook[6], A. Ijiri[7], C. März[8] and Expedition 323 Shipboard Scientists
1. EPS and GEMOC, Macquarie, 2. Moss Landing Marine Laboratories, USA, 3. Ocean Research Institute, University of Tokyo, Japan, 4. Department of Geology, ETH Zurich, Switzerland, 5. Department of Geosciences, University of Massachusetts, USA, 6. Geosciences Department, Williams College, USA, 7. JAMSTEC, Japan, 8. ICBM, Germany

The petrogenesis of A-type granite: an end-member of granite formation mechanisms
J. Foden[1] and S. Turner[2]
1. TRAX, School of Earth and Environmental Science, University of Adelaide, 2. GEMOC, Macquarie

U-series isotopic characterisation of an arid region sedimentary-hosted uranium mineralised system
M.J. Murphy[1], A. Dosseto[2], B.F. Schaefer[1], S.P. Turner[1], H.K. Handley[1] and G. McConachy[3]
1. GEMOC, Macquarie, 2. GeoQueST Research Centre, School of Earth and Environmental Sciences, University of Wollongong, 3. Heathgate Resources Pty Ltd

The tectonics of tiny worlds: Enceladus and the spectrum of planetary dynamics
C. O'Neill[1] and F. Nimmo[2]
1. GEMOC, Macquarie, 2. Department of Earth and Planetary Science, UCSC, USA

Towards understanding Orogenic collapse: investigating the role of sub-continental lithospheric mantle using geochemical approaches
M.J. Pankhurst, B.F. Schaefer and S.P. Turner
GEMOC, Macquarie

A reconnaissance study of $^{176}Hf/^{177}Hf$ ratios in zircons from the New England Batholith
S. Shaw and R. Flood
GEMOC, Macquarie

Advances in geochemistry, past, present and future
S. Turner
GEMOC, Macquarie

THE 20TH GENERAL MEETING OF THE INTERNATIONAL MINERALOGICAL ASSOCIATION - IMA2010 BONDS AND BRIDGES: MINERAL SCIENCES AND THEIR APPLICATIONS, BUDAPEST, HUNGARY, 21-27 AUGUST 2010

Mass loss in chromite and ferritchromite formation during metamorphism of chromite ores in the Golyamo Kamenyane serpentinite massif (Eastern Rhodopes, Bulgaria)
F. Gervilla[1], T. Kerestedjian[2], J.M. González-Jiménez[3], I. Sergeeva[2] and A. Hadjiev[2]
1. Departamento de Mineralogía y Petrología and Instituto Andaluz de Ciencias de la Tierra, University of Granada, Spain, 2. Geological Institute, Bulgarian Academian of Sciences, Sofia, Bulgaria, 3. GEMOC, Macquarie

Composition and evolution of the SCLM, and the origin of its diamonds
W.L. Griffin and S.Y. O'Reilly **Plenary**
GEMOC, Macquarie

"Maltese-Cross" diamonds: a spectroscopic approach to understanding formation conditions and element partitioning
D. Howell, W.L. Griffin, S.Y. O'Reilly, C. O'Neill, N. Pearson and K. Grant
GEMOC, Macquarie

Imaging diamond: using birefringence and infrared to map strain and impurities
D. Howell[1,2], W.L. Griffin[1], S.Y. O'Reilly[1], C. O'Neill[1], I. Wood[2], D. Dobson[2] and A. Jones[2]
1. GEMOC, Macquarie, 2. Earth and Planetary Sciences Department, University College London, UK

Metasomatic hide and seek: Origins of the Roberts Victor eclogites, South Africa
J.-X. Huang[1,2], Y. Gréau[1], W.L. Griffin[1] and S.Y. O'Reilly[1]
1. GEMOC, Macquarie, 2. School of Earth Sciences and Resources, China University of Geosciences, Beijing, China

Archean lithospheric mantle: Its formation, composition and today's remnants
S.Y. O'Reilly and W.L. Griffin **Keynote**
GEMOC, Macquarie

Natural silicon carbide from kimberlites: polytypes, trace elements, inclusions and speculations on its origin
A.A. Shiryaev[1], W.L. Griffin[2], M.D. Tomshin[3] and A. Okrugin[3]
1. Institute of Physical Chemistry and Electrochemistry, RAS, Moscow, Russia, 2. GEMOC, Macquarie, 3. Institute of Geology, Yakutsk, Russia

Major and trace element composition of diamond-forming fluids: what do they tell us?
Y. Weiss[1], W.L. Griffin[2] and O. Navon[1] **Keynote**
1. The Fredy and Nadine Herrmann Institute of Earth Sciences, the Hebrew University of Jerusalem, Israel, 2. GEMOC, Macquarie

AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS (ASEG) AND PETROLEUM EXPLORATION SOCIETY OF AUSTRALIA (PESA), 21ST INTERNATIONAL GEOPHYSICAL CONFERENCE AND EXHIBITION, SYDNEY, NSW, 22-26 AUGUST 2010

3D thermal modelling versus down-hole temperature extrapolation in the Sydney Gunnedah-Bowen Basin and the implications for targeting potential geothermal anomalies
C. Danis and C. O'Neill
GEMOC, Macquarie

The application of geologically-constrained 3D heat conduction models to geothermal exploration
C. O'Neill[1], C. Danis[1], R. Hassan[2], S. Quennette[2] and L. Moresi[3]
1. GEMOC, Macquarie, 2. Victorian Partnership for Advanced Computing, Monash University, Vic, Australia, 3. Department of Geosciences, Monash University, Vic, Australia

14TH INTERNATIONAL SYMPOSIUM ON DEEP SEISMIC PROFILING OF THE CONTINENTS AND THEIR MARGINS (SEISMIX2010), CAIRNS, AUSTRALIA, 29 AUGUST - 3 SEPTEMBER 2010

Understanding continental structure: integrating crust and mantle information
G.C. Begg[1,2], W.L. Griffin[1], S.Y. O'Reilly[1], E. Belousova[1] and L. Natapov[1]
1. Minerals Targeting International, West Perth, WA, Australia, 2. GEMOC, Macquarie

EVOLVING EARLY EARTH, 5TH INTERNATIONAL ARCHEAN SYMPOSIUM (5IAS), PERTH, WA, 5-9 SEPTEMBER 2010

The lithosphere, geodynamics and metallogeny of the early Earth
G.C. Begg[1,2], W.L. Griffin[2], S.Y. O'Reilly[2] and L. Natapov[2] **Keynote**
1. Minerals Targeting International, West Perth, WA, Australia, 2. GEMOC, Macquarie

The *TerraneChron*® approach to crustal evolution studies and implications for continental growth
E.A. Belousova[1], W.L. Griffin[1], G. Begg[1,2] and S.Y. O'Reilly[1]
1. GEMOC, Macquarie, 2. Minerals Targeting International, West Perth, WA, Australia

Paleoarchean to Neoarchean granitoids and migmatites making up the crustal structure of Volgo-Urali
S.V. Bogdanova[1], B. De Waele[2], E.V. Bibikova[3], E.A. Belousova[4], A.V. Postnikov[5] and L.P. Popova[5]
1. Department of Earth and Ecosystem Sciences, Lund University, Sweden, 2. SRK Consulting, West Perth WA, 3. Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow, Russia, 4. GEMOC, Macquarie, 5. Gubkin State University of Oil and Gas, Moscow, Russia

The evolution and extent of Archean continental lithosphere: implications for tectonic models
W.L. Griffin[1], S.Y. O'Reilly[1], J.C. Afonso[1] and G.C. Begg[1,2] **Keynote**
1. GEMOC, Macquarie, 2. Minerals Targeting International, West Perth, WA, Australia

Isotopic geochemistry of the Northern Goldfields, Yilgarn Craton, Western Australia: setting the scene for komatiite emplacement
C. Isaac[1], M. Fiorentini[1], K.F. Cassidy[2], T.C. McCuaig[1], N. Thebaud[1], E. Belousova[3], C. Perring[4], S. Wyche[5] and C. Kirkland[5]
1. Centre for Exploration Targeting, The University of Western Australia, Crawley, WA, Australia, 2. Bare Rock Geological Services Pty Ltd, Fremantle, WA, 3. GEMOC, Macquarie, 4. BHP Billiton, Perth, WA, Australia, 5. Geological Survey of Western Australia; Department of Mines and Petroleum, East Perth, WA, Australia

What do current geophysical models of Archean lithosphere really tell us? An example from southern Africa
A.F. Kobussen, J.C. Afonso, W.L. Griffin and S.Y. O'Reilly
GEMOC, Macquarie

Lithospheric controls on the localization of komatiite-hosted nickel-sulfide deposits
D.R. Mole[1], M. Fiorentini[1], N. Thebaud[1], C. McCuaig[1], K.F. Cassidy[1], S.J. Barnes[2], E.A. Belousova[3], I. Mudrovska[1] and M. Doublier[4]
1. Centre for Exploration Targeting, University of Western Australia, Crawley, Western Australia, 2. CSIRO Earth Science and Resource Engineering, WA, Australia, 3. GEMOC, Macquarie, 4. Geological Survey of Western Australia, East Perth, WA, Australia

Persistence of Archean lithospheric mantle beneath continents and oceans
S.Y. O'Reilly[1], W.L. Griffin[1], M. Zhang[1], G.C. Begg[1,2] and J. Hronsky[1,3] **Invited**
1. GEMOC, Macquarie, 2. Minerals Targeting International, West Perth, WA, Australia, 3. Western Mining Services (Australia), West Perth, WA, Australia

Mantle geochronology and the age of the sub-cratonic lithosphere
N.J. Pearson[1], W.L. Griffin[1], S.Y. O'Reilly[1] and O. Alard[2]
1. GEMOC, Macquarie, 2. CNRS, Université de Montpellier, France

INTERNATIONAL CONFERENCE 'GEOCHEMISTRY OF MAGMATIC ROCKS' AS A PART OF THE SCHOOL 'GEOCHEMISTRY OF ALKALINE ROCKS', CRIMEAN PENINSULA, UKRAINE, 12-16 SEPTEMBER 2010

Origin of diamondites
E.V. Rubanova, W.L. Griffin and S.Y. O'Reilly
GEMOC, Macquarie

XXX REUNIÓN DE LA SOCIEDAD ESPAÑOLA DE MINERALOGÍA SEM, MADRID, SPAIN, 13-16 SEPTEMBER 2010

El papel del Titanio como indicador petrogenético en las cromititas ofiolíticas ricas en Al
S. Henares[1], F. Gervilla[1], J.A. Proenza[2] and J.M. González-Jiménez[3]
1. Departamento de Mineralogía y Petrología and Instituto Andaluz de Ciencias de la Tierra, University of Granada, Spain, 2. Departament of Mineralogia, Cristal·lografia i Diposits Minerals, University of Barcelona, 3. GEMOC, Macquarie

The use of in-situ Os-Isotopes in understanding the segregation of immiscible sulphide melts in the Caridad chromite deposit, Cuba
J.M. González-Jiménez[1], F. Gervilla[2], J.A. Proenza[3], W.L. Griffin[1], S.Y. O'Reilly[1], C. Marchesi[4] and N.J. Pearson[1]
1. GEMOC, Macquarie, 2. Departamento de Mineralogía y Petrología and Instituto Andaluz de Ciencias de la Tierra, University of Granada, Spain, 3. Departament of Mineralogia, Cristal·lografia i Diposits Minerals, University of Barcelona, 4. Géosciences Montpellier, UMR5243, CNRS-Université Montpellier II, Montpellier, France

Sulphide mineralogy in peridotite xenoliths from the Calatrava volcanic field (central Spain)
J.M. González-Jiménez[1], C. Villaseca[2], W.L. Griffin[1], E. Ancochea[2], S.Y. O'Reilly[1] and F. Gervilla[3]
1. GEMOC, Macquarie, 2. Departamento de Petrología y Geoquímica, UCM-CSIC, Facultad de Geología, Spain, 3. Departamento de Mineralogía y Petrología and Instituto Andaluz de Ciencias de la Tierra, University of Granada, Spain

STATE OF THE ARC CONFERENCE (SOTA 2010): SUBDUCTION TO ERUPTION, SYROS AND SANTORINI, GREECE, 19-26 SEPTEMBER 2010

Comparing U-Th-Ra disequilibria between arc front and back-arc basin: Insights from the Tonga Arc and Fonualei Spreading Centre
J.T. Caulfield[1], S.P. Turner[1] and R.J. Arculus[2]
1. GEMOC, Macquarie, 2. Research School of Earth Sciences, ANU, ACT, Australia

Variations of H_2O contents during the ascent of arc magmas – Implications for eruption variability and associated hazards
M.B Turner[1], S. Turner[1], H.S.C. O'Neill[2], J. Hermann[2] and K.J. Grant[1]
1. GEMOC, Macquarie, 2. Research School of Earth Sciences, Australian National University, ACT, Australia

AUSTRALIAN SPACE SCIENCE CONFERENCE 2010, BRISBANE, QUEENSLAND, AUSTRALIA, 27-30 SEPTEMBER 2010

Constraints on crustal rheology from the evolution of Venus' geological landforms
E. Schinella and C. O'Neill
GEMOC, Macquarie

SOCIETY OF ECONOMIC GEOLOGISTS, SEG 2010 CONFERENCE KEYSTONE RESORT, COLORADO, 30 SEPTEMBER - 9 OCTOBER 2010

Plumes, cratons and Ni-Cu-PGE deposits
G.C. Begg[1,2], J.A.M. Hronsky[3,4], W.L. Griffin[2], S.Y. O'Reilly[2] and N. Hayward[4]
1. Minerals Targeting International PL, West Perth, WA, Australia, 2. GEMOC, Macquarie, 3. Western Mining Services (Australia), West Perth, WA, Australia, 4. Centre for Exploration Targeting, School of Earth and Environment, The University of Western Australia, Crawley, WA, Australia, 5. Teck Resources Limited, Perth, WA, Australia

Gold, seismic tomography and an emerging regional targeting paradigm
G.C. Begg[1,2], S.Y. O'Reilly[1], W.L. Griffin[1], L. Natapov[1], J.C. Afonso[1], S. Grand[3], C.J. O'Neill[1] and E. Belousova[1]
1. Minerals Targeting International PL, West Perth, WA, Australia, 2. GEMOC, Macquarie, 3. University of Texas at Austin, USA

5TH SHRIMP WORKSHOP AND INTERNATIONAL WORKSHOP ON ADVANCES IN HIGH RESOLUTION SECONDARY ION MASS SPECTROMETRY (HR-SIMS) AND LA-ICPMS GEOCHRONOLOGY: APPLICATION TO GEOLOGICAL PROCESSES, BEIJING, CHINA, 12-13 OCTOBER 2010

Using geochronology to track the evolution of the deep crust and lithospheric mantle beneath eastern China
S.Y. O'Reilly[1], W.L. Griffin[1], N.J. Pearson[1], M. Zhang[1], J.P. Zheng[1,2], J.H. Yu[1,3], X.S. Xu[1,3], K.L. Wang[1,4], J.H. Yang[1,5] and L.J. Wang [1,3] **Invited**
1. GEMOC, Macquarie University, Sydney, Australia, 2. Earth Sciences, China University of Geosciences, Wuhan, China, 3. Earth Sciences, Nanjing University, China, 4. Institute of Earth Sciences, Academia Sinica, Taipei, R.O.C., 5. Inst. Geology and Geophysics, CAS, Beijing, China

INTERNATIONAL ZIRCON GEOCHRONOLOGY TRAINING COURSE, BEIJING, CHINA, 15-16 OCTOBER 2010

Zircon and crustal evolution or: Beyond U-Pb dating - how Hf isotopes can help you understand the Earth
W.L. Griffin, E. Belousova, S.Y. O'Reilly and N.J. Pearson **Invited**
GEMOC, Macquarie

2010 CHINESE NATIONAL SYMPOSIUM OF PETROLOGY AND GEODYNAMICS, PEKING UNIVERSITY, BEIJING, 30 OCTOBER - 2 NOVEMBER 2010

Metasomatic hide and seek: new results for the Roberts Victor eclogites, South Africa and implications for their origin
J.-X. Huang[1,2], W.L. Griffin[1] Y. Greau[1] and S.Y. O'Reilly[1]
1. GEMOC, Macquarie, 2. School of Earth Sciences and Resources, China University of Geosciences, Beijing, China
(Jinxiang Huang was awarded the prize for "Excellent Student Presentation")

GROUNDWATER 2010: THE CHALLENGE OF SUSTAINABLE MANAGEMENT CANBERRA, 31 OCTOBER - 4 NOVEMBER 2010

A static method for collecting temperatures in deep groundwater bores for geothermal exploration and other applications
C. Danis and C. O'Neill
GEMOC, Macquarie

AUSTRALIAN GEOTHERMAL ENERGY CONFERENCE, ADELAIDE, 16-19 NOVEMBER 2010

3D thermal modelling *vs* down-hole temperature extrapolation and the implications for targeting potential geothermal anomalies: a Sydney Basin case study
C. Danis and C. O'Neill
GEMOC, Macquarie

NEW ENGLAND GEOLOGY SYMPOSIUM, UNE, ARMIDALE, NOVEMBER, 2010

The New England Batholith: Interpretations from zircon Hf isotopic ratios
S.E. Shaw, R.H. Flood and N.J. Pearson
GEMOC, Macquarie

Contrasting metamorphism and deformation of mingled mafic and felsic rocks, Stewart Island, New Zealand
R.H. Vernon[1], W.J. Collins[2] and N.D.J. Cook[3]
1. GEMOC, Macquarie, 2. JCUNQ, 3. private address, Ipswich

AGU'S 2010 FALL MEETING, SAN FRANCISCO, CALIFORNIA, USA, 13-17 DECEMBER 2010

Hf-Nd isotope and trace element constraints on subduction inputs at island arcs: limitations of Hf anomalies as sediment input indicators
H.K. Handley[1], S. Turner[1], C. Macpherson[2], J.P. Davidson[2] and R. Gertisser[3]
1. GEMOC, Macquarie, 2. Department of Earth Sciences, Durham University, Durham, United Kingdom, 3. School of Physical and Geographical Sciences, Earth Sciences and Geography, Keele University, United Kingdom

High-resolution linear Radon transform and its applications in surface waves from ambient seismic noise data
Y. Luo[1], Y. Xu[1] and Y. Yang[2]
1. Institute of Geophysics and Geomatics, China University of Geosciences, Wuhan, China, 2. GEMOC, Macquarie

Stopping the Palaeoproterozoic plate tectonic machine: effects on melt production from 3D mantle convection simulations
C. O'Neill[1] and A. Lenardic[2] **Invited**
1. GEMOC, Macquarie, 2. Rice University, Houston, TX, USA

New geochemical and isotope data for recent Galapagos volcanic rocks
K. Berlo[1], H.K. Handley[2], C. Beier[3] and S. Turner[2]
1. Earth Sciences, University of Oxford, Oxford, United Kingdom, 2. GEMOC, Macquarie, 3. GeoZentrum Nordbayern, Universität Erlangen-Nürnberg, Erlangen, Germany

Element diffusion ability in metasomatic agents and its effect on chemical characteristics of metasomatized peridotites
J. Yu[1] and S.Y. O'Reilly[2]
1. Department of Earth Sciences, Nanjing University, Nanjing, China, 2. GEMOC, Macquarie

Ultra-deep subduction of continental material: Results from coupled thermodynamic-thermomechanical numerical modelling
S. Zlotnik[1] and J.C. Afonso[2]
1. Matematica Aplicada III, Universitat Politecnica de Catalunya, Barcelona, Spain, 2. GEMOC, Macquarie

How widespread is 2.4-2.2 Ga continental crust?
K.C. Condie[1] and E. Belousova[2]
1. Earth and Environmental Science, New Mexico Tech, Socorro, NM, USA, 2. GEMOC, Macquarie

Validation of 3D Southern California velocity model CVM-H6.2 based on ambient seismic noise
Q. Liu[1], C. Tape[2], Y. Luo[3], J. Tromp[3] and Y. Yang[4]
1. Department of Physics, University of Toronto, Toronto, ON, Canada, 2. Geophysics Institute, University of Alaska, Fairbanks, AK, USA, 3. Department of Geosciences, Princeton University, Princeton, NJ, USA, 4. GEMOC, Macquarie

Petrofabrics and water contents of peridotites from the Western Gneiss Region (Norway): Implications for fabric transition of olivine in continental subduction Zones
Q. Wang[1], Q. Xia[2], S.Y. O'Reilly[3], W.L. Griffin[3] and E. Beyer[3]
1. Department of Earth Sciences, Nanjing University, Nanjing, China, 2. School of Earth and Space Sciences, University of Science and Technology of China, Hefei, China, 3. GEMOC, Macquarie

Continents, super-continents, mantle thermal mixing, and mantle thermal isolation
A. Lenardic[1], M. Jellinek[2], C. O'Neill[3], C.M. Cooper[4], L. Moresi[5] and C. Lee[6]
1. Rice University, Houston, TX, USA, 2. University of British Columbia, Vancouver, BC, Canada, 3. GEMOC, Macquarie, 4. Washington State University, Pullman, WA, USA, 5. Monash University, Victoria, VIC, Australia, 6. Rice University, Houston, TX, USA

Geothermal structure of Australia's east coast basins
C.R. Danis and C. O'Neill
GEMOC, Macquarie

3D structures of crust and uppermost mantle and azimuthal anisotropy in Tibet and surrounding regions from ambient noise tomography
Y. Yang[1], Y. Zheng[2] and M.H. Ritzwoller[2]
1. GEMOC, Macquarie, 2. Department of Physics, University of Colorado at Boulder, Boulder, CO, USA

Processes and timescales of magma evolution prior to the 1815 eruption of Tambora volcano, Sumbawa, Indonesia
R. Gertisser[1], S. Self[2], L.E. Thomas[2], H.K. Handley[3], P.W. Van Calsteren[2] and J.A. Wolff[4]
1. Earth Sciences and Geography, Keele University, Keele, United Kingdom, 2. Department of Earth and Environmental Sciences, The Open University, Milton Keynes, United Kingdom, 3. GEMOC, Macquarie, 4. School of Earth and Environmental Sciences, Washington State University, Pullman, WA, USA

The compositional signature of seismic velocities in the upper mantle: a hopeless problem?
J.C. Afonso[1] and D. Schutt[2]
1. GEMOC, Macquarie, 2. Department of Geosciences, Colorado State University, Fort Collins, CO, USA

Appendix 5: Funded research projects

GRANTS AND OTHER INCOME FOR 2010

2010 Funding Source	Investigators	Project Title	Amount
ARC Discovery	Griffin, O'Reilly, Pearson, Stachel, Navon, Harris	Diamond genesis: cracking the code for deep-Earth processes	$120,000
ARC Discovery	Turner, Dossetto, Reagan	The application of short-lived Uranium-series isotopes to constraining Earth system processes	$98,000
ARC Discovery	O'Neill	The role of supercontinents in Earth's dynamic evolution (DP0880801)	$111,272
ARC Discovery	Rushmer	Partial melting in natural metal-silicate systems: rheological and geochemical implications for the Earth and other planets	$55,000
ARC Linkage Infrastructure and partner contributions	Griffin et al.	Frontiers in integrated laser-sampled trace-element and isotopic geoanalysis	$1,110,000
ARC Linkage Project with Heathgate Resources	Turner, Schaefer, McConachy	A novel approach for economic uranium deposit exploration and environmental studies (including industry contribution)	$167,500
ARC Linkage Project with BHPB	O'Reilly, Griffin, O'Neill	Global lithosphere architecture mapping II	$67,500
ARC Linkage Project with De Beers Group Services	Griffin, O'Reilly, Pearson	Composition, structure and evolution of the lithospheric mantle beneath Southern Africa: improving area selection criteria for diamond exploration	$118,000
ARC Future Fellowship	O'Neill	Strength and resistance along oceanic megathrust faults: implications for subduction initiation	$73,686
CoRE Start up grant	Yang	Research Grant	$50,000
Department of Earth and Planetary Sciences	O'Reilly	GAU maintenance contribution	$30,000
MQSIS Research Infrastructure Special Reserve Fund	O'Reilly	Laser ablation microprobe sample cells	$40,000
DIISR French-Australian Science and Technology Program	O'Reilly, Griffin, Pearson, Alard, Ildefonse, Demouchy	Probing the composition of the early Solar System and planetary evolution processes	$22,000
MQRDG	Dazcko	Resurrecting Rodinia? The role of east Antarctica in supercontinent assembly	$15,583

2010 Funding Source	Investigators	Project Title	Amount
MQRDG	Rushmer	Developing permeability in the Earth's crust: A coupled experimental and numerical study of geologically important fluids in a dynamic environment	$23,343
MQ Safety Net	Daczko	Did obesity kill the arc? A model from the Fiordland Arc, New Zealand	$19,649
MQ Safety Net	Afonso	The evolution of oceanic lithosphere and upper mantle: a novel petrological-geophysical approach	$10,000
MQ Safety Net	Schaefer	Nature, antiquity and length scales of compositional anomalies in the convecting Earth	$18,280
MQ New Staff	Schaefer	Planetary differentiation early solar system materials: an integrated isotopic and experimental approach	$19,265
ARC LIEF	O'Reilly CI (ANU Lead Institution)	IOPD	$1,200,000
ARC LIEF (MQ contribution)	O'Reilly CI (ANU Lead Institution)	IOPD	$45,000
Deputy Vice-Chancellor (Research) Discretionary Fund	O'Reilly	ARC Centre of Excellence Application Preparation: O'Reilly	$15,000
NCRIS AuScope (www.auscope.org.au)	O'Reilly	A4.45: Macquarie University Project - Earth Composition and Evolution	$166,158
NCRIS (MQ contribution)	O'Reilly	A4.45: Macquarie University Project - Earth Composition and Evolution	$50,000
APA	Danis	Geothermal structure of Eastern Australian Basins	$22,860
iMQRES	Donnelly	Mantle xenoliths, kimberlites and related rocks of the Kuruman Kimberlite Province, Kaapvaal Craton, South Africa	$43,700
MQRES	Dunkley	Hf isotopic behaviour in turbidites, migmatites and granites at Mount Stafford, central Australia	$22,500
iMQRES	Foley	Generation of continental crust during subduction initiation	$50,325
iMQRES	Fonfrege	Geochemical and isotopic characterisation of magma mixing: comparative studies in volcanic and plutonic settings	$27,825
iMQRES	Genske	Assessing the heterogeneous source of the Azores mantle plume	$50,325
iMURS	Gréau	Elemental and isotopic fractionation of siderophile and chalcophile elements: A new perspective on eclogite origin	$50,325

Appendix 5: Funded research projects

2010 Funding Source	Investigators	Project Title	Amount
Cotutelle iMQRES + CSC	Huang	Origin of eclogite and pyroxenite xenoliths in kimberlites and basalts	$50,325
iMURS	Locmelis	Understanding nickel deposits using platinum group element geochemistry	$7,015
APA	Murphy	A novel U-series isotopic approach for investigation of the Beverley U mine, South Australia	$22,500
MQRES	Pankhurst	Geodynamic significance of shoshonitic magmatism within the Andean Altiplano	$22,500
iMQRES	Rubanova	Fluid processes in the deep mantle: Geochemical studies of diamonds and related minerals	$50,325
APA	Saunders	Gold distribution and mobility within the mantle and its significance to mineralised provinces	$20,955
APA	Schinella	Processes shaping the Venusian landscape	$22,500
iMQRES	Taneja	Origin of intraplate volcanism in the east Indian Ocean	$48,420
Cotutelle iMQRES + CSC	Wang	Precambrian crust evolution of the Yangtze Block	$50,325
Cotutelle iMQRES + CSC	Yu	The evolution and tectonic dynamics of the subcontinental lithospheric mantle, SE China	$50,325
PGRF	Huang	Origin of eclogites in kimberlites	$4,000

FUNDED RESEARCH PROJECTS FOR 2011

2011 Funding Source	Investigators	Project Title	Amount
ARC Discovery	Griffin, O'Reilly, Pearson, Statchel, Navon, Harris	Diamond genesis: cracking the code for deep-Earth processes (Relenquished due to CoE)	
ARC Discovery	Turner, Dossetto, Reagan	The application of short-lived Uranium-series isotopes to constraining Earth system processes	$98,000
ARC Discovery	O'Neill, Afonso	The effective strength of oceanic plate bounding faults	$65,000
ARC Discovery	Rushmer, Turner	Origin of silicic magmas in a primitive island arc: the first integrated experimental and short-lived isotope study of the Tongan-Kermadec system	$90,000
ARC Discovery	Rushmer	Partial melting in natural metal-silicate systems: rheological and geochemical implications for the Earth and other planets	$60,000
ARC Linkage Project with Heathgate Resources	Turner, Schaefer, McConachy	A novel approach for economic uranium deposit exploration and environmental studies (including industry contribution)	$163,500
ARC Linkage Project with De Beers Group Services	Griffin, O'Reilly, Pearson	Composition, structure and evolution of the lithospheric mantle beneath Southern Africa: improving area selection criteria for diamond exploration	$60,000
ARC Future Fellowship	O'Neill	Strength and resistance along oceanic megathrust faults: implications for subduction initiation	$156,530
MQ Academic Non-Discretionary Fund	O'Neill	Start up funds for Future Fellowship	$100,000
MQ Enterprise Partnership Pilot Research Grant (Minerals Targetting International Pty Ltd)	Griffin, O'Reilly, Pearson, Belousova	Lithospheric architecture mapping in Phanerozoic orogens (including industry contribution)	$110,000
Department of Earth and Planetary Sciences	O'Reilly	GAU maintenance contribution	$30,000
Australian Antarctic Division	Daczko, Clark	The tectonic significance of regional flat-lying fabrics in rocks (logistic support)	$100,000
MQNS	Yang	Understanding the growth of the Tibetan Plateau: Unveiling the final-scale 3D structure of the crust and upper mantle beneath the Tibetan Plateau	$19,608
MQRDG	Dazcko	Resurrecting Rodinia? The role of east Antarctica in supercontinent assembly	$19,545

Appendix 5: Funded research projects

2011 Funding Source	Investigators	Project Title	Amount
MQ Safety Net	Daczko	The nature of the lower crust	$16,519
MU Fellowship	Turner, M	Research costing relating to Michael Turner's NZ S&T Fellowship	$30,000
ARC LIEF	O'Reilly CI (ANU Lead Institution)	IOPD	$1,200,000
ARC LIEF (MQ contribution)	O'Reilly CI (ANU Lead Institution)	IOPD	$45,000
AuScope/MQ Education Investment Fund Project	O'Neill	AuScope Australian Geophysical Observing System - Geophysical Education Observatory	$50,000
NCRIS AuScope (www.auscope.org.au)	O'Reilly	A4.45: Macquarie University Project - Earth composition and evolution	$100,000
NCRIS (MQ contribution)	O'Reilly	A4.45: Macquarie University Project - Earth composition and evolution	$50,000
APA	Danis	Geothermal structure of eastern Australian basins	$22,860
MQRES	Dunkley	Hf isotopic behaviour in turbidites, migmatites and granites at Mount Stafford, central Australia	$22,860
APA	Firth	Integrating the volcanological and magmatic record of a young ARC volcano: Yasur Vanuatu	$22,860
iMQRES	Foley	Generation of continental crust during subduction initiation	$52,355
iMQRES	Gaildry	Island arc processes as seen through Vanuatu volcanism and geochemistry	$52,355
iMQRES	Genske	Assessing the heterogeneous source of the Azores mantle plume	$52,355
iMQRES	Huang	Origin of eclogite and pyroxenite xenoliths in kimberlites and basalts	$52,355
APA	Murphy M	A novel U-series isotopic approach for investigation of the Beverley U mine, South Australia	$22,860
MQRES	Murphy R	Stabilising a craton: origin and emplacement of the 3.1 Ga Mpuluzi batholith (Swaziland/RSA)	$22,860
MQRES	Pankhurst	Geodynamic significance of shoshonitic magmatism within the Andean Altiplano	$22,860

2011 Funding Source	Investigators	Project Title	Amount
iMQRES	Rubanova	Fluid processes in the deep mantle: Geochemical studies of diamonds and related minerals	$52,355
APA	Saunders	Gold distribution and mobility within the mantle and its significance to mineralised provinces	$22,860
APA	Schinella	Processes shaping the Venusian landscape	$22,860
iMQRES	Taneja	Origin of intraplate volcanism in the east Indian Ocean	$52,355
Cotutelle iMQRES + CSC	Yu	The evolution and tectonic dynamics of the subcontinental lithospheric mantle, SE China	$52,325
MQPGRF	Danis	Geothermal structure of Eastern Australian Basins	$4,000
MQPGRF	Genske	Assessing the heterogeneous source of the Azores mantle plume	$4,711
MQPGRF	Murphy	A novel approach for economic uranium deposit exploration: Understanding mineralisation at the Beverley roll-front U-deposit, South Australia	$4,487
MQPGRF	Pankhurst	Investigating post-orogenic collapse through magmatic records	$5,417
MQPGRF	Saunders	Geochemical mobility of gold within the mantle, and its significance to crustal endowment	$5,000
MQPGRF	Schinella	Processes shaping the surface of Venus	$4,064
MQPGRF	Yu	The evolution, dynamics and water inventory of the subcontinental lithospheric mantle, SE China	$5,000

ARC Research Projects initiated prior to 2010 are available at our website: http://www.gemoc.mq.edu.au/
Follow the Annual Report Link to *Appendix 5* of the previous Annual Reports.

Appendix 6: GEMOC postgraduate opportunities

POSTGRADUATE OPPORTUNITIES

GEMOC has a flourishing postgraduate research environment with postgraduate students from many countries (currently 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

Postgraduate scholarship information as well as a list of scholarships currently open for application is available at: http://www.hdr.mq.edu.au/information_about/scholarships

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

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

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

Examples of broad PhD project areas include:

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

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

Contact details

http://www.gemoc.mq.edu.au/
gemoc@mq.edu.au

GEMOC
Department of Earth and Planetary Sciences
Macquarie University NSW 2109
AUSTRALIA

Carol McMahon
Administrator
Phone: 61 2 9850 8953
Fax: 61 2 9850 8943 or 6904
Email: carol.mcmahon@mq.edu.au

Professor Suzanne Y. O'Reilly
Director
Phone: 61 2 9850 8362
Fax: 61 2 9850 8943
Email: sue.oreilly@mq.edu.au

Professor W.L. Griffin
Program Leader
Phone: 61 2 9850 8954
Fax: 61 2 9850 8943
Email: bill.griffin@mq.edu.au

Dr Norman Pearson
Manager, Geochemical Analysis Unit
Phone: 61 2 9850 8361
Fax: 61 2 9850 8943 or 6904
Email: norman.pearson@mq.edu.au

GLOSSARY

ACILP	Australia China Institutional Links Program
AMIRA	Australian Mineral Industry Research Association
ANU	Australian National University
APA (I)	Australian Postgraduate Award (Industry)
ARC	Australian Research Council
BHPB	BHP Billiton
BSE	Backscattered Electrons
CCFS	Core to Crust Fluid Systems
CNRS	French National Research Foundation
CoE	Centre of Excellence
CoRE	Concentrations of Research Excellence
CSC	China Scholarship Council
CSIC	Consejo Superior de Investigaciones Científicas (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 Access MQ Limited
DP	Discovery Project
EAPE CoRE	Earth and Planetary Evolution Concentration of Research Excellence
EMP	Electron Microprobe
(D)EPS	(Department of) 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
FTIR	Fourier Transfer Infrared Spectroscopy
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
ICPMS	Inductively Coupled Plasma Mass Spectrometer
iMURS	International Macquarie University Research Scheme
IODP	Integrated Ocean Drilling Program
IPRS	International Postgraduate Research Scholarship
LAM-ICPMS	Laser Ablation Microprobe - ICPMS
LIEF	Linkage Infrastructure, Equipment and Facilities
MC-ICPMS	Multi-Collector - ICPMS
MDU	"Minerals Down Under" CSIRO Flagship program
MERIWA	The Minerals and Energy Research Institute of Western Australia
MQNS	Macquarie University New Staff Research Grants Scheme (formerly MUNS)
MQRDG	Macquarie University Research Development Grant
(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