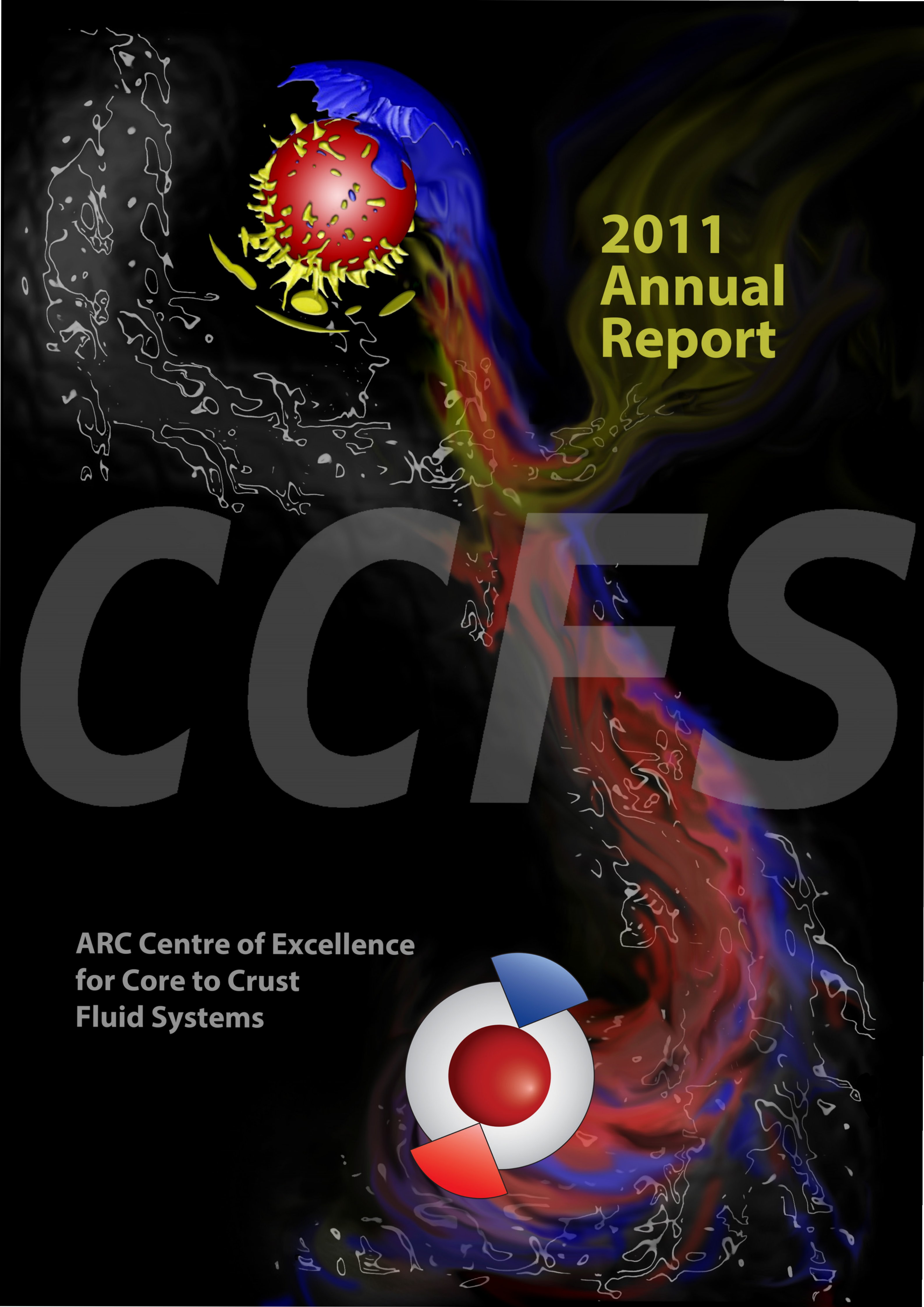
2011 Annual Report

CCFS



ARC Centre of Excellence for Core to Crust Fluid Systems

- CCFS information is accessible on WWW at:

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The CCFS Annual Report is available from our website http://www.ccfs.mq.edu.au/ as a downloadable pdf file or in html format, and by mail on USB on request.

Front Cover: The cover image depicts the evolution of the CCFS logo, abstracted from the 3-D model image of Earth's plumbing system from 1000 to 320 years ago (from Zhong, S., Zhang, N., Li, Z.X., Roberts, J.H., 2007. Supercontinent cycles, true polar wander, and very long-wavelength mantle convection. Earth and Planetary Science Letters, 261, 551-564).

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Australian Government
Australian Research Council

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

CCFS

Director's preface

This report summarises the activities of the Australian Research Council Centre of Excellence for Core to Crust Fluid Systems since its start in mid 2011, in accordance with ARC requirements. Activities include research, technology development, industry interaction, international links and research training.

The overarching goal of CCFS is to understand Earth's internal dynamics, evolution and fluid cycles from core to crust. CCFS multiplies the capabilities of three national centres of research excellence in Earth and Planetary Sciences: Macquarie University (Administering Institution), Curtin University and the University of Western Australia (Collaborating Institutions). The Geological Survey of Western Australia is a Partner Institution and researchers from Monash University and the University of New South Wales are formally affiliated.

Five overseas nodes are led by Partner Investigators in France (University of Montpellier), China (Institute of Geology and Geophysics, China Academy of Sciences), Canada (University of Saskatchewan), Germany (Bayreuth University) and the USA (University of Maryland). They are contributing resources and provide access to a wide variety of complementary expertise and instrumental capabilities.

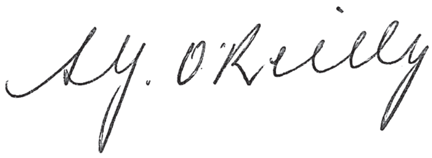
CCFS builds on pre-existing centres within the Administering and Collaborating Institutions: the GEMOC Key Centre (http://www.gemoc.mq.edu.au/) at Macquarie University retains its structure and is fully incorporated within CCFS to capitalise on its global recognition; the research and strategic activities of the Centre for Exploration Targeting (http://www.cet.edu.au/) at the University of Western Australia lie within CCFS; and the activities of TiGeR (http://tiger.curtin.edu.au/) at Curtin University are also aligned with CCFS.

2011 was our founding year, and CCFS was formally opened in October 2011 by Professor Margaret Sheil (CEO of ARC at the time). Contractual finalisation occupied the first half of 2011 so that many projects had a delayed start; full activities of CCFS will commence in 2012, although the Research Highlights in this report evidence a high level of activity with frontline scientific outcomes.

Research projects are designed to address particular defined aspects of three Themes within the funding framework provided: the Early Earth, its formation and fluid budget; Earth's Evolution (fluids in crustal and mantle tectonics; recycling of fluids into the deep mantle); and Earth Today (dynamics, decoding geophysical imaging, and Earth resources). A targeted synergy across the three nodes uses the combined expertise covering geophysics, geodynamics, experimental petrology, mineral physics, geochemistry, mineral systems, paleomagnetics and numerical modelling. In particular, the integration of paleomagnetic and seismic data with 3D fluid-dynamic models and geochemical studies is a new approach to understanding how Earth's dynamics evolved and what drives them.

Recruitment and mentoring of early- and mid-career researchers is a high-level goal in CCFS: the foundation early-career researchers and the Future Fellows are highlighted in the Personnel section.

We look forward to an exciting year of new discoveries that will expand our horizons even further and 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.



Simon Wilde, T. Cambell McCuaig, Sue O'Reilly, Margaret Sheil, Ian Gould, Clinton Foster and Paul Heithersay at the CCFS launch held at Macquarie University in October 2011. (photographed by Effy Alexakis, photowrite)

Introducing
The Australian Research Council Centre of Excellence for Core to Crust Fluid Systems (CCFS)

Vision A world-leading Centre of Excellence, driving innovative interdisciplinary research toward a new understanding of Earth's origins, fluid budgets and evolution, and delivering outcomes of tangible benefit to society.

Goals–The Mission

- to reach a new level of understanding of Earth's internal dynamics and fluid cycles, and how these have evolved to generate the hydrosphere, continents and atmosphere
- to provide a world-leading interdisciplinary research environment for the development of the next generation of Australia's geoscientists
- to deliver new concepts about the spatial and temporal distribution of Earth resources to the minerals and energy industries
- to develop new educational approaches that can renew and revitalise Australian research in the Earth Sciences

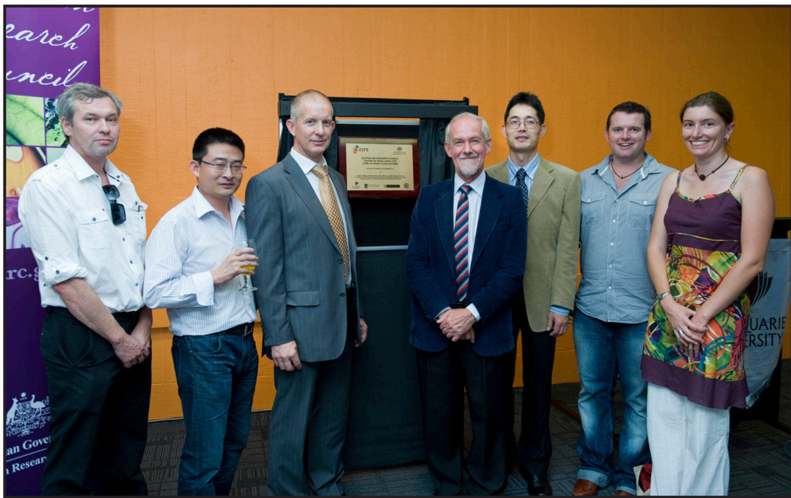
CONTEXT

Water is essential for human existence, indeed for life's beginning. The circulation of water and other fluids lubricates the deep-seated dynamics that keep Earth geologically alive, and its surface habitable. Several oceans' worth of water may be present inside Earth, and the exchange of water and other fluids between the surface and the deep interior plays a crucial role in most Earth systems, including the evolution of the surface, the hydrosphere, the atmosphere/ biosphere, and the development of giant ore deposits.

Subduction - the descent of oceanic plates into the mantle - carries water down into the Earth; dehydration of the subducting crustal slabs at high pressure and temperature releases

The Macquarie team at the centre launch. (photographed by Effy Alexakis, photowrite)

CCFS Launch



Representatives from Curtin: Alexander Nemchin, Xuan-Ce Wang, Steve Reddy, Simon Wilde, Zheng-Xiang Li, Chris Clark and Marion Grange. (photographed by Effy Alexakis, photowrite)

Representatives from The University of Western Australia: Marco Fiorentini, Cam McCuaig, Mark Barley, Marek Locmelis, Estelle Dawes and Yongjun Lu. (photographed by Effy Alexakis, photowrite) these fluids into the mantle, causing melting and controlling the strength, viscosity, melting temperature and density of rocks in the deep Earth, and the structure of major seismic discontinuities at 410 and 660 km depth. The partial return of some of these materials to the surface through mantle-plume activity provides a mechanism for tectonic cyclicity, which may have varied over geological time. These effects dominate solid-Earth dynamics and make plate tectonics possible, but the origin, abundance, speciation and movements of fluids in the deep interior are largely unknown, and represent key issues in modern geoscience.

Until recently, a real understanding of the workings of Earth's deep plumbing system has been tantalisingly out of our reach. Now, rapid advances in geophysics are producing stunning new images of variations in physical properties such as seismic velocity and electrical conductivity in the deep Earth, but interpretation of these images in terms of processes and Earth's evolution is another key issue. It requires new kinds of data on deep-Earth materials, and especially on the effects of deep fluids and their circulation.

To provide the knowledge needed to reach a new level of understanding of Earth's evolution, dynamics and fluid cycle(s) through time, CCFS will integrate information across geology, tectonics, experimental and analytical geochemistry, petrophysics, geophysics, and petrophysical and dynamical modelling. These disciplines have traditionally represented "research silos", but we will bring them together to provide a significant increase in our national research capability.

Centre Launch

On behalf of the Collaborating Partners, the Deputy Vice-Chancellor of Research at Macquarie University, Professor Jim Piper, officially launched the Australian Research Council Centre of Excellence for Core to Crust Fluid Systems on November 9, 2011. Our special guest for the afternoon was Professor Margaret Sheil, Chief Executive Officer of the ARC.

CENTRE RESEARCH

Research projects within the Centre are focused to provide maximum synergy for the scope enabled by the resource base. It is not possible to encompass the full range of research about the Earth's fluid cycle and deep Earth dynamics. In particular, all applied and mature strategic research will be carried out in parallel, supported by other funding sources, and the basic research projects have been selected initially to capitalise on CCFS resources and to fit within the funding base.

The research activity of the CoE is built around three linked interdisciplinary and cross-institutional Themes, each with several Programs. We have structured these to promote synergy and interchange of ideas and information between the Programs, across the Themes, and especially across the three nodes. More detailed information is given in "*Foundation Research Projects*" and "*Research Highlights.*"

Themes

Theme 1: Early Earth

Theme 2: Earth's Evolution

Theme 3: Earth Today

Photograph curtesy of Heather Handley

THEME 1:

The Early Earth - Its formation and fluid budget. This theme focuses on the nature of Earth's early differentiation and the role of fluids in it. Ancient (>3 Ga) rocks may yield evidence for early life, and analysing the mass-independent fractionation of Fe and S isotopes will allow us to test the involvement of biological processes in ancient deposits.

The earliest record of Earth's magnetic field will provide new information on when the core's geodynamo formed and the geometry and intensity of its field, and will be used to track the movement of Archean tectonic plates. The geochemical nature and dynamic behaviour of the mantle in the early Earth will be assessed using *in situ* analysis of targeted minerals from a variety of mantle rock types and tectonic environments, coupled with dynamic modelling.

THEME 2:

Earth's Evolution - Fluids in crustal and mantle tectonics; recycling of fluids into the deep mantle; hydrosphere, atmosphere and the deep Earth. Earth has evolved through cycles of crustal formation and destruction, punctuated by "tipping points", when rapid cascades of interlinked events produced dramatic changes in the composition of the oceans, the oxygen levels of the atmosphere, the tectonic behaviour of the crust and mantle, and the distribution of mineral and energy resources. These events changed the distribution and behaviour of fluids in the deep Earth, and each altered Earth's evolution irreversibly.

Key issues are: when did subduction start; how did it contribute to the cooling of Earth; how has this process evolved through time? Isotopic studies will define the rates of continental growth vs recycling through time, and test linkages between crust and mantle events. Geophysical imaging and dynamic modelling will be used to build 3D models of subduction dynamics, thermal evolution and geodynamic cycles. Stable-isotope studies will track water and other fluids in their cycles through the earth and the hydrosphere.

THEME 3:

Earth Today - Dynamics, decoding geophysical imaging, and Earth resources. Geophysical imagery gives us a snapshot of the current status of the deep Earth but also carries the imprints of past processes. Realistic interpretation of these data will give us new insights into Earth's internal dynamics and will have practical consequences, e.g. for resource exploration. We will develop thermodynamically and physically self-consistent dynamic codes to model complex processes and their expression in geophysical and geochemical observables. This code will be used to identify the processes that have controlled the fluid cycle through Earth's history.

Measurement of the physical properties of potential deep Earth materials at extreme conditions will feed into petrophysical modelling of seismic data in terms of composition, temperature and anisotropy. Measurements of metal complexing at realistic conditions that mimic real ore system fluids/melts will provide new ways to interpret observations on fluid/melt inclusions in minerals. We will investigate the role of organo-metallic compounds in metal transport, using the capabilities of the Australian Synchrotron, to understand the role of such compounds in the formation of large mineral systems.

CCFS participants

The new CCFS CoE builds on a world-class infrastructure base, and multiplies the capabilities of three internationally recognised centres of research excellence: Macquarie University (lead institution), Curtin University and the University of Western Australia. The Geological Survey of Western Australia is a Partner Institution and researchers from Monash University and the University of New South Wales are formally affiliated. Five overseas nodes led by Partner Investigators in France, China, Canada, Germany and the USA are contributing resources and provide access to a wide variety of expertise and instrumental capabilities. CCFS incorporates several pre-existing centres within the Administering and Collaborating Institutions: the GEMOC Key Centre (http//www.gemoc.mq.edu.au/) at Macquarie University retains its structure and is fully incorporated within CCFS; the research and strategic activities of CET (Centre for Exploration Targeting; http://www.cet.edu.au/) at the University of Western Australia lie within CCFS; and the activities of TiGeR (http://tiger.curtin.edu.au/) at Curtin University are also aligned with CCFS.

There is active national collaboration with state Geological Surveys, Geoscience Australia (GA), CSIRO, the Australian National University (RSES), Newcastle University, the University of Sydney, the University of Wollongong, the University of Adelaide and several major industry collaborators (national and global), across a broad range of projects related to the CCFS strategic goals. A distinctive feature of CCFS 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 are evolving as new alliances become relevant to the foundation research of CCFS and to new initiatives.

Administering Organisation

Macquarie University

Collaborating Organisations

University of Western Australia

Curtin University

Australian Partner

Geological Survey of Western Australia

International Partners

CNRS and University of Montpellier, France

Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China

University of Maryland, USA

University of Saskatchewan, Canada

Bayreuth University, Germany

Chief Investigators

Professor Suzanne Y. O'Reilly - Director; Macquarie University

Professor Simon Wilde - Curtin University

Professor T. Campbell McCuaig - University of Western Australia

Professor William Griffin - Macquarie University

Professor Neal McNaughton - Curtin University

Professor Zheng-Xiang Li - Curtin University

Professor Mark Barley - University of Western Australia

Professor Simon Turner - Macquarie University

Associate Professor Norman Pearson - Macquarie University

Professor Martin van Kranendonk - University of New South Wales (from 2012)

Australian Partner Investigator

Dr Klaus Gessner - Geological Survey of Western Australia (from 2012)

International Lead Partner Investigators

Dr David Mainprice (Montpellier)

Professor Fuyuan Wu (CAS Beijing)

Professor Michael Brown (Maryland)

Professor Rob Kerrich (Saskatchewan)

Professor Catherine McCammon (Bayreuth)

A full list of CCFS participants is given in Appendices 3 and at http://www.ccfs.mq.edu.au/.

Red sandstone hills in southwest Jordan close to the border with Saudi Arabia, visited by Simon Wilde during the Jordanian-Egyptian Basement Evolution (JEBEL) field excursion in October 2011.

CCFS FUTURE FELLOWS

The application for the CoE CCFS foreshadowed that such a Centre of Excellence would become an attractor for rising stars and research leaders in relevant disciplines and fields of interest. The success of CCFS participants in the two previous Future Fellow rounds emphasises this role of our Centre in recruiting high-flyers at early to mid-career levels. Four Future Fellows have projects relevant to CCFS goals as profiled below.

Dr Elena Belousova

Elena started her research career working as a mineralogist in the Department of Geology at Kiev State University (1988-1995) after graduation from the same University in 1988. Her further research, following from her PhD work at Macquarie, has been instrumental in developing leading-edge geochemical and tectonic methodologies based on zircon geochemistry. This research provided a baseline for the development of the *TerraneChron*® methodology, where she was closely involved in the development of *in situ* U-Pb age dating of zircons using the laser-ablation microprobe ICPMS and *in situ* Hf-isotope analysis using the Nu Multicollector ICPMS. The award of an ARC-APD fellowship in 2003-2006 enabled her to concentrate on this research track. The Vice-Chancellor's Innovation Fellowship (2006-2008) was industry-oriented, but it allowed further research developments and gave an opportunity to extend her expertise beyond the initial focus on zircon, to a wider spectrum of minerals and analytical methods.

Elena's Future Fellow project is focused on the processes involved in crust–mantle evolution and their interaction throughout Earth's history. Are there any consistent differences in the evolution of different layers of the lithosphere: upper crust, lower crust and upper mantle? Was the evolution of the continental crust related to underlying mantle processes? This Future Fellowship project will use *in situ* chemical and isotopic microanalysis of the accessory minerals extracted from crustal and mantle rocks to answer these fundamental questions. It will contribute to new models for the timing of crustal formation and the tectonic and genetic links between Earth's crust and mantle. The results will be relevant to the localisation of a wide range of mineral resources.

Associate Professor Marco Fiorentini

Marco Fiorentini received his PhD from the University of Western Australia in 2005. He subsequently has become a recognised authority on the genesis of Ni-Cu-PGE deposits. The implications of his studies for understanding the evolution of the early Earth's mantle, lithosphere and hydrosphere-atmosphere, have been recognised and published in international journals (*Nature, Science*). The keys to Marco's research success are his enthusiasm and his capacity

to collaborate with the best national and international researchers in several fields, creating the necessary synergy to achieve ambitious research goals. In his research, a non-conventional "out of the box" approach is coupled with cutting-edge analytical techniques to generate new working hypotheses in highly controversial fields of both fundamental and applied research.

The title of Marco's Future Fellowship is "*From Core to Ore: emplacement dynamics of deep-seated nickel sulfide systems*". Unlike most mineral resources, which are generally concentrated in a wide range of crustal reservoirs, nickel and platinum are concentrated either in the core or in the mantle of our planet. In punctuated events throughout Earth history, large magmatic events have transported and concentrated these metals from their deep source to upper crustal levels. With this Fellowship, he will unravel the complex emplacement mechanisms of these magmas and constrain the role that volatiles such as water and carbon dioxide played in their emplacement and metal endowment.

The scientific program of this study aims at radically shifting the research focus on magmatic ore deposits and will address the key research breakthroughs that can provide a step-change in the exploration for nickel-sulfide systems in Australia and overseas. The study stems from a careful examination of the current state of knowledge and research focus on mineral systems associated with magmatic processes. This examination was undertaken in conjunction with the mineral industry, which outlined a substantial misalignment between academic research and industry needs.

Dr Craig O'Neill

Craig O'Neill completed his BSc (Adv), and received the University Medal, at the University of Sydney. He subsequently went on to complete a PhD at the University of Sydney in 2004, on thermochemical convection on the Earth and planets. Craig was a postdoctoral researcher at Rice University, Houston, exploring mantle convection models incorporating volcanism, before coming to Macquarie on a Macquarie Research Fellowship in 2006. He was a finalist in the "Fresh Science" competition in 2006, and was selected The Australian newspaper's "Young Scientist of the Year" that same year. He was awarded a NSW "Young Tall Poppy" award in 2007. He was also awarded an ARC-APD in 2007 looking at the role of supercontinents in Earth's evolving mantle.

In 2011 Craig was awarded a Future Fellowship, looking at the role of serpentinisation in controlling the long-term fault strength of oceanic plate-boundary faults. Oceanic plate boundaries control the global tectonic engine, and their strength determines whether or not active tectonics is even possible. However, the rheology of oceanic faults is poorly understood, particularly the role of strength-limiting phases such as serpentinite minerals. The future fellowship project will look at one particular area of interest – the Hjort Trench, an area of incipient subduction, to understand the long term evolution of plate-bounding faults and how this feeds into the long-standing question of subduction initiation.

Dr Sandra Piazolo

Many large-scale geological processes, such as plate tectonics and mountain building, are controlled by the rate of flow of rocks. This "rheology" is fundamental, yet is difficult to determine for the complex, variable rock types of the lower crust. Sandra Piazolo's Future Fellowship project will use a novel cross-disciplinary approach combining field, laboratory and numerical techniques in order to constrain lower crustal rheology. The outcomes will have a profound significance, as the accuracy of the latest large-scale geodynamic models is dependent on the correct rheological constants. The resultant data will be implemented in advanced geodynamic models and applied to the important plate tectonic scenario of continental extension.

This project requires a sound understanding of the underlying physical and chemical processes. To translate this knowledge to large scale phenomena, numerical simulations at different scales need to be performed. Thus, the research field of the project lies between the disciplines of structural geology, metamorphic petrology and computational geoscience. In each of these fields Piazolo has made significant contributions throughout her research career. Her research path started as a metamorphic petrologist (Freiburg, Germany) and continued as a structural geologist during her PhD (Mainz, Germany). During her postdoctoral work she focused on the tectonometamorphic evolution of Archean and Proterozoic rocks of West Greenland as well as on applying material science principles and materials to geological questions (Liverpool, UK). She is well-known for her use of microstructural analysis of rocks and metals to derive deformation mechanism and rheology. She also has an international standing in numerical simulations of microstructures and extensive experience in field-based research on high grade rocks. Sandra has experience in leading international research efforts; for example the successful multi-disciplinary European project "*Fundamentals of Substructure Dynamics*", which brought together experts in experimental geology, computational geoscience, material science and field geology.

EARLY CAREER RESEARCHERS (ECR)

The second primary goal of CCFS (see above) concerns the recruitment, development and mentoring of Early Career Research (ECR) staff "for the development of the next generation of Australia's geoscientists".

A Government White Paper in 2010 "*Meeting Australia's research workforce needs*" stated that "There is a looming gap in the pool of potential leaders in geoscience research and training in Australia; the current crop of leaders is a senior generation, and there are few in the demographic down to people now in their 30s or younger. We need to bring some of this younger group along rapidly, and begin generating a new pool of potential leaders, to avoid a collapse in a research field that is essential to national wealth creation."

As part of the solution to this problem, the CCFS proposal specifically targeted funding toward several outstanding ECRs newly employed at the partner institutions. It also foreshadowed that "the employment of… Centre-funded postdoctoral fellows will bring in young people with targeted expertise and potential, and develop them into the next generation of leaders in research and training."

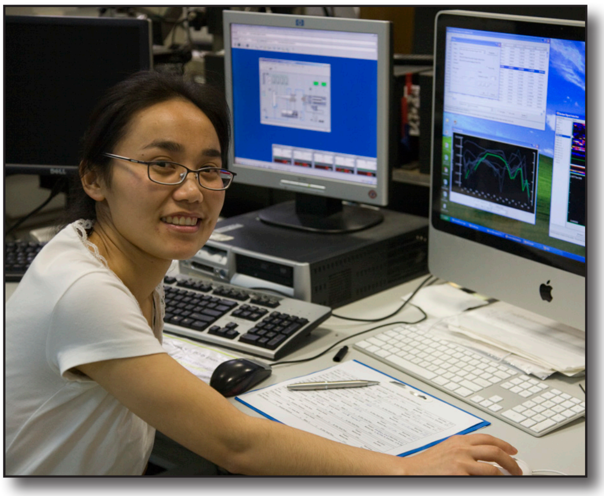
The initial awarded funding framework of CCFS resulted in a revision of the ECR recruitment capacity. However, the ARC provided an opportunity to apply for additional post-award funding dedicated to ECRs. The success of that application allowed CCFS to enhance the ECR training capability within CCFS. It also represents a strategic intention to further expand our network of overseas investigators, to further enhance strands of research that currently are under-represented in Australia. The post-award funding allowed the recruitment of four postdoctoral fellows on terms analogous to the DECRA grants (ARC Discovery Early Career Researcher Award). These positions within CCFS have been named "ECSTAR": Early Career Start-up Awards for Research. Two have commenced research in CCFS and two positions are under selection.

The following profiles present 2011 ECRs (including the two appointed ECSTARs in CCFS) and summarise their expertise and research areas.

Dr Marion Grange completed her PhD, focused on understanding the origin and emplacement age of alkaline magmatic massifs in Portugal, in 2007 at the University of Nice-Sophia Antipolis (France). She moved to Perth in March 2008 to work at Curtin University, and joined the CCFS in early 2011. Marion's present research focuses on the early history of the Solar System. She is interested in providing better timing constraints on the early stages of differentiation and the early meteoritic impact history of Earth and Moon by studying the isotopic systems of ancient materials from both planetary bodies. Her recent work concentrated on careful textural characterisation and *in situ* geochemical and geochronological analyses of zircon and apatite grains from lunar impact melt breccias to resolve 'primary' magmatic characteristics of these grains from 'secondary' features created by impact events. This allows us to establish a precise chronological record of both magmatic and impact events on the Moon. Within the CCFS, she is working on characterising magmatic and alteration minerals and related fluids in Martian meteorites using a combination of high resolution imaging, chemical and isotope methods. This project aims at understanding fluid regimes in early planetary bodies and to better constrain the composition and origin of these fluids. She is also working on calibrating Raman spectroscopy for Carbon-isotope analysis of CO_2, which will enable non-destructive measurements of $\delta^{13}C$ in individual CO_2 inclusions a few microns in size.

Dr Dan Howell is a postdoctoral research associate in CCFS working on the scientifically and economically valuable mineral, diamond. Diamonds are the product of fluids in the mantle and therefore the mineral and fluid inclusions they can contain represent some of the deepest direct samples available to study. Dan has obtained a very broad analytical and experimental background, and has applied many of these methods and techniques to the study of diamonds. Having developed a new spectroscopic technique during his PhD, he has developed a new method of processing the abundant data produced by infrared mapping to investigate the distribution and behaviour of impurities in diamonds. Combining this method with the abundant geochemical equipment available within the CCFS CoE is allowing Dan to investigate the specific growth conditions (i.e. pressure, temperature, chemistry and oxygen fugacity) of a special type of natural diamonds that have been an enigma for 50 years. He is also using his geochemical knowledge and experimental abilities to develop a new method for measuring the very low levels of trace elements found in natural diamonds using laser ablation mass spectrometry.

Dr Jin-Xiang Huang did her undergraduate study in the honour class of geology in China University of Geosciences, Beijing and was one of the top students in her class. Upon completion she commenced a PhD at GEMOC, Macquarie University and completed in December 2011; her thesis project was a study of the metasomatism and origin of xenolithic eclogites from Roberts Victor, South Africa. During her PhD study, she gained extensive experience working in clean labs and on state-of-the-art instruments to get accurate geochemical data on her samples; she was also trained to process the data effectively and to integrate a wide range of information into one model. She discovered that mantle metasomatism had completely changed the petrography and chemical and isotopic compositions of most eclogites. This demonstrated that the evidence from metasomatised samples cannot be used to support the popular idea that they represent subducted oceanic crust, while the information from primary eclogites favoured their origin from deep earth magmas.



After her PhD, she joined CCFS as a postdoctoral research associate, working on Mg and O isotopes of mantle rocks (both eclogites and peridotites). Combining her geological and analytical background with the whole range of different geochemical facilities available within CCFS, she will investigate the behaviour of Mg and O isotopes in different mantle processes (e.g. magma crystallisation, mantle metasomatism). This will provide a better understanding of mantle processes and further constraints on geodynamics.

Dr José María González-Jiménez is a geologist/mineralogist specialising in the mineralogy and geochemistry of the Platinum-Group Elements (PGE), especially in ore deposits associated with mafic/ultramafic rocks. He received his PhD from University of Granada (Spain) in 2009, having investigated the mechanisms of concentration and remobilisation of PGE in ore deposits from ophiolite complexes in Cuba, Bulgaria and New Caledonia. His research is focused on the mineralogy and geochemistry of the PGE, to find out how these noble metals are concentrated into economic deposits in Earth's upper mantle and how they are re-mobilised during post-magmatic events. His work as a Research Fellow at CCFS has taken several new directions. One is the application of Re-Os isotopic systematics to the Platinum-Group Minerals (PGM), using *in situ* microanalysis by LAM-ICPMS; another is based on the analysis of trace-element patterns in chromite from different styles of magmatic deposits. Combining mineralogical, petrologic, geochemical, isotopic and thermodynamic approaches, he is modelling the mechanism(s) of magmatic concentration of the Platinum Group Metals and Chromium. This work is providing an improved explanation for the genesis and tectonic setting of PGE-bearing chromite deposits. Another relevant aspect of his work at CCFS is a statistical study of the size distribution of the PGM in different microstructural settings and the characterisation of their Os-isotope composition. This has lead to the discovery that the PGE can be re-mobilised/re-concentrated by the hydrothermal/metasomatic fluids that commonly affect lithospheric mantle rocks. This process also affects the Os-isotope signatures of Os-rich minerals, in contrast to accepted ideas.

Dr Yoann Gréau joined GEMOC in 2007 as a PhD candidate (graduated 2011) after obtaining a Masters degree from the University of Montpellier II (France), where he trained in ultramafic petrology and geochemistry, studying ultra-refractory abyssal peridotites. During his PhD studies, he investigated the origin and history of eclogite xenoliths brought up from the lithosphere-asthenosphere boundary by kimberlitic magmas. His research focused on the petrology and geochemistry of the sulfide phases, looking at siderophile and chalcophile elements (e.g. Cu, Ni, Se, Te, PGEs and S isotopes). He also examined the relationships between microstructures and mineral geochemistry (e.g. REE, HFSE, LILE and O isotopes) of the main silicate phases, demonstrating strong links between mantle eclogites and metasomatic processes occurring within the sub-continental lithospheric mantle.

Yoann has recently joined the *TerraneChron®* team in CCFS, which uses a specifically developed methodology to study the evolution of the continental crust through time by using integrated *in situ* analysis of zircons for U-Pb ages and O and Hf isotopic composition. The team will benefit from his multi-system approach and his experience with *in situ* analytical methods.

Dr Mary-Alix Kaczmarek joined CCFS in April 2011 as a postdoctoral research fellow. She graduated with a PhD from the University of Neuchâtel (Switzerland) in 2007, with a thesis focused on upper-mantle shear zones. After her PhD, she took a postdoctoral CNRS position at Géosciences Montpellier (France), working on the microstructures and geochemistry of mantle xenoliths from southeastern Algeria. She then moved to Curtin University (Perth) in 2010, and joined the CCFS in April 2011. The principal objectives of her work are to explore the relationships between deformation mechanisms and reactive fluid/melt transport. These factors have implications for the initialisation of shearing and on the underlying controls this has on the way tectonic plates deform. To study these processes she applies state-of-the-art micro-analytical techniques such as EBSD and LA-ICPMS to investigate the role that fluid/melt and mineral chemistry plays in the mechanical stability of the rock. Since 2011, her research has concentrated on peridotites from rifting and ocean-continent transition environments (Project 2b), and Martian meteorites (Project 7). She investigates the peridotites to constrain the interaction between deformation and fluid flow, with a special interest in the interaction between intragrain and intergrain deformation processes and chemical reactions associated with hydration of the mantle. The aim of the Martian study is to characterise the fluids and their interaction with minerals, and to obtain information on primitive mantle deformation mechanisms and processes.

Dr Marek Locmelis joined the CCFS, as part of CET's research team on Magmatic Mineral Systems, to unravel the mysteries associated with the formation of nickel-sulfide ore systems in the deep lithosphere and metal and fluid transport processes in the Earth's mantle. Marek is currently based at Macquarie University as CET's eastern outpost.

Marek obtained his Diploma in Geosciences at the University of Hannover in Germany in 2005. In collaboration with the German Federal Institute for Geosciences and Natural Resources, he studied oxidised platinum ores of the Great Dyke in Zimbabwe to contribute to the development of new beneficiation techniques. Since then he has specialised in linking the academic and industrial worlds. Shortly after completing his Diploma degree, Marek moved to Sydney to undertake a PhD at Macquarie University as a joint PhD student with the CET. He investigated the mechanisms of platinum-group element (PGE) fractionation in mafic and ultramafic melts. He also developed ways to apply the PGE signatures of specific minerals to the exploration for komatiite-hosted nickel deposits.

After the completion of his PhD, Marek joined the CET where he is now involved in a CCFS project that investigates the genesis of deep-seated magmatic nickel-sulfide deposits. Most world-class nickel deposits formed relatively close to the Earth's surface, but a few uncommon and small deposits originated deep in the Earth, up to 200 km below the surface. This project combines experimental studies with novel analytical approaches to investigate how these deep deposits form, with a special focus on metal sources and transport mechanisms in the deep lithosphere.

Yongjun Lu completed his PhD at the University of Western Australia's Centre for Exploration Targeting (CET). Before coming to CET, Yongjun had obtained B.S. (2005) at China University of Geosciences (Beijing) and his M.S. (2008) at Peking University.

Yongjun's expertise lies in geochronology, igneous petrology, geochemistry and economic geology. During his PhD, he studied the tectonic setting, magmatic evolution and metallogenesis of Paleogene potassic intrusions in western Yunnan, SE Tibetan Plateau. His key research interests include: (a) *in situ* elemental and isotopic analysis, e.g. combining U-Pb, oxygen and hafnium isotopes to study granite petrogenesis, targeting fertile porphyry intrusions and mapping 4D lithospheric architecture; (b) origin and evolution of mafic and felsic magmas/metals/fluids from porphyry Cu systems in accretionary and collisional orogenies from the Archean to the Cenozoic; (c) experimental constraints on the genesis of K-adakite and associated post-collisional porphyry Cu (Mo-Au) deposits from the Tibetan Plateau; (d) the relationship between Au-rich felsic porphyry, K-mafic melt, and mantle metasomatism, and its application in regional province targeting in Au exploration.

Yongjun joined CCFS as a research associate on the Foundation Project "*4D lithospheric Evolution and Controls on Mineral System Distribution: The Western Superior-Yilgarn Comparison*", lead by Professor T. Campbell McCuaig. Together with Associate Professor Marco Fiorentini and Dr Robert Loucks, Yongjun has also initiated a pilot study involving trace-element analysis of experimental melts of amphibolites, with the aim of understanding the genesis of ore-forming hydrous adakitic melts. This pilot study will contribute to the CCFS Foundation Project "*Metal Sources and Transport Mechanisms in the Deep Lithosphere*" lead by Associate Professor Marco Fiorentini.

Dr Michael Turner arrived at Macquarie University in September 2009, assisted by a three-year Post-Doctoral Fellowship from the New Zealand Foundation of Science and Technology. He graduated with a PhD from Massey University (New Zealand) in 2009, having studied physical volcanology and magma genesis of Mt. Taranaki (New Zealand). At Macquarie, he is using short-lived U-series isotopes to determine the timescales of magma degassing events. He will supplement the isotopic research by in situ analysis of water in pyroxene phenocrysts. Pyroxenes crystallise over a large range of magmatic temperatures and pressures, and can potentially record the water contents of their host magmas during differentiation. The results will help understand the driving forces behind explosive volcanic eruptions.

Dr Xuan-Ce Wang completed his PhD in 2008 at Guangzhou Institute of Geochemistry, Chinese Academy of Sciences (CAS). He received the 2008 President's Scholarship from the Chinese Academy of Sciences, which is awarded to outstanding PhD graduates with great potential in science. He joined CAS' Institute of Geology and Geophysics as a Postdoctoral Fellow in 2008, and commenced a postdoctoral fellowship at Curtin University in October 2009. Wang is a geochemist whose research is directed at understanding (1) the thermochemical state of Earth's mantle and the effects of deep water cycling on its evolution, (2) the differentiation of early silicate Earth, and (3) the role of mantle plumes or superplumes in the breakup of supercontinents. Wang's most significant contribution to this field has been in the identification of direct petrologic and geochemical evidence for the occurrence of mantle plumes during the break-up of the supercontinent Rodinia (*Geology, 2007, 35:1103-1106; GSA Bull., 2008, 120:1478-1492*) and a lower mantle-rooted young plume close to major subduction zones (*CCFS Publication #24*). Another significant contribution was related to paleoclimate. His recent work has demonstrated that low-$\delta^{18}O$ magmatic zircons in South China should not be used as a geochemical proxy for a cold paleoclimate (*CCFS Publication #77)*. His primary role in CCFS is to examine possible linkages between plate tectonics and mantle plume dynamics, to test the effects of deep water cycling on the thermal evolution of the Earth's mantle, and to identify evidence for plume-related magmatism in Australia and other continents.

CCFS organisation and structure

The CoE is an Unincorporated Joint Venture between the University Partners, with nodes at Macquarie (Administering Institution), University of Western Australia and Curtin University.

Professor Suzanne O'Reilly is Director, supported by a Chief Operating Officer and a Publicity and Development Officer. Node Directors administer the UWA and CU nodes. Node Directors are responsible for providing leadership in their respective nodes, bringing together researchers to form a coherent team with a shared vision of the whole CoE's aims and objectives. The Geological Survey of Western Australia has a nominated representative.

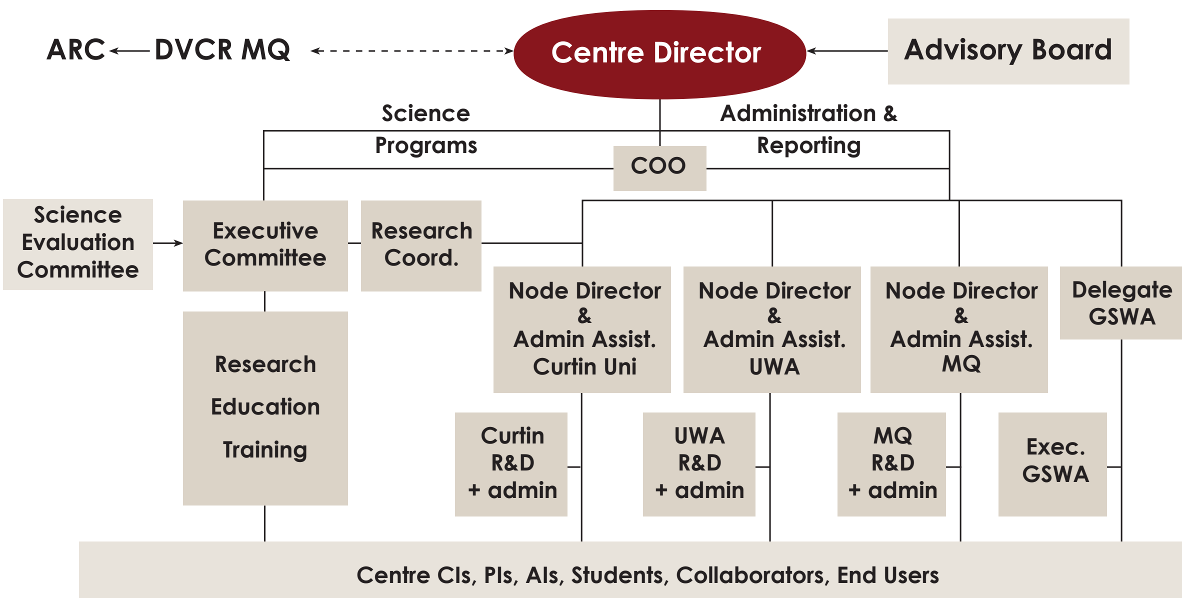
Professor O'Reilly chairs an Executive Committee consisting of two other CCFS participants from each node, including the Node Directors. Financial auditing is done at each institution, with MQ responsible for the final reporting to ARC through the DVC Research.

The development and implementation of the Centre's research plan is guided by the Theme Teams, consisting of the CIs and at least one ECR investigator from each node. These Teams participate in workshopping the Themes and their interactions, define and develop research strands, and make recommendations to the Executive Committee. An inaugural Centre Workshop developed the Foundation Projects.

The Advisory Board includes senior representatives from industry and other end users such as Geoscience Australia. This model has proven highly productive during the lifetimes of the GEMOC Key Centre and CET. The Board meets annually to provide advice on the research program and governance, and any other matters relevant to CCFS. The Board's recommendations will be incorporated into a Strategic Plan.

The Science Advisory Committee will provide advice on research progress and future directions.

CCFS aims to implement efficient research and financial management; timely, accurate reporting by each Node and the Centre; annual Advisory Board meetings; transparent and accountable financial management and positive responses from end users.



2011 MAIN MANAGEMENT ROLES

Professor Suzanne O'Reilly: Director CCFS

Professor T. Campbell McCuaig: Node Director, UWA

Professor Simon Wilde: Node Director, Curtin University

Professor William Griffin: Deputy Node Director (Research), MQ

Associate Professor Norman Pearson: Director, GAU MQ

Associate Professor Matt Kilburn: CCFS Liaison Research Coordinator, CMCA, UWA

Professor Neal McNaughton: CCFS Liaison Research Coordinator, de Laeter Centre Curtin/UWA

Professor Zheng-Xiang Li: Director, Palaeomagnetic Facility, Curtin/UWA

Professor Simon Turner: Leader U-Series Group, MQ

Dr Ian Tyler: GSWA CCFS Coordinator

Ms Casey Windrum: Chief Operating Officer

Ms Sally-Ann Hodgekiss: Development and Business Officer

Ms Estelle Dawes: CCFS Administrator, UWA

ADVISORY BOARD EXTERNAL MEMBERS 2011

Four representatives of major end-user groups are on the Advisory Board:

Dr Ian Gould (Chair): Chancellor, University of South Australia; past CEO of CRA, Rio Tinto and Normandy; Chair, CSIRO Minerals Sector Advisory Council

Dr Jon Hronsky: Principal, Western Mining Services; former global Director Generative and Strategic Services, WMC and BHP-B

Dr James Johnson: Chief of Division (Onshore Energy and Minerals) Deputy CEO, Geoscience Australia

Dr Paul Heithersay: Leader PIRSA Minerals and Energy Resources, South Australia (named DMITRE from 2012)

CCFS inaugural Board Meeting: Jim Piper, Bill Griffin, Paul Heithersay, T. Campbell McCuaig, Jon Hronsky, Sue O'Reilly, James Johnson, Simon Wilde, Ian Gould, and Craig O'Neill.

CCFS inaugural Board Meeting held in March, 2011: Ian Gould, and Paul Heithersay (right), Jon Hronsky, T. Campbell McCuaig and Simon Wilde (below), Craig O'Neill and James Johnson (lower right).

SCIENCE ADVISORY COMMITTEE

The Science Advisory Committee (SAC) has been set up to provide an independent, external advisory perspective on CCFS' scientific programs. The SAC will:

- evaluate research: strategy, structures and outcomes
- advise on tactical research plans

The SAC comprises a minimum of three internationally leading researchers, spanning CCFS programs. Membership will be rolling appointments to achieve the dual aims of continuity and new approaches.

The first SAC meeting will precede the 34th International Geological Congress in Brisbane in August 2012 to capitalise on the presence of high-profile international delegates.

The Inaugural Science Evaluation Committee members are:

Professor Marjorie Wilson: Professor of Igneous Petrogenesis; Faculty Pro-Dean for Research, University of Leeds (UK)

Professor Julian Pearce: Professorial Research Fellow, Cardiff University (UK)

Professor Alan Jones: Head of Geophysics Section and Senior Professor, Dublin Institute for Advanced Studies (Ireland)

The CCFS research program

The CCFS CoE builds on world-class infrastructure and will multiply the capabilities of the Collaborating and Partner Institutions. The research program aims to amplify existing strengths in geology, geochemistry, geophysics, experimental petrology and petrophysical/dynamic modelling, aiming at closer integration of these disparate fields.

Major Research Objectives

- to determine, using constraints from Earth's oldest crust and mantle, lunar samples and meteorites, the role of fluids in creating a dynamic planet
- to understand how Earth's core-mantle system and its interaction with fluids has produced periodic cataclysms and controlled the evolution of the crust, hydrosphere and atmosphere
- to develop new approaches to petrophysical and dynamic modelling, integrating geophysics, geodynamics and geochemistry
- to develop an integrated Earth model linking tectonics, internal structure and dynamics, and the fluid-mediated transport of mass and energy from the interior to the surface
- to develop new approaches to interpreting geophysical imagery, for application to basic science and resource exploration
- to develop a new understanding of the timing and distribution of giant resource systems, based on a new level of understanding of Earth's fluid plumbing systems, processes and dynamics
- to underatake the strategic, frontline developments in hardware, analytical methodologies, theory and software technology that are required to fulfil the research goals

These objectives are being addressed through the Research Projects described below and within the framework of the three Themes:

THEME 1: The Early Earth

THEME 2: Earth's Evolution

THEME 3: Earth Today

The scope of the research, and thus of the inaugural projects, is determined by the funding base for 2011 with strategic leverage planned to expand available resources.

FOUNDATION RESEARCH PROJECTS

Foundation Projects have a substantial funding component from the ARC Centre funds allocation. The first tranche of these Foundation Projects was chosen from formal applications by CCFS participants based on presentations and discussions at a 2-day meeting in October 2010, ratified by the Executive Committee, and accepted on report to the Advisory Board. Additional requirements for the Foundation Projects include cross-node research participation, an interdisciplinary perspective and/or topics reflecting ARC grants relinquished consequent on the award of the CoE CCFS.

The range of topics covered by the Foundation Projects reflects studies within the three major proposed Themes prioritised within the imposed funding framework. Projects range across understanding Early Earth, identifying deep Earth fluids and element transport, tracking mantle evolution, geophysical imaging of deep-Earth flow, geodynamics of the Australian continent in the Proterozoic, and the 3-D architecture of the Yilgarn Craton (Australia) from new deep seismic and magnetotelluric datasets and crustal geochronology (see *full list p. 24*).

Principles for Foundation Funding

Project applications were submitted using a short, but comprehensive, template providing information on researchers involved, aims/context/methods/innovation of the project, funding requested and justification, predicted outcomes and outputs with timetable and relevance to CCFS goals and Themes. Cross-node collaboration and participation of postgraduate students and early-career researchers were key factors in selecting the Foundation Projects.

Criteria for funding also included:

1) relevance to Centre goals

2) scientific merit and innovation

3) collaborative nature and cross-node participation

4) predicted outcomes and outputs within a timeframe

Foundation Projects also include three whole-of-Centre projects undertaking Technology Development, one of the key goals embedded in the Centre strategy.

For Foundation Project summaries, progress for 2011 and plans for 2012 see *Appendix 1*. Independently funded basic research projects are listed in *Appendix 2*.

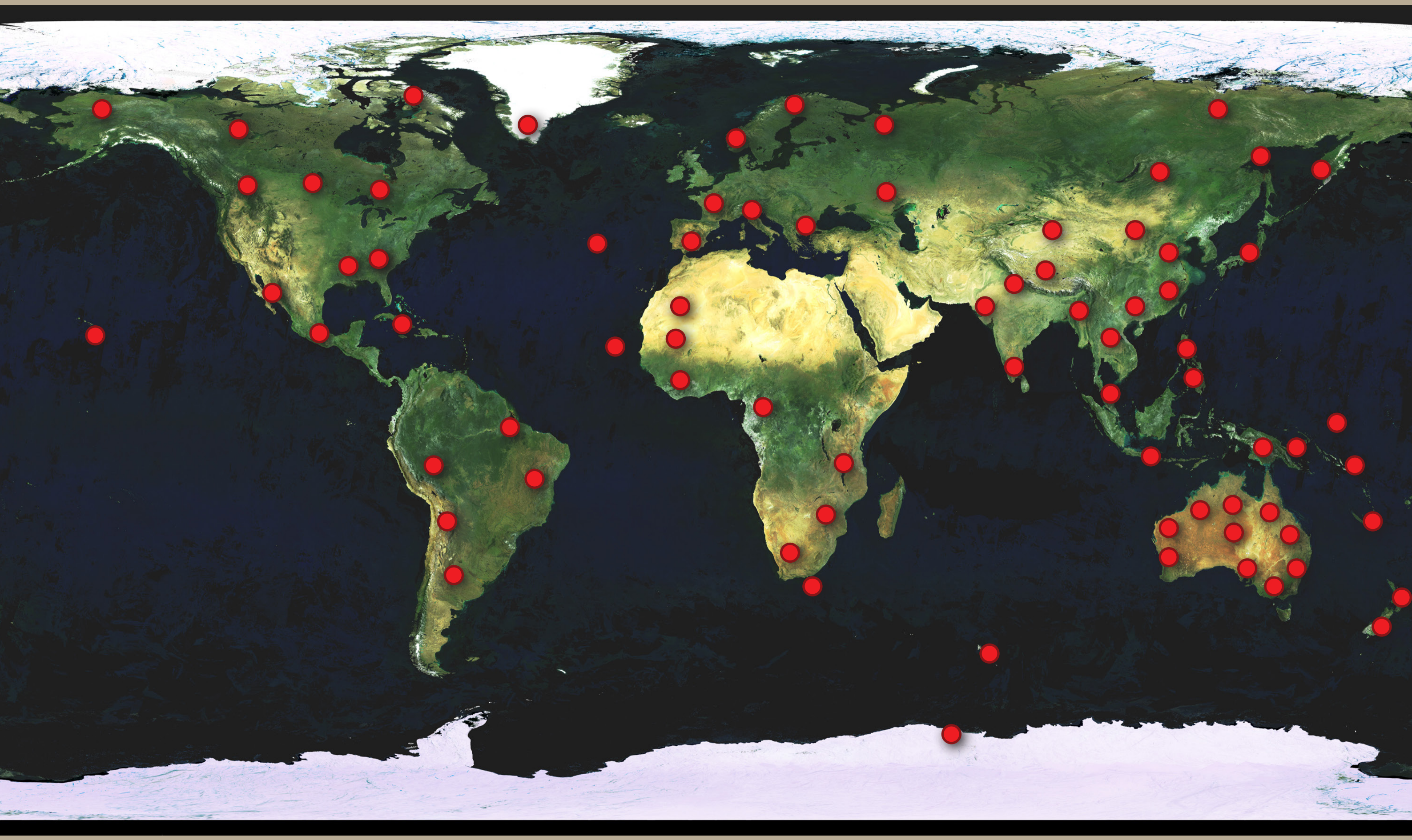
FOUNDATION RESEARCH PROJECTS

Project	Coordinator and main Centre personnel
1. The TARDIS project: Tracking ancient residues distributed in the silicate Earth (Relinquished)	O'Reilly, Griffin, Pearson, Fiorentini, O'Neill, González-Jiménez (ECSTAR, ECR), Huang (ECR), Xiong and McGowan (PhDs)
2a. Metal sources and transport mechanisms in the deep lithosphere	Fiorentini, McCuaig, Barley, Rushmer, Griffin, Pearson, Evans, Reddy, Kilburn, Locmelis, Turner, O'Reilly, PhDs to be named
2b. Dynamics of Earth's mantle: assessing the relatives roles of deformation and magmatism	Reddy and Kaczmarek (ECR)
3. Generating and stabilising the earliest continental lithosphere - Late granite blooms	Griffin, O'Reilly, O'Neill, Pearson, van Kranendonk, Belousova, Murphy (PhD)
4. Two-phase flow within Earth's mantle: modelling, imaging and application to flat subduction settings	O'Neill, Afonso, Yang, Li, Gorczyk, PhDs to be named
5. Early evolution of the Earth system and the first life, from multiple sulfur isotopes	Barley, Fiorentini, Kilburn, Wacey, Wilde, Nemchin, Griffin, PhDs to be named
6. Detecting Earth's rhythms: Australia's Proterozoic record in a global context (Relinquished)	Li, Pisarevsky, Wang (ECR, ECSTAR), Wingate, Reddy, PhDs to be named
7. Fluid regimes and the composition of the early Earth	Wilde, Nemchin, Grange (ECR), Barley, Kusiak, Pidgeon, PhDs to be named
8. Diamond Genesis: Fluids in deep-Earth processes (Relinquished)	Griffin, O'Reilly, Pearson, Cliff, Kilburn, Howell (ECR), Ekaterina Rubanova (PhD)
9. 4D lithospheric evolution and controls on mineral system distribution: The Western Superior-Yilgarn comparison	McCuaig, Fiorentini, Kemp, Belousova, Cliff, Kirkland, van Kranendonk, McNaughton, PhDs to be named
10a. 3D architecture of the western Yilgarn Craton	Gessner, van Kranendonk, Tyler, Belousova, Yang, Afonso, O'Neill, Gorczyk (Research Associate to be appointed)
10b. Zircon Lu-Hf constraints on Precambrian crustal evolution in Western Australia	Wingate, Belousova, Tyler

FOUNDATION CENTRE TECHNOLOGY DEVELOPMENT PROJECTS

Project	Coordinator and main Centre personnel
Cameca Ion microprobe development: maximising quality and efficiency of CCFS activities within UWA Ion Probe Facility	Kilburn, Cliff, Fiorentini, McCuaig, Barley, Pearson, Reddy
Frontiers in integrated laser-sampled trace-element and isotopic geoanalysis	Pearson, Cliff, Griffin, O'Reilly, Kilburn
Optimising mineral processing procedures: From rock to micro-grains	Pearson, Belousova, Daczko, Centre users

WHERE IN THE WORLD IS CCFS?



CCFS communications 2011

CCFS web resources provide information on background, research and downloadable files of the Annual Report and Research Highlights.

Links to the GEMOC website (http://www.gemoc.mq.edu.au/) provide past GEMOC Annual Reports, updated details on its methods, 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.

Links to the CET (Centre for Exploration Targeting) website (http://www.cet.edu.au/) provide access to wider information about CET activities beyond its involvement in CCFS and especially the wide base of end-user interaction.

Links to The Institute for Geoscience Research (TiGer) website (http://tiger.curtin.edu.au/) provide information about their facilities, participants and research activities.

Strong industry interaction in CCFS in 2011 ranged from presentations to specific industry groups in their offices to numerous formal and informal workshops at CET and GEMOC, and invited and plenary presentations at peak industry symposia, workshops and conferences nationally and internationally.

CCFS PUBLICATIONS FOR 2011 ARE GIVEN IN *APPENDIX 4*

The 94 CCFS Publications that were published in 2011 are mainly in high-impact international journals as listed by the internationally recognised Thomson ISI Citation data, and designated previously as A* and A journals by the earlier ARC ERA (Excellence in Research) official journal ranking. The publication list includes some resulting from research prior to 2011, but from ARC grants that were relinquished because of their close alliance with Centre research, or from CET or GEMOC activity which are now part of CCFS.

PARTICIPATION IN WORKSHOPS, CONFERENCES AND INTERNATIONAL MEETINGS IN 2011 (AND BEYOND)

CCFS Investigators, associated staff, early-career researchers and postgraduates had a high profile at peak metallogenic, geodynamic and geochemical conferences as convenors, invited speakers, or presenters, with 162 presentations including:

Professor Simon Wilde presenting his talk on the Early Earth at the IV Cuban Earth Science Convention, Havana, Cuba, in April.

- 23rd Colloquium of African Geology (Johannesburg, South Africa)
- Gordon Research Conference on Geobiology of Precambrian Earth (Ventura, CA, USA)
- DGG/EAGE 2011 (Cologne, Germany)
- Prospectors and Developers Association of Canada (PDAC) (Toronto, Canada)
- 42nd Lunar and Planetary Science Conference (The Woodlands, USA)
- West Australian Geothermal Energy Symposium (Perth, Australia)
- European Geosciences Union, General Assembly 2011 (Vienna, Austria)

- V Cuban Earth Science Convention (Havana, Cuba)
- American Association of Petroleum Geologists 2011 (Lima, Peru)
- "Minerals at Extreme Conditions: Integrating Theory and Experiment" Elizabeth and Frederick White Conference (Canberra, Australia)
- International Conference on Craton Formation and Destruction (Beijing, China)
- Frontiers in Mineral Systems: The Inaugural Solomon Meeting (Yallingup, Australia)
- Opportunities in Research of Metals and Minerals (Victoria, Australia)
- GAC - MAC - SEG - SGA Annual Meeting (Ottawa, Ontario, Canada)
- Earthscope National Meeting (Texas, USA)
- The 6th International Conference on Arctic Margins (ICAM VI) (Fairbanks, USA)
- Conference - Eclogite and Granulite Complexes in the Earth History (Petrozavodsk, Russia)
- The Evolution of Photosynthesis and Oxygenation of the Earth Symposium (Sydney, Australia)
- IUGG 2011 General Assembly, Earth on the Edge: Science for a Sustainable Planet (Melbourne, Australia)
- The XVII International Congress on the Carboniferous and Permian (Perth, Australia)
- Seventh Hutton Symposium on Granites and Related Rocks (Avila, Spain)
- Australian Mars Exploration Conference (Perth, Australia)
- 9th International Eclogite Conference, 2011 (Mariánské Lázne, Czech Republic)
- The 8th Annual Meeting of the Asia Oceania Geosciences Society (AOGS) (Taipei, Taiwan)
- Goldschmidt 2011 (Prague, Czech Republic)
- 7th International Symposium on Digital Earth (Perth, Australia)
- Deformation Mechanisms, Rheology and Tectonics, DRT Conference (Oviedo, Spain)
- Penrose Conference on "Comparative evolution of past and present accretionary orogens: Central Asia and the Circum-Pacific" (Urumqi, Xinjiang Uygur Autonomous Region, China)
- Geological Processes From Global to Local Scales, Associated Hazards and Resources (Munich, Germany)
- Fermor 2011 - Ore Deposits in an Evolving Earth (Piccadilly, London)
- International Field Workshop on the Precambrian evolution of Korea, and East Asian tectonics (KBSI Ochang Center, South Korea)
- 18th International Conference on Secondary Ion Mass Spectrometry (SIMS XVIII) (Riva del Garda, Italy)
- Geological Survey of Norway (Trondheim, Norway)
- Gondwana 14 (Buzios, Brazil)
- 11th Biennial SGA meeting (Antofagasta, Chile)

Yongjun Lu and Colleagues at the 11th Biennial SGA meeting held in Antofagasta, Chile.

- 11th Australian Space Science Conference 2011 (Canberra, Australia)
- XXXI Reunion de la Sociedad Españoloa de Mineralogía (Barcelona, Spain)
- GSA Annual Meeting (Minneapolis, Minnesota, USA)
- Geological Survey of Western Australia (Perth, Australia)
- Jordanian-Egyptian Basement Evolution (JEBEL) Workshop and Field Excursion "Basement Complex of Southwest Jordan" (Amman, Jordan)
- Ice deformation; from the model material to ice in natural environments (Grenoble, France)
- 2011 Sprigg Symposium: Unravelling the Northern Flinders and Beyond (Adelaide, Australia)
- AGU 2011 Fall Meeting (San Francisco, California, USA)

INVITED TALKS AT MAJOR CONFERENCES 2011

Conference	Presentation
Gordon Research Conference on Geobiology of Precambrian Earth, 30 January - 4 February 2011	**M. Barley**. The early evolution of Earth's atmosphere, links to tectonics and life. **Invited**
Prospectors & Developers Association of Canada (PDAC): Toronto, Canada, 6-9 March 2011	**T.C. McCuaig**. Integrated interpretation and targeting under cover. **Invited** **T. C. McCuaig** and **Jon M.A. Hronsky**. Exploration targeting in a business context. **Keynote** **T.C. McCuaig**. Managing success - Strategies for keeping the leadership edge: Exploration Targeting. **Invited**
European Geosciences Union (EGU) General Assembly 2011, Vienna, Austria, 3-8 April 2011	**S. Pisarevsky**. Neoproterozoic paleogeography: paleomagnetic perspective. **Invited** **J.C. Afonso** et al. The lithosphere-sublithospheric upper mantle system beneath the Atlantic-Mediterranean Transition Region: advances and limitations from recent multidisciplinary approaches. **Invited** F. Gervilla, I. Fanlo, T. Kerestedjian, R. Castroviejo, **J.M. González-Jiménez** et al. Alteration mechanism of chromite in podiform chromitites from two metamorphosed ophiolitic complexes: Golyamo Kamenyane (Bulgaria) and Tapo (Peru). **Keynote**
IV Cuban Earth Science Convention, Havana, Cuba, 4-8 April 2011	**S.A. Wilde**. Unravelling the first 500 million years of Earth history. **Invited**
"Minerals at Extreme Conditions: Integrating Theory and Experiment" Elizabeth and Frederick White Conference, Canberra, Australia (Australian Academy of Science) 13-15 April, 2011	**W.L. Griffin** and **S.Y. O'Reilly**. Fluids in diamonds: samples from the deep lithosphere. **Invited** **S.Y. O'Reilly**. Tracking Earth's plumbing system in time and space: an interdisciplinary strategy towards understanding Earth's evolution. **Invited** **C. O'Neill** et al. The effect of D" and post-perovskite on the dynamics of plumes. **Invited** **S. Turner**, J. Caulfield, **M. Turner** et al. Direct evidence for the nature and timing of sub-arc mantle metasomatism. **Invited**
International Conference On Craton Formation And Destruction, Beijing, China, 25-29 April 2011	**S.Y. O'Reilly**, **W.L. Griffin**, M. Zhang, **N.J. Pearson**, J. Zheng, X. Xu, J. Yu and **J.-H. Yang**. Deep and ancient lithosphere rules supreme: a 3.6 Ga story of persistence, transformation, dispersal and re-assembly. **Keynote** **W.L. Griffin**, N. Nikolic, **S.Y. O'Reilly** and **N.J. Pearson**. Coupling, decoupling and metasomatism: Crust-mantle relationships beneath NW Spitsbergen. **Invited** J.-P. Zheng, **W.L. Griffin**, C. Yu, **S.Y. O'Reilly** et al. Continental accretion and reworking beneath the North China Craton: Evidence from deep-seated xenoliths. **Invited** **S.A. Wilde**. Phanerozoic Crustal Growth: Sorting out facts from fiction. **Keynote**
Frontiers in Mineral Systems: The Inaugral Solomon Meeting, Yallingup, Western Australia, 8-13 May 2011	**M. Fiorentini**. Multiple sulfur isotopes in magmatic systems. **Invited** **S. Reddy**. Mineral system deposition and timing: Constraints from quantitative microanalysis. **Keynote**

Conference	Presentation
Opportunities in Research of Metals and Minerals, Deakin University, 12 May 2011	**S. Piazolo**. Integrating in-situ experiments with numerical simulations. **Invited**
The Evolution of Photosynthesis and Oxygenation of the Earth Symposium, UNSW, Sydney, Australia, 28-29 June 2011	**M.J. van Kranendonk**. Contingent events leading to an oxygenated environment. **Keynote**
IUGG 2011 General Assembly, Earth on the Edge: Science for a Sustainable Planet, Melbourne, Australia, 28 June - 7 July 2011	**S. Pisarevsky**. Precambrian supercontinents and paleomagnetic data, or how "super" are supercontinents? **Invited**
Goldschmidt 2011, Prague, Czech Republic, August 14-19 2011	**W.L Griffin**, G. Begg, **S.Y. O'Reilly** and **N.J. Pearson**. Ore deposits and the SCLM. **Keynote** **M.J. van Kranendonk**. Geology, age and origin of the oldest terrestrial rocks and minerals. **Keynote** **S. Turner,** J. Caulfield, **M. Turner**, et al. Direct evidence for the nature and timing of sub-arc mantle metasomatism. **Invited**
Penrose Conference on "Comparative evolution of past and present accretionary orogens: Central Asia and the Circum-Pacific", Urumqi, Xinjiang Uygur Autonomous Region, China, 4-10 September 2011	**E. Belousova**, R. Seltmann, **W.L. Griffin** and **S.Y. O'Reilly**. Hf isotopes in zircons from the CAOB: Crustal evolution history and tectonic significance. **Invited** **S.A. Wilde**, et al. Tectonic evolution of the CAOB in NE China. **Invited**
International field workshop on the Precambrian evolution of Korea, and East Asian tectonics, KBSI Ochang Center, South Korea, 19-24 September 2011	**S.A. Wilde**, et al. A >1300 km-long Late Pan-African Khondalite Belt along the southern margin of the CAOB. **Invited**
18th International Conference on Secondary Ion Mass Spectrometry (SIMS XVIII), Riva del Garda, Italy, 18-23 September 2011	**M. Kilburn**. Chemistry at the sub-µm scale with NanoSIMS. **Invited**
Geological Survey of Norway, Trondheim, Norway, 23 September 2011	**M.J. van Kranendonk**. A chronostratigraphic division of the Precambrian: possibilities and challenges. **Invited** **M.J. van Kranendonk**. Vertical to horizontal tectonics: Secular evolution of the Archaean Pilbara Craton, Western Australia. **Invited** **M.J. van Kranendonk**. Contingent drivers of environmental change across the Archean-Proterozoic transition. **Invited**
Geological Survey of Western Australia, Perth, Australia, 17 October 2011	**M.J. van Kranendonk**. Romance in geology: The marriage and breakup of continents. **Invited**

Conference	Presentation
Ice deformation; from the model material to ice in natural environments, Grenoble, France, 7-9 November 2011	**S. Piazolo**. Strain heterogeneities and recrystallization in polycrystalline materials: Characterization and Interpretation. **Invited**
AGU's 2011 Fall Meeting, San Francisco, California, USA, 5-9 December 2011	**O. Alard**. Ubiquitous old depleted mantle in the Oceanic mantle. **Invited** **J.C. Afonso** and S. Zlotnik. The subductability of the continental lithosphere: results from coupled thermodynamic-thermomechanical numerical modeling. **Invited** A. Dosseto and **S. Turner**. Reappraisal of magma genesis under the Kamchatka arc with uranium-series isotopes. **Invited** M.H. Ritzwoller, F.-C. Lin, W. Shen, J. Xie, **Y. Yang**, Y. Zheng and Z.L. Quan. Crustal and uppermost mantle anisotropy in the western US and China inferred from surface wave dispersion. **Invited** **Y. Yang** et. al. Surface wave tomography on large-scale seismic arrays combining ambient noise and teleseismic earthquake data. **Invited**

A full list of abstract titles and authors for Conferences and Workshops attended is given in Appendix 6 and on the CCFS website.

OTHER CONFERENCE ROLES

- Dr Klaus Gessner was a member of the organising committee and convened the Session "*Building a regional geoscientific framework"* at the West Australian Geothermal Energy Symposium, 21-22 March 2011.
- Associate Professor Tracy Rushmer was one of the organisers of the Elizabeth and Frederick White Conference *"Minerals at Extreme Conditions: Integrating Theory and Experiment"* held in Canberra at the Australian Academy of Science 13-15 April, 2011.
- Dr Zheng-Xiang Li was co/vice-chairman of the international Scientific committee and Serge Pisarevsky was on the Conference organising committee for the International Symposium *"Large Igneous Provinces of Asia, Mantle Plumes and Metallogeny"* held in Irkutsk, Russia, August 2011.
- Professor Bill Griffin Chaired session at the 9th International Eclogite conference, 2011, Czech Republic, August 6-9, 2011 entitled "*Mantle Dynamics, Fluid Flow in the Subduction Zone and HP Melting*".

- CCFS was well represented at the 2011 Goldschmidt conference held in Prague, Czech Republic, 14-19 August:
  - Professor Simon Turner was a member of the scientific program committee and a co-coordinator of Theme 06: *"Recycling: Subduction, The Mantle Wedge and Arc Volcanism"*

CCFS participants and friends enjoying a scenic evening dinner cruise at the Goldschmidt, Prague: (L-R) Lora Armstrong (Bristol University, UK), Mel Murphy, Yao Yu, Ed Saunders, Dan Howell, and Heather Handley (photograph courtesy of Heather Handley.

    - Dr Heather Handley co-chaired sessions 9e: *"Geochemistry of volcanic systems and natural hazards"* and *"Timescales of Magma Evolution, Degassing, and Ascent through the Crust"*
    - Associate Professor Marco Fiorentini co-convened session 11b: *"Ore Deposits and the Role of the Lithospheric Mantle"*
    - Professor Martin van Kranendonk was a co-convener and Chair of session 05c: *"Continent Formation through Time"*
    - Dr Craig O'Neill was co-convenor for session 5e: *"Petrologic, Geochemical and Tectonic Links between the Continental Crust and Lithospheric Mantle"*

- CCFS will also contribute to many of the Themes and Symposium at the 34th IGC to be held in Brisbane in August, 2012:
    - Professor T. Campbell McCuaig is convening the *"Exploration Geoscience"* Theme and symposia 8.2: *"The science of exploration"*
    - Professors Sue O'Reilly and Bill Griffin is convening Theme 16: "*The Deep Earth*". Professor Bill Griffin, Associate Professor Norman Pearson, Dr Juan Carlos Afonso, Dr Craig O'Neill and Dr Yingjie Yang are convening/co-convening symposia within the Theme; O'Neill: "*The lithosphere-asthenosphere boundary: nature, formation and evolution from Hadean to now*"; Griffin/Pearson: "*The crust-mantle lithosphere system*"; Yang/Afonso: "*Lithosphere structure from ambient noise and other seismology*"
    - Professor Martin van Kranendonk is convening Theme 17: "*The Early Earth: Hadean and Archean Development of a Habitable Planet*" and symposium: "*Rates and mechanisms of Archean crust formation – the relative contribution of plume versus plate tectonics*". Contributors within this session include Dr David Wacey: "*The habitats and paleobiology of early life on Earth, and the rise of oxygen*"; Professor Martin van Kranendonk and Dr Craig O'Neill: "*Early Earth geodynamics and evolution – uncovering links between changing early Earth and biological diversification*"
    - Associate Professor Robert Pidgeon is convening a symposium within Theme 20: *"Planetary Sciences"* titled *"Lunar research and exploration in the 21st century"*
    - Associate Professor Simon George is convening a symposium within Theme 26: *"Antarctic and Arctic Geoscience"* titled *"Antarctic marine biogeochemistry"*
    - Professor Martin van Kranendonk is convening a symposium within Theme 35: *"Geostandards"* titled *"International Subcommision on Precambrian stratigraphy: a chronostratigraphic division of the Precambrian: possibilities and challenges"*

WORKSHOPS

- On the 17th May CCFS hosted a geothermal workshop for Professor Mary O'Kane, in her capacity as NSW Chief Scientist. The workshop, "*Geothermal Energy Exploration – Approaches to Resource Assessment and Modelling*", was attended by leading geothermal experts from government and industry.

Professor Mary O'Kane (second from left) with attendees at the geothermal workshop including Sue O'Reilly and Jim Piper from Macquarie.

- Dr Juan Carlos Afonso was a main organiser of the workshop "*Thermodynamic-Geophysical characterization of the upper mantle: the next step*" held at the Dublin Institute for Advanced Studies, Ireland, in November: http://www.dias.ie/ThermoDynaMixIII/index.html.
- Professor Steve Reddy (Curtin) organised a Workshop titled "*Introduction to Quantitative Microstructural Analysis Using Electron Backscatter Diffraction*", held at Curtin University.
- Professor Campbell McCuaig (convenor/lecturer), Marco Fiorentini and Bill Griffin (lecturers) participated in the CET Masters workshops: MTEC MSc Computer-aided Exploration Targeting Course 4-5 July 2011; MTEC MSc Ore Deposit Conceptual Models Course 9-10 November 2011.

One of our International Partner investigators, Professor Michael Brown, and student examining the famous migmatites at Mt. Tiashan in Shandong Province, China, in preparation for a Beijing SHRIMP Center workshop to be held in 2012.

- Professor Martin van Kranendonk co-convened the workshop "*Friends of the Precambrian*", as part of the 2011 GSA Annual Meeting in Minneapolis, 11 October 2011; co-sponsored by the International Commission on Stratigraphy.
- Dr Dan Howell was a presenter at a Diamond school/workshop in the early part of last year (http://www.socminpet.it/diamond2011/home.htm). The full report is available at: https://dco.gl.ciw.edu/sites/dco.gl.ciw.edu/files/images/DCO_REPORT_Nestola.pdf.
- Simon George held a one day biogeochemistry workshop for the Genes to Geoscience Research Centre, as part of our postgraduate training "*Where biology, geology and chemistry meet*" in July 2011.

INVITED SEMINARS

- Dr Elena Belousova gave a departmental seminar at the University of Wollongong on the 2nd of November, 2011 titled "*The TerraneChron® approach to crustal evolution studies and implications for continental crust growth*".
- Professor Bill Griffin gave a departmental seminar at the University of Wollongong titled "*Global Lithospheric Architecture Mapping (the GLAM project)".*
- Dr Craig O'Neill presented a talk on *"COE for Core to Crust Fluid Systems"*, at Monash during the Workshop *"De-risking Geothermal Energy Demonstration through Collaboration"* in March, and a talk on *"The evolution of Precambrian tectonics"* at Adelaide University in Oct 2011.
- Professor Martin van Krenendonk presented talks at; Harvard University Boston: "*A chronostratigraphic division of the Precambrian: possibilities and challenges*" (September), the Carnegie Institution of Washington: "*Vertical to Horizontal tectonics: Secular evolution of the Archaean Pilbara Craton, Western Australia*" (September) and at the University of Wisconsin, Madisonin: "*800 Ma that changed the world: Contingent drivers of environmental change across the Archean-Proterozoic transition*" (October).

ESTEEM FACTORS AND OUTREACH

Awards

- Dr Elena Belousova, Dr Sandra Piazolo, and Associate Professor Marco Fiorentini were awarded ARC Future Fellowships.
- Professor Bill Griffin was awarded the title of Distinguished Professor at Macquarie University. The "Distinguished Professor Awards recognise professors who have made an outstanding contribution to their field of scholarship or discipline and to the University" reflecting "exceptional distinction and an outstanding contribution to his discipline". He joins CCFS's Professor Sue O'Reilly who was awarded Distinguished Professor at Macquarie University in 2010 and Professor Simon Wilde who was named John Curtin Distinguished Professor in 2010.

Bill Griffin (fifth from left) and some of the Macquarie CCFS participants who attended the presentation of his Distinguished Professor Awards 2011.

Norman Pearson after the graduation ceremony for two of his postgraduate students, and now CCFS ECR's, Yoann Gréau and Marek Locmelis, April 2011.

- Dr Norman Pearson received the MUPRA Supervisor of the Year award. The judges stated that, "What stood out was the way his students value him, not only for what he contributes to their research, but also the support and care he has shown them".
- Professor Sue O'Reilly was awarded "Docteur Honoris Causa" at Lyon University in a ceremony at Jean Monnet University, St Etienne, France.
- Dr Monika Kusiak of the Polish Academy of Sciences in Warsaw was awarded a Marie Curie Fellowship to work with Professor Simon Wilde on "The Earth in Transition: from Earliest Crust to Earliest Preserved Rocks"; she will spend two years at Curtin University and a further year at the Natural History Museum in Stockholm under the guidance of Professor Martin Whitehouse.
- Professors Sue O'Reilly and Bill Griffin were invested as Guest Professors at China University of Geosciences at Wuhan in April 2011.
- Professor Martin van Kranendonk received the 2012 European Association for Geochemistry Eminent Speaker Award.
- Earth Sciences Research in Earth Sciences at Macquarie University received the highest possible rating in ERA 2010 - 'performance well above world standard'; http://mq.edu.au/research/era/research-areas/earth-science.html/. Macquarie University and CCFS's Partner Institutions, the University of Western Australia and Curtin, were all among the top 6 rated institutions for Earth Sciences.

Sue O'Reilly accepting her Docteur Honoris Causa at Lyon University.

Outreach:

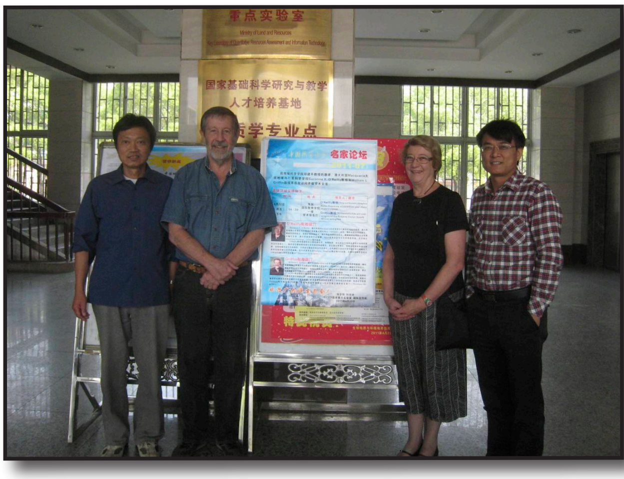
- On the 18th July Professor Sue O'Reilly presented a talk to teachers from North Sydney High School as part of "Uni for a day". The teachers were given details about undergraduate study at Macquarie followed by a tour of CCFS's specialist laboratory, the Geochemical Analysis Unit (GAU).
- Dr Juan Carlos Afonso, Dr Heather Handley, Dr Dan Howell and Dr Craig O'Neil worked with 6 high school students from NSW to promote careers in science, technology, engineering and maths (STEM) as part of the STEM NERD project (http://stemcareer.com/).
- Dr Juan Carlos Afonso, Dr Heather Handley and Dr Mark Lackie attended Macquarie University 'Science High Achievers Awards Dinner' to help promote Earth Science research at MQ to academically outstanding high school students, their parents and teachers.
- As part of the 2011 Macquarie University Colloquium Lecture Series, Professor Sue O'Reilly delivered a public lecture at the city campus of the Macquarie Graduate School of Management. The lecture, titled: "*Journey to the Centre of the Earth – Volcanoes, Diamonds and Earthquakes*" attracted an audience of 90 school children, university students and aspiring geologists. The event was publicised in the mainstream press (The Sydney Morning Herald) and via the Macquarie University web site. The lecture can be viewed via You Tube at http://marketing.mq.edu.au/events_at_macquarie/lecture_series/macquarie_university_colloquium/professor_sue_oreilly/
- Dr Craig O'Neill participated in a solar and renewable energy summit held at the University of Newcastle.
- Professor Simon Wilde compiled the 'Jack Hills' and 'Hadean' sections of the Encyclopedia of Astrobiology, published in 2011 by Springer (see *CCFS Publications #118,119*).
- In July 2011 Associate Professor Simon George attended a "Spaceward Bound" expedition in the Pilbara with NASA scientists and the Mars Society

Esteem:

- Professor Sue O'Reilly continued as a member of the International Kimberlite Conference Committee; a member of the Scientific Committee for the "*International Conference on Craton Formation and destruction*" held in Beijing April 25-29, 2011, and is a foundation member of the Theo Murphy Think Tank Action Group "*Searching the deep Earth: The future of Australian resource discovery and utilization*".
- Professor T. Campbell McCuaig is the Chair of the MTEC Mineral Geoscience Masters implementation committee; a Member of the MTEC MGM/MGH Steering committee; a Council Member of the Society of Economic Geologists(SEG); a member of the SEG curriculum committee; a Member of the Science Advisory Committee for Discovery Theme of Minerals Down Under CSIRO Flagship; a Member of the GSWA Mineral Exploration Technical subcommittee and a Member of the AMEC Congress Steering Committee.
- Professor Simon Wilde is Deputy Director of the International Precambrian Research Centre of China (IPRCC) at Beijing SHRIMP Centre and the Department of Geology, Chinese Academy of Geological Sciences.
- Professor Bill Griffin continued is a member of the Scientific Committee, "*International Earth Science Colloquium on the Aegean Region*", 1-5 October 2012 and continued as an invited founding core member of the of the International Precambrian Research Centre of China (IPRCC) at Beijing SHRIMP Centre and the Department of Geology, Chinese Academy of Geological Sciences.

- Professor Simon Turner continued as a Director of the Geochemical Society and served on the AuScope II steering committee.
- Associate Professor Marco Fiorentini became a Member of the UWA CAMECA IMS1280 Science Advisory Committee in 2011 and continued as a Member of the Geological Society of Australia, the Society for Geology Applied to Mineral Deposits and the Society of Economic Geologists.
- Associate Professor 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"*.
- Professor Martin van Kranendonk was Chair of the Precambrian Subcommission of the International Commission on Stratigraphy, continued as a Scientific Advisory Committee Member at the University of Western Australia, was a Core Member, International Precambrian Research Centre of China and continued as Assistant Director, Australian Centre for Astrobiology
- Associate Professor Tracy Rushmer is a NSF (National Science Foundation) panel member for Geochemistry and Petrology (2010-2012).
- Michael Wingate is a Member of the Steering Committee, IAVCEI Large Igneous Provinces Commission and is a member, John de Laeter Centre SHRIMP Advisory Group, Curtin University.
- Dr 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.
- Dr Juan Carlos Afonso continued as Division Officer of the European Geosciences Union (Geodynamics Division) and EGU Officer Geodynamics Division (Outstanding Young Scientist committee)

CCFS Representation on editorial boards included: Lithos (Griffin, O'Reilly, Rushmer); Geological Society of America Bulletin (Griffin); Journal of Petrology (Turner); Precambrian Research (Barley, Pisarevsky, van Kranendonk), Solid Earth (Schaefer); Acta Geologica Sinica (Griffin), Journal of Asian Earth Sciences (Li, Wilde), Acta Geoscientia Sinica (Li), EGU Journal Solid Earth (Afonso), Chemical Geology (Wilde); American Journal of Science (Wilde); Journal of Jilin University – Earth Science (Wilde), Advisory Board: Gondwana Research (Wilde).



Ming Zhang, Bill Griffin, Sue O'Reilly and Jianping Zheng at Wuhan University with poster advertising the Guest Professor ceremony.

MEDIA

CCFS participants featured prominently in the media in 2011.

Sue O'Reilly:

- "*Rock wiz: Unveiling Earth's deep interior*" Quest p 8-10 Research at Macquarie University Issue 3, 2011 marketing.mq.edu.au/public/download/?id=24759
- Interview titled "*Gem of a centre*" 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.

- CCFS was featured in the article *"Depths of 'plumbing' within reach"* 8 NOV 11 by Robert Kennard in the Northern District times. http://northern-district-times.whereilive.com.au/news/story/depths-of-plumbing-within-reach
- New research centre to focus on the mysteries of deep Earth's water circulation system, 3 November 2011, http://www.mq.edu.au/newsroom/control.php?page=story&item=4733
- Sue O'Reilly contributed two invited articles to the Mantle Plumes website: http://www.mantleplumes.org/LithosphereRemnants.html, http://www.mantleplumes.org/CapeVerde.html

Wang Tao, Simon Wilde and Alfred Kroner at the opening of the workshop on the Precambrian Evolution of Korea, organised by the KBSI SHRIMP Center, South Korea in September 2011.

Simon Wilde:

- Simon Wilde filmed segments at Jack Hills for a television program entitled 'Australia: the Land that Time Forgot' to be shown on ABC 1 in early 2012. He also recorded segments for a TV program on the Early Earth for Arte France.

T. Campbell McCuaig:

- small-centre-doing-big-work-in-minerals _ News _ Minerals and Resources_080611.pdf

Zheng-Xiang Li:

- Article for Australasian Science Magazine "The big twist" (*July 2011 issue, pp. 37-38*).
- ABC radio (8 February) on all rural ABC radio broadcasts. Synopsis from the newsreader: *"New research shows that WA may once have had a mountain range higher than Mount Kosciuszko. Professor Zheng Xiang Li from Curtin University says that tectonic movements created a mountain range about 600 million years ago and was eroded 50 million years later".* The broadcast also announced that tectonic movements may have resulted in considerable quantities of untapped gold deposits in WA and Queensland.
- ScienceNetwork Western Australia online story *"Curtin ends controversy '1000 million' years in the making"* (21 January 2011; http://www.sciencewa.net.au/Minerals-and-Resources/Minerals-and-Resources/Curtin-ends-controversy-1000-million-years-in-the-making.html).
- Science Alert online article *"Geology tells Australia's story"* (7 February 2011; http://www.sciencealert.com.au/news/20110701-21720-3.html)

Marco Fiorentini:

- Marco Fiorentini is the official SBS Italian Radio commentator for news related to a variety of geologically related topics, such as global warming, utilisation of geothermal energy, mining and exploration, etc. This experience has proven to be a very effective means to liaise and communicate with members of the wider community.

Craig O'Neill:

- Cosmos *"The Anatomy of a megathrust earthquake"*. http://www.cosmosmagazine.com/features/online/4203/the-anatomy-a-megathrust-earthquake?page=0,0
- ABC redio Wednesday, 10 August 2011 (Stuart Gary) *"Dust particles may run rings around Pluto"* http://www.abc.net.au/science/articles/2011/08/10/3290120.htm?site=galileo/starstuff/starstuff&topic=space

- ABC Science *"How Jupiter shaped the Solar System"* http://www.abc.net.au/science/articles/2011/06/06/3234155.htm

Steve Reddy:

- Moon impact zircon (see paper details below): Media release - "Curtin Geologists make a 'shocking' discovery": http://news.curtin.edu.au/news/curtin-geologists-make-a-'shocking'-discovery/
- Media release on the paper Timms et al. (2012) published in MAPS on Curtin University website. This research is the first to report precise crystalline characteristics of micro-deformation features in lunar zircon and highlights the importance of micro-scale study to understand large meteorite impacts on the Moon.

Nature Geoscience paper creates media attention:

CCFS's Dr David Wacey, Associate Professor Matt Kilburn and Associate Professor John Cliff were three of the authors of a Nature Geoscience paper published online in August 2011 titled *"Microfossils of sulphur-metabolizing cells in 3.4-billion-year-old rocks of Western Australia"*, describing their discovery of Earth's oldest microfossils (for full reference see below). It was picked up by much of the world's media. Over 8,000 articles from around the world covered the story in the first few weeks following its publication. Here are some highlights:

- BBC: http://www.bbc.co.uk/news/science-environment-14614832
- BBC science highlights of 2012: http://www.bbc.co.uk/news/science-environment-15531040
- Radio 4 material world: http://www.bbc.co.uk/iplayer/episode/b013fm6c/Material_World_25_08_2011/
- New York Times: http://www.nytimes.com/2011/08/22/science/earth/22fossil.html
- Washington Post: http://www.washingtonpost.com/national/health-science/oldest-microfossils-hail-from-34-billion-years-ago-raise-hopes-for-life-on-mars/2011/08/19/gIQAHK8UUJ_story.html?wprss=rss_homepage
- The Guardian (UK): http://www.guardian.co.uk/science/2011/aug/21/fossil-microbes-western-australia
- The Independent (UK): http://www.independent.co.uk/news/science/oldest-known-fossils-prove-life--began-more-than-34bn-years-ago-2341671.html
- New Scientist: http://www.newscientist.com/article/dn20813-oldest-reliable-fossils-show-early-life-was-a-beach.html
- Nature news: http://www.nature.com/news/2011/110821/full/news.2011.491.html?s=news_rss
- Der Spiegel: http://www.spiegel.de/wissenschaft/natur/0,1518,781573,00.html (plus article in print)
- Science news: http://news.sciencemag.org/sciencenow/2011/08/worlds-oldest-fossils-found-in-a.html
- CBC (Canada): http://www.cbc.ca/news/technology/story/2011/08/22/science-oldest-fossils-bacteria-sulphur.html
- Cosmos Magazine: http://www.cosmosmagazine.com/news/4646/early-life-consumed-sulphur
- Discovery News: http://news.discovery.com/space/microfossil-bacteria-oldest-earth-110821.html
- MSNBC: http://www.msnbc.msn.com/id/44221621/ns/technology_and_science-space/#.TlNPuDtw8yY
- The China Post: http://www.chinapost.com.tw/life/discover/2011/08/23/314299/Earths-oldest.htm

- Science illustrated: http://scienceillustrated.com.au/blog/science/early-life-on-earth-had-sulphur-based-metabolisms/#more-2899
- Australian Geographic:http://www.australiangeographic.com.au/journal/worlds-oldest-fossil-found-in-western-australia.htm
- News.com.au: http://www.news.com.au/technology/sci-tech/scientists-claim-fossils-discovered-in-port-headland-are-over-34-billion-years-old/story-fn5fsgyc-1226119426081
- Sydney Morning Herald: http://www.smh.com.au/technology/sci-tech/new-pilbara-find-fuels-debate-on-earliest-life-20110822-1j5qv.html
- Canberra Times (print only)
- Herald Sun: http://www.heraldsun.com.au/technology/sci-tech/scientists-claim-fossils-discovered-in-port-headland-are-over-34-billion-years-old/story-fn5iztw3-1226119426081
- Brisbane Times: http://www.brisbanetimes.com.au/technology/sci-tech/new-pilbara-find-fuels-debate-on-earliest-life-20110822-1j5qv.html
- Sunday Times (Perth) – behind the scenes type article

And many more!

Dr David Wacey is an advisor to WA Chief Scientist Lyn Beazley who presented their work on Earth's oldest microfossils at the National Geographical Society London.

There were also live radio interviews:

- Dr Dave Wacey did live interviews with: ABC Sydney, ABC North (Karratha, Port Hedland), ABC Perth
- Professor Mark Barley was interviewed by Science Network WA, Science Illustrated Australian Media Properties.
- Collaborator Brasier did live interviews with BBC Radio 4 – Material World (headline story)
- Commentaries were also featured in: Daily Express, Daily Mail, Daily Telegraph, International Herald Tribune, Times of India, Straits Times Singapore, ABC online, Boston Globe, San Fransisco Chronicle, New Zealand Herald, El Mundo.

VISITORS

CCFS 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 5*.

They have participated in:

collaborative research

technology exchange

seminars, discussions and joint publications

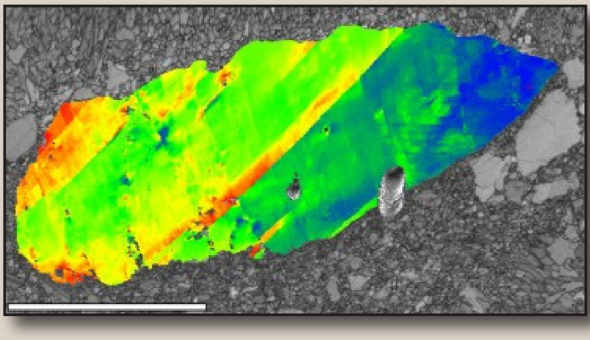
collaboration in postgraduate programs

PUBLICATION SPOTLIGHT

CCFS Publication #86, **Wacey, D.**, **Kilburn, M.R.**, Saunders, M., **Cliff, J**. and Brasier, M.D. (2011) Microfossils of sulfur metabolizing cells in ~3.4 billion year old rocks of Western Australia. Nature Geoscience 4 (10), 698-702 - This publication featured as a 'news and views' article in Nature Geoscience as well as being featured in Science, Nature, New Scientist and media throughout the world (see *p. 37* for web urls etc.)

CCFS Publication #114, **Locmelis, M.**, **Pearson, N. J.**, Barnes, S.J., **Fiorentini, M.L.**, 2011. The role of chromite in the fractionation of ruthenium - new insights from *in situ* laser ablation ICP-MS analysis. Geochimica et Cosmochimica Acta, 75, 3645-3661 - Top 25 (4th) hottest articles in Geochimica et Cosmochimica Acta in April – June 2011 (http://top25.sciencedirect.com/subject/earth-and-planetary-sciences/9/journal/geochimica-et-cosmochimica-acta/00167037/archive/33/)

CCFS Publication #147, Timms, N.E., **Reddy, S.M.**, Healy, D., **Nemchin, A.A.**, **Grange, M.L.**, **Pidgeon, R.T.**, and Hart, R., (2012) Resolution of impact-related microstructures in lunar zircon: A shock deformation mechanism map. Meteoritics and Planetary Science. 47 (1), 120-141 - This article also received media attention (*see p. 37*)



Microstructure of a lunar zircon created from electron backscatter diffraction data. Colour variations indicate variations in lattice orientations caused by a impact events at the Moon's surface (CCFS Publication #147).

GEMOC Publication #547. Begg, G.C., **Griffin, W.L.**, **Natapov, L.M.**, **O'Reilly, S.Y.**, Grand, S.P., **O'Neill, C.J.,** Hronsky, J.M.A., Poudjom Djomani, Y., Swain, C.J., Deen, T. and Bowden, P. 2009. The Lithospheric architecture of Africa: Seismic tomography, mantle petrology and tectonic evolution. Geosphere, 5, 23-50 - This article was a 'Most-Cited' Geosphere article in early 2011 and still remains there in 2012.

GEMOC Publication #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, 3-4, 457-466. doi:10.1016/j.lithos.2010.07.024. - Was the hottest article in Lithos from June to October 2010 and remained 2nd on the most-downloaded list to June 2011.

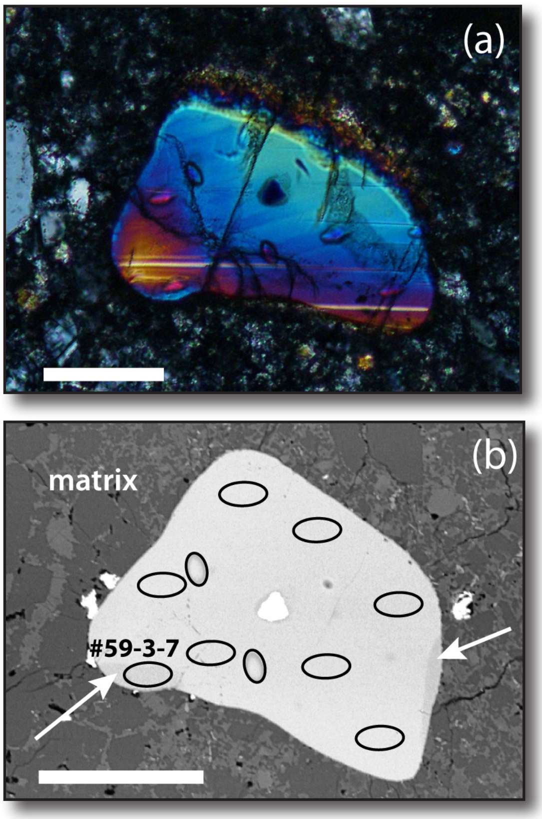
GEMOC Publication #650, **O'Reilly, S.Y.** and **Griffin, W.L.** 2010. The continental lithosphere-asthenosphere boundary: Can we sample it? Lithos, 120, 1-13. doi:10.1016/j.lithos.2010.03.016 - Was the hottest article in Lithos from October to December 2010 and remains the most downloaded paper in Lithos from November 2010 to June 2011.

Research highlights 2011

Moon impacts on origin of Earth and Solar System

Material from the Moon can provide insights into the early history of the solar system and help us to understand the mechanisms of planetary differentiation. On Earth, traces of early differentiation have been erased by tectonic events, whereas the Moon has been relatively inactive for almost 4 billon years. Therefore the Moon provides a unique opportunity to study early differentiation processes on a planetary scale. In addition, the early solar system was affected by intense meteoritic bombardment. The heavily cratered surface of the Moon testifies to this bombardment, which is still ongoing. Evidence of the early bombardment is difficult to find as the lunar surface is continuously reshaped and modified by the influx of meteorites. One source of information is old grains of zircon, which can be extracted from lunar rocks and soils.

Lunar zircons are useful because they can give information about both differentiation (as they crystallised in deep-seated plutonic bodies) and impact processes. They are not easily destroyed by impact metamorphism, but often carry signs of partial reworking during the impacts. They are found in impact melt breccias, which are rocks composed of pieces of broken rocks, loose minerals (or pieces of broken minerals) set in a matrix made up of crystallised impact melt. Zircons found in thin sections are imaged using an optical microscope and then a scanning electronic microscope (SEM) to reveal their internal features (Fig. 1). They are then dated *in situ* by the U-Pb technique using an ion microprobe: this allows us to target specific areas of the zircon grains and extract ages related



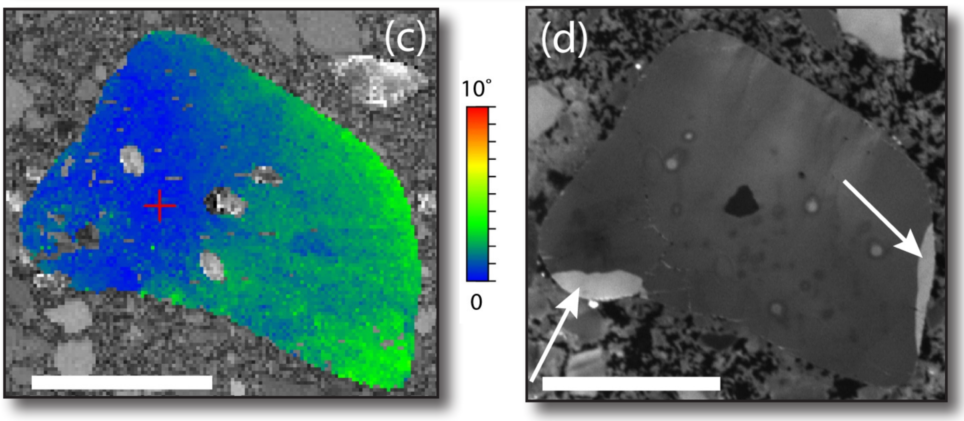


Figure 1. Images of zircon grain 73235-59#3 (the tiger).

either to magmatic events or impact deformation.

One special zircon grain, nicknamed "Tiger" because of its striped appearance, shows several features that are often observed in lunar zircons and are especially significant for the interpretation of their history. The stripes are Planar Deformation Features (or PDFs) corresponding to defects in the crystalline lattice that can only be created at the very high pressures generated by an impact. These PDFs are visible in the optical microscope (Fig. 1a) and with the SEM. In addition, the zircon grain is plastically deformed, testifying to deformation that occurred during the heating generated by the impact (Fig. 1c). The Tiger grain also shows some recrystallised areas (Fig. 1 arrows); as no fluids are known to be available on the Moon, these recrystallised zones probably were generated following changes induced by an impact. These recrystallised zones in lunar zircon provide a unique way of dating the impact that generated them. In the case of the Tiger grain, the area is large enough to fit an ion probe spot on it. This zone proved to be ~250 million years younger than the main part of the zircon, which records the time of the zircon's original crystallisation from the melt (Fig. 2).

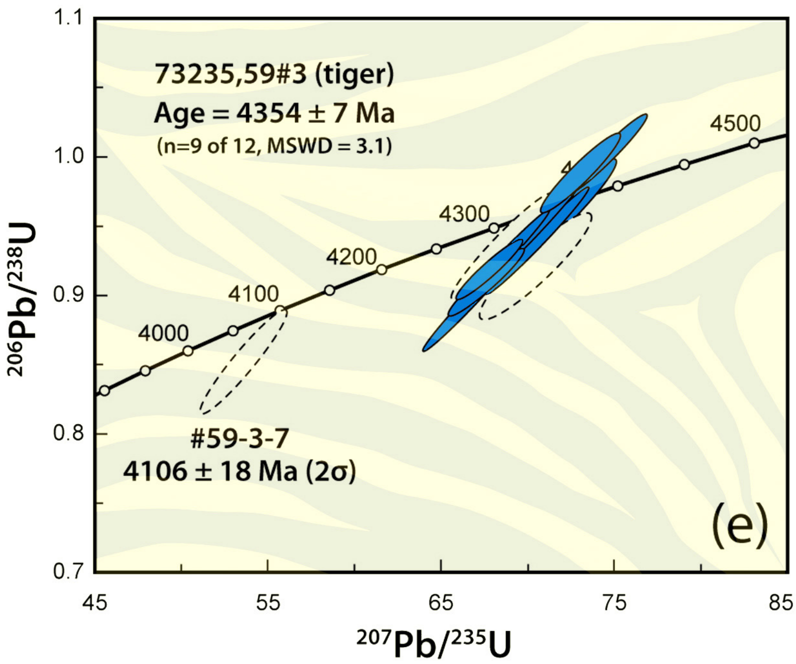


Figure 2. Concordia plot showing ages of primary zircon (filled symbols) and PDFs.

This study shows that many zircon grains can be used to determine both the time of their magmatic crystallisation and the timing of their modification by impacts. Study of the relationships between different impact features preserved in some grains allows us to reconstruct the P-T paths followed by these grains in the immediate aftermath of the impact. We hope that in the future we will be able to use this information to link individual zircon grains to specific impact craters on the Moon and determine from which part of the crater this zircon was excavated. For more of this story, see *CCFS Publications 126 and 147*.

Contacts: Alexander Nemchin, Marion Grange

Funded by: CCFS, Curtin University and ARC Discovery (from 2012)

Sulfur in unique ancient Australian rocks may unlock Earth and life secrets

The relationship between the evolution of Earth's atmosphere and hydrosphere during the Archean, and the beginning of life are major questions in Earth Science. The mass-independent fractionation (MIF) of sulfur isotopes (expressed as $\delta^{34}S$, $\Delta^{33}S$ and $\Delta^{36}S$) was caused by ultraviolet photolysis of atmospheric SO_2 in the Archean when the atmosphere was oxygen-poor and the ocean was sulfur-poor. There are significant variations in the degree of mass-independent fractionation during the Archean; it was lowest in the Mesoarchean (from 3.3 to 2.8 Ga), and these variations carry very important information. This low point has been suggested to be a result of an early rise in atmospheric oxygen. However, more recent studies (Farquar et al., 2007 *Nature*) show there is no clear evidence that oxygen rose then. The strongest Mesoarchean $\Delta^{33}S$ MIF values ranged from -0.13 to 1.31 between 2.96 Ga and 2.9 Ga (Fig. 1); this coincides with the only major volcanic events during this period, after the stabilisation of the first cratons (Kaapvaal and Pilbara). These events are linked to the start of plate tectonics and subduction (from 3.1 to 2.95 Ga), which poured volcanic gasses into the atmosphere, contributing to the development of sulfur isotope MIF and the high levels of Mesoarchean sulfur. Prior to 2.7 Ga there is a very limited rock record, and most samples showing sulfur MIF from the Mesoarchean are from continental-margin sedimentary ocean basins on the two new cratons; therefore the lack of significant negative $\Delta^{33}S$ values is not really evidence for oceanic sulfate (or atmospheric oxygen) during this period.

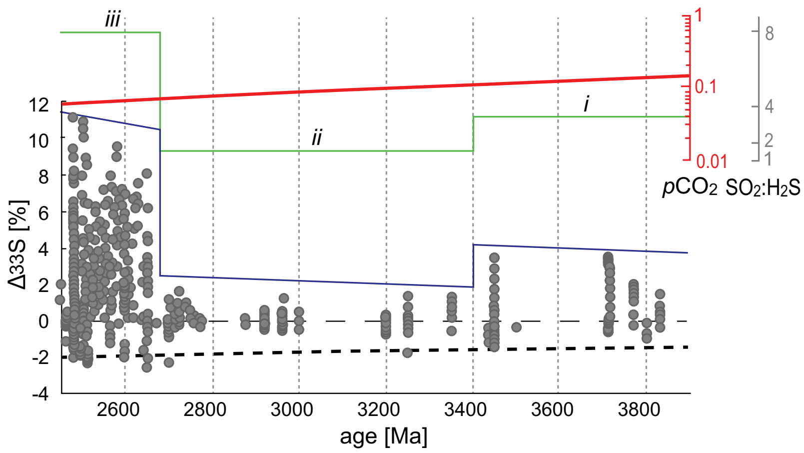


Figure 1. The global SMIF database 2010 showing the first significant Mesoarchean positive SMIF data from the margins of the first stable cratons. (Halvey et al. 2010, Science).

Australia is the only place where a wide variety of marine deposits of this key age occur, that can fill the gap in the existing global database. Recently, we have obtained the first excellent Mesoarchean results from deep ocean environments in the 2.9 Ga Lake Johnston Belt and the Murchison province of the Yilgarn. Those samples show key evidence for variations in the sulfur cycle through this time range, rather than just minor oxygen-fugacity variations before the Great Oxidation Event (Figs. 2-4). However, the ~2.9 Ga Lake Johnston Greenstone belt in the Yilgarn Craton is a marine rift with submarine volcanic rocks (basalts, felsic volcanics and komatiites) shales and banded iron formations (BIFs); it also contains low-temperature volcanogenic massive sulfides (VMS) and the Maggie Hays komatiite-hosted Ni

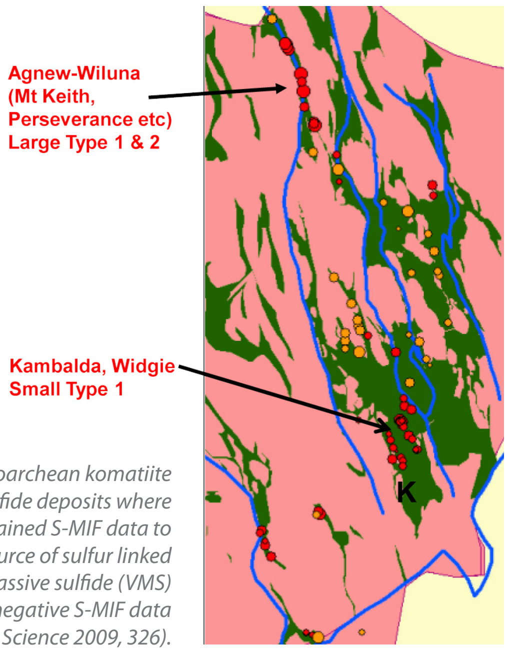


Figure 2. Neoarchean komatiite hosted Ni sulfide deposits where we have obtained S-MIF data to define the source of sulfur linked to volcanic massive sulfide (VMS) deposits with negative S-MIF data (Bekker et al., Science 2009, 326).

sulfide deposit. The new $\Delta^{33}S$ values we recently obtained from a key set of samples from this belt range from -1.7 to 0.1, providing the first and only strongly negative $\Delta^{33}S$ data from the Mesoarchean. These observations are consistent with the reduction of inorganic sulfate, similar to that observed in the Neoarchean VMS, komatiite-hosted Ni sulfides (Figs. 2, 3 and 4) and BIFs. This provides the only evidence for a Mesoarchean sulfate reservoir linked to a subaerial volcanic plume and an oceanic volcanic plume with volcanic island eruptions. These data show that the strongest positive and negative $\Delta^{33}S$ variations in the Mesoarchean sulfur MIF record are lower than the range of sulfur MIF variations in the Paleoarchean and Neoarchean. They are linked to the only preserved evidence for Measoarchean Large Igneous Province volcanic events with some subaerial volcanism producing the key volcanic gas. Our new data from the largest 2.95 Ga Mesoarchean deep submarine volcanic massive sulfide deposit, Golden Grove, are evidence for major suphur recycling after plate tectonics started.

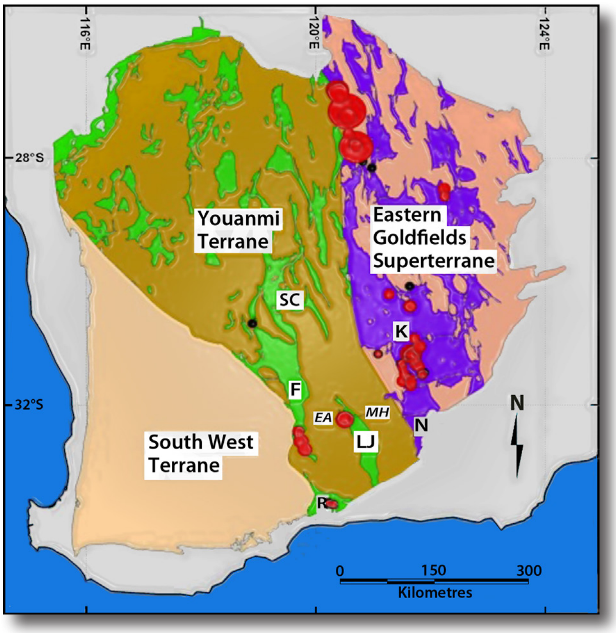


Figure 3. Similar-looking komatiite hosted Ni Sulfide deposits, with adjacent VMS deposits and banded iron formations, where we have found the only significant Mesoarchean negative S-MIF data.

Contacts: Mark Barley, Marco Fiorentini

Funded by: ARC Discovery (initial work until relinquished in early 2011) and CCFS Foundation Research Project 5 (see p. 24)

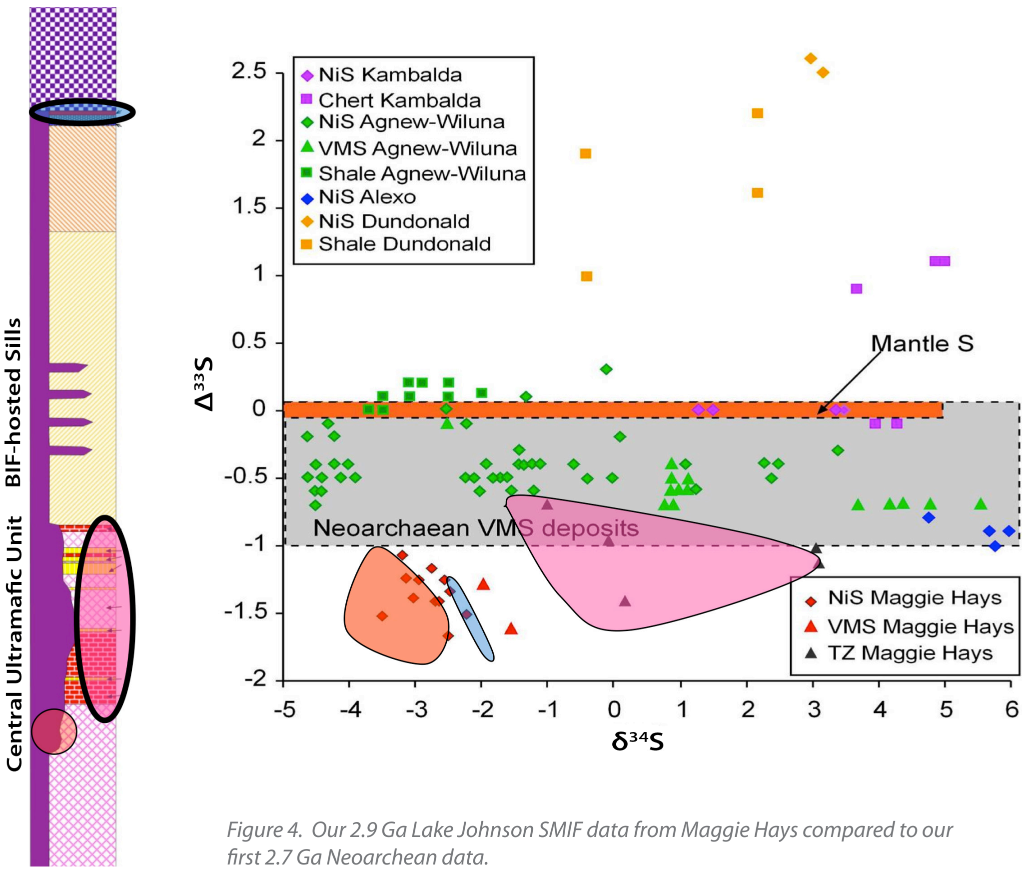


Figure 4. Our 2.9 Ga Lake Johnson SMIF data from Maggie Hays compared to our first 2.7 Ga Neoarchean data.

Minute but noble mineral grains yield insights into mantle processes

Pods of monomineralic chromite (chromitites) often occur in the zone between the mantle and the crustal sections of ophiolites, pieces of oceanic lithosphere that were emplaced on land during the closure of oceanic basins. These "podiform chromitites" usually contain high levels of the platinum-group elements (PGE: Os, Ir, Ru, Rh, Pt, Pd). The PGE concentrate in mantle rocks and minerals, and can be used to trace the mechanism of mass transfer between the upper mantle and the crust, and the recycling of crust into the mantle. Podiform chromitites are of particular interest since they tend to concentrate the most incompatible PGE (i.e. Os, Ir, Ru), which are found as minute inclusions of platinum-group minerals (PGM) made up mostly of these elements [e.g. Os-Ir alloys; erlichmanite (OsS_2), osarsite (OsAsS), laurite (Ru, Os)S_2].

The development of micro-analytical techniques of laser ablation at CCFS enables measurement of Re-Os isotopes *in situ* on single grains of PGM ~5 µm across. The application of this approach to primary PGM inclusions in podiform chromitites from the Mayarí-Baracoa Ophiolitic Belt (eastern Cuba) has let us decipher heterogeneities in $^{187}Os/^{188}Os$ at the km, hand-sample, thin-section, and even single-grain scales (Fig. 1). These observations lead directly to the conclusion that the observed Os-isotope heterogeneity in PGM reflects the presence in the upper mantle of melts derived from rock volumes with widely varying Os-isotope composition, perhaps even bodies of ancient subducted crust. This isotopic heterogeneity also suggests that the Os-isotope compositions of PGM hosted in the podiform chromitites may be representative of the large volumes of the convecting mantle that would need to be melted to accumulate these concentrations of Cr and PGEs (see *CCFS Publication #13*).

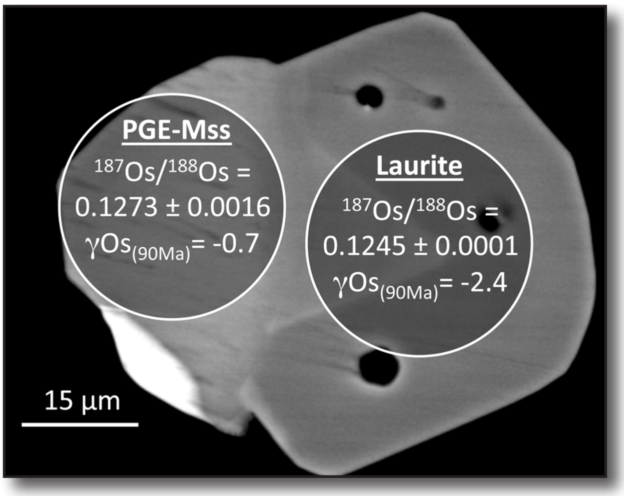


Figure 1. Re–Os systematics in the analysed sulfides of the Caridad chromitite (Mayarí-Baracoa Ophiolitic Belt, eastern Cuba). Black spots correspond to minute inclusions of millerite and/or chalcocite; the brighter mineral associated with PGE-rich Mss is cuproiridsite.

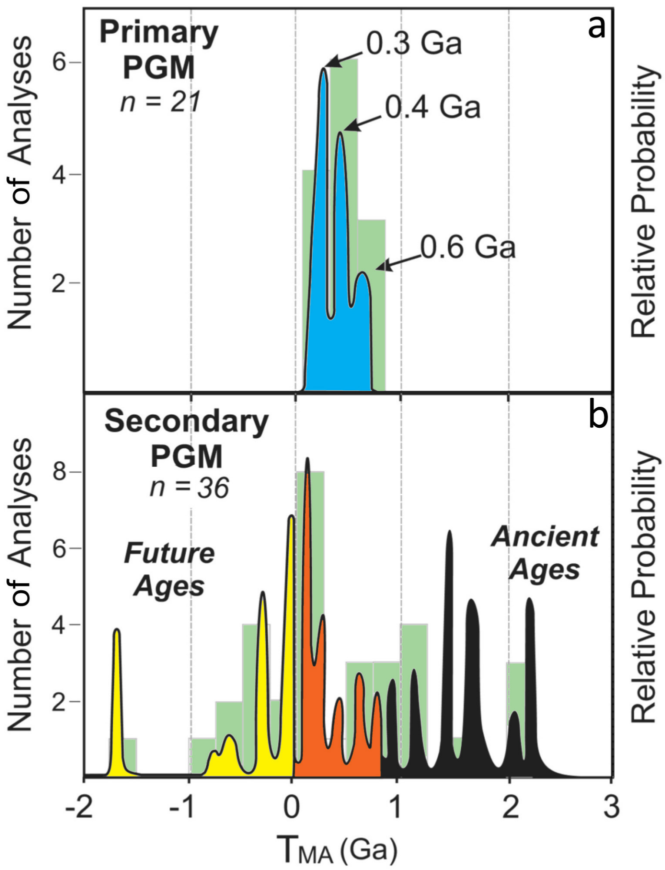
However, podiform chromitites, like their mantle-derived host rocks (i.e. dunite, harzburgite, lherzolite), can be altered by fluids during post-magmatic events, such as serpentinisation or metamorphism. During these processes the PGM can be released and exposed to the circulating solutions as the host chromite reacts. Pre-existing PGM may be partially or completely replaced by secondary PGM (e.g. sulfides reduced to alloys or oxides; Fig. 2) and/or new secondary PGM can be formed, stable at the conditions imposed by the alteration. The *in situ* laser ablation analysis of PGM from metamorphosed chromitites in Bulgaria (*CCFS Publication #42*) reveals that primary PGM hosted in unaltered chromite are isotopically different from secondary PGM related to the metamorphic overprint (Fig. 2).

These differences between primary and secondary PGM indicates that a significant part of the Os-isotope heterogeneity described in many PGM suites, and interpreted to be mantle-derived, is actually due to post-magmatic disturbance by hydrothermal processes. The fact that secondary PGM in the metamorphosed chromitites of Dobromirtsi yield $^{187}Os/^{188}Os$ within the range of depleted to enriched mantle sources suggests that much of the Os-isotopic variability previously reported for PGM taken out of their microstructural setting (e.g. mineral concentrates or detrital grains collected from streams), and interpreted as a magmatic feature, may instead be related to secondary alteration processes. Therefore, interpretations of mantle events based on the *in situ* analysis of PGM nuggets from placers may be need to be re-considered. Moreover, the observation that metamorphosed chromitites may carry primary and secondary PGM with very distinct $^{187}Os/^{188}Os$ suggests that previously reported Os-isotope compositions of metamorphosed chromitites, which were determined using whole-rock analysis, might reflect mixing of primary (magmatic) and secondary Os remobilised during metamorphism, rather than primary magmatic values.

Once again, *in situ* microanalysis is providing insights impossible to derive from bulk analysis – and providing grounds for caution about our understanding of some mantle processes!

Contacts: José María González-Jiménez, Bill Griffin, Norman Pearson, Sue O'Reilly

Funded by: ARC, CCFS Foundation Project



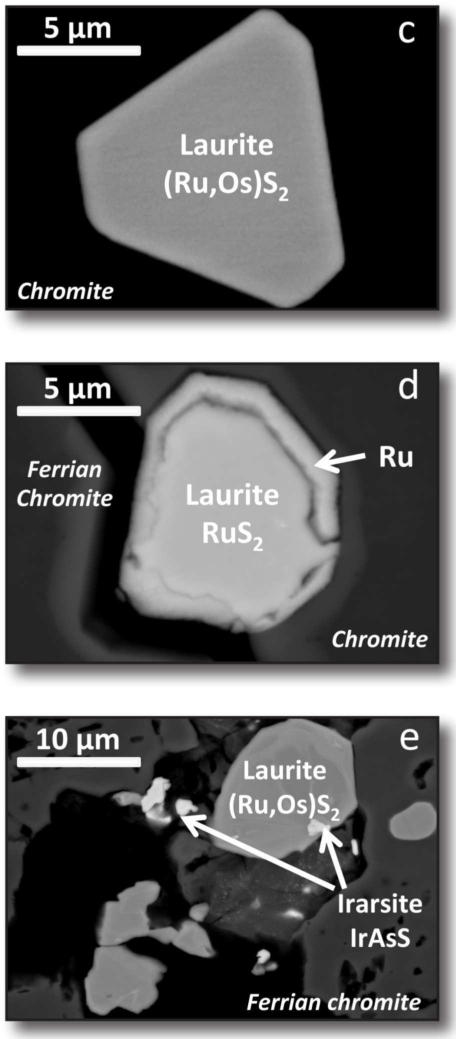


Figure 2. Isotopic heterogeneity in PGM suites. T_{MA} model ages of primary (a) and secondary (b) PGM grains from the Dobromirtsi chromitites. Photos are backscattered electron images of primary PGM (c) hosted in unaltered chromite, and altered (secondary) PGM (d, e) found in altered zones of the chromitites. Note scale bars - these are tiny, but analysable, grains.

A window of opportunity for plate tectonics?

Plate tectonics is the machine that shapes the Earth's surface, from mountain ranges to ocean depths. It is the cornerstone of modern geology, yet it appears that the process only occurs on one known planet - Earth. Additionally, a serious debate continues as to when plate tectonics started on Earth - current estimates range from over 4.4 billion years ago - almost the age of the planet - to just one billion years ago – geologically speaking, our recent past.

It is fairly well accepted that as a planet cools, and its lithosphere - the strong, outer layer that carries the crust - gets thicker, the planet will develop a stagnant "lid". This is defined by the end of active surface tectonics on a planet. Mars, the Moon, and Mercury all seem to have passed into this twilight regime. However, recent work at CCFS/GEMOC has indicated that stagnant-lid tectonics can operate at the other end of the spectrum, too. For extremely hot planets, the high interior temperatures result in low internal viscosities. This breaks down the coupling between the convecting mantle and the plates, and tectonics again becomes unsustainable. A type example of this sort of hot stagnant lid model could be Io, the most volcanically active planetary body in the solar system.

This model predicts an evolution in tectonics over the course of a planet's slow cooling, from a hot stagnant mode in its early history, to an active tectonic regime, waning into a cold stagnant mode as the planet ages. Recent simulations at CCFS/GEMOC, presented at the American Geophysical Union meeting in December 2011, confirm this evolutionary trend. These models for the first time incorporated not only the decay in heat production in the mantle through time, but also realistically-evolving conditions in the core of the planet. The starting conditions were the results from equilibrium convection simulations under Hadean thermal conditions. These models commonly showed an evolution from hot stagnant behaviour initially, to an episodic subduction mode, where periods of quiescence are interspersed with periods of rapid, violent subduction. This progressed into a steadier plate tectonic mode, under mantle conditions similar to today. Eventually the lithosphere thickened beyond the point of sustainable surface behaviour, and the system progressed into a cold stagnant-lid regime. The exact timing and progress depend strongly on the simulation parameters and the initial conditions chosen. However, the results confirm that rather than an end-member tectonic regime, plate tectonics is a phase in a planet's tectonothermal evolution - which has large implications for exosolar planetary conditions.

Contact: Craig O'Neill
Funded by: ARC Discovery, Future Fellowship, MQ

Did the Earth start off without plates?

Tracking water in the Earth's mantle

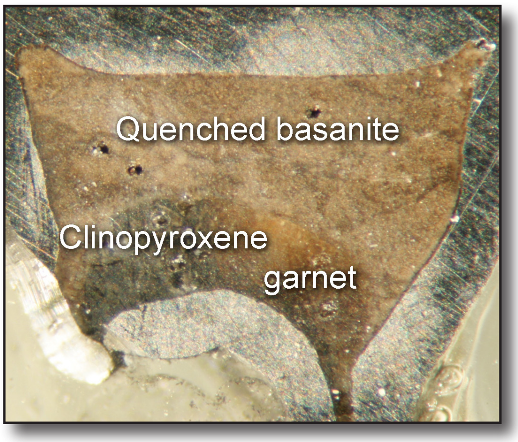


Figure 1. Experimentally grown crystals of dark green clinopyroxene and brown garnet in a quenched, hydrous, basanite melt. The experiment was conducted at 1190 ºC and 3.5 GPa.

Water is a very efficient fluxing agent, and is likely to have a strong influence on both the distribution and styles of melting within the Earth's mantle. Knowledge about its distribution and behaviour is critical for our understanding of geochemical fractionation within the Earth's mantle. However, other factors, including pressure and temperature, are also critical because the effects of water in real magmas can be difficult to distinguish from those produced by P and T. To unravel these effects, we have compared the compositional and structural properties of clinopyroxene (an important mantle phase) crystallised from both water-rich and water-poor magmas.

High-pressure experiments have been performed at 1.0-3.5 GPa and 1025-1190 ºC on a hydrous, intraplate magma (nepheline-basanite). Water contents ranging from 5.8 to 16.3 wt % were dissolved in the co-existing melts. Clinopyroxenes (Fig. 1) crystallised from these hydrous experiments were analysed for major elements using an electron microprobe at the GEMOC Analytical Facility. Crystal-chemical structural data for the these pyroxenes, including structure refinements and lattice parameters, were obtained by Fernando Camera and Roberta Oberti using single-crystal X-ray diffractometry at the CNR-Institute of Geoscience and Georesources, University of Pavia, Italy. Water concentrations in the melts were estimated from mass balances between run products and starting materials.

Increasing pressure of formation has a marked effect on both the compositions and structural properties of the clinopyroxenes crystallised from the hydrous melts. Crystals become more jadeite-rich ($NaAlSi_2O_6$) but less calcic and Ti-rich as pressures of synthesis increase. These changes are accompanied by a systematic decrease in cell volumes. Higher temperature causes increases in both the clino-enstatite/clino-ferrosalite components ($(Mg, Fe)_2SiO_6$) and the Ca-Tschermaks component ($CaAl.AlSiO_6$). Inclusion of these latter components also reduces cell volumes.

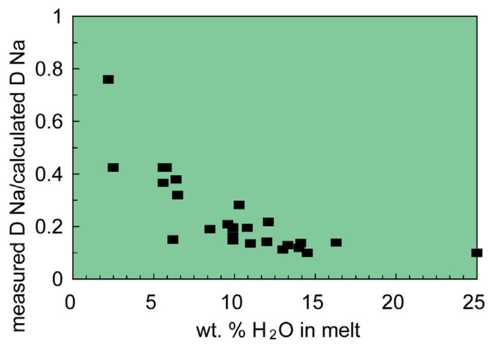


Figure 2. The effect of water on the partitioning of sodium between clinopyroxene and melt. The vertical axis shows the ratios of measured partition coefficients for hydrous melts and values calculated for anhydrous melts.

We evaluated the effects of H_2O by applying the single-crystal clinopyroxene barometer of Nimis and Ulmer (*Contrib. Mineral. Petrol., 133: 122-135, 1998*) to our data. This barometer is based on the overall response of the crystal structure (principally cell volume) to pressure, rather than to specific compositional changes. It was also calibrated primarily for anhydrous melt compositions. When applied to our data, the Nimis and Ulmer barometer systematically underestimates the pressures of synthesis, and the underestimation increases at higher pressure. This is due to the comparatively large volumes of the crystals grown in our experiments. Thus at constant pressure, clinopyroxenes crystallised from H_2O-rich melts have larger volumes than those crystallised from equivalent anhydrous systems. At least in part, this can be attributed to the effects of H_2O on the activity coefficients of pyroxene-forming melt components such as jadeite (Fig. 2). When compared to anhydrous experiments, the data also reflect changes in the activity coefficients of components within the clinopyroxene crystal structure (e.g. Tschermaks, clino-enstatite and clino-ferrosalite) caused by the lower temperatures of the hydrous experiments. Further work is underway to evaluate these effects quantitatively and link them to water concentrations in mantle-derived hydrous magmas.

Contacts: John Adam, Trevor Green, Tracy Rushmer

Funded by: Macquarie University Development Grant, ARC Discovery, MQ

Coupling, decoupling and fluid infiltration: a torrid history of crust-mantle relationships beneath NW Spitsbergen

The Bockfjord area of NW Spitsbergen (Norwegian Arctic; Fig. 1) exposes a long history of crustal evolution, ending in the Caledonian (400-500 Ma) orogeny; prior to the opening of the North Atlantic Ocean, this area was part of the Laurentian (Greenland) side of the orogen. The N-striking Breibogen-Bockfjord (BB) fault marks the western margin of a large graben filled with Devonian redbeds (Fig. 2). West of the fault the basement consists of gneisses, schists and granites of the Hekla Hoek formation, apparently a Caldeonian thrust sheet. U-Pb and Hf-isotope data for detrital zircons from this area show that the protoliths of the Hekla Hoek rocks formed ca 1.8 Ga ago, but were heavily reworked ca 800-1000 Ma ago, and again during the Caledonian orogeny.

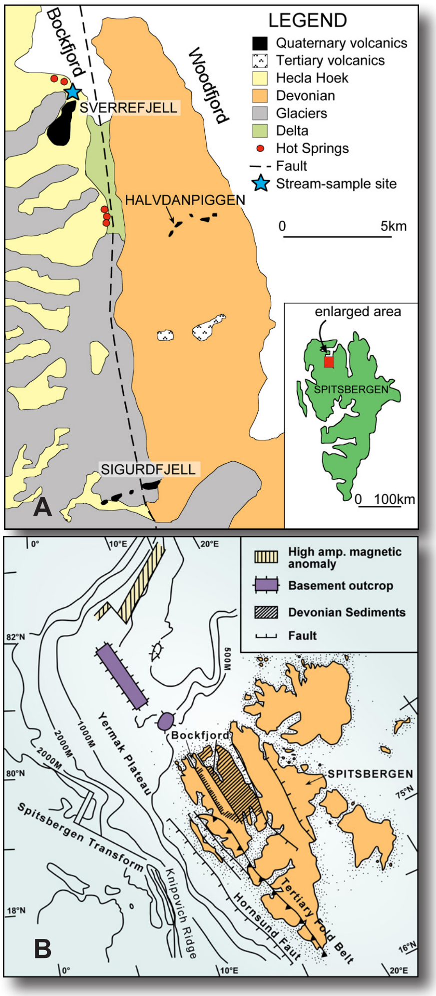


Figure 1. A) Map of the Bockfjord area, with the BB fault nd volcano locations. B) Regional setting, showing possible remnants of Spitsbergen lithosphere on the Yermak Plateau.

Figure 2. Redbeds along Bockfjord.

Quaternary alkali-basalt volcanism has provided abundant xenoliths of mantle and crustal rocks from both sides of the BB fault. Sverrefjell, a large (but glaciated) cinder cone (Fig. 3) may be the world's single largest source of mantle- and crustally-derived xenoliths, with an estimated volume of about one-third of a cubic kilometer. Lower-crustal xenoliths are mainly mafic to intermediate granulites. Most zircons from eight xenoliths have Neoarchean/Paleoproterozoic and Paleozoic U-Pb ages; several also contain zircons with ages and/or Hf model ages >3.2 Ga.

The peridotite xenoliths are mainly spinel lherzolites, metasomatised to varying extents. Xenoliths from basalts east of the BB fault commonly contain amphibole, phlogopite and apatite; peridotites from west of the fault rarely have these metasomatic phases. *In situ* Re-Os isotope analysis of sulfides in the peridotites shows another dichotomy. Xenoliths from west of the fault contain sulfides with Re depletion (T_{RD}) model ages extending back to 3.3 Ga, with major populations at 2.4-2.6 Ga, 1.6-1.8 Ga and 1.2-1.3 Ga (Fig. 4); the Caledonian orogeny is only weakly represented. East

Figure 3. Sverrefjell.

of the BB fault the peaks in the T_{RD} spectrum are at 900-1100 Ma and 400-500 Ma; only a few grains have T_{MA} >2.5 Ga.

The data show a major disjunct, on both sides of the BB fault, between the Archean lower crust and a Proterozoic-Paleozoic upper crust; this suggests that the original Archean upper (and middle?) crust was detached and replaced by thrust sheets of younger material during the Caledonian orogeny (Fig. 5). The striking differences in the sub-continental lithospheric mantle (SCLM) across the BB fault suggest that major transcurrent movement has juxtaposed lithospheric sections that evolved independently. This may have happened during the long transport of these terranes from north of Greenland, during the opening of the Arctic Sea.

West of the BB fault, the presence of Archean lower crust overlying Archean SCLM suggests that the crust and mantle have remained coupled for ≥3 Ga. East of the fault, similar Archean lower crust overlies an apparently younger, more fertile SCLM. The pervasive melt-related metasomatism that refertilised the SCLM east of the BB fault may have obscured its Archean origin.

Typical Archean SCLM is 150-250 km thick, whereas the Bockfjord volcanoes carry no samples from deeper than 80 km. The detached lower part of the Archean SCLM may now lie beneath the Gakkel Ridge to the NW (Fig. 1A), as proposed by Goldstein et al. (2008) on the basis of basalt geochemistry. This proposition is supported by the mean T_{RD} of the Sverrefjell sulfides (1740±718 Ma), which is similar to the oldest whole-rock T_{RD} values for peridotites dredged from the Gakkel Ridge (1.8-2.2 Ga; Liu et al., 2010).

Contacts: Bill Griffin, Sue O'Reilly, Norman Pearson
Funded by: ARC and GEMOC, CCFS Foundation Project

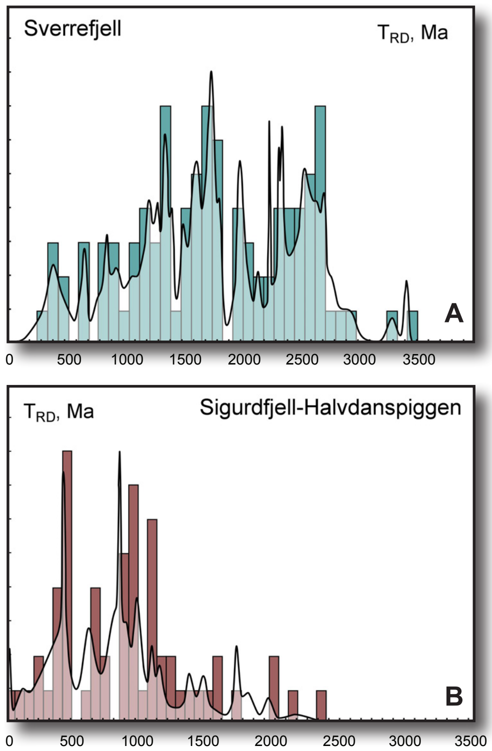


Figure 4. Distribution of Os model ages of sulfides in peridotite xenoliths from either side of the BB fault.

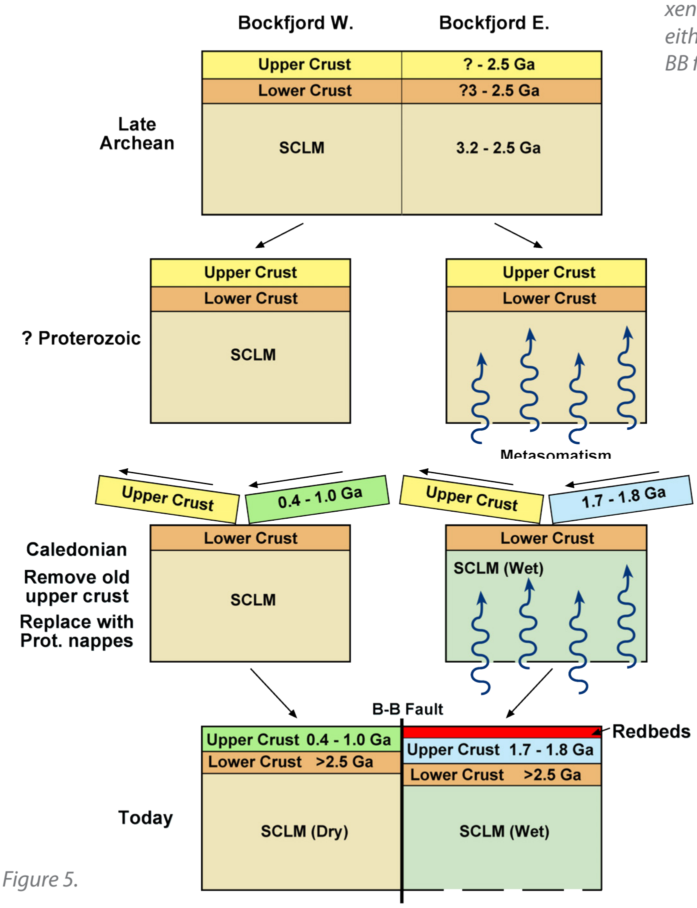


Figure 5.

Remaking an old continent - A 40° twist between northern and southern Australia 600 million years ago

The basement rocks beneath the western two-thirds of Australia are mostly older than 1800 million years old (Ma) and host the vast majority of Australia's mineral wealth; the eastern one-third is younger than 540 Ma (Fig. 1). It has long been assumed that the older part of the continent has been in its present-day shape for at least 1000 Ma. However, a re-examination of the tiny magnetic needles trapped in some of Australia's old rocks has revealed a previously unknown 40° twist between the continent's two halves some 600 million years ago (Fig. 2).

Palaeomagnetism is a research method that measures the orientation of tiny magnetic particles trapped in rocks. These act as a fossil compass that records the movement of each continent on the Earth's surface in the deep past. Such fossil magnetic records, called apparent polar wander paths, work like a magnetic barcode for each continent or a piece of a continent. When two pieces of continent travel together on the Earth's surface, their bar codes match exactly. If the two continental pieces later moved apart, their previous palaeomagnetic 'barcodes' would split. This allows us to detect when continents joined together, when they broke apart, and how they moved relative to each other and to the geographic North Pole (Earth's rotation axis).

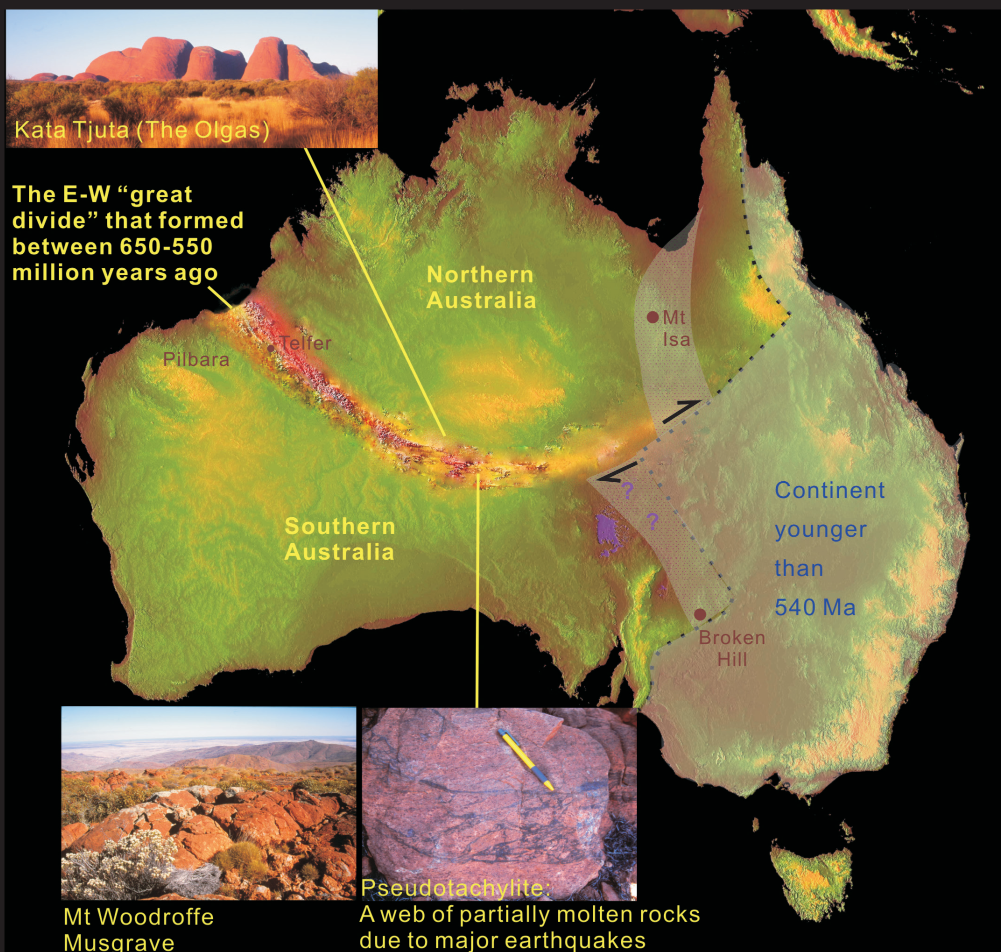


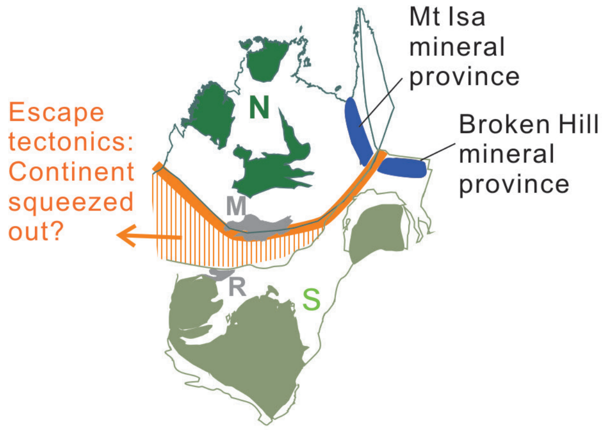
Figure 1. A cartoon of the mighty east-west trending mountain range formed between 650-550 million years ago placed on the present-day Australian landscape. Sediments shed from the northern slope of the mountains formed Uluru (Ayers Rock) and Kata Tjuta (The Olgas).

During a reanalysis of geological and palaeomagnetic data from Australia, we noticed that the palaeomagnetic 'bar codes' (i.e., apparent polar wander paths) between the northern and southern halves of the old Australian continent share comparable shapes but with a systematic offset in their present-day continental configuration. However, this offset disappears if we rotate southern Australia about 40° relative to northern Australia (Fig. 2a).

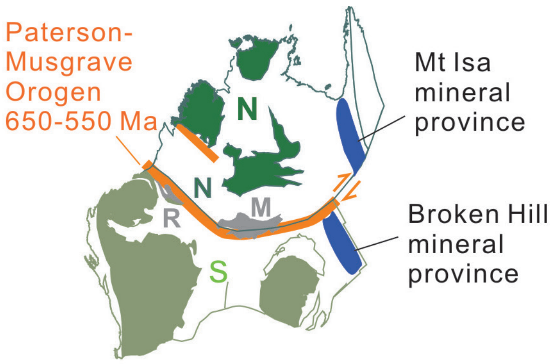
This disjunction between the two halves of the old Australian continent coincides with traces of a major 650–550 Ma mountain belt, which runs from the Paterson Ranges off the eastern boundary of the Pilbara to the Petermann and Musgrave ranges of Central Australia, and disappears into central Queensland (Figs. 1, 2b). This east-west trending zone probably was a mighty mountain range, comparable to the Tianshan ranges in central Asia. There are webs of locally molten rocks in the Musgrave Ranges (Fig. 1) caused by large earthquakes that occurred during this major upheaval. The rotation event would also have laterally offset the northern and southern halves of the old continent by over 500 km, and would provide a setting for forming new mineral deposits. Sediments shed off the northern slope of this mighty mountain range formed the present-day cultural and landscape icons, Uluru (Ayers Rock) and Kata Tjuta (The Olgas) (Fig. 1).

Australia probably lost a bit of real-estate during this event, as land that used to fill in the narrow triangular gap in the western part of the continent was probably squeezed out to the west during the rotation. However, Australia did gain in mineral endowment, such as the large Telfer gold deposit in Western Australia. There is potential for finding more such deposits along this long mountain belt. This new interpretation also solves one of the long-standing puzzles about where the southern extension of the Mt Isa mineral zone went. Our work indicates that the two mineral belts may indeed, as previously speculated by geologists, have formed as parts of a single belt that was cut into two halves and offset by over 500 km during an intracontinental rotation some 650–550 million years ago (Figs. 1 and 2).

Our new geotectonic model also resolves a longstanding controversy surrounding the configuration and breakup history of the supercontinent Rodinia (lifespan ca 900–700 Ma), consisting of almost all continents that existed at the time. It implies that Rodinia didn't break up until much later than we thought, placing the breakup much closer to the time of the hypothesised first 'Snowball Earth' event. This makes it more plausible that the breakup of the supercontinent and accompanying geographical and chemical changes led to catastrophic global chilling events (opposite to global warming events) between 750 and 600 million years ago. Both events probably played roles in the Cambrian explosion of complex life on Earth. The formation and subsequent erosion of the mighty mountain range across Australia may also have contributed to the oxygenation of the atmosphere, thus making the Earth more habitable for complex life.



(a) Before 650 million years ago



(b) 550 million years ago to present

Figure 2. Maps of the old part (>540 million years old) of the Australian continent now (b) and before final tectonic assembly (a) – omitting the eastern third of the continent which had not yet formed. Dark green 'N' = northern Australia; Olive green 'S' = southern Australia; M = Musgrave Block; R = Rudall Complex of the Paterson orogen. Note that the two halves of an originally continuous Mt Isa-Broken Hill mineral province are now offset by ~550 km.

Contacts: Zheng-Xiang Li, David A.D. Evans (Yale University)
Funded by: ARC Discovery

Arkansas was built over collision zone of Archean microcontinents

The upper crust across the southern half of North America consists of a series of Proterozoic orogenic belts (Fig. 1: the 1.6-1.8 Ga Yavapai and Mazatzal terranes, the 1.5-1.3 Ga Granite-Rhyolite Province, the 1.3-1.0 Ga Grenville Province, and finally the Phanerozoic Appalachian belt) successively accreted onto the Archean continental core. This pattern suggests a simple concentric growth of the continent over about a billion years. However, the seismic tomography in Figure 1 suggests that the situation is more complex – high-velocity anomalies like those typically associated with Archean continental roots are visible in a wide band stretching southward from the Canadian Shield. Although these anomalies become less prominent to the south, they are still obvious down to the Gulf of Mexico. What is high-velocity lithospheric mantle doing under young orogenic belts? Unfortunately, there are no volcanic rocks that sample the high-veolcity mantle, and the few that have intruded along the edges of the high-velocity volumes (Fig. 1) rarely carry xenoliths that could reveal the nature of the subcontinental lithospheric mantle (SCLM).

The Cretaceous Prairie Creek - Twin Knobs lamproites of southern Arkansas intrude Proterozoic crust near the boundary between the Granite-Rhyolite Province and the Grenville orogen. On the seismic tomography, they lie along the boundary between two blocks of high-velocity

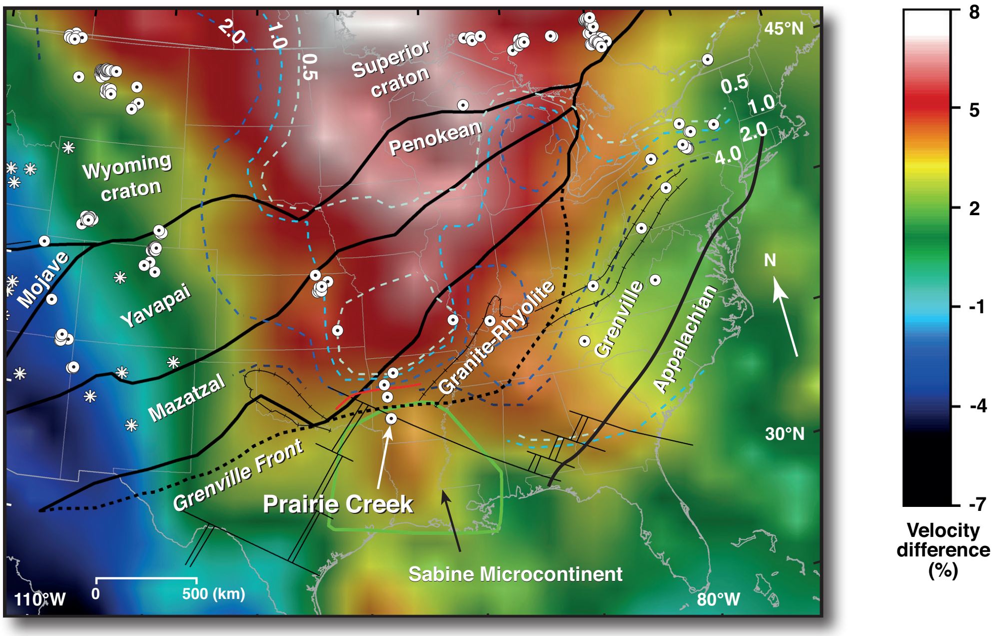


Figure 1. Seismic tomographic image (100-175 km depth slice, courtesy of Steve Grand) covering part of southern North America. The image highlights the spatial relationship between shear wave velocity (Vs) and crustal features. Reference velocity is 4.5 km/sec. "Hot" colours represent high Vs, while "cold" colours represent low Vs. The Prairie Creek lamproite field is indicated by an arrow. Solid thick black lines are crustal province boundaries of Whitmeyer and Karlstrom (2007). Short black dashes show the interpreted northwestern extent of Grenville lithospheric reworking. Green line shows approximate outline of the Sabine microcontinent, which is surrounded on its west, north and northeast sides by the Ouachita orogen thrust front. Ticked thin black lines are Late Neoproterozoic to Cambrian aulocogens. Thin black lines are the proposed latest Neoproterozoic rifts and transform faults for southernmost Laurentia (Thomas, 2006). Solid red line is the approximate northern extent of Ouachita Orogen thrusts. Long-dashed lines are contours of Phanerozoic sediment thickness (km indicated). Dots are kimberlites and lamproites, and asterisks are Quaternary volcanoes.

mantle. They carry xenocrysts and rare xenoliths derived from the SCLM and the deep crust; these were studied by Dr David Dunn for his PhD thesis, and he has collaborated with us to find out more about them. U-Pb dating of groundmass perovskite in the Prairie Creek lamproites gives a poorly constrained Cretaceous age, consistent with local stratigraphy. U-Pb dating and *in situ* Sr and Nd isotope data show that perovskite micronodules in the Twin Knobs 2 lamprophyre are ca 600 Ma old, and may represent samples of older rift-related alkalic magmas derived from a juvenile mantle. A lithologic section constructed from mantle-derived garnet xenocrysts (Fig. 2) shows a moderately depleted SCLM that has experienced a high degree of melt-related metasomatism, especially in the depth range 150-140 km. *In situ* Re-Os analysis of sulfide grains in the xenoliths (Fig. 3) yields model ages ranging up to 3.4 Ga, with major peaks at 1.4-1.5 Ga and 200-300 Ma. The scatter of Early Paleoproterozoic model ages appears to reflect mixing between residual Archean high-Os sulfides and later low-Os sulfide melts (Fig. 3b).

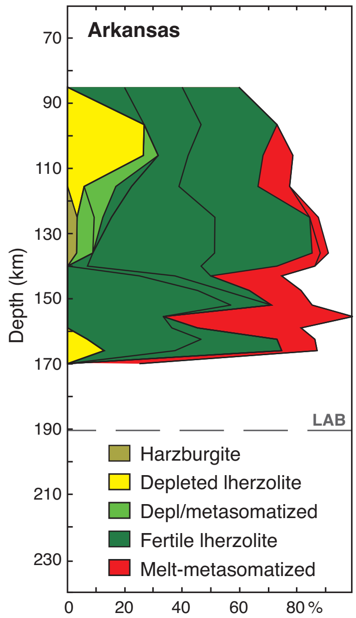


Figure 2. "Chemical Tomography" section showing the relative proportions of depleted and metasomatised rock types versus depth, as derived from Cr-pyrope xenocrysts. The relatively high proportion of fertile lherzolites is typical of the SCLM beneath many Proterozoic terranes. The figure is constructed by calculating the relative proportions of each garnet type at 50 °C intervals, using a sliding window 100 °C wide, to take account of probable uncertainties in the depth estimates.

These data suggest that the SCLM beneath the Prairie Creek area formed in Archean time, and has been progressively refertilised by a series of magmatic events, which appear to correlate in time with events in the overlying crust. The Archean SCLM sampled by the lamproites may represent the mantle root of the Sabine microcontinent, which is recognisable in the seismic tomography (Fig. 1) as the higher-Vs feature (100-175 km depth) that lies mainly to the south of the lamproite field. Seismic tomography also shows several blocks with high Vs beneath the Grenville province to the east, which may represent other microcontinental blocks. These findings suggest that the growth of individual continents is significantly affected by the accretion of older microcontinental blocks, and that the extent of old SCLM, and of early continental crust, therefore may be greater than generally estimated.

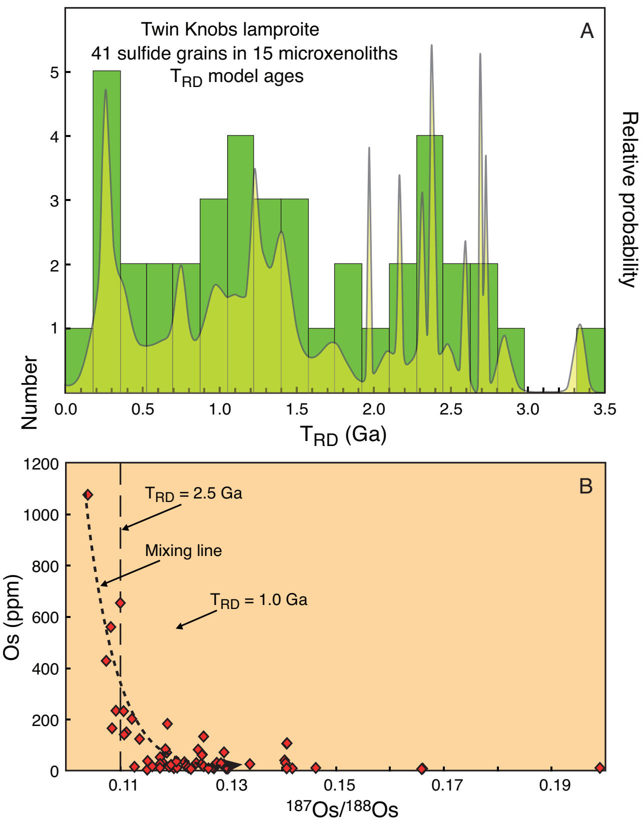


Figure 3. Re-Os data for sulfide grains in xenoliths from the Twin Knobs lamproite. (A) Cumulative-probability plot and histogram for Re-depletion ages (T_{RD}); (B) Plot of Os content vs $^{187}Os/^{188}Os$; the negative correlation at low $^{187}Os/^{188}Os$ suggests reaction (mixing) between old high-Os sulfides and younger sulfide melts with low Os and high $^{187}Os/^{188}Os$. Vertical dashed lines show $^{187}Os/^{188}Os$ corresponding to T_{RD} = 2.5 Ga and 1.0 Ga.

Contacts: Bill Griffin, Sue O'Reilly, Graham Begg

Funded by: ARC Discovery and Linkage Projects

Zircons reveal 3.5 billion-year old crust beneath central Spain

Our first results on zircons from the lower-crustal granulite xenoliths of the Variscan orogenic belt of central Spain provide evidence for the existence of Paleoproterozoic-Archean (up to 3.5 Ga) components in the deep crust, even though the exposed crust is much younger (GEMOC/CCFS *Publication #721*). This is supported by both widespread Paleoproterozoic-Archean Hf model ages and the presence of inherited zircon cores with comparable U–Pb ages. Around 75% of zircon grains show inherited cores defining age clusters in Archean (3371–3453 Ma), Proterozoic (618–1680 Ma) and Early Paleozoic (440–573 Ma) time (Fig. 1).

Hf-isotope data are useful for estimating the timing of significant production and/or preservation of juvenile continental crust. Thus, the presence in an outcropping migmatite (the Cervatos anatexite) and in the granulite xenolith U152 of two old zircon cores showing markedly positive εHf values (+4.4 and +13.1, at 2180 and 3371 Ma, respectively; Fig. 1), suggests the possibility of juvenile addition during Palaeoproterozoic and Archean times. Figure 2 presents a summary of the Hf model-age data collected on the studied granulitic rocks as well as the range of whole-rock Nd model ages available for them. The resulting juvenile continental-growth histogram shows a continuum between 0.95 and 2.3 Ga, with a predominance of 1.0–1.8 Ga ages and a peak at 1.6–1.7 Ga. Nd and Hf model ages in the range of 1.4–1.7 Ga may represent mixing of Late Proterozoic juvenile components with variable proportions of older crust of Paleoproterozoic and possibly Archean age. The presence of very old crustal components in Neoproterozoic successions deserves a thorough debate in the future, when forthcoming data from metamorphic rocks of the Iberian Massif are available.

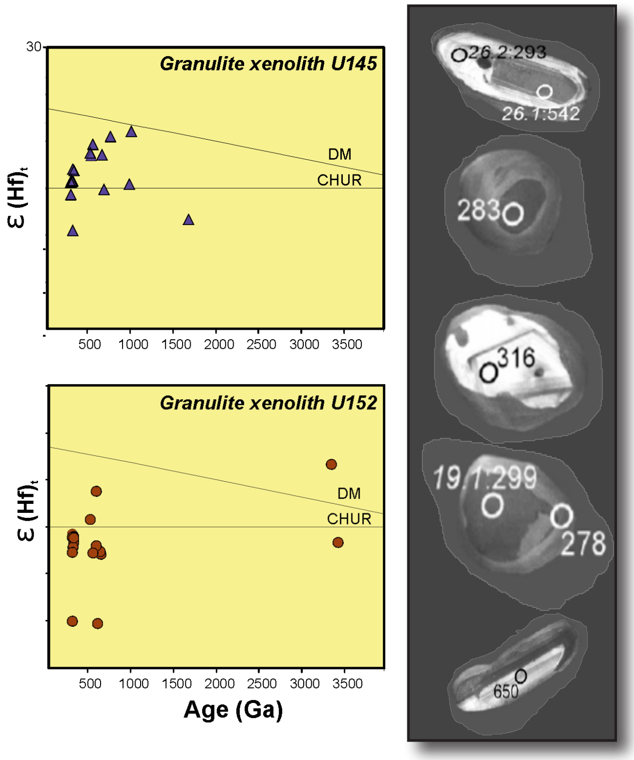


Figure 1. Initial εHf values of individual zircon grains from some of the studied granulite xenoliths.

Some of the recent paleogeographic reconstruction models suggest northern African sources for the Mesoproterozoic inheritances in the metasediments of the Central Iberian Zone. In this study age populations in the interval 800–1250 Ma are interpreted as evidence of the location of NW Iberia between the West African Craton and the Saharan and Arabian–Nubian shields (Fig. 3). The Hf-isotope data presented here record only a minor mantle input at 1.0–1.2 Ga in central Iberia, which is markedly younger than the more widespread crust-forming event at 1.3–1.6 Ga recorded in other continental blocks (e.g. Amazonia, Australia, Ukraine). On the other hand, crustal-generation events in central Africa at 1.0–1.3 Ma, reported recently for detrital zircons

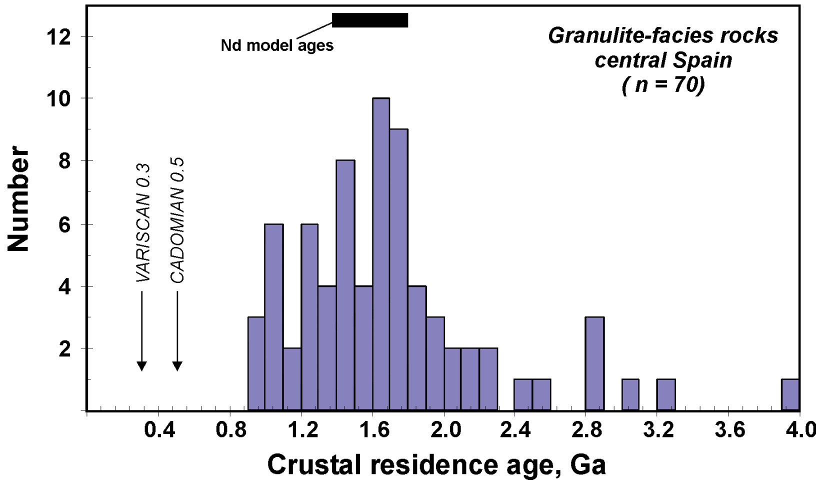


Figure 2. Histogram of Hf Model ages of zircons from the four studied granulite-facies rocks from central Spain. The range of whole-rock Nd model ages is shown for comparison.

from central Africa (Congo Craton), match the distribution of Hf model ages of the granulite zircons from central Spain better than those from the Amazonian and West African cratons. This implies that during early Neoproterozoic and late Mesoproterozoic times, NW Iberia was far from the Amazonian Craton, and that its position to the north-east of the West African Craton might be a more reasonable option (Fig. 3). Furthermore, palaeogeographic reconstructions for Early Paleozoic time, based on benthic faunas, support the idea that NW Iberia was probably closer to the Algerian Sahara or Libya than to the Moroccan part of the North Gondwanan shelf.

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Funded by: ARC Discovery (O'Reilly, Griffin, Pearson), Industry

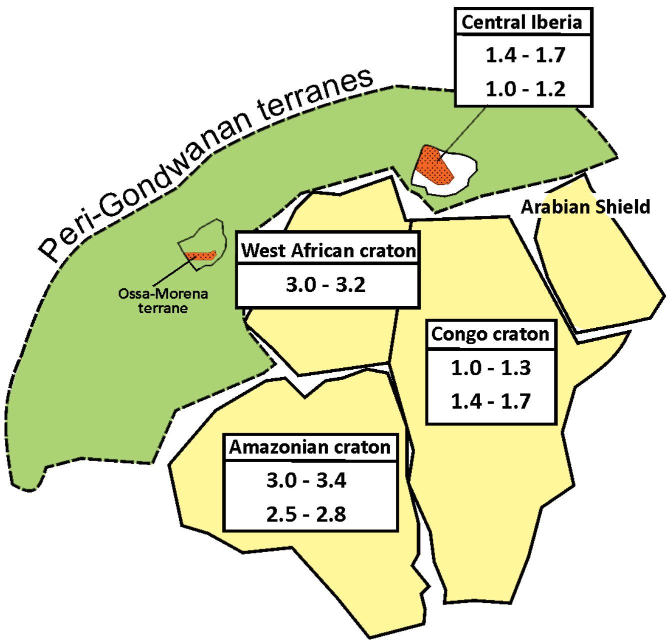

Figure 3. Hf-isotope data of granulite zircons agrees with recent palaeogeographical reconstruction models that show central Iberia as a Peri-Gondwanan terrane located between the West African craton and the Arabian shield, far from the Amazonia microplate. The main Hf-isotope T_{DM} peaks in relative-probability histograms are shown for different cratons (Amazonia, West Africa, central Africa).

Zircons from South China Block, reveal hot (non-glacial) origin

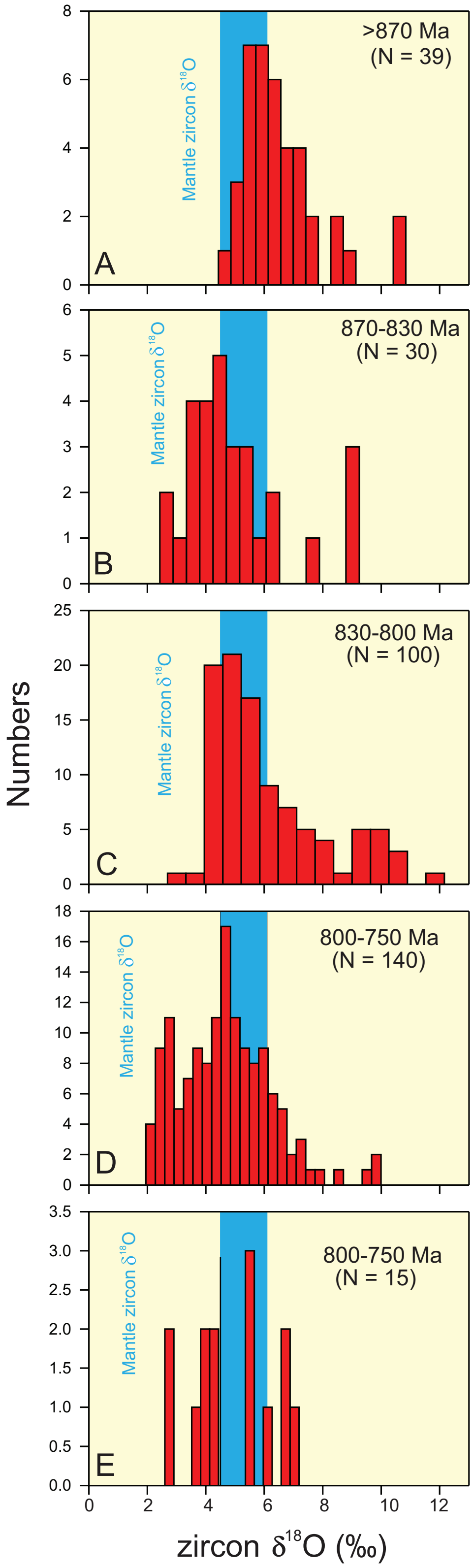

Figure 1. Oxygen isotope compositions of zircons with ages of (A) >870 Ma, (B) 870–830 Ma, (C) 830–800 Ma, (D) 800–750 Ma, and (E) 750–700 Ma. Number of bins in (D) is 25 and 15 for others (Modified after Wang et al., 2011, Geology, v. 39, no. 8, p. 735-738).

Low $\delta^{18}O$ signatures in supracrustal rocks have been regarded as a signal of cold paleoclimates such as glaciations. Unusually low $\delta^{18}O$ values in Neoproterozoic igneous rocks in parts of the South China Block have thus been genetically linked to Neoproterozoic glaciation events. However, the oxygen isotope compositions of Neoproterozoic magmatic zircons in central South China, measured using *in situ* techniques, argue against such an interpretation. Our results show that low-$\delta^{18}O$ magmatic zircons started to appear in South China from ca 870 Ma, coinciding with the tectonic switching from the Sibao Orogeny to post-orogenic extension, which occurred >150 Ma prior to the first glaciation event. The most abundant low-$\delta^{18}O$ magmatic zircons have ages of 800–700 Ma. 830–700 Ma magmatic zircons show a bimodal distribution of $\delta^{18}O$: mantle-like (+ 4.4 to +5.8‰) and high $\delta^{18}O$ (+9.3 to +10.8 ‰). A sharp temporal change in maximum zircon $\delta^{18}O$ values in South China coincided with the onset of continental rifting and the possible arrival of a plume head. No negative-$\delta^{18}O$ zircons have been identified in this study, contrary to previous studies (Figs. 1 and 2). These features strongly argue against a glaciation origin for low to negative $\delta^{18}O$ values in Neoproterozoic magmatic zircons from South China. We propose that two stages of high-temperature water-magma interaction during plume-driven magmatism and continental rifting best explain the low-$\delta^{18}O$ magmas. The most important implication of this study is that formation of such low $\delta^{18}O$ magmatic zircons was not necessarily related to glacial events and should not be used as a geochemical marker of a cold paleoclimate.

This study shows that the extremely negative $\delta^{18}O$ values from the Dabie-Sulu UHP metamorphic rocks are most likely due to metamorphic processes. The main evidence for this is the presence of extremely low-δ¹⁸O metamorphic minerals including garnet (δ¹⁸O = +5.6‰ to -10‰), omphacite (δ¹⁸O = +7.0‰ to -9.4‰), and phengite (δ¹⁸O = 1.3‰ to -9.1‰) (Zheng et al., 1998, *EPSL, v. 155, 113–129*). Air-abraded zircons gave higher δ¹⁸O values (0.1‰–1.0‰) than those processed without air abrasion (Zheng et al., 2004). Recently, new oxygen-isotope and U-Pb age records of metamorphic zircon grains from UHP eclogites from the Dabie Sulu belt showed that δ¹⁸O values of 850-720 Ma igneous zircon cores are similar to our results and all the negative δ¹⁸O values are found in metamorphic rims on zircon grains (Chen et al*., GCA, v.75, 4877-4898, 2011*). We therefore propose a two-stage high-temperature alteration model to explain the extremely low δ¹⁸O values found in the Dabie-Sulu metamorphic rocks. The first stage represents pre-glaciation high-temperature hydrothermal alteration as discussed earlier. The second stage involves meteoric-hydrothermal alteration under ice age conditions at ≤720 Ma. The oxygen isotopes of pre-glaciation magmatic and sedimentary rocks preserved in the rift basins may have acquired negative δ¹⁸O values during the second stage, although their magmatic zircons would have retained their primary features. Such altered rocks served as the protoliths of UHP metamorphic rocks, thus generating metamorphic minerals and zircon rims with extremely negative δ¹⁸O values.

Contacts: Xuan-Ce Wang, Xian-Hua Li, Zheng-Xiang Li, Qiu-Li Li

Funded by: NSFC grant (CI: Professor Xian-Hua Li, commencing 2011, Partner Institution CAS)

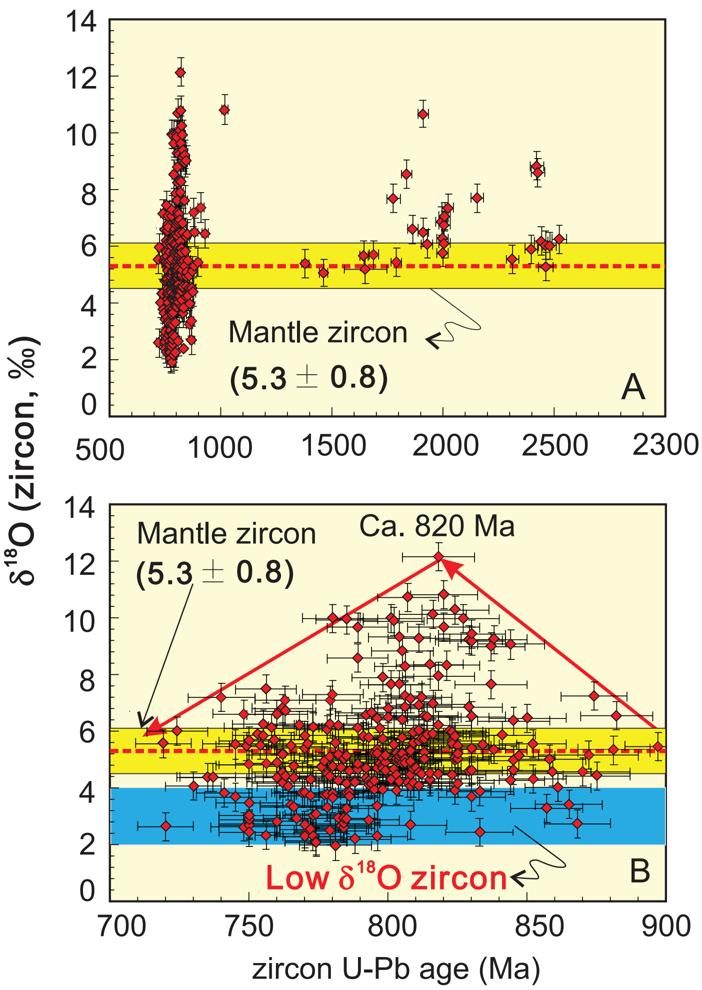

Figure 2. Zircon δ¹⁸O values versus U-Pb ages for (A) all analysed grains and (B) 900–700 Ma grains. The thick arrow lines in (B) show the evolution of maximum oxygen isotopes (Wang et al., 2011, Geology, v. 39, no. 8, p. 735-738).

Yilgarn Seismic Reflection Survey released

The Youanmi deep seismic reflection survey, acquired across the Yilgarn Craton in May and June 2010, has been released on 22 February 2012 (http://www.dmp.wa.gov.au/13230.aspx). The deep seismic reflection data and the magnetotelluric data are part of a GSWA-led project within the Centre of Excellence for Core to Crust Fluid Systems, aimed at developing a 3D understanding of the lithospheric structure of the northwest Yilgarn Craton, its development through time, and the link to large-scale mineralisation.

The survey was funded through the Western Australian Government's Royalties for Regions Exploration Incentive Scheme (EIS). Terrex Seismic Pty Ltd (http://www.terrexseismic.com/), an Australian company based in Perth, carried out the seismic data acquisition, and Geoscience Australia (GA) managed acquisition, processing and interpretation.

The survey builds on the existing network of deep-crustal seismic surveys that have imaged the Yilgarn Craton and its margins, and will improve the understanding of the crustal structure of Western Australia. Three individual seismic lines (YU1, YU2 and YU3), along with complementary magnetotelluric data, were acquired as part of the survey.

The three lines cross the northern part of the Yilgarn Craton from the Narryer Terrane in the northwest, across major bounding and internal structures of the Youanmi Terrane and into the Kalgoorlie Terrane of the Eastern Goldfields Superterrane (Fig. 1). The eastern end of YU2 (Fig. 2) crosses major structures on the western side of the Eastern Goldfields Superterrane, which were also imaged by the 2001 GA deep seismic reflection line (01AGS–NY1), about 120 km to the southeast.

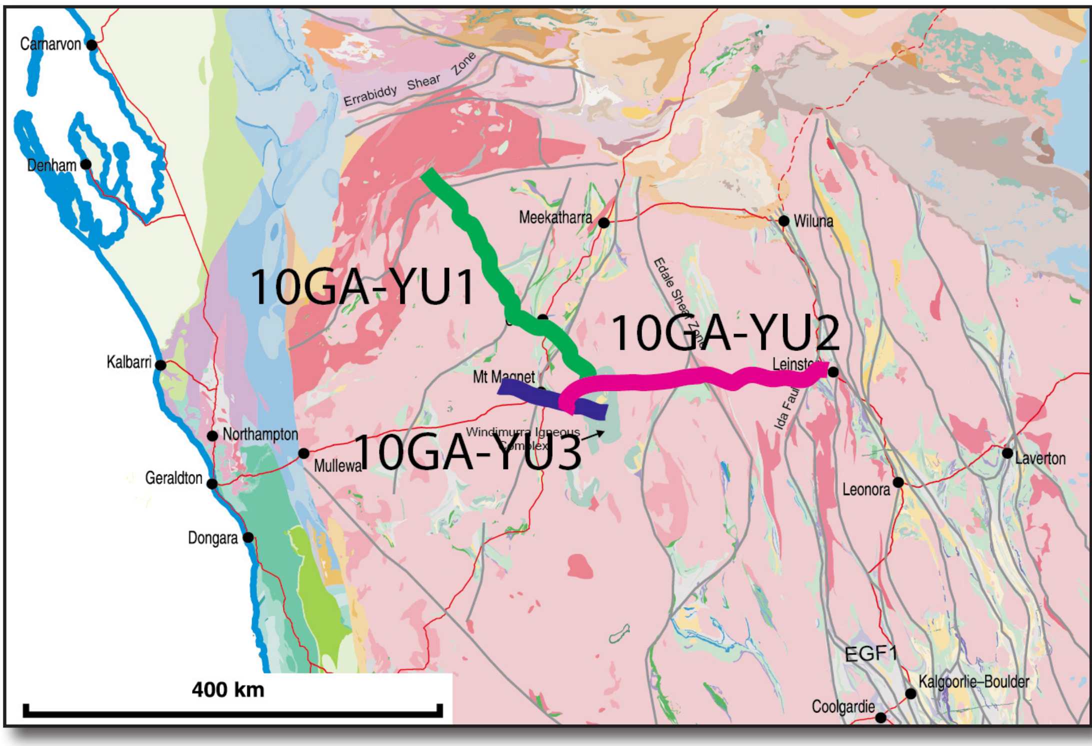

Figure 1. Location of the YU1, YU2 and YU3 seismic reflection lines in the Yilgarn Craton, Western Australia.

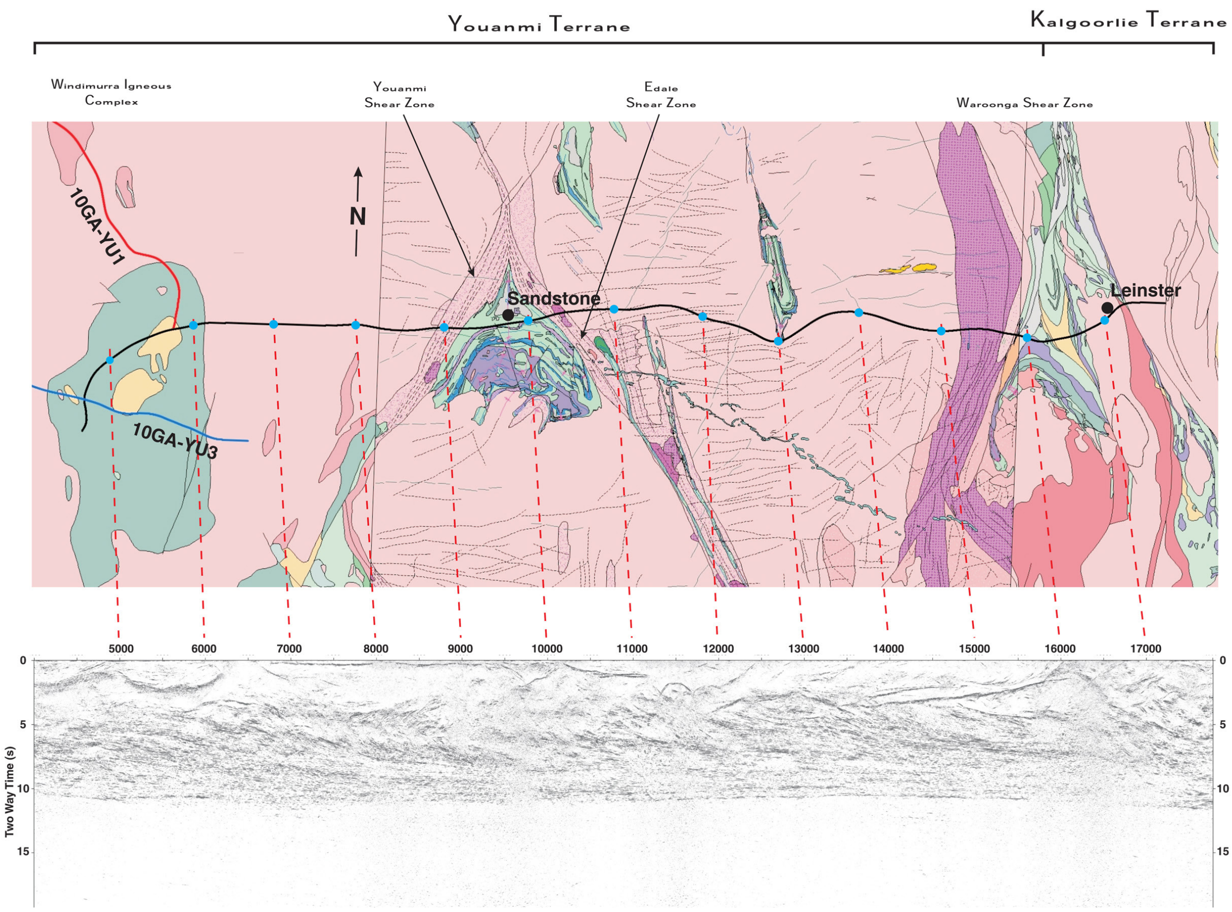

Figure 2. Geological map and preliminary migrated seismic reflection data of line YU2.

The main objectives for the Youanmi deep seismic reflection survey are to:

- Image deep structure in the Narryer Terrane, the oldest component of the Yilgarn Craton, and the region that contains the oldest known crust in Australia;
- Image the contact between the Narryer Terrane and the adjacent, highly mineralised Murchison Domain of the Youanmi Terrane;
- Investigate the nature of granite–greenstone contacts and the overall shape, depth, and structure of greenstone belts;
- Compare the nature, orientation, and crustal penetration of mineralised and unmineralised structures;
- Develop a 3D image of the mafic–ultramafic Windimurra Igneous Complex;
- Image the Ida Fault, the boundary between the Youanmi Terrane and the Kalgoorlie Terrane in the Eastern Goldfields Superterrane, and compare the deep structure in the adjacent terranes;
- Link with previously acquired deep-crustal seismic traverses in the Eastern Goldfields Superterrane.

Interpretation of the seismic lines will be undertaken ahead of a public release workshop planned for October/November 2012.

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Funded by: NCRIS AuScope, Geoscience Australia, GSWA, CCFS Foundation Project

A new tectonic history for the Yilgarn predicts eastward expansion of gold prospects

The Albany–Fraser Orogen is an arcuate orogenic belt along the southern and southeastern margins of the Archean Yilgarn Craton in Western Australia. Previous studies ascribed the main tectonic and metamorphic features of the belt to the Mesoproterozoic Albany–Fraser Orogeny. However, a significant tectonomagmatic event is now known to have taken place during the Paleoproterozoic within the Biranup Zone of the orogen, and also suggests an allochthonous setting for much of the orogen. Magmatism in the Biranup Zone commenced at ca 1710 Ma, and the Hf-isotope signature indicates that the magmas were derived predominantly by melting of an Archean (Yilgarn craton) source (Fig. 1a). Younger intrusions, with crystallisation ages between 1680–1665 Ma, show a progressively higher proportion of juvenile mantle–derived material in their source. Lu–Hf and U–Pb data from individual zircons, as well as data from entire intrusive bodies, indicate more juvenile additions through time. This rapidly-evolving tectonomagmatic history, and the original Yilgarn-like Hf-isotope signature modified by juvenile material, suggests that an extensional setting, possibly a back-arc, on the margin of the Yilgarn Craton is a feasible tectonic setting for the Biranup Zone of the Albany–Fraser Orogen. Thus, the Hf- isotope data imply an autochthonous origin for much of the orogen. New Lu–Hf results

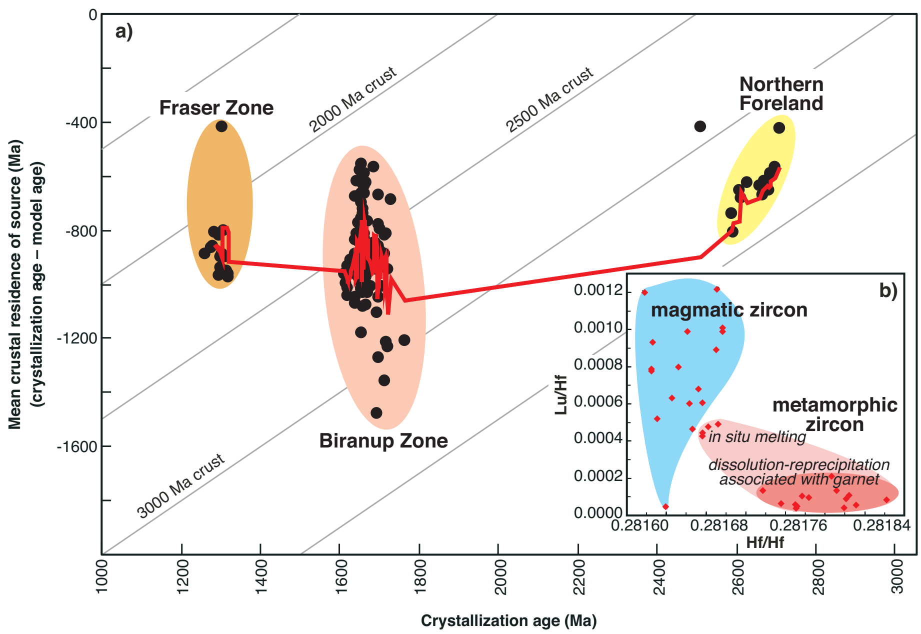


Figure 1. Lu–Hf data used to determine tectonic affiliations of Albany–Fraser Orogen rocks. (a) Event signature diagram showing the general trend with time produced by reworking (downwards), mixing (horizontal), or juvenile input (upwards). The vertical axis shows the "crustal residence time" (age) of the magma sources. The data are from three lithostratigraphic domains: the Biranup and Fraser Zones and the Northern Foreland. The Northern Foreland shows crustal-residence times consistent with an Eastern Goldfields Superterrane (Yilgarn Craton) heritage. The Biranup Zone displays a range of crustal residence times, from old signatures similar to the Eastern Goldfields Superterrane to values considerably less negative, suggesting juvenile addition to the crust. The Fraser Zone Hf is situated mainly between the 2.0 and 2.2 Ga crustal evolution lines and is compatible with the Fraser Zone having reworked Biranup Zone material. (b) Differences in Hf isotopes and Lu/Hf of magmatic zircon, and metamorphic zircon linked to garnet growth.

indicate that the Fraser Zone represents addition of juvenile (mantle-derived) material into the crust of the Biranup Zone. This implies that basement to the Fraser Zone is Biranup Zone material, and the extent of rocks considered to be prospective for gold mineralisation probably increases eastward further than previously suspected.

Lu–Hf isotopes also provide information on the growth mechanism of zircon (Fig. 1b), which is important for linking the growth of dateable minerals to the development of other minerals in the rocks. Metamorphic zircon rims produced during Stage II of the Albany–Fraser Orogeny consistently show more radiogenic Hf-isotope signatures, and lower Lu/Hf ratios, than those of igneous zircons. This relationship is best explained by breakdown of igneous zircon and the growth of garnet, depleting the metamorphic reservoir in heavy rare-earth elements (HREE). This metamorphic reservoir, with high $^{176}Hf/^{177}Hf$ but low Lu/Hf, was the source from which metamorphic zircon grew. This indicates that Stage II metamorphic zircon growth occurred under amphibolite-facies (or higher-grade) conditions.

Hf-isotope data from zircons in intrusive rocks of the western Musgrave Province indicate apparent crustal reworking following juvenile input events at ca 1900 and 1600–1550 Ma. Although no juvenile material is known from the older event, radiogenic addition into the crust is required to account for consistent Hf (and Nd) isotope evolution patterns, which show no indication of mixing processes. The timing of juvenile addition and the lack of similarity to Albany–Fraser and Arunta crust suggests that the ca 1900 Ma event reflects development of a mafic underplate on the margin of an Archean Craton. Oxygen isotopes in zircons with ca 1950–1900 Ma model ages indicate that their parent melts were not contaminated by near-surface material, so these model ages represent crustal generation. Correspondence in time between extraction of material from the mantle and the reworking of Archean material strongly supports a coupled response of the upper and lower crust to a juvenile crustal-generation event at ca 1900 Ma. The crustal evolution defined by Hf (and Nd) isotopes allows refinement of paleogeographic reconstructions and has implications for mineralisation styles.

Contact: Michael Wingate
Funded by: GSWA

Mapping Earth's thermochemical structure in 3D

There are basically two sources of information we can use to constrain the compositional and temperature structure of Earth's mantle: geophysical data (e.g. gravity anomalies, travel-time data, surface heat flow, etc.) and studies of mantle samples (e.g. xenoliths, tectonically-exposed massifs). Experimental petrology and numerical simulations can complement these observations, but they cannot really constrain the physical state of the mantle. Both geophysical data and mantle samples have advantages and limitations when used to infer the physical and chemical structure of the mantle. The geophysical data offer a larger and more continuous spatial coverage, but their conversion into estimates of composition and temperature is full of difficulties -- and they only reflect present-day conditions. The mantle samples, on the other hand, carry direct information on the compositional and thermal structure of the mantle when they were erupted or exhumed, but their spatial and temporal coverage is limited.

The most reliable way to map the thermochemical structure of the Earth's interior would be via "multi-observable probabilistic inversions", using many types of data and an internally consistent thermodynamic/geophysical formulation. However, the theory and implementation of such inversion schemes still are immature and greatly understudied. None of the current methods can handle the simultaneous, internally consistent inversion of 3D data for surface heat flow, gravity and geoid anomalies, electrical conductivity, absolute elevation, seismic velocities and composition. Moreover, available methods/software used to model the Earth's interior cannot handle some major problems: i) the system is strongly non-linear, ii) the temperature effect on geophysical properties is much greater than the compositional effect, so the latter is hard to isolate, iii) the compositional data are non-unique (different compositions can fit seismic and potential-field data equally well), iv) strong correlations between physical parameters and geophysical observables complicate the inversion and their effects are poorly understood, and v) there are trade-offs between temperature and composition in seismic wave speeds.

We now have developed a new full-3D multi-observable inversion method particularly designed to circumvent these problems. Some key aspects of the method are: a) it combines multiple datasets (ambient noise tomography, receiver function analysis, body-wave tomography, magnetotelluric, geothermal, petrological, and gravity) in a single thermodynamic-geophysical framework, b) a general probabilistic (Bayesian) formulation is used to appraise the data, c) neither initial models nor well-defined *a priori* information are required, d) it provides realistic uncertainty estimates, e) it offers critical insights into the incompatibilities between traditional stand-alone methods, and f) it can incorporate geochemical/petrological information. The combination of different observables reduces the uncertainties because they are differently sensitive to shallow/deep, thermal/compositional anomalies. This allows a better control of the lateral and vertical variations of the bulk properties of the lithosphere and mantle.

The fundamental goal of this method is the conversion of observations into robust estimates of temperature and composition in the lithosphere and upper mantle. This requires the assessment of two different but related levels of functional relationships (or parameterisations). The first is between the raw observations and the set of governing physical parameters; e.g. the physical relationship between travel times and the subsurface seismic velocity structure or between variations in the surface electromagnetic field and the subsurface electrical conductivity structure. The second level of functional relationships is between the set of governing physical parameters (e.g. seismic velocity) and a more fundamental set of model parameters represented by the major-element composition and temperature of the rocks. Since this set of parameters (e.g. composition) controls the second set of governing physical parameters (e.g. shear velocity), they are commonly referred to as the primary and secondary parameters.

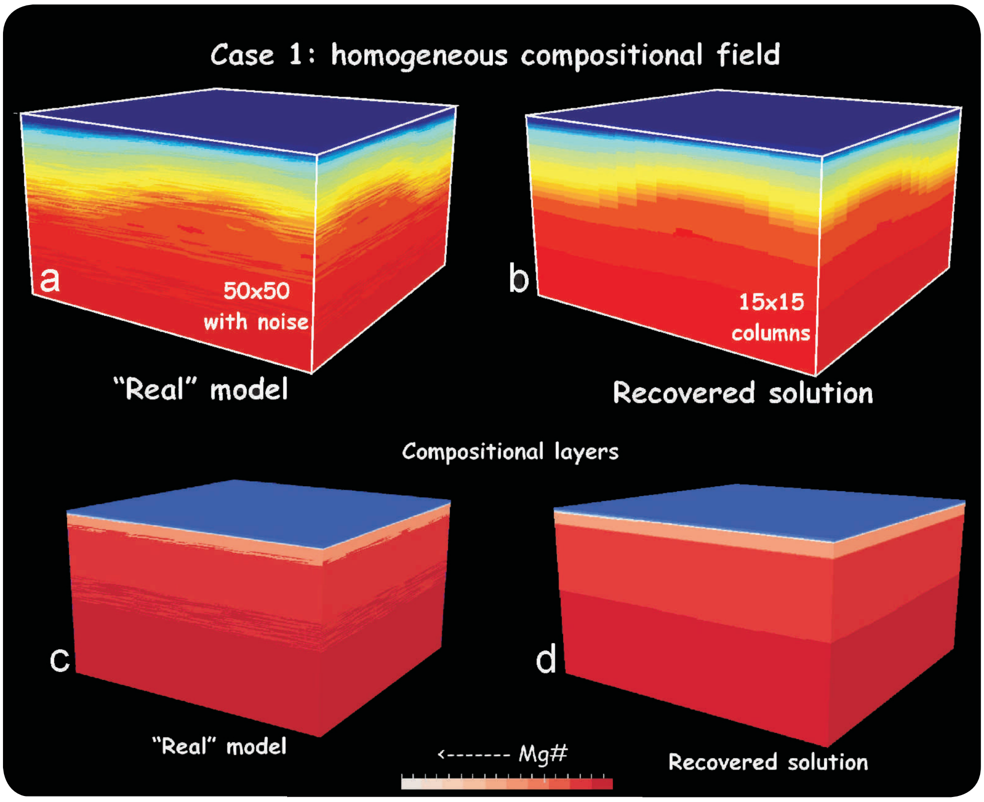
This first level is the simplest and most widely used in conventional inversion methods. Typically, we assume an appropriate physical theory (e.g. seismic wave propagation) and use that to relate the secondary model parameters to the observations during the inversion. The final result is one or more sets of secondary physical parameters (i.e. Earth models), such as shear velocity or electrical conductivity, that show an acceptable fit to the data. The second level of functional relationships is commonly ignored in inversion studies or treated as *a posteriori* independent (not self-consistent) corrections. Partly because of this, but also due to its intrinsic complexities (e.g. different compositions give the same seismic velocity), this functional level and its relationship with geophysical observables are less well-understood.

Figure 1 shows the comparison of a "real" input thermochemical model and the solution recovered after inverting surface and body waves, geoid and gravity anomalies, surface heat flow, and elevation. No magnetotelluric data have been included in this example. The input model and its observables were calculated with the software LitMod3D in a mesh of 50x50x204 nodes. The thermal structure is heterogeneous and contains added "noise" while the compositional structure is horizontally homogeneous, featuring three layers with distinct Mg#. Although the inversion mesh is much coarser (15x15x190), the two recovered structures are in excellent agreement with the original structure. This example shows that our probabilistic inversion scheme can distinguish between thermal and compositional signatures, something that other available methods cannot achieve.

Although the method still is being tested and benchmarked, our preliminary results are encouraging. They demonstrate that inversion of multiple geophysical and petrological data to obtain a thermochemical "tomography" of the upper mantle is possible and more reliable than other standard methods. This new approach opens the way to migrate from standard "parameter tomography" (e.g. seismic tomography) to future "multi-observable thermochemical tomography" schemes, the ultimate goal of geophysical methods.

Contact: Juan Carlos Afonso
Participants: Juan Carlos Afonso, Javier Fullea, Yingjie Yang, Bill Griffin, Sue O'Reilly, Alan G. Jones, James A.D. Connolly, Sergei Lebedev and Nick Rawlinson
Funded by: ARC Discovery

Figure 1.



High strain below Tibet – mapping a mid-crustal low velocity zone

The Tibetan Plateau results from the convergence between the Indian and Eurasian plates, which has been going on since Late Cretaceous to Early Paleocene times. There is lively debate about the processes that have controlled the deformation of Tibet, particularly the potential localisation of deformation either in the vertical or horizontal directions. Two general models are commonly proposed. The first is the "rigid block" model in which deformation is primarily localised along active faults on the edges of the blocks. The second is the "internal deformation" model in which the crust is treated as a non-rigid continuum, like gummy candy, and deformation is spread across the blocks. In this model, strain disperses in the deeper crust into much broader ductile shear zones, in which the lithosphere may deform more or less homogeneously. This might be via "vertically coherent deformation" or by more rapid, ductile "channel flow" in the middle to lower crust.

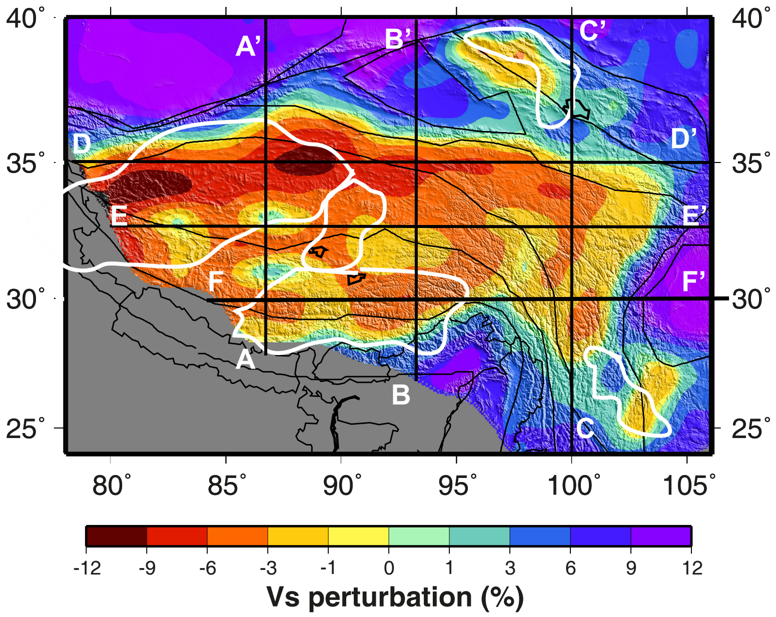


Figure 1. (a) Map of the amplitude of the crustal low-velocity zone across the region relative to 3.4 km/s. Yellows, oranges, and reds denote velocities at 30 km depth (relative to sea level) less than 3.4 km/s. White contours identify strong radial anisotropy found in the study of Shapiro et al. (2004). Note that the distribution of strong radial anisotropy is largely coincident with strong LVZs in western and central Tibet. Agreement is weaker in eastern Tibet, but this is probably due to the reduction of resolution in this region in the study of Shapiro et al (2004).

Geophysical data can help us discriminate between these competing models. In particular, it is important to determine whether Tibet deforms in a way that mimics the surface expression of crustal blocks and faults, and whether we can observe pervasive, interconnected weak layers or channels in the crust. There is a growing body of evidence that suggests the Tibetan crust is warm and thus presumably ductile. These observations are often taken as *prima facie* evidence for the existence of partial melts or aqueous fluids in the middle or deep crust beneath Tibet. Some have argued for the decoupling or partitioning of strain between the upper crust and uppermost mantle. This raises several questions. How pervasive are the phenomena that support the existence of crustal partial melt? In particular, do we see mid-crustal low velocity zones (LVZs) across Tibet? If we do, what is the geometry or inter-connectivity of the crustal LVZs across Tibet?

We addressed these questions by producing a new 3-D model of crustal and uppermost mantle shear wave speeds (illustrated by Fig.1 and 2). We used the Rayleigh wave dispersion observed on cross-correlations of long time series of ambient seismic noise, recorded from about 600 stations in the Chinese Provincial networks, FDSN, and PASSCAL experiments.

The 3-D model shows significant, apparently inter-connected, zones of low shear velocity across most of the Tibetan Plateau at mid-crustal depths (20-40 km). These low-velocity zones (LVZs) do not correspond to surface faults and, significantly, are most prominent near the periphery of Tibet. The observations support the internal-deformation model in which strain is dispersed in the deeper crust into broad ductile shear zones, rather than being localised near the edges of rigid blocks. The prominent LVZs coincide with strong mid-crustal radial anisotropy (Shapiro et al., 2004) in western and central Tibet. The anisotropy probably results at least partially from the alignment of anisotropic minerals by deformation, which mitigates the need to invoke partial melts to explain the observations. Irrespective of their cause (partial melts or mineral alignment), mid-crustal LVZs reflect deformation, and their amplification near the edges of the Tibetan plateau provides new information about the mode of deformation across Tibet.

There are two specific seismic observations that are needed to extend and clarify inferences from the results presented here. First, higher-resolution Love wave phase velocity measurements obtained from ambient noise across all of Tibet are needed to infer Vsh in the middle crust. These observations will help to determine whether the observed LVZs result entirely or only partially from mineral alignment. Second, azimuthal anisotropy, observed both for the crust from ambient noise and for the uppermost mantle from earthquake records, will constrain the vertical continuity of the strain and will help to discriminate between channel flow and vertically coherent deformation. Both types of observations will be obtained in planned future studies.

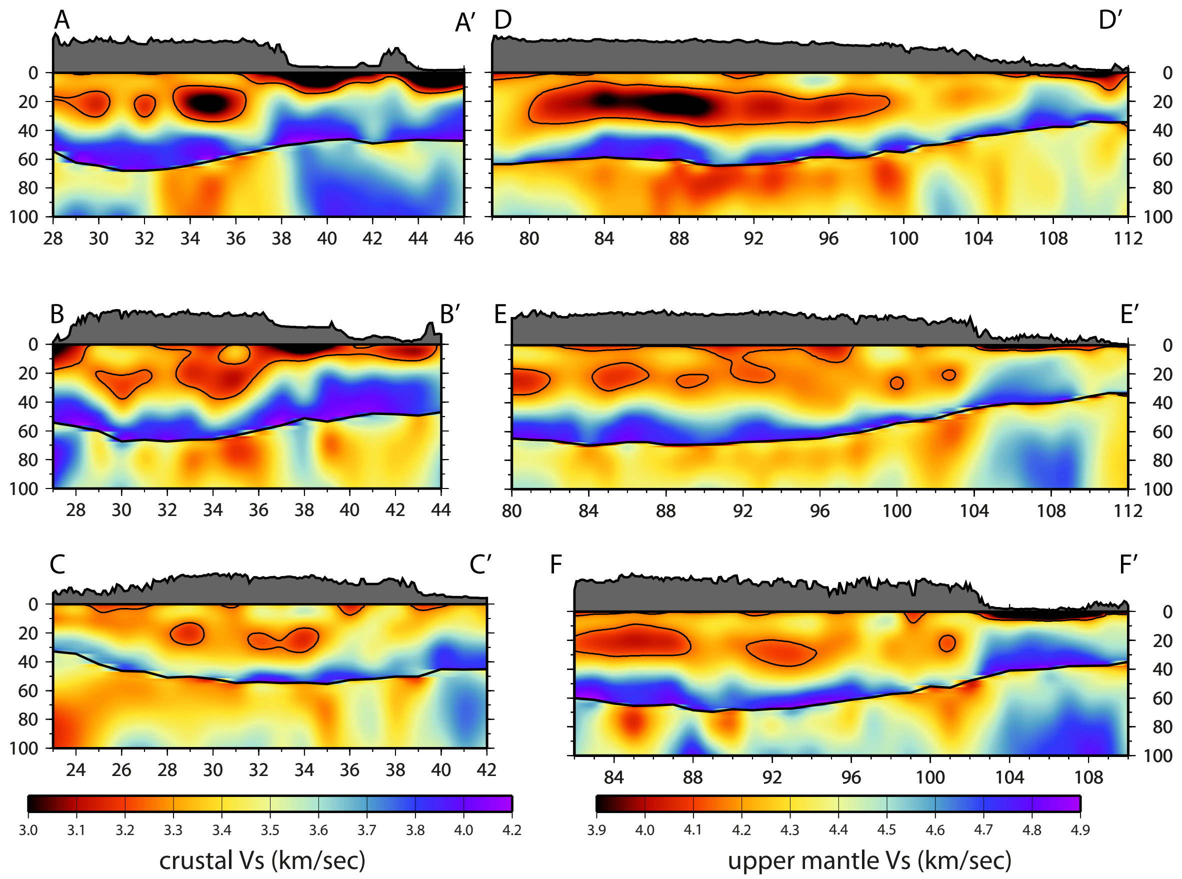


Figure 2. Vertical cross-sections of Vsv along the six profiles identified in Figure 1. Surface topography is shown at the top of each panel. Shear-wave speeds are presented in absolute units, but with different colour scales in the crust and mantle. Very low shear-wave speeds in the crust (<3.25 km/s) are outlined by black contours. All depths are relative to sea level.

Contact: Yingjie Yang
Funded by: MQ New Staff Grant

Komatiites deliver volatiles to early Earth's surface

Komatiites are ancient volcanic rocks, mostly over 2.7 billion years old, which formed through high-degree partial melting of the mantle. Establishing the volatile content of komatiites is crucial to constraining the thermal evolution of the Early Earth and its primordial atmosphere. However, existing models are mainly based on evidence from komatiite flows, whereas komatiite intrusions have been neglected.

Our observations on komatiites from the Agnew-Wiluna greenstone belt of Western Australia show that komatiite flows must have degassed during emplacement, flow and crystallisation: flows ~150 metres thick contain vesicles, amygdales and segregation structures, showing a significant volatile content, but those less than 10 metres thick lack any textural or petrographic evidence of primary volatile contents. This implies that komatiite intrusions retained higher proportions of their primary volatile budget, and contain volatile-bearing mineral phases that reflect the presence of magmatic water in the parental magma. This means that evidence from komatiite intrusions, rather than lava flows alone, should be used to evaluate the thermal architecture of the Early Earth and the volatile inventory of the primordial atmosphere.

The results of this study indicate the possibility of a range of volatile contents in different komatiite types. In fact, our observations suggest that some komatiites were initially volatile-bearing and subsequently lost their volatiles. This would be facilitated by the low viscosity of komatiite magmas, allowing volatiles to bubble out more easily, and (or) by emplacement in shallow marine environments (i.e. low confining pressures). The diversity in the physical evidence for magmatic volatile contents may reflect different proportions of degassing caused by variable confining pressure and proximity to vent. Komatiite flows that lack hydrous magmatic minerals and textural or petrographic evidence of primary volatile interaction may be the degassed equivalents of volatile-bearing liquids. Alternatively, they could represent melts that were actually anhydrous. If so, the variable physical evidence for volatile content in komatiite units globally may reflect the presence of "wet" and "dry" komatiites, which were most likely emplaced in different geodynamic environments, just as a diversity of basalt types exist in more recent terrains.

The principal significance of the presence of magmatic amphiboles in some komatiitic and ferropicritic sills in the Agnew-Wiluna (Australia), Abitibi (Canada) and Pechenga (Russia) greenstone belts is that they reflect the crystallisation of hydrous parental magmas. The diverse nature of the physical evidence for magmatic volatiles in komatiite units that solidified at different distances from vent highlights means that we need to focus on evidence from proximal intrusions or thick flows, which may have retained a significant proportion of their primary volatile budget. Previous studies have mainly focused on thin lava flows without considering the effects of degassing, whereas thicker flows or intrusions have been generally neglected.

A re-assessment of the primary volatile content of komatiite magmas from intrusive settings has key implications for the thermal and petrological evolution of the Early Earth, localisation of nickel-sulfide ores, and development of the primordial atmosphere. The extreme Archean geothermal gradients advocated to explain the formation of komatiites in dry settings may have not been necessary to extract komatiites from volatile-bearing portions of the mantle. The localisation of "dry" and "wet" komatiites may reflect the presence of different Archean geodynamic environments (e.g. rift settings versus subduction zones). Correlation of H_2O

contents and physical evidence of volatile content with proximity to Archean volcanic centres and intrusions could be significant in petrologic models and in mineral exploration. A relatively high water content, reflected by presence of magmatic amphibole, may reflect proximity to vents. Therefore, if komatiite-hosted nickel-sulfides form preferentially in proximal extrusive and dynamic intrusive environments, careful mapping of the physical evidence for volatile contents in different volcanic facies may help to identify areas with greater potential for nickel-sulfide deposits.

Finally, degassing of komatiites would have also contributed to the development of an early atmosphere, through volatile exchange at the ocean surface. Since komatiite flow fields were extremely voluminous and occupied extensive areas of the seafloor, volatile exsolution during their emplacement and crystallisation could have influenced physical and chemical parameters in the primordial oceans, and indirectly contributed to the creation of a complex zonation at the interface between water and seafloor.

Contacts: Marco Fiorentini, Steve Beresford
Funded by: ARC Discovery

An Australian komatiite outcrop.

Water deep in the mantle-A key to transforming the Lithosphere?

Besides the visible H_2O on the Earth's surface, there is another unexpected and invisible H_2O reservoir at depth. This is the H_2O in the mantle, 'dissolved' as hydroxyl in the crystal structure of major mantle minerals. It relates not only to the probability of life, but also to geological processes.

Refractory subcontinental lithospheric mantle (SCLM) is produced by the removal of partial melts from mantle rocks; this process includes the removal of this deep H_2O. The nature and evolution of the SCLM are strongly influenced by hydrous melts and fluids, which affect the physical and chemical properties of mantle minerals and rocks. Like some light rare earth elements (LREEs) (La, Ce) or large ion lithophile elements (LILs) (K), H_2O behaves as an extremely incompatible component (Dperidotite/melt = <0.01) in a melt/solid system, which makes it a sensitive tracer of melt-extraction and metasomatism in the SCLM. Thus an understanding of the H_2O inventory of the SCLM provides another tool to study the nature and the evolution of the SCLM, and the role H_2O has played during lithospheric modification.

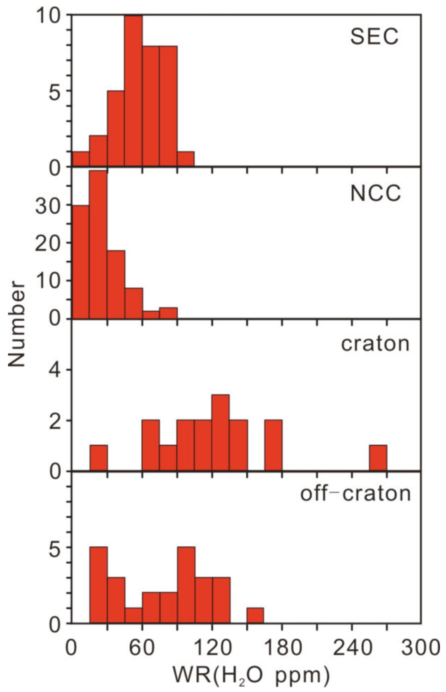


Figure 1. Comparison of H_2O contents whole-rock (WR) of the Cathaysia (SE China) xenoliths in this study with those of North China Craton (NCC), craton and off-craton peridotites. For the references of data for NCC, cratonic and off-cratonic peridotites see CCFS Publication #2.

Peridotite xenoliths in alkali basalts consist mainly of nominally-anhydrous minerals (e.g. olivine, pyroxene) and these can be analysed to measure the actual H_2O budget of the SCLM. This study has focused on determining the H_2O contents of peridotite xenoliths from four localities (Mingxi, Anyuan, Niutoushan and Qilin) in the Cathaysia block of SE China, using Fourier Transform Infrared Spectroscopy (FTIR). We studied (1) the homogeneity of water distribution within single pyroxene grains; (2) the partitioning of water between cpx and opx (mean Dcpx/opx = 2.3); and (3) the correlations between the H_2O contents and major element concentrations in cpx. From these data it appears that the pyroxenes have largely preserved the water content of their mantle sources.

The whole-rock water contents calculated from mineral modes range from 12 to 94 ppm (average 60±20 ppm). This is much higher than the previously-reported water contents of xenoliths from the North China Craton (NCC) (average 26±17 ppm). However, it is still quite low compared to those of continental lithospheric mantle worldwide, as inferred from analyses of typical cratonic (122±54 ppm) and off-craton (81±40 ppm) peridotites (Fig. 1). The present relatively low water budget has evolved through multiple geological events over the long history of this SCLM, e.g. hydration due to paleo-Pacific plate subduction, dehydration by melt extraction during Yanshanian magmatism (Fig. 2a) and subsequent rehydration due to the fluxing by low-degree asthenospheric melts after lithospheric thinning (*CCFS Publication #2*) (Fig. 2b). This is evidenced by young basaltic volcanism at the surface. Water itself plays an important role during the modification of the subcontinental lithospheric mantle. The garnet lherzolites, which represent the deepest portion of the SCLM (~1.9 GPa) sampled in this study, have the highest water contents (>80 ppm). This fertile garnet-facies layer, at depths of 50-100 km, appears to have lost very little water. It may represent young lithosphere accreted at the bottom of the pre-existing lithosphere (Fig. 2b). It marks the completion of the lithospheric thinning episode and the upwelling of the asthenosphere.

A negative correlation between pyroxene water contents and oxygen fugacity has been found only in xenoliths from Niutoushan (Mg# < 90), which lies on the Changle–Nan'ao fault zone. The fault may have facilitated the infiltration of the Niutoushan peridotites by oxidised fluids (or hydrous melts) rising from the subducting Pacific plate.

Contacts: Yao Yu, Bill Griffin, Sue O'Reilly

Funded by: NSFC Grant 40730313, ARC Discovery and Linkage grants (O'Reilly and Griffin), iMQRES, EPS Postgraduate Fund

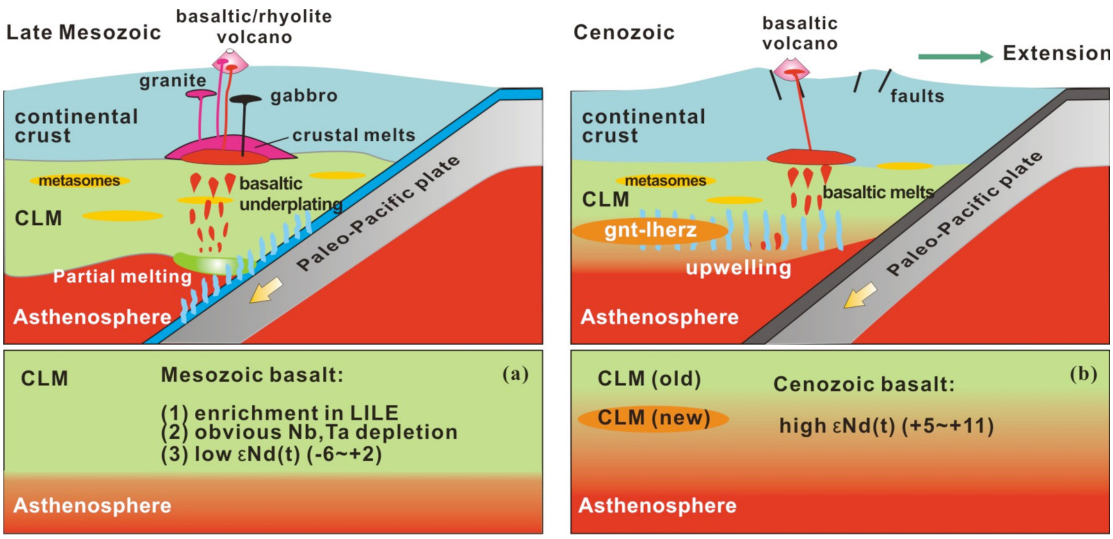
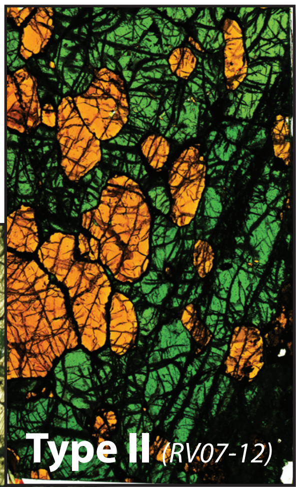
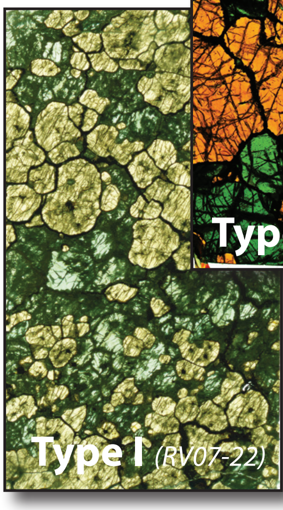


Figure 2. Cartoon showing (a) hydration due to water released from the subducted slab, and dehydration after melt extraction in Yanshanian magmatism. The enriched signatures in the Late Mesozoic basalts reflect contributions from the hydrated SCLM; (b) rehydration by low-degree asthenospheric melts after lithospheric thinning. The upwelling and decompressional melting of asthenosphere is supported by decreasing contribution from SCLM in basalts in SE China over time, with εNd (t) of –6~+2, and +5~+11 for Late Mesozoic and Cenozoic, respectively.

Metasomatic highways - 200 km below Earth's surface

Figure 1. Examples of microstructures in Type I and Type II eclogite xenoliths from Roberts Victor.





Mantle eclogites are amazing and enigmatic messengers coming directly from the base of the cratonic lithosphere (180-220 km down). Although the processes that originally produced these rocks are yet to be fully understood, they are critical samples to constrain the dynamics of the sub-continental lithospheric mantle (SCLM). Because of their privileged position at the lithosphere-asthenosphere boundary (LAB), they are witnesses of the interactions between the lithospheric mantle and the asthenosphere.

Eclogite xenoliths recovered from the Roberts Victor kimberlite pipe (Kaapvaal Craton; South Africa) reveal peculiar features that indicate that the rocks have been modified since their emplacement. Recent studies done at CCFS/GEMOC (*CCFS/GEMOC Publication #003/772*) have shown that most of the Roberts Victor eclogites (Type I eclogites) underwent intensive metasomatism, provoked by substantial melt/fluid percolation not long before the kimberlite eruption (Fig. 1). Although this process was inferred from entirely metasomatised xenoliths, the transformation has also been recorded in some composite xenoliths that contain both original and metasomatised lithologies.

HRV77 is a remarkable example (Fig. 2), which highlights how metasomatic fluids have percolated through the eclogite body via metasomatic channels. This sample is composed of two parts. One is a clinopyroxene macrocryst associated with a few clear, ovoid garnet grains. The surrounding part is mostly bimineralic (grt+cpx) but also contains sulfide, phlogopite and calcite. In this part the garnets are cloudy, show irregular shapes (irregularity increasing with distance from the contact) and contain blebs similar to melt pockets. From these petrographic observations, we conclude that the bimineralic part represents a metasomatic channel, in which cpx and grt recrystallised and metasomatic minerals have been added. Supporting these observations, major- and trace-elements also show clear differences between the two parts. While the cpx macrocryst shows a LREE-depleted pattern similar to the un-metasomatised Type II eclogites, cpx from the bimineralic part shows enrichment in LREE, as observed in the dominant Type I metasomatised eclogites. *In situ* Sr-isotope analyses of the clinopyroxene also support such a dichotomy. The cpx macrocryst has $^{87}Sr/^{86}Sr = 0.7029$ (cpx from Type II eclogites have $^{87}Sr/^{86}Sr = 0.7013 – 0.7030$) while the bimineralic part with $^{87}Sr/^{86}Sr = 0.7068$ is typical of Type I eclogites ($^{87}Sr/^{86}Sr = 0.7060 – 0.7064$).

These obvious contrasts of chemistry and microstructure in such an intimate relationship imply that the bimineralic part witnessed the transit of a melt/fluid with which it interacted, while the macrocrystic part represents the wall-rock of this percolation vein (Fig. 3).

This kind of sample is of the greatest interest because they are the "missing link" between the two main types of eclogites recovered at Roberts Victor. They offer a spatial connection between

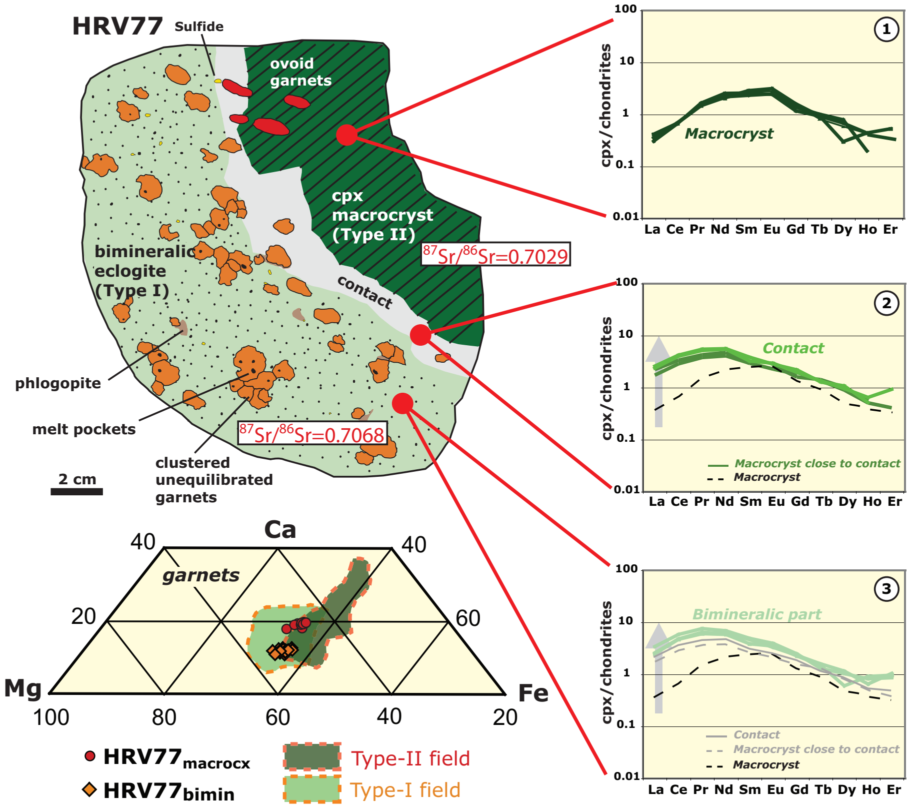
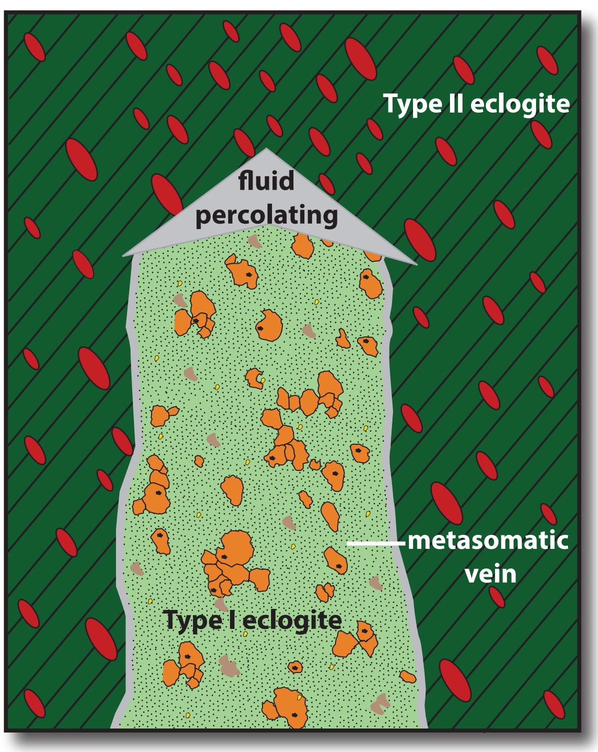


Figure 2. Sketch of the petrographic structure of composite xenolith HRV77 and the associated chemical variability. Cpx boundaries are not represented in the bimineralic part but grain-size is similar to garnet. Contact is composed of the macrocrystic cpx showing features of destabilisation. Bottom quadrilateral shows variations of major-element compositions between dusty garnets sitting in the bimineralic part (diamonds) and ovoid clear garnets sitting in the cpx macrocryst (circles). Right side REE patterns of cpx: (1) macrocrystic cpx; (2) macrocrystic cpx close to contact and contact itself; (3) cpx in the bimineralic part. Note the progressive enrichment in LREE from a Type II pattern to the typical Type I pattern.



the two types, indicating that their relationship is of a "mother-daughter" nature; they are not simply cousins as has been previously inferred in the literature.

Contacts: Yoann Gréau, Jin-Xiang Huang, Bill Griffin, Sue O'Reilly

Funded by: ARC Discovery (O'Reilly, Griffin), iMURS, EPS postgraduate Fund

Figure 3. Cartoon showing the possible fluid percolation mechanism and the formation of (metasomatised) Type I eclogites at the expense of Type II.

Diamonds highlight mantle fluid processes

Diamonds are "time capsules" that can preserve the geochemical signatures of their formation environment and trap inclusions from their matrix, providing unique insights into the mantle environment. They are carried from the mantle to the surface by very deep-seated, violent volcanic eruptions, from depths greater than 150 km. It is very likely that COH fluids percolating through the deep mantle caused the eruptions and also were the source of carbon for diamond formation. Interaction of oxygen and carbon in mantle processes defines and controls diamond formation (for example, precipitation and dissolution of diamonds, transportation of incompatible elements).

This project aims to combine the information that can be extracted from diamonds and other minerals, formed in the mantle. Studying the internal structure, physical and chemical properties of diamonds and related minerals, we are trying to uncover the mystery of the carbon source, which still is a controversial subject. Using the diamond and coexisting minerals we can provide a better understanding of diamond formation processes, which are related to major mantle processes and mantle composition, and can help us to understand the geological evolution of our planet.

We use diamondiferous mantle xenoliths from African and Siberian kimberlites as a source of information about mantle processes. This work, combined with the PhD studies of Yoann Gréau and Jin-Xiang Huang (see *Research Highlight, p. 70*) has shown that mantle metasomatism (chemical alteration by fluids) plays an important role in diamond formation and is responsible for changes in geochemistry of silicates. In 2011 a new approach was taken, looking at the genesis and evolution of polycrystalline diamond aggregates (diamondites; Fig 1). Using the Electron Backscattered Diffraction (EBSD) technique, we made the first observations and interpretations of diamondite microstructures. The technique produces maps of the

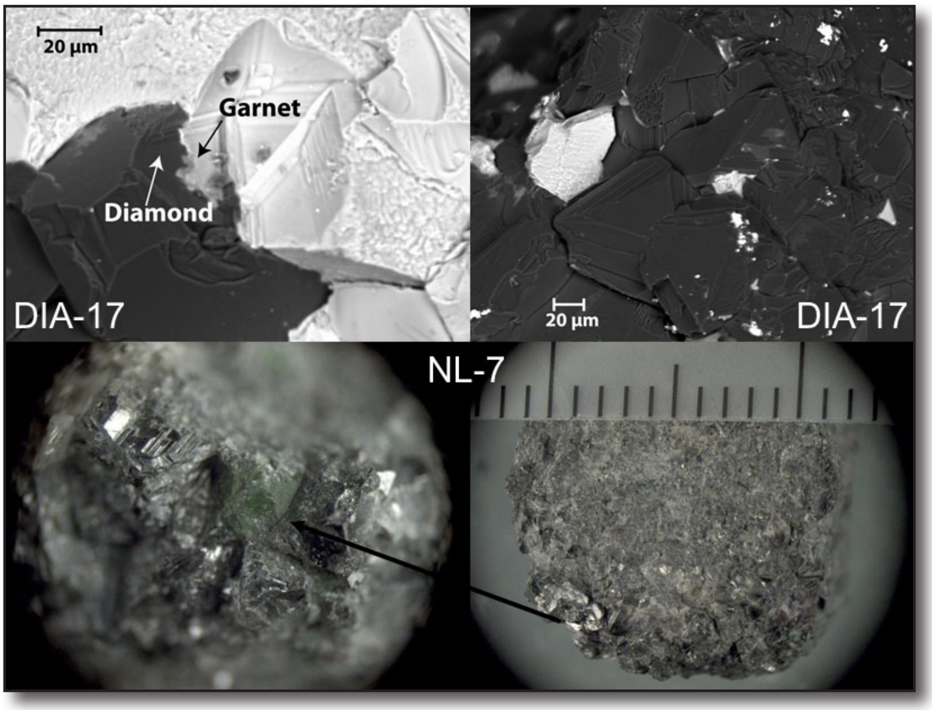


Figure 1.

crystallographic orientation of the different diamond crystals in the aggregate, and also maps the distribution of silicate minerals that occur as inclusions and interstitial grains (Fig. 2). The study demonstrated that most diamondites have been significantly modified by deformation and recrystallisation processes. Many originally crystallised as relatively coarse-grained diamonds with abundant silicate inclusions; as they recrystallised under stress the grain sizes were reduced and the silicate phases moved to grain boundaries. Using integrated datasets including microstructural observations and *in situ* analyses of trace elements, C-isotopes in diamond and O-isotopes in the silicates, we found that many diamondites have an extended mantle-residence history including deformation/crystallisation processes and fluid interaction after initial crystallisation. The fluids changed the crystallisation environment (chemical composition of silicates) and may have provided carbon for secondary diamond formation. Based on the differences in chemical composition of the enclosed and interstitial silicates and zoning in the carbon isotopic composition of diamonds we can conclude that the host fluids were Mg-rich. An important conclusion was that polycrystalline diamond aggregates should not be interpreted as the products of primary crystallisation shortly before eruption, and detailed observations of their internal structures must play an important role in the interpretation of their genesis.

This study offers us new insights into mantle processes including diamond formation, deformation and fluid/melt interaction, and illustrates the complexity of the mantle system and the important role of fluids in it. The understanding of the fluids' compositions and interactions in the mantle is probably a clue to the variation in the geochemistry of the mantle system itself.

Contacts: Ekaterina Rubanova, Dan Howell, Bill Griffin, Sue O'Reilly, Norman Pearson
Funded by: ARC Discovery, CCFS Foundation Project, iMURS, EPS postgraduate fund

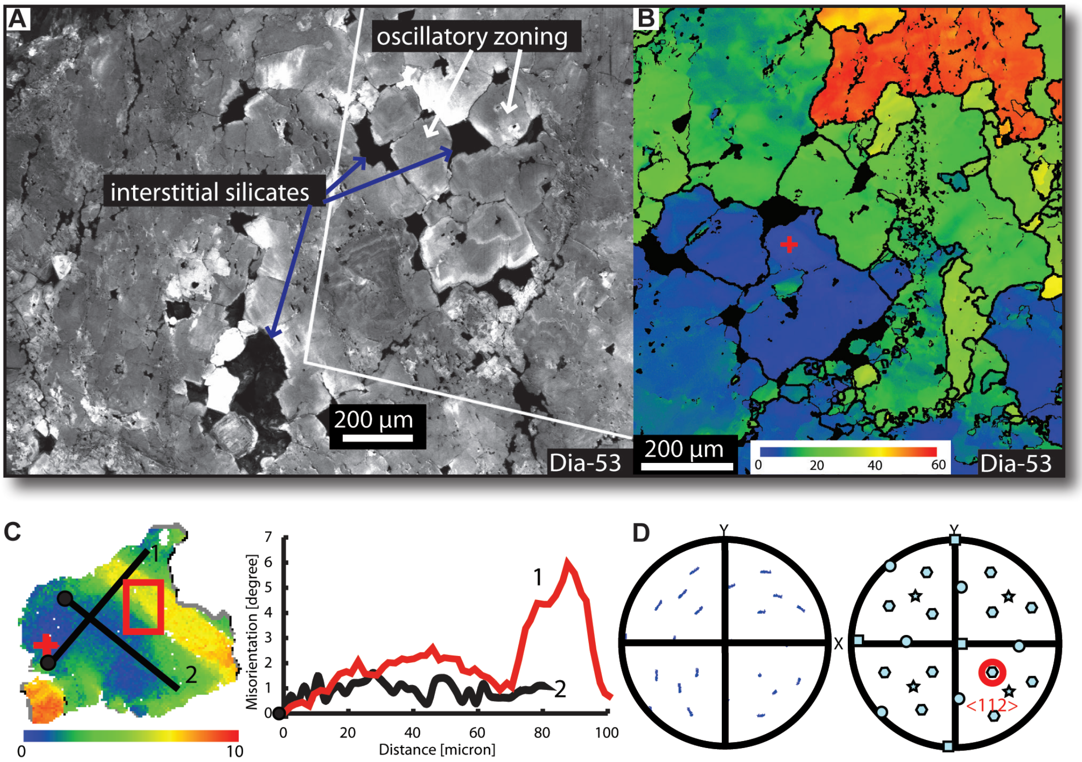


Figure 2. Photomicrograph (A) of a polished diamondite. (B) EBSD image of the field outlined in (A). Different colours show different crystallographic orientations. (C) Traverses across a weakly deformed diamond grain. (D) Orientations of diamonds in (B).

Unveiling fluid histories in deep mantle eclogites with sulfide compositions

Eclogite xenoliths are commonly found in kimberlites that erupted in cratonic areas. These rocks, sampled by the ascending magma, are minor but important constituents of the sub-continental lithospheric mantle (SCLM). However a long-lived debate still rages about why such mafic lithologies occur in the SCLM. The currently dominant line of argument sees mantle eclogites as remnants of subducted oceanic slabs stored in the cratonic SCLM, while other researchers regard mantle eclogites as deep-seated mafic melts trapped near the lithosphere-asthenosphere boundary (LAB). A recent study (*CCFS Publication #003*) pointed out that the "subuction" hypothesis was mostly based on the study of the more common Type I eclogites (defined by higher levels of the minor elements Na and K in garnet and clinopyroxene, respectively). These eclogites were shown to possibly not be the best choice as their microstructures and lithophile-element geochemistry indicate that they have been intensively over-printed by at least one metasomatic event. The less common Type II eclogites may represent primary, or at least less-altered, compositions.

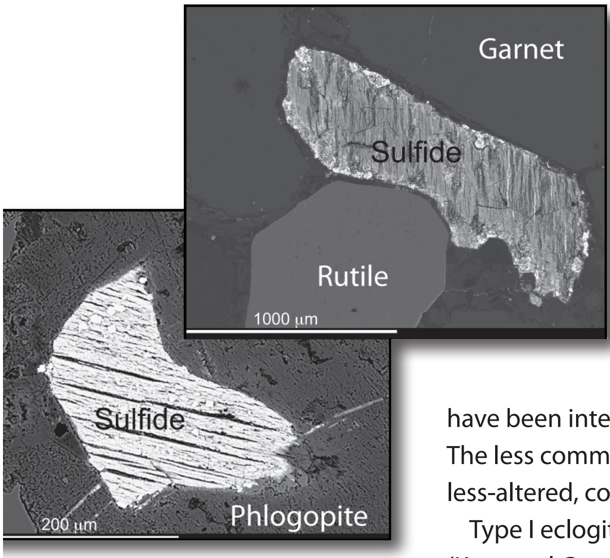


Figure 1. Eclogitic sulfides associated with metasomatic minerals, rutile and phlogopite.

Type I eclogite xenoliths recovered from Roberts Victor kimberlite (Kaapvaal Craton; South Africa) contain abundant polyphase sulfides (up to several modal %). Although many of these sulfides have undergone supergene weathering (i.e. transformation to violarite, smythite and pyrite), some samples present fresh unaltered assemblages made of pyrrhotite (Po) + pentlandite (Pn) + chalcopyrite (Cp). This typical magmatic assemblage is similar to sulfide inclusions found in Roberts Victor eclogitic diamonds, and more generally the reconstructed bulk sulfides are similar to sulfide inclusions in eclogitic diamonds worldwide (Fig. 1).

In Roberts Victor eclogites, although sulfides are systematically lacking in

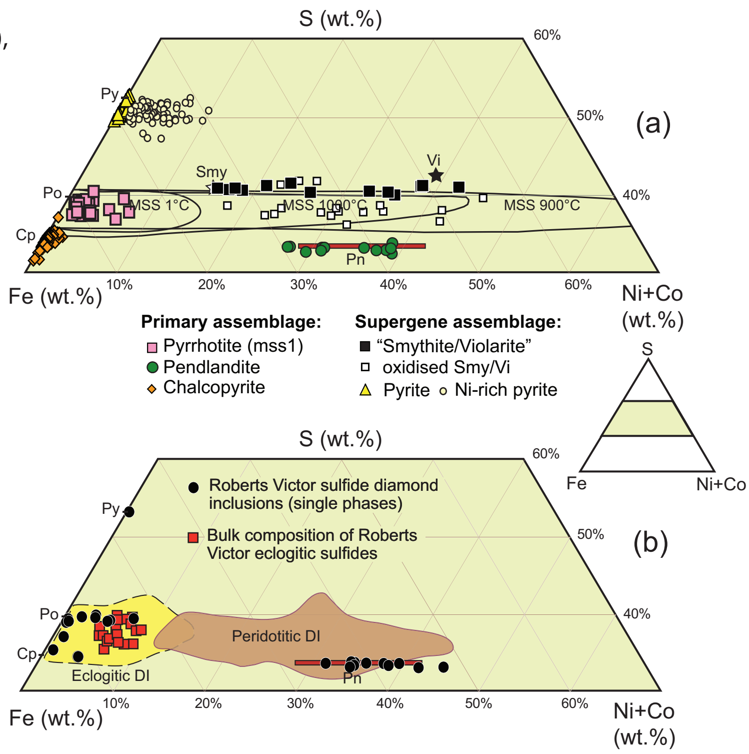


Figure 2. Electron-probe analyses of individual phases plotted on Fe-Ni-S diagrams.

Type II eclogites, they are ubiquitous in Type I, and are often found in close association with metasomatic minerals like phlogopite and rutile (Fig. 2). It is therefore perhaps not accidental that both diamonds and sulfides are only found in Type I eclogites. A growing body of evidence indicates that diamonds are metasomatic minerals, but is this the case for the eclogitic sulfides? Chalcophile elements (elements with affinities for sulfur) such as Cu or Se might be the clue; they will be mostly carried by sulfides, and they can therefore be used as proxies to trace their origin.

Correlations between the whole-rock budgets of these elements and typical metasomatic tracers such as (La/Sm) or ΣLREE (Fig. 3) clearly indicate that the sulfides are related to the metasomatism affecting the silicate assemblage. Furthermore, a negative correlation between the Cu content of clinopyroxene and ΣLREE shows how Cu is leached from the silicates during the crystallisation of sulfide associated with the metasomatic event. These data provide another line of evidence to confirm that Type I eclogites have been heavily over-printed by metasomatism, meaning that Type II are the only suitable rocks to constrain the origins of mantle eclogites.

Contacts: Yoann Gréau, Bill Griffin, Sue O'Reilly, Olivier Alard (Montpellier)
Funded by: ARC Discovery (O'Reilly, Griffin), iMURS, EPS postgraduate Fund

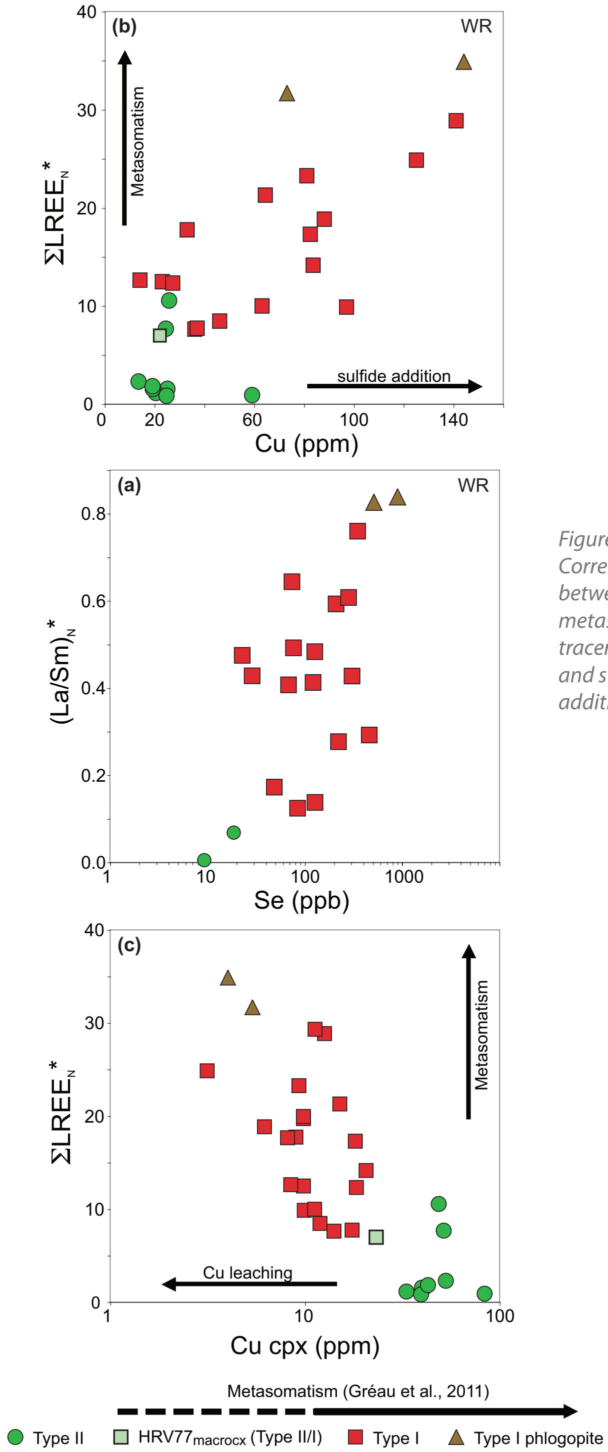


Figure 3. Correlations between metasomatic tracers and sulfide addition.

The Hainan Plume samples an ancient mantle reservoir

Subduction of oceanic slabs to the core-mantle boundary (CMB) as part of plate tectonic processes, and hot mantle plumes that rise from the lower mantle, are two of the major phenomena that have operated through much of Earth's history. However, it is unclear how they interact with each other and whether they are parts of a single geodynamic system; this is a gap in our understanding of how the Earth works. Southeast Asia is a unique site to test possible genetic linkages between deep subduction and plume generation because both phenomena have been seismically detected in the deep Earth in this region.

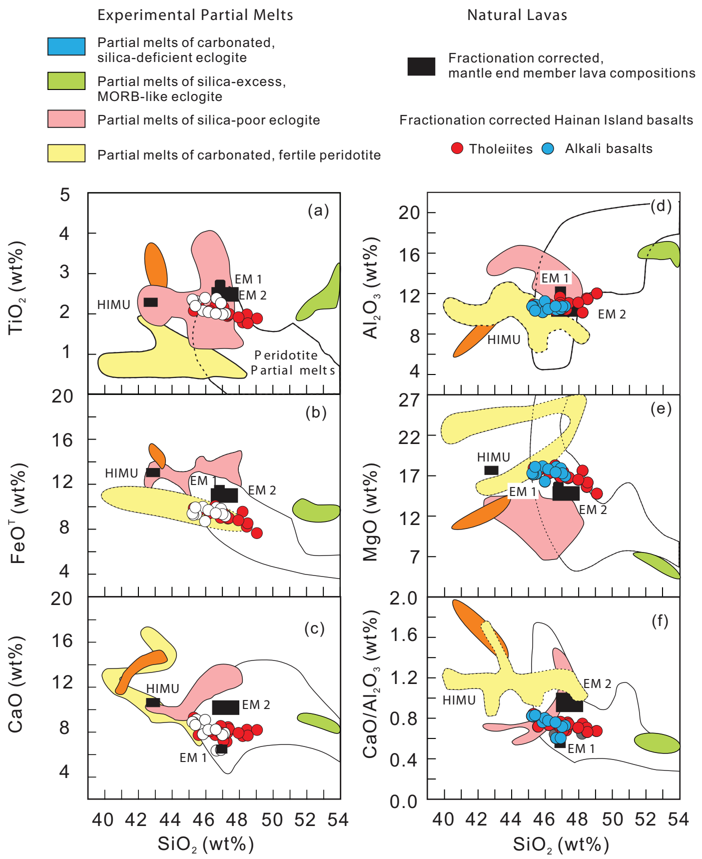


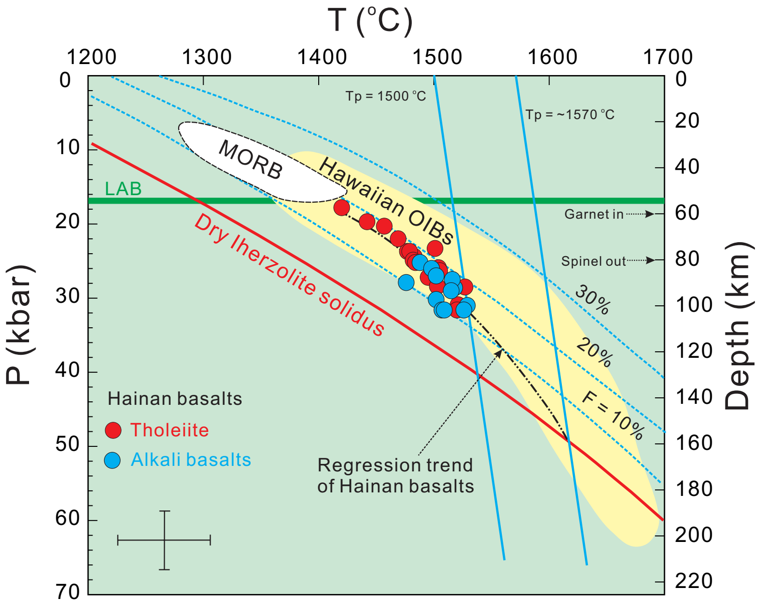
Figure 1. Comparison of fractionation-corrected Hainan basalts (compositions in equilibrium with Fo90.7, corrected for olivine addition), with experimental partial melts. Also shown for reference are the primary-melt estimates of HIMU, EM1, and EM2 mantle end members (CCFS Publication #24).

Recent geophysical studies made a surprising discovery: a plume-like low-velocity structure, called the Hainan plume, beneath Hainan Island and the Leizhou peninsula (Leiqiong) in Southeast Asia. This low-velocity structure goes down 1300–1900 km and may emanate from the lowermost mantle, making it one of perhaps a dozen postulated lower-mantle plumes worldwide. Global occurrences of mantle plumes and subducting slabs since the Mesozoic generally are found in different areas, with plumes in the broad Pacific and African mantle upwelling zones (commonly called superplumes) and subduction in mantle downwelling zones. However, seismic tomographic studies show that the plume-like Hainan low-velocity structure sits close to the subduction zones of the Pacific, Philippine Sea and South China Sea slabs to the east, and the Indo-Australian slab to the south and west, and is far from both superplumes. This suggests that the Hainan plume is unique in being linked to the subduction of tectonic plates; if so, it sheds new light on the workings of the global geodynamic system.

The primary melts for the Hainan basalts have been estimated using the most forsteritic olivine (Fo90.7) as the final olivine and less evolved bulk samples (MgO >9.0 wt% and CaO >8.0 wt%), assuming a constant Fe-Mg exchange partition coefficient of KD = 0.31 and Fe^{3+}/FeT = 0.1. The calculated primary melt compositions are similar to those of fractionation-corrected EM-1 and EM-2 type OIBs (Fig. 1) and plot within the overlapping experimental fields defined by partial melting of silica-deficient eclogites and peridotite (Fig. 1). According to the primary melt compositions, the effective melting pressures (Pf) and melting temperatures (T) form an array that plots systematically above the dry lherzolite solidus but below the base of the lithosphere (Fig. 2). The Pf-T array ($Pf = 0.0105 \times e^{0.0052T}$, $R^2 = 0.81$) begins at about 18 kbar (about 60 km) and intersects the dry peridotite solidus at about 50 kbar (ca 160 km). This intersection translates into a mantle potential temperature beneath Hainan Island of about 1500–1600 °C, which is approximately 200 °C hotter than ambient mantle but typical of thermal mantle plumes such as the Hawaiian plume (Fig. 2). Pb-isotope analyses suggest that the Leiqiong flood basalts were derived mainly from an ancient (4.5–4.4 Gyr) primitive-mantle reservoir preserved near the core-mantle boundary (CMB). Their Nd- and Os-isotope compositions also suggest a lower-mantle origin. The lower-mantle isotopic compositions and high mantle potential T, together with the lower mantle-rooted plume-like seismic velocity structure, all point to the existence of a deep Hainan mantle plume. The Hainan plume thus provides a rare example of a young lower mantle plume close to deep slab subduction.

Contacts: Xuan-Ce Wang, Zheng-Xiang Li, Xian-Hua Li
Funded by: NSFC grant and ARC CCFS, ECSTAR and Foundation grants

Figure 2. Temperatures and pressures calculated for the Hainan basalts. Curved lines represent melting adiabats where F(%) represents fraction of melting. Near-vertical lines represent solid mantle adiabats. The lithosphere-asthenosphere boundary (LAB) beneath Hainan Island is at about 55 km depth as constrained by geophysical data (CCFS Publication #24). Garnet-in and spinel-out reactions occur at about 60 and 80 km for a steady-state geotherm.



Nickel in natural diamonds

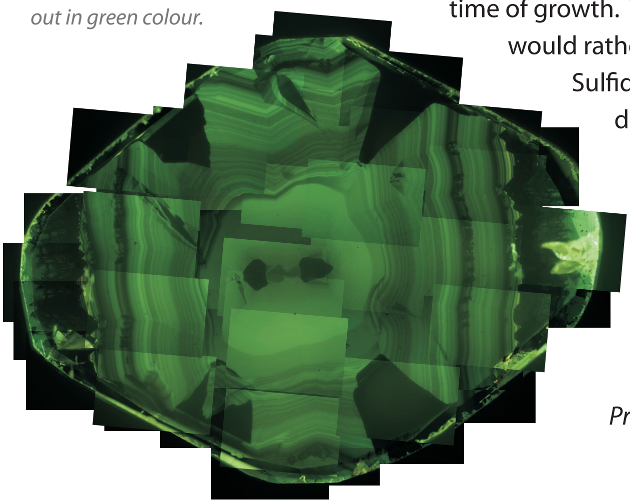
Diamonds, along with the mineral and fluid inclusions they can contain, represent the deepest direct samples from the Earth's mantle. Studying these diamond "capsules" as well as their contents has shed a lot of light on the chemistry of mantle fluids. An important tool for studying the chemistry of the fluids from which the diamonds grew is laser ablation mass spectrometry (LA-ICPMS), a technique pioneered at GEMOC for measuring trace elements in diamonds. This has been shown to be of most use for fibrous diamonds that contain abundant fluid micro-inclusions. Due to the low concentrations of trace elements in gem quality diamonds, a key requirement has been to trap a lot more material to analyse than is produced during a typical laser-ablation analysis.

To do this, we have had to develop a different way of ablating diamonds. Instead of passing the ablated material (suspended in gas) directly into the mass spectrometer, we pass it through a liquid. The gas bubbles off through the liquid and the ablated material is left behind in solution, where it can be analysed by ICP-MS. This allows us to ablate for several hours instead of minutes, capturing far more material than traditionally possible. Typical ablation pits made using this method measure 500 x 500 x 120 microns, compared with the 50-micron-diameter pits of most LAM-ICPMS analysis. While this method sacrifices the spatial resolution of regular LAM-ICPMS analysis, it achieves very low levels of detection for many trace elements.

Mixed-habit diamonds are those that show periods of smooth faceted octahedral growth and rough, hummocky cuboid growth, occurring at the same time. This often results in a centre-cross feature, which may or may not be visible to the naked eye. These types of diamonds have been known to contain nickel, only in the cuboid sectors. This impurity is responsible for the green luminescence that is characteristic of these types of diamonds, but was something long thought to only occur in synthetic diamonds. While no measure of nickel concentrations in these diamonds has been made before, levels were estimated to be in the order of <0.1 ppm. Preliminary LA-ICPMS analysis performed here at GEMOC has revealed concentrations ranging between 2 and 20 ppm. These samples were the motivation to measure even smaller concentrations of trace elements, to see if any other elements were preferentially partitioned into the cuboid sectors rather than the octahedral ones. It is already know that nitrogen is preferentially taken up into the octahedral sectors and important question marks remain regarding variations of hydrogen.

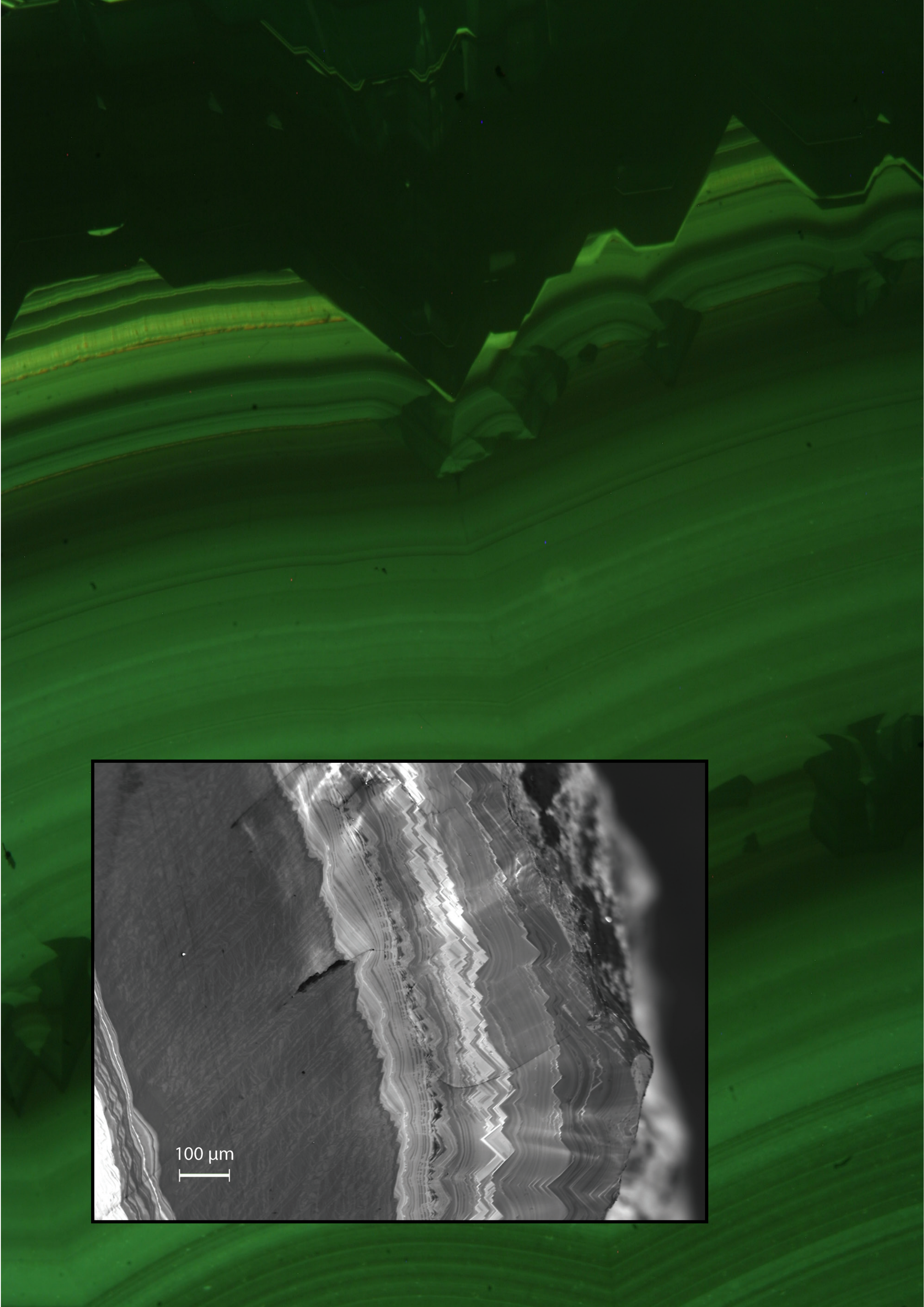
For nickel to be found in diamond suggests an absence of any sulfide phases during the time of growth. This is because nickel is a chalcophile element – one that would rather react with sulfur than with oxygen (i.e. to form silicates). Sulfides are one of the most common types of inclusions found in diamonds, so their absence may be indicative of the physical and chemical growth conditions that resulted in this special type of diamond growth. Further analysis of the impurities in these types of diamonds should help reveal more information about the role of fluids in the mantle.

Figure 1. CL image of a complexly-zoned mixed-habit diamond - cuboid sections stand out in green colour.



Contacts: Dan Howell, Bill Griffin, Sue O'Reilly, Norman Pearson

Funded by: ARC Discovery (relinquished), CCFS Foundation Project


100 µm

Chromites from dirt - a new pathfinder for nickel deposits

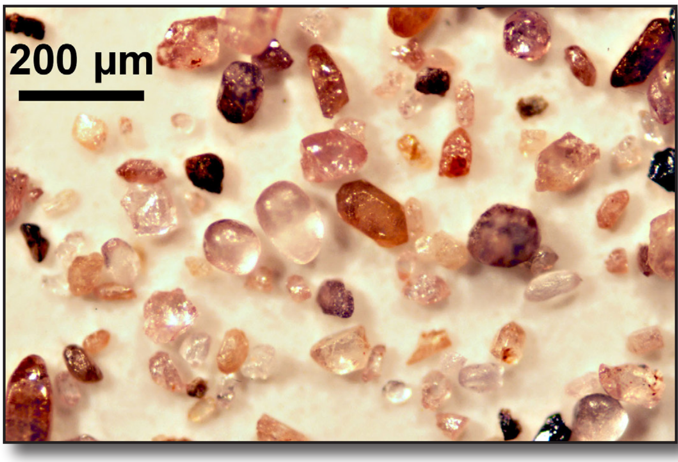


Figure 1. Black chromite grains in a heavy mineral concentrate. (photo: Elena Belousova).

The ever-increasing demand for global metal resources is creating many challenges for the metal exploration industry. Mineral deposits are not renewable and it is likely that all easily accessible giant deposits close to the surface have already been found. As a consequence, exploration for new 'hidden' deposits has to be extended to remote areas and deeper into the Earth itself, which is like looking for a needle in a haystack.

One way to aid exploration in a fast and cost-effective way is the analysis of resistate mineral phases from heavy mineral concentrates (Fig. 1). When water and wind erode rocks, mineral grains are liberated and may be deposited in nearby rivers. Minerals that are heavier and more resistant to destructive erosion than others are often trapped and concentrated in low-velocity parts of river beds and these "heavy mineral concentrates" provide an easily recovered sample of the entire catchment area of a drainage system. The minerals are analysed for their major- and trace-element compositions to identify element signatures that might indicate the nearby presence of a mineral deposit. This approach is used, for example, in diamond exploration, where garnet, chrome diopside and chromite are used as resistate indicator minerals to determine if a terrane is prospective for diamonds.

In 2011, GEMOC investigated the potential use of heavy mineral concentrates in the exploration for komatiite-hosted nickel-sulfide deposits. Komatiites contain some of the world's highest-grade nickel-sulfide deposits and the Archean Yilgarn Craton in Western Australia hosts several of these. The development of reliable prospectivity indicators to target exploration towards mineralised

Figure 2a. Australian komatiite outcrops like this one are rare....

Figure 2b. …therefore geochemical exploration is often restricted to diamond drill cores.

komatiite units has been a long-standing goal, particularly in Australia where komatiites rarely outcrop at the surface and geochemical exploration is often restricted to drill cores (Fig. 2a, b). Accordingly, the identification of an effective resistate indicator mineral for nickel-sulfide deposits that can be sampled at the surface could provide a major breakthrough in the exploration for mineralised komatiites.

Earlier research at GEMOC has shown that the ruthenium content of chromite can be used to discriminate mineralised from barren komatiites in pristine rocks from deep drill cores. Chromites from mineralised komatiites have distinctly lower ruthenium contents than chromites from unmineralised environments (see *GEMOC annual report 2010*). The research was extended in 2011 to see if the ruthenium content of chromites from heavy mineral concentrates can also be used in the exploration for nickel-sulfide deposits. As well as metamorphism and alteration, detrital chromites have inevitably undergone strong weathering, and primary ruthenium signatures may be obliterated by chemical modification of the chromite. To investigate how postmagmatic processes affect the ruthenium content of chromite, GEMOC's state-of-the-art laser ablation ICP-MS facility (Fig. 3) has been used to analyse more than 500 chromite grains from komatiites, komatiitic basalts and ferro-picrites from the Yilgarn Craton of Western Australia, the Superior Craton of Canada and the Fennoscandian Shield of Finland and Russia. The sample suite included rocks that have undergone different degrees of metasomatism and alteration, and sampling depths ranged from several hundred metres below the surface to near-surface rocks that have undergone extensive weathering.

The results show that ruthenium is essentially immobile during postmagmatic processes and that chromite cores (as opposed to their rims) are relatively resistant to destructive metamorphism and alteration, as well as lateritic weathering. Therefore, primary magmatic ruthenium signatures can be preserved in chromites. Based on currently available evidence, high-ruthenium chromites are largely, if not entirely, restricted to unmineralised komatiites. Hence the presence of mixtures of high- and low-ruthenium chromite, of appropriate major element chemistry, in detrital heavy mineral concentrates is a reliable signal of mineralised komatiite sequences, and varying proportions of high- and low-Ru grains may be an indicator of proximity.

As chromite is a widespread component of resistate heavy mineral suites, and large sample collections exist from previous diamond exploration programs, a prime opportunity has been created to investigate these sample collections, using an analytical technique that was unavailable when much of that material was originally investigated. Therefore, this technique could be an effective way to detect komatiite-hosted nickel-sulfide deposits, and could be used together with other geological, structural, geophysical and volcanological exploration techniques.

Contacts: Marek Locmelis, Norman Pearson, Marco Fiorentini
Funded by: CCFS Foundation Project

Figure 3. GEMOC's state-of-the-art laser ablation ICP-MS facility.

Copper can concentrate by collision

Porphyry copper deposits are in great demand with today's exploration industries, supplying nearly 70 percent of the world's copper, 50 percent of its molybdenum and 25 percent of its gold. Most of these deposits are formed above subduction zones, where one oceanic plate sinks beneath another continental or oceanic plate, such as in the Eastern Pacific. Traditionally, porphyry Cu deposits were found in subduction area such as in Chile and Peru. However in the last decade it has been discovered that porphyry copper deposits also can be found in continental collisional zones, where two continents collided after oceanic subduction terminated. However, our understanding of the processes of their creation remain limited.

Such deposits have been discovered mainly in the Alpine-Himalayan orogenic belt. Examples include the Eocene-Oligocene Yulong porphyry Cu-Mo belt of East Tibet, the mid-Miocene Gangdese porphyry Cu belt in southern Tibet, and the Neogene porphyry Cu-Au deposits of the southwest Pacific. Their formation involves distinct but as-yet poorly-understood processes unrelated to active subduction, ranging from deep generation of magmas and metal sources to exsolution and evolution of ore-forming fluids in the upper crust.

This CET study has examined porphyry copper systems in Western Yunnan, south-eastern Tibetan Plateau and resulted in new insights into the formation of porphyry Cu systems in continental collisional tectonic settings. The study reported the systems' geology, whole-rock geochemistry, Sr-Nd-Pb isotopes and Hf-O isotopes in zircon, to document the geochemical characteristics of three intrusive suites and determine their magma/metal sources and petrogenesis.

The results revealed a strong indication that continental collision zones hold potential for both porphyry Cu±Mo and Cu±Au deposits. There are five critical factors to this formation, in sequence: (1) an early phase of subduction-modification of continental lithospheric mantle; (2) decompressional melting of upwelling asthenosphere after orogenic delamination; (3)

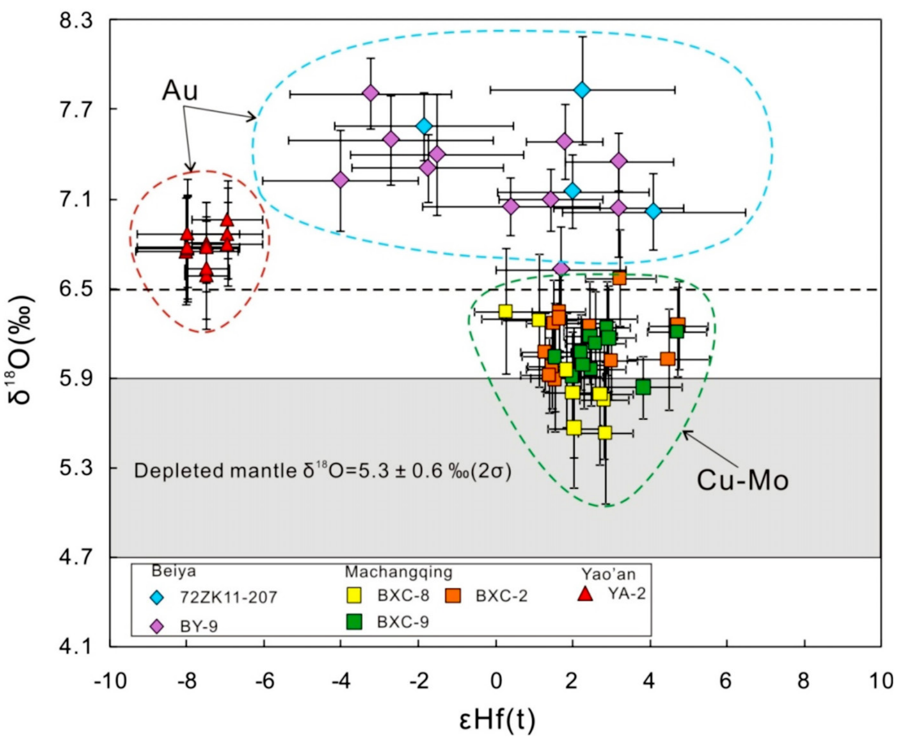


Figure 1. In situ zircon Hf-O isotope data for the Yao, Machangqing and Beiya intrusions.

underplating of mafic magmas from the asthenosphere at Moho depths and partial melting of lower crust; (4) melts from residual metasomatised mantle lithosphere; and (5) collectively generating a bimodal suite where porphyry mineralisation is present in alkaline granitoids.

This research shows that porphyry Cu deposits can certainly form in collisional settings apart from a subduction setting. However, the geological processes related to the formation of these collision zone deposits are still not fully understood. Future research will aim to understand the origin and evolution of the water, metal and sulfur in the collision-zone porphyry deposits.

Contacts: Yongjun Lu, T. Campbell McCuaig
Funded by: CAGS

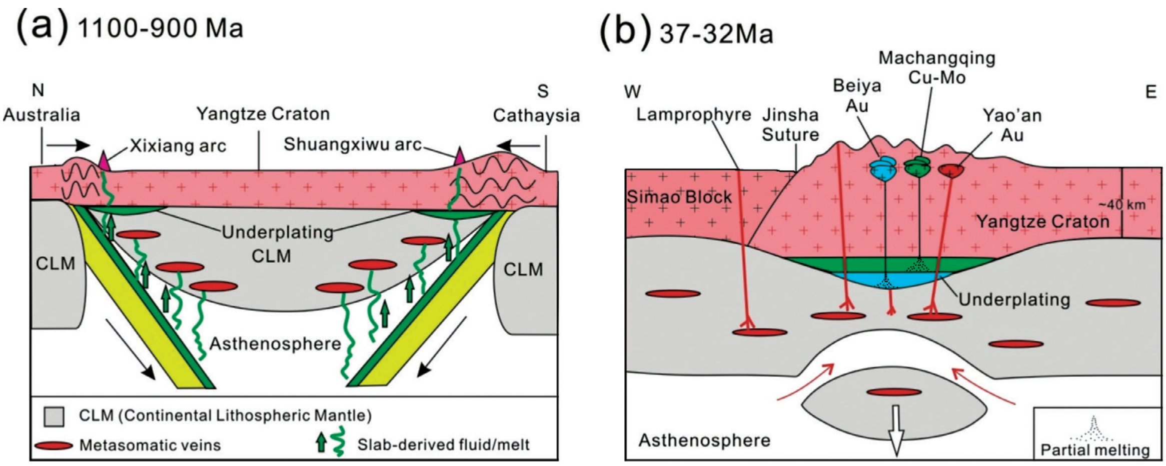


Figure 2. Metallogenic model for the formation of western Yunnan post-collisional porphyry Cu systems.

The perfect conditions for gold in the West Qinling Orogen

The West Qinling orogenic belt in Central China has an abundant supply of gold ore, but most discoveries of gold deposits in the region only took place during the last four decades. Located between the North China and South China cratons, this orogen now represents one of the most prospective gold provinces in China. With over 500 tonnes of gold reserves identified, it holds a great deal of potential for the future. However the nature of gold formation in this region remains a contentious issue.

Previous research in this region has examined the conditions behind gold formation with a view to aiding exploration targeting efforts, but has not considered factors affecting preservation of the deposits within the Earth's crust. Gold ore is formed underground and over millions of years through a combination of uplift and surface erosion, bringing the ore to within mining levels (exhumation). It is therefore not sufficient for industry to simply conclude that an area has the right conditions for gold mineralisation. If there has been too much erosion the gold will have been destroyed, but if there has not been enough it is inaccessible. Part of Qingtao Zeng's research tests this link between different mineralisation styles and the exhumation history of their host rocks.

The two major gold mineralisation styles that have been reported in the West Qinling Orogen are (1) orogenic gold and (2) Carlin-type gold mineralisation. The Liba goldfield and the Dashui gold deposit are selected to represent these two styles. The work on the Liba and Dashui gold deposits has been published online and submitted to Mineralium Deposita.

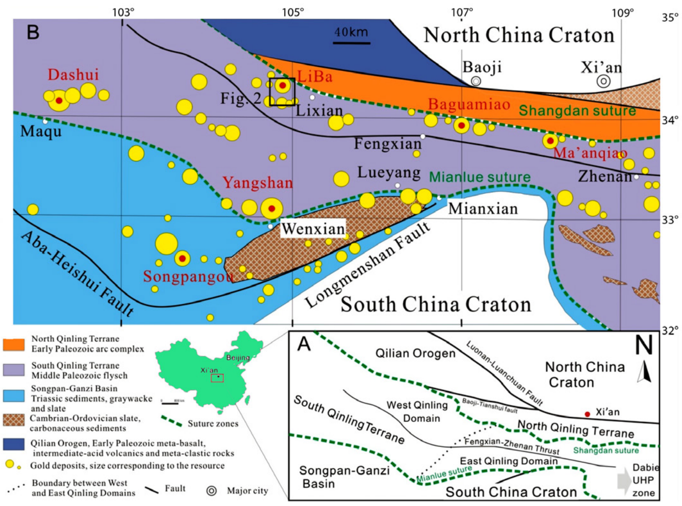


Figure 1.

The exhumation history of the deposits has been examined through thermochronology and a comparative study was conducted to understand how and why there were such huge differences in mineralisation profiles. Thermochronology is a subfield of geology where the time that a sample has spent at a particular depth in the Earth's crust can be determined. The technique combines radiometric dating and a knowledge of the closure temperature for different isotopic systems in individual minerals, to derive a geothermal gradient. The results from this research tell us that in the Liba area, exploration should focus on relatively deep expressions of gold mineralisation, because approximately 5 km of overburden has been eroded away. In the Dashui area, however, erosion has been much less, and a higher priority for gold exploration in the region should be given to shallow mineralisation styles.

By using the knowledge acquired through this research, exploration companies can determine both whether the ore is accessible and what style it will be. After all, "you can only find what you are looking for". In summary, Qingtao's study has increased our understanding of the localisation of gold mineralisation in terms of both genesis and preservation, providing a tool for designing exploration strategy in the West Qinling Orogen.

Contacts: Qingtao Zeng, T. Campbell McCuaig
Funded by: Peking University

CCFS honours students

The following honours projects in CCFS were completed in 2011

Macquarie

Cameron Adams: Gravity modelling of the Thomson Orogen, northwest New South Wales

Amanda Bernasconi: The subcontinental lithospheric mantle of easternmost Zealandia: A mantle xenolith study of the Chatham Islands

Patrick Carr: Geochemical characterisation of the volcanics surrounding Prominent Hill, South Australia: implications for the geodynamic setting of the northeastern Gawler Craton

Emma Chisholm: Age and geochemistry of the volcanic and plutonic rocks in the Yerranderie area

Nick Tefay: Petrographic characterisation and zircon geochronology of the Cobungra Granite and Low-P high-T Omeo metamorphic complex, Lachlan Fold Belt

Curtin

Jed Bridges: (1st class Hons) Structural and microstructural characterisation of high pressure serpentinite and implications for subduction zone seismic anisotropy (Piemonte Zone, NW Italian Alps)

CCFS postgraduates

Vanuatu fieldwork May 2011 - PhD research for Clement Gaildry and Chris Firth. People from left: Shane Cronin (Massey University, NZ), Douglas Charlie (local geologist), Michael Turner, Heather Handley, Chris Firth, Clement Gaildry standing on the ash plain in front of Yasur volcano (one of the most active volcanoes in the world).

CCFS POSTGRADUATE STUDENTS include those already in progress before 2011 with projects relevant to CCFS Research Themes, as well as those who commenced in 2011. Six papers by CCFS postgraduates were published in high-profile international journals in 2011, including *Precambrian Research, Lithos* and *Geochimica Cosmochimica Acta*, and eleven presentations were made at international conferences. Yongjun Lu was awarded the Best Student Presentation Award at the 2011 11th SGA Biennial meeting held in Antofagasta, Chile.

MACQUARIE

Soumaya Abbassi (PhD): Mass balance of generation and escape of methane on the North West Shelf of Australia in the Tertiary; *MQRES* (commenced 2010)

Raul Brens (PhD): Origin of silicic magmas in a primitive island arc; (commenced 2011)

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)

Tracy Rushmer and Cara Danis at the MQ Faculty of Science Research day.

Cara Danis (PhD): Geothermal state of the Sydney-Gunnedah-Bowen Basin system; *APA, ARC DP* (commenced 2008, Submitted Oct 2011)

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

Chris Firth (PhD): Integrating the volcanological and magmatic record of a young Arc volcano: Yasur Vanuatu; *APA* (commenced 2011)

Fiona Foley (PhD): Magmatic consequences of subduction initiation and its role in continental crust formation; *iMQRES* (commenced 2009)

Clement Gaildry (PhD): Island arc processes as seen through Vanuatu volcanism and geochemistry; *iMQRES* (commenced 2011)

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

Christopher Grose (PhD): Geodynamics of the oceanic lithosphere; *iMQRES* (commenced 2011)

Yosuke Hoshino (PhD): Demonstrating the syngeneity and interpreting the palaeobiology of hydrocarbon biomarkers in the Fortescue Group (2.7 Ga); *ARC DP* (commenced 2011)

Jin-Xiang Huang (PhD): Origin of eclogite and pyroxenite xenoliths in kimberlites and basalts; *China Government Scholarship and cotutelle with China University of Geosciences, Beijing* (commenced 2008 Submitted 2011)

Pablo Lara (PhD): Late Neoproterozoic 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 (commenced 2011)

Rosanna Murphy (PhD): Stabilising a craton: origin and emplacement of the 3.1 Ga Mpuluzi batholith (Swaziland/RSA); *MQRES* (commenced 2011)

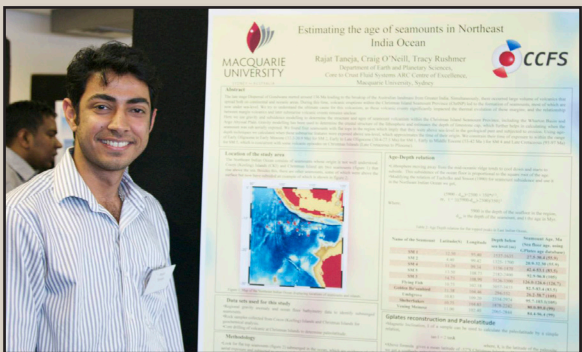
Matt Pankhurst (PhD): Geodynamic significance of shoshonitic magmatism within the Andean Altiplano; *MQRES* (commenced 2009)

Ekaterina Rubanova (PhD): Fluid processes in the deep mantle: Geochemical studies of diamonds and related minerals; *iMQRES* (commenced 2010) *see Research Highlight p. 72.*

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

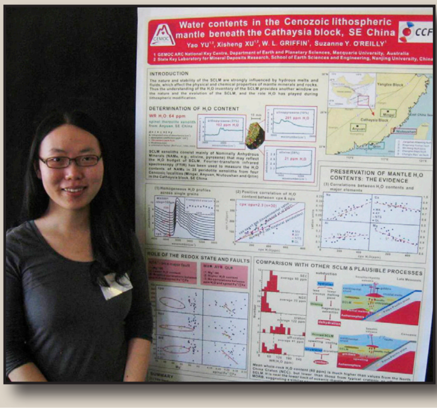
Elyse Schinella (PhD): Landform evolution on Venus; *APA* (commenced 2010)

Rajat Taneja (PhD): Geodynamic evolution of the NE Indian Ocean; *iMQRES* (commenced 2010)



Rajat Taneja with his poster at the MQ Faculty of Science Research day.

Jennifer van Holst (PhD): Understanding microbial gasification of coal: A study of the stable isotope composition of microbial gas generation (commenced 2010)



Yao You at the MQ Faculty of Science Research day.

Yao Yu (PhD): The evolution and tectonic dynamics of the subcontinental lithospheric mantle, SE China; *China Science Council Scholarship and cotutelle with Nanjing University* (commenced 2010) *see Research Highlight p. 68.*

Qing Xiong (PhD): Shenglikou and Zedang peridotite massifs, Tibet: Upper mantle processes and geodynamic significance; *China Science Council Scholarship and cotutelle with China University of Geosciences, Wuhan* (commenced 2010)

COMMENCING 2012: Nicole McGowan and **Yuya Yao**

UWA

Carissa Isaac (PhD): 4D architecture of the Eastern Goldfields Superterrane in the Yilgarn Craton of Western Australia, in order to constrain the role of the lithospheric structure at 2.7 Ga in the localisation of nickel mineral systems; *ARC Linkage* (commenced 2009)

Margaux LeVaillant (PhD): Hydrothermal footprints of magmatic nickel sulfide deposits; *MERIWA* (commenced 2011)

PM Julia Gillard meets student Yongjun Lu at UWA's Edward de Courcy Clarke Earth Science Museum prior to announcing the International Mining For Development Centre (IM4DC). (photograph courtesy of UWA)

Yongjun Lu (PhD): Tectonic setting, magmatic evolution, and metallogeny of Paleogene potassic instrusions in western Yunnan, southeastern Tibetan Plateau; *UWA IPRS* (commenced 2008, submitted 2011) *see Research Highlight p. 82.*

David Mole (PhD): Quantifying melt-lithosphere interaction in space and time: understanding nickel mineral systems in the Archaean Yilgran craton; *UWA Scholarships for International Research Fees, ARC Linkage* (commenced 2008)

Luis Parra (PhD): 4D evolution of felsic magmatic suites and lithospheric architecture of the Paleoproterozoic Birimian terranes, West Africa; *UWA SIRF UIS, Ad Hoc Safety-Net Top-Up Scholarship, ARC Linkage* (commenced 2011)

Christian Schindler (PhD): Petrogenesis of intrusive rocks in the Telfer region, Patterson orogen, Western Australia: implications for gold mineralisation; *UWA Scholarships for International Research Fees, Industry Funding* (commenced 2010)

Qingtao Zeng (PhD): Geology, geochronology and genesis of gold deposits in the West Qinling Orogenic Belt, central China; *UWA Scholarship for International Research Fees China, Peking University, China Science Council* (commenced 2008) *see Research Highlight p. 84.*

Jianwei Zi (PhD): Indosinian tectono-magnetic evolution of the Yidun Arc in the Sanjiang Region, Southwestern China; *UWA Scholarship for International Research Fees China, Top-up Scholarship for China Science Council* (commenced 2008)

Curtin

Huiqing Huang (PhD): The petrogenesis of Jurassic granitic rocks in the Western Nanling Ranges of South China and Tectonic Implications; *A joint Curtin-CAS PhD under a Curtin University Scholarship* (commenced 2009)

Yingchao Liu (PhD): Recognising Gold Mineralisation Zones using GIS-Based modelling of multiple ground and airborne datasets; *Curtin University Scholarship (APRA)* (commenced 2010)

Liping Liu (PhD): Timing and kinematics of Mesozoic-Cenozoic mountain building and cratonic thinning in eastern North China: a combined structural and thermochronological study; *China Science Council and Curtin University joint Scholarship* (commenced 2010)

Jiawen Niu (PhD): Neoproterozoic paleomagnetism of South China and implications for global geodynamics; *Curtin University, ARC DP scholarship* (commenced 2008)

Chongjin Pang (PhD): Basin record of Mesozoic tectonic events in South China; *China Science Council and Curtin University joint Scholarship* (commenced 2010)

Ni Tao (PhD): Thermochronological record of vertical tectonic movements in Mesozoic-Cenozoic South China; *Curtin University, ARC DP scholarship* (commenced 2011)

Weihua Yao (PhD): Lower Palaeozoic basin record in Southern South China: Nature of the Cathaysia basement and evolution of the Wuyi-Yunkai Orogeny; *China Science Council and Curtin University joint Scholarship* (commenced 2010)

Kongyang Zhu (PhD): Petrogenesis and tectonic setting of Phanerozoic granitic rocks in eastern South China; *China Science Council and Curtin University joint Scholarship* (commenced 2010)

CCFS PhD students (Liping Liu, Yingchao Liu, Chongjin Pang and Weihua Yao) and Zheng-Xiang Li joined a five-day GSWA field workshop to the Albany-Fraser Belt in September 2011. This was the first time these students had ventured into the bush in Australia. During the workshop they interacted with staff from GSWA – a CCFS partner organisation, and geologists from a wide range of institutions (including many industry representatives). They all enjoyed it so much that they did not want to come back to campus after the trip.

Infrastructure and technology development

CCFS links three internationally recognised concentrations of analytical geochemistry infrastructure: GEMOC's Geochemical Analysis Unit (Macquarie University) and the associated Computing Cluster, the Centre for Microscopy, Characterisation and Analysis (UWA/Curtin) and the John de Laeter Centre of Mass Spectrometry. All are nodes for the NCRIS AuScope and Characterisation Capabilities, and have complementary instrumentation and laboratories. In addition, Curtin and UWA share a leading facility for paleomagnetic studies.

CCFS/GEMOC INFRASTRUCTURE, LABORATORIES AND INSTRUMENTATION

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

The GAU contains:

- a Cameca SX-100 electron microprobe
- a Zeiss EVO MA15 Scanning electron microscope
- four Agilent ICPMS (industry collaboration; two 7500cs; two 7700cx)
- a custom-built UV laser microprobe, usable on the Agilent ICPMS
- three New Wave laser microprobes (one 266 nm, two 213 nm, each fitted with large format sample cells) 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
- 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
- clean labs and sampling facilities provide infrastructure for ICPMS, XRF and isotopic analyses of small and/or low-level samples
- 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 GEMOC FACILITY FOR INTEGRATED MICROANALYSIS (FIM) AND MICRO-GIS DEVELOPMENT

Within CCFS, 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 (fs-LAM); a high-sensitivity magnetic-sector ICPMS; a quadrupole ICPMS. The quadrupole ICP-MS was purchased and installed in 2010; a Photon Machines femtosecond laser system and a Nu Attom ICP-MS are on order and will be installed in 2012.

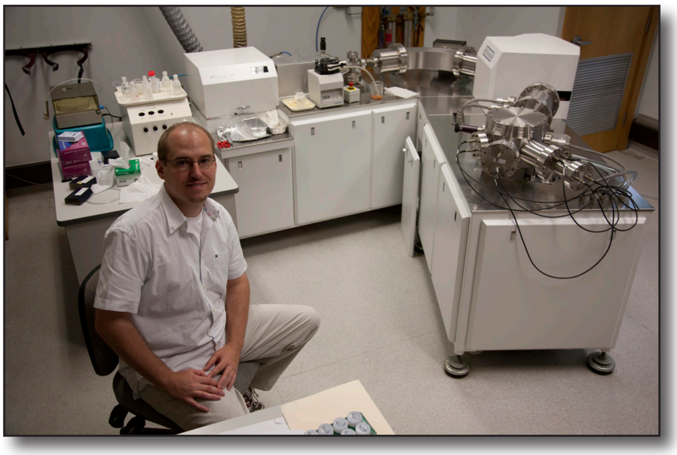
PROGRESS IN 2011

1. Facility for Integrated Microanalysis

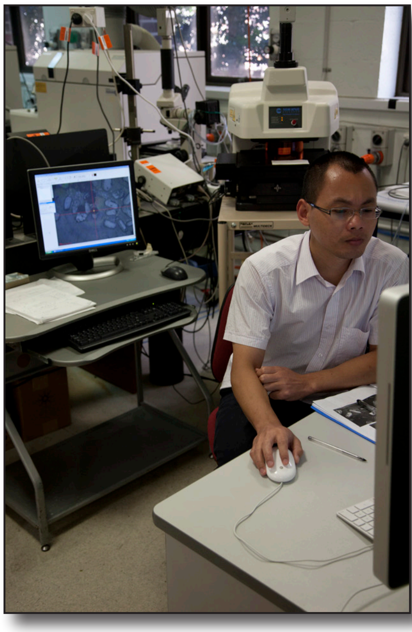
a. Electron Microscope; Electron Microprobe: The Zeiss EVO MA15 SEM carried the electron imaging workload, providing high-resolution BSE and CL images for *TerraneChron*® (http://www.gemoc.mq.edu.au/TerraneChron.html) and all other research projects, including diamonds and diamondites, and PGM in chromitites. The SX100 serviced the demands for quantitative mineral analyses and X-ray composition maps for all projects including analysis of perovskite in kimberlites; analysis of base metal sulfides and platinum group minerals; minor and trace element analysis of metals.

b. Laser-ablation ICPMS microprobe (LAM): Output from the LAM laboratory in 2011 increased from 2010 and the facility was used by thirteen Macquarie PhD thesis projects, twelve international visitors, four Honours students, and several in-house funded research projects and industry collaborations. Projects included the analysis of trace elements in the minerals of mantle-derived rocks, in sulfide minerals and 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 Australia (NSW, WA, SA), New Zealand, France, Laos, Serbia, Papua New Guinea, Turkey, Zambia, Mongolia, Russia, Germany, Mauritania and Chile. The LAM laboratory also routinely provides data for projects related to mineral exploration (diamonds, base metals, Au) as a value-added service to industry.

Marek Locmelis using the MC-ICPMS.



c. MC-ICPMS: The continued increase of *TerraneChron*® activities (see http://www.gemoc.mq.edu.au/TerraneChron.html) involving the measurement of Hf isotopes, coupled with the growing demand for *in situ* analysis of other radiogenic isotope systems (e.g. Re-Os analysis in sulfide and PGM; Nd-Sm and Rb–Sr in perovskite) and stable isotope analysis, created severe competition for instrument time on the LAM MC-ICPMS.



The Laser-ablation ICPMS microprobe.

Major applications during 2011 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, New Zealand, France, Laos, Serbia, Papua New Guinea, Turkey, Zambia, Mongolia, Russia, Germany, Mauritania and Chile. We carried out Re-Os studies on xenoliths from eastern China, Siberia, Mongolia, France, Spain, the USA and South Africa. Sr and Nd isotopes were measured *in situ* in kimberlitic perovskites from South Africa.

d. Laboratory development: The clean-room facility established in 2004 continued to be used primarily for isotope separations for analysis on the Triton TIMS and Nu Plasma MC-ICPMS. Routine procedures have been established for Rb-Sr, Nd-Sm, Lu-Hf and Pb isotopes, as well as U-series methods (U, Th and Ra).

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. Sales are handled by Access MQ and GEMOC provides customer service and technical backup. During 2011 a further 15 full licences of GLITTER were sold bringing the total number in use to 186 worldwide, in forensics and materials science, as well as earth science applications. Dr Will Powell continued in his role in GLITTER technical support and software development through 2011. The current GLITTER release is version 4.4.3 and is currently available without charge to existing customers and accompanies all new orders (http://www.glitter-gemoc.com/).

2. Energy dispersive XRF

A Spectro XLAB2000 energy-dispersive X-ray spectrometer, installed in November 2000 in a joint venture with Tasman Resources, provided high-quality major- and trace-element data through 2011.

3. Whole-rock solution analysis

An Agilent 7500cs ICPMS produces trace-element analyses of dissolved rock samples for the projects of GEMOC researchers and students and external users, supplementing the data from the XRF.

Further advances were made in the analysis of 'non-traditional' stable isotopes and included the development of separation techniques and analytical protocols for Mg isotopes in garnet and the refinement of methods for the separation and analysis of Li isotopes in ultramafic rocks. The permanent availability of one of the Agilent 7500cs instruments for solution analysis greatly benefited the development of the separation techniques.

4. Diamond preparation and analysis

The GEMOC laser-cutting system (donated by Argyle diamonds in 2008), was used during 2011 to cut thin plates of single diamond crystals as part of the on-going research into diamond genesis. The plates are used for detailed spatial analysis of trace elements, isotopic ratios and the abundance and aggregation state of nitrogen. The nitrogen measurements are made using the ThermoFisher iN10FTIR microscope, which allows the spatial mapping of whole diamond plates at high resolution with very short acquisition times. The DiaMap software for creating these maps was developed by Dan Howell and Craig Smith.

5. selFrag – a new approach to sample preparation

Elena Belousova using the selFrag.

The first selFrag instrument in Australia was installed in GEMOC in May 2010 and was used extensively through 2011 for mineral liberation. 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 the 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.

6. Computer cluster

A 64-core ARC-funded computer cluster (Enki) came online in 2010, with the capability to run massively parallel high-resolution geodynamics simulations in 3D at a global scale. Further funding in 2011 was used to expand the cluster into a 160-core machine. Updated rack storage and power supplies have been completed, and the upgraded machine is currently in full operation.

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 four Honours student projects, as well as two ongoing PhD projects, and underpins at least four successful ARC Discovery projects.

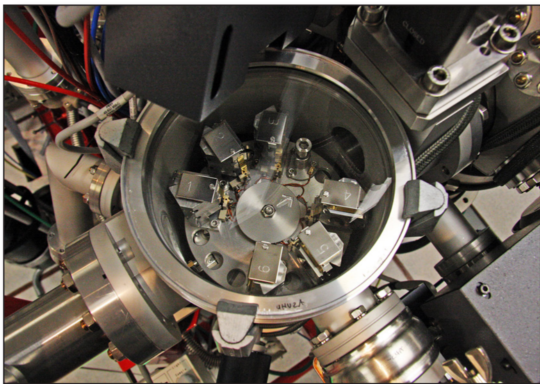
Internal capacity in this kind of computing is necessary as externally available clusters (e.g. At AC3/Intersect, or at NCI) are specifically for "production" runs only – not for research and development of experimental codes. However, many of these codes have absolute minimum resolution requirements which can only be met by a large cluster. For example, CitcomS requires at least 12 nodes to run, or 96 for a fully resolved simulation, which is often necessary for the testing of new modules. This cannot be done on a desktop machine, and since testing is not allowed on the public machines, the in-house cluster is essential to the development of the next generation of simulation tools.

CMCA TECHNOLOGY DEVELOPMENT AND INSTRUMENTATION

The University of Western Australia's Centre for Microscopy, Characterisation and Analysis (CMCA) is a $40M core facility providing analytical solutions across a diverse array of scientific research. The world-class facilities and associated technical and academic expertise are the focus of micro-analytical and characterisation activities within Western Australia, while strong links and collaborations have earned the CMCA an excellent national and international reputation. The CMCA incorporates the Western Australian Centre for Microscopy, and is a node of the NCRIS Characterisation capabilities, the National Imaging Facility (NIF) and the Australian Microscopy and Microanalysis Research Facility (AMMRF). It is also associated with the NCRIS-funded Australian National Fabrication Facility (ANFF) and AuScope, which have made a substantial contribution to facilities run by CMCA.

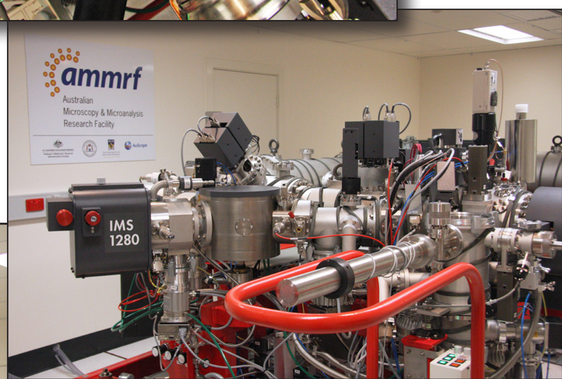
CMCA capabilities:

- CAMECA IMS 1280 and CAMECA NanoSIMS 50 ion microprobes
- JEOL JXA 8530F electron microprobe, with Cathodoluminescence imaging (CL)
- Transmission Electron Microscopes (JEOL 3000F, 2100 and 2000FX), with EDS and energy-filtered EELS analysis capabilities
- Scanning electron microscopes (Zeiss 1555, 2 JEOL 6400, Philips XL30)
- X-ray powder diffraction (Panalytical Empyrean)
- NMR spectroscopy (2 Bruker Avance and 2 Varian spectrometers)
- Optical and confocal microscopy
- Micro-CT (to be installed 2012)
- Bioimaging, flow cytometry, cell sorting, and laser micro-dissection
- X-ray crystallography
- GC and HPLC mass spectrometry
- Biological sample cryo-preparation and ultramicrotomy

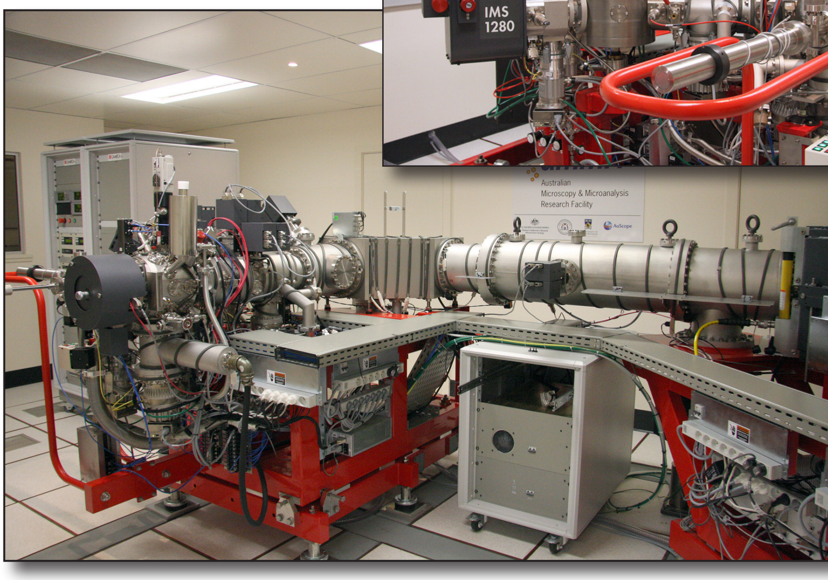


THE AMMRF FLAGSHIP ION PROBE FACILITY

The CAMECA IMS 1280 and NanoSIMS 50 are flagship instruments of the Australian Microscopy and Microanalysis Research Facility (AMMRF). The AMMRF Flagship Ion Probe Facility offers state-of-the-art secondary ion mass spectrometry (SIMS) capabilities to the Australian and international research communities, allowing *in situ*, high-precision isotopic and elemental analyses, secondary ion imaging, and depth profiling on a wide range of samples.



The IMS 1280 large-geometry ion probe, installed in 2009, was co-funded by the University, the State Government of Western Australia, and the Federal Government's Department of Innovation, Industry, Science and Research (DIISR) under the 'Characterisation' (AMMRF) and 'Structure and Evolution of the Australian Continent' (AuScope) capabilities of the National Collaborative Research Infrastructure Strategy (NCRIS). The NanoSIMS 50, installed in 2003, was funded through the Federal Government's NCRIS-precursor, the Major National Research Facility scheme (NANO-MNRF).



The instruments are managed by the Western Australia Ion Probe Management Committee, which also manages the two SHRIMP II ion probes located at Curtin University. Access to the Ion Probe Facility is subsidised for publicly-funded researchers within Australia via a merit-based competitive application scheme, where projects are assessed by a scientific committee of international experts.

The Ion Probe Facility is a key characterisation component within the ARC Centre of Excellence for Core to Crust Fluid Systems. To ensure the highest levels of quality and throughput, the CCFS has provided funding for a Research Associate position within the Ion Probe Facility, to facilitate direct scientific and technical interaction for all CCFS users and projects.

PROGRESS IN 2011

Standards development:

2011 has seen a continued progress in developing more modes of SIMS analysis. In addition to the standard analyses being performed in the IMS 1280 lab (including B, C, O, S, and U isotopic measurements) development has begun on H, Li, Mg, Si, Cl, Fe and Sr and Pb isotopic analysis. Most of these analyses are hampered by the availability of appropriate isotopic standards and thus a continued effort is underway to develop such standards for a variety of systems. Collaborative links have been forged with Geoscience Australia and the Geological Survey of Western Australia to obtain a supply of zircons that can be used for dating and as Hf-O-isotope standards. Sulfur isotopic systems are also becoming increasingly popular with users, due to the fact that the IMS 1280 can easily measure *in situ* $\delta^{33}S$ and $\delta^{34}S$ to better than 0.1 ‰ and $\delta^{36}S$ to better than 0.2 ‰, and therefore determine $\Delta^{33}S$ and $\Delta^{36}S$ to identify mass-independent fractionation signatures. Due to the global scarcity of well-characterised sulfide standard materials, the Ion Probe Facility has sought to develop in-house standards, utilising collaborative links with Marco Fiorentini (CCFS), James Farquhar (The University of Maryland), Bos Wing (McGill University) and Sue Golding (University of Queensland). This has resulted in the successful development of S-isotope standards for pyrite, pyrrhotite and pentlandite. Similar development of more standards for sulfur, zircon, garnet, apatite and iron-oxide is underway.

Personnel:

Ion probe specialist Sten Littman left UWA to return to Germany at the end of 2011, and the CMCA is currently in the process of appointing his replacement. In addition, the position for the CCFS Technical Development project (Cameca ion microprobe development) was advertised in the second half of 2011, with the recruitment process set to conclude in early 2012. The Ion Probe Facility is managed by Matt Kilburn and John Cliff. Also in 2011, the CMCA recruited David Adams from the USGS to provide support to the newly-commissioned electron microprobe.

New electron microprobe:

In 2010, the CMCA installed a new state-of-the-art JEOL 8530F electron microprobe, equipped with five WDS spectrometers, a silicon drift detector and field-emission electron gun. This $1.6M instrument was funded through the 2009 ARC LIEF scheme with partners Curtin, Edith Cowan and Murdoch Universities, CSIRO and ALCOA, to provide the Western Australian earth science community with a cutting-edge platform. This instrument will be heavily utilised by WA-based CCFS researchers.

In addition to the instrument software, the electron microprobe is also equipped with ProbeSoftware Inc.'s Probe for EPMA microanalysis software, increasing the capability of the microanalyses that are performed particularly for the earth/geosciences. The electron microprobe is also equipped with an Ocean Optics spectroscopic cathodoluminescence system allowing simultaneous analysis of characteristic x-ray and cathodoluminescence maps of materials.

Research highlights:

The continued development of isotopic analysis using the NanoSIMS 50 resulted in three publications during 2011, including one in Nature Geoscience that sparked a media-frenzy around the world. The paper revealed evidence of the fossilised remains of microbial cells in a 3.45 Ga sandstone from the Pilbara region of Western Australia, using data from both the NanoSIMS and IMS 1280. Media highlights included being the most-read article on the New York Times website on the day of publication, August's entry in the BBC's top science stories of 2011 alongside the Japanese tsunami and the detection of the Higgs-boson, and featuring as a News Brief in New Scientist (see *p. 37* and *CCFS Publication #86*).

JOHN DE LAETER CENTRE

The John de Laeter Centre houses a suite of mass spectrometry instruments and is a collaborative research venture involving Curtin University, the University of Western Australia, CSIRO and the Geological Survey of WA. It hosts over $25M in infrastructure in key facilities supporting research in: geosciences (geochronology, thermochronology and isotope studies); environmental science and global change; isotope metrology; forensic sciences; economic geology (minerals and petroleum); marine sciences; nuclear sciences. The components are organised into nine major facilities.

The Advanced Ultra-Clean Environment (ACE) Facility: This consists of a ~400m^2 class 1000 containment space that houses four class 10 ultra-clean laboratories, a class 10 reagent preparation laboratory and a –18°C class 10 cold clean laboratory, located at Curtin University. The extremely low ultimate particle counts are achieved with successive 'spaces within spaces' and HEPA (99.999% high efficiency particle arresting) filtration at each stage.

Inductively-Coupled Plasma Mass Spectrometry (ICPMS) Facility: This facility is located at UWA and consists of:

- TJA (VG/Fisons) PlasmaQuad 3 Quadrupole ICP-MS. The system has a high sensitivity interface to facilitate ultra-low detection limits.
- TJA (VG/Fisons) Laserlab high resolution 266nm (Frequency quadrupled Nd-YAG) laser. The laser system is adapted with a high-resolution interface to facilitate the ablation of craters down to 10µ in diameter.
- GBC Optimas 8000 Time of Flight ICP-MS
- Leco Renaissance Time of Flight ICP-MS
- A wide range of chromatographic and thermal dissociation interfacing is also available.

Argon Isotope Facility: This is located at Curtin and is equipped with a MAP 215-50 mass spectrometer with a low-blank automated extraction system coupled with a NewWave Nd-YAG dual IR (1064 nm) and UV (216 nm) laser, an electron multiplier detector and Niers source. Laser analysis allows for high spatial resolution up to 10µm beam size for UV laser and 300µm for IR laser. Larger sample sizes (>8-10 mg) are accommodated by an automated Pond-Engineering low-blank furnace. The extraction line has a Nitrogen cryocooler trap and three GP10 getters that allow gas purification. An Argus VI Mass Spectrometer and a Photon Machines Laser have been ordered for the JdL facility.

A joint ANU-John de Laeter Centre for Mass Spectrometry (JdL) Argon Facility has been established following a successful ARC bid. A total of ~$988,200 will be expended with the ARC contribution being $420,000. A management committee comprising two Facility Directors (Dr Marnie Forster, RSES, and Dr Fred Jourdan, JdL), Director JdL (Professor Brent McInnes), Mr Michael Avent (School Manager, RSES) and Professor Gordon Lister (RSES and named Project Manager and Chief Investigator on the ARC grant) has been set up and approved by all Collaborating and Partner Organisations.

We have been granted formal approval to purchase two Argus VI Mass Spectrometers for the Joint Argon Facility at ANU and JdL at Curtin University at an approximate cost of $A630,000. These machines have been ordered, and will arrive in March 2012. The ancillary items required for the facility are now in the process of being purchased, and/or constructed. A Photon Machines Laser has been ordered for the JdL facility. A decision was made to purchase a commercially available cryopump and to build our own cryo-cooler using this unit, and an assembly built at RSES, allowing for considerable saving. The cryopumps will arrive in February 2012 at which point the design will be tested. The extraction lines have been designed, with 3D drawings, and their construction will shortly commence. A step-heating furnace design is under consideration. Different options for valves, etc. are still under consideration. The mass spectrometers at both RSES and Curtin University will be located in special purpose, newly renovated rooms, with the costs of these extensive renovations borne by RSES and JdL. These include air conditioning to allow ±1°C temperature control with set humidity, vibration tests, anti-vibration mats and legs, electrical updating, internet and ethernet connectivity, updating lighting, repainting and rebuilding ceilings and walls.

Organic Geochemistry Facility: This facility is located within Applied Chemistry at Curtin and the instruments used for biomarker, petroleum and water studies include:

- GCMS (Gas Chromatograph Mass Spectrometer)
- GC-HRMS-MS (Gas Chromatograph-High Resolution Mass Spectrometer)
- Py-GC-MS (Pyrolysis-Gas Chromatograph-Mass Spectrometer)
- LCTOFMS (Liquid Chromatograph-Time of Flight-Mass Spectrometer)
- LC-MS-MS (Liquid Chromatography-Mass Spectrometry-Mass Spectrometer)
- HPSEC-DAD (High Performance Size Exclusion Chromatograph-Diode-Array Detection)
- GCIRMS (Gas Chromatograph-Isotope Ratio-Mass Spectrometer)
- TD-GC-IRMS (Thermal Desorption-Gas Chromatograph-Isotope Ratio-Mass Spectrometer)
- EA-IRMS (Elemental Analysis-Isotope Ratio-Mass Spectrometer)

Sensitive High Resolution Ion Micro Probe (SHRIMP): The facility at Curtin has two automated SHRIMP II ion microprobes capable of 24-hour operation, together with a preparation laboratory. The equipment allows *in situ* isotopic analysis of chemically complex materials with a spatial resolution of 5-20 microns. The main application of the SHRIMP instruments at Curtin is for U-Th-Pb geochronology of mineral samples. Zircon and other U-bearing minerals, including monazite, xenotime, titanite, allanite, rutile, apatite, badelleyite, cassiterite, perovskite and uraninite are the main minerals studied, where multiple growth zones commonly require high spatial resolution analyses.

Stable Isotope Ratio Mass Spectrometry (SIRMS) Facility: The West Australian Biogeochemistry Centre (WABC) at UWA is associated with the WA John de Laeter Centre of Mass Spectrometry and provides a range of analytical and interpretive services to researchers both within UWA and in the broader scientific community. The WABC currently operates three isotopic ratio mass spectrometers (IRMS) plus a considerable range of further analytical instrumentation (GC, HPLC, CE autoanalyser) routinely used in biogeochemical studies. A fourth IRMS (especially for small-sample $\delta^{13}C$ and $\delta^{18}O$ and carbonate analysis) is now being commissioned. Our IRMS are coupled with a variety of sample preparation modules to facilitate analysis of a broad range of sample matrices. Consequently, a wide range of applications of stable isotopes is supported by this facility.

Thermal Ionization Mass Spectrometry (TIMS) Facility: The TIMS facility at Curtin incorporates a Thermo Finnegan Triton™ and a VG 354 multicollector mass spectrometer. The Triton is equipped with a 21-sample turret and 9 faraday cups, enabling a precision of 0.001% on isotopic ratios. As well as geological applications within the broad field of isotope geochronology (Re/Os, U/ Pb, Pb/Pb, Sm/Nd, Rb/Sr) the TIMS instruments can be applied to a variety of subject areas involving isotope fingerprinting, such as mantle geodynamics, forensics and the environmental impact of human activities. The TIMS instruments are also widely used in chemical metrology for the calibration of isotopic standards, and the calculation of isotopic abundances and atomic weights.

(U-Th)/He Facility: The laboratory at Curtin hosts the prototype of the Alphachron™ automated helium microanalysis instrument marketed by Australian Scientific Instruments in Canberra and will house a new Alphachron™ machine in 2012. (U-Th)/He thermochronology involves the measurement of the amount of ^{4}He in minerals generated by the radioactive decay of U and Th. Helium is an inert gas that is quantitatively retained by minerals at low temperature, but is gradually lost from the mineral lattice by diffusion at elevated temperatures. Some minerals are more retentive to helium than others (e.g. zircon = 200°C vs apatite = 75°C), a unique characteristic that, when integrated with other techniques such as U-Th-Pb and Ar-Ar dating, can be used to produce complete time-temperature histories through a temperature interval from 900°C to 20°C. The CSIRO/JDLC (U-Th)/He Facility provides thermal-history analysis of metallogenic and petroleum systems by integrating several age-dating capabilities along with 4D thermal modelling. The Facility is also involved in fundamental collaborative research in the fields of orogenic tectonics, volcanology and quantitative geomorphology.

K-Ar Geochronology Facility: The K-Ar facility utilises the following instrumentation and techniques:

- VG3600 noble gas mass spectrometer
- Heine double vacuum resistance furnace
- Clay mineral separation laboratory utilising cryogenic disaggregation of rock samples
- XRD, SEM, TEM, particle size analysis for clay characterisation
- Vacuum encapsulation station for Ar-Ar dating of ultrafine samples
- Clays – illite: Dating the timing of diagenetic and deformation events
- Fault gouge dating (illite) – earthquake and hazard assessment

WESTERN AUSTRALIA PALAEOMAGNETIC AND ROCK-MAGNETIC FACILITY

The Western Australia Palaeomagnetic and Rock-magnetic Facility was established at the University of Western Australia by CCFS CI Z.X. Li in 1990, funded by a UWA start-up grant to the late Professor Chris Powell. It was subsequently upgraded through an ARC Large Instrument Grant in 1993 to purchase a then state-of-the-art 2G Enterprises AC-SQUID cryogenic magnetometer and ancillary demagnetisation and rock magnetic instruments. It was upgraded again in 2006 into a regional facility, jointly operated by Curtin University, UWA and the Geological Survey of WA through an ARC LIEF grant with a 4k DC SQUID system plus a Variable Field Translation Balance (VFTB). A MFK-1FB kappabridge was installed in 2011.

The facility is one of the three similar laboratories in Australia, with major instruments including:

- 2G cryogenic magnetometer upgraded (LE0668377) to a 4K DC SQUID system
- MMTD80 (one) and MMTD18 (two) thermodemagnetisers
- Variable Field Translation Balance (VFTB)
- MFK-1FB kappabridge
- Bartington susceptibility meter MS2 with MS2W furnace

A wide range of research topics have been investigated using the facility, including reconstructing the configuration and drifting history of continents all over the world from the Precambrian to the present, analysing regional and local structures and deformation histories, dating sedimentary rocks and thermal/chemical (e.g. mineralisation) events, orienting rock cores from drill-holes, tracing ancient latitude changes, palaeoclimates, and recent environmental pollution.

Program 1: Regional and Global Tectonic Studies

Palaeomagnetism and rock magnetism are employed to study tectonic problems ranging from global to microscopic scales. The WA research group plays a leading role in a worldwide effort to establish the configuration and evolution of supercontinents Pangaea, Gondwanaland, Rodinia, and pre-Rodinia supercontinents.

Program 2: Ore genesis studies and geophysical exploration

We carried out a major research program on the timing and genesis of the giant iron ore deposits in the Pilbara region, and obtained a systematic set of petrophysical parameters for rock units in the region that enables more reliable interpretations of geophysical survey results (gravity and magnetic).

Program 3: Magnetic signatures in sediments as markers of environmental change

Sediments in suitable environments can incorporate a large number of environmental proxies. A major strength of environmental-magnetism analyses, such as magnetic susceptibility and saturated isothermal magnetism, is that they provide a rapid and non-destructive method of obtaining information on changes in palaeoclimate and environment of sedimentation. In addition, rock magnetism can be used for monitoring and tracing industrial pollution.

Program 4: Magnetostratigraphy

We are conducting major research programs in the Canning Basin and in East Timor, both linked to petroleum resources.

Industry interaction

INDUSTRY INTERACTION AND TECHNOLOGY TRANSFER ACTIVITIES

CCFS has a strategic goal to interact closely 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 industry and to the scientific community in several ways:

- collaborative industry-supported Honours, MSc and PhD projects
- short courses relevant to industry and government-sector users, designed to communicate and transfer new technologies, techniques and knowledge in the discipline areas relevant to CCFS
- 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 on a collaborative research basis with industry and government organisations, extending our industry interface
- use of consultancies and collaborative industry projects (through the commercial arms of the national universities) which employ and disseminate the technological and conceptual 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 continues to be 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)

The Centre for Exploration Targeting (CET) at UWA (http://www.cet.edu.au/industry-linkage) provides CCFS with a unique interface with a broad spectrum of mineral exploration companies and many CET activities (e.g. research projects, workshops and postgraduate short courses).

SUPPORT SOURCES

CCFS industry support includes:

- direct funding of research programs
- industry subscriptions (CET)
- "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 University External Collaborative Grants (e.g. Macquarie's Enterprise Grant Scheme) 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 by industry personnel for interaction and research
- ongoing informal provision of advice and formal input as members of the Advisory Board

ACTIVITIES IN 2011

- *TerraneChron*® studies (see *p. 103* or http://www.gemoc.mq.edu.au/TerraneChron.html) have enjoyed continued uptake by a significant segment of the global mineral exploration industry. This methodology, currently unique to CCFS/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 of regional terranes (http://www.gemoc.mq.edu.au/TerraneChron.html). 19 Major Industry Reports were completed for collaborative industry projects related to *TerraneChron*® at CCFS/GEMOC.
- AMIRA and MERIWA supported a CET project aimed at unravelling the processes and mechanisms that result in PGE fractionation and concentration in mafic and ultramafic melts.
- An ARC Linkage project commenced, aimed, at understanding the lithospheric architecture and mineral systems across the Neoarchaean to Paleoproterozoic time periods, specifically comparing the Yilgarn Craton, Tanami Orogen, and western African craton. This project is based at CET but involves cross-node participation in CCFS.
- During 2011, Macquarie increased its collaborative project activity with Barrick Gold of Australia, applying the *TerraneChron*® method to their copper-gold exploration programs in Papua New Guinea and South America.
- The Paleomagnetic group at Curtin and UWA were funded for a collaborative project with MMG (Minerals and Metal Group) to explore the spatiotemporal and tectonic controls on the location of clastic lead-zinc concentrations.
- The ARC Linkage Project titled "*Global Lithosphere Architecture Mapping*" (GLAM) was extended as the "LAMP" (Lithosphere Architecture Mapping in Phanerozoic orogens) project through a Macquarie University Enterprise Grant with Minerals Targeting International as the external Industry partner.
- A sub-licencing agreement was executed with Minerals Targeting International to accommodate Dr Graham Begg's role and access to GLAM IP (in relationship to Macquarie, BHP Billiton and the GLAM project) as Director of this company. Dr Begg spent significant research time at GEMOC through 2011 as part of the close collaborative working pattern for this project.
- GEMOC's development of a methodology for analysis of trace elements in diamond continued to open 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 2011 by CCFS funds consequent on relinquishing an existing ARC Discovery Project, on which Dr Dan Howell is employed as a Research Associate.
- The GEMOC technique for dating the intrusion of kimberlites and lamproites using LAM-ICPMS U-Pb analysis of groundmass perovskite continued. This rapid, low-cost application has proven very attractive to the diamond exploration industry, and has led to several small collaborative projects; it was also applied in a 2011 ARC Linkage project sponsored by De Beers.
- The application of U-series isotopes to groundwater studies for both exploration and investigation of palaeoclimate continued in 2011. 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.

TerraneChron®

A new tool for regional exploration for minerals and petroleum

GEMOC CCFS

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

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MACQUARIE UNIVERSITY

What is *TerraneChron*®?

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

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

What kind of samples?

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

Applications to mineral exploration

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

Applications to oil and gas exploration

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

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

- Geodynamic modelling capabilities have now been extended to industry-related projects. An ongoing collaboration between GEMOC and Granite Power Ltd has led to important data exchange, and to a paper (*CCFS Publication #165*) on the thermal and gravity structure of the Sydney Basin.
- Studies on the controls of fractionation and concentration of platinum-group elements (PGE) in ultramafic magmas were finalised to the first stage in 2011 as part of the PhD project of Marek Locmelis, funded by AMIRA Project P710a. He continued this research as a Research Associate, and then joined CCFS Foundation Project 1, bringing his skills in this area. One research goal is to develop reliable geochemical indicators to guide 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. There is cross-node collaboration between the Centre for Exploration Targeting / University of Western Australia and Macquarie University, which also involves CSIRO Exploration and Mining and the Australian National University.
- A continuing collaborative relationship with New South Wales Geological Survey is applying *TerraneChron*® to investigations of the provenance of targeted sequences in the Paleozoic sedimentary terranes of eastern Australia, and the development of the Macquarie Arc.
- A collaborative research project continued in 2011 with the Geological Survey of Western Australia as a formal CCFS Foundation Project, 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.

Cam McCuaig addressing the participants at the CET corporate members day, December 2011.

- CET held their annual "Corporate Members Day", 10 December 2011, to showcase its research to its Corporate Members. The day provided members with the opportunity to discuss the innovative work of the CET, including its involvement in CCFS, and also gave the CCFS ECR and postgraduate students a chance to interact with industry (http://www.cet.edu.au/industry-linkage).
- Industry visitors spent varying periods at Macquarie and UWA (CET) in 2011 to discuss our research and technology development (see *visitor list, Appendix 5*). This face-to-face interaction has proved highly effective both for CCFS researchers and industry colleagues.
- DIATREEM (an AccessMQ Project) continued to provide LAM-ICPMS analyses of garnets and chromites to the diamond-exploration industry on a collaborative basis.
- CCFS publications, preprints and non-proprietary reports are available on request for industry libraries.

- CCFS participants were prominent in delivering keynote and invited talks and workshop modules at national and international industry peak conferences in 2011. See *Appendix 6* for abstract titles and *Appendix 4* for recent Publications.

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

CCFS projects funded by industry in 2011 are summarised below.

CURRENT AND 2012 INDUSTRY-FUNDED COLLABORATIVE RESEARCH PROJECTS

These are brief descriptions of 2011 and current CCFS projects that have direct cash support from industry, with either formal ARC, internal University or State Government support 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 databases (with varied confidentiality considerations). Such projects are administered by the commercial arms of the relevant universities (e.g. Access MQ Limited, at Macquarie).

CCFS industry collaborative projects are designed to develop the strategic and applied aspects of the basic research programs, and are many are 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. Basic research strands translated to strategic applications include the use of geochemical data on crustal and mantle rocks and integration 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 Paleomagnetic group at Curtin and UWA are exploring the spatiotemporal and tectonic controls on the location of clastic lead-zinc concentrations, based on their basic research focus of reconstructing continental configurations.

CCFS PROJECTS FUNDED BY INDUSTRY (INCLUDING ARC LINKAGE)

Lithospheric Architecture Mapping in Phanerozoic Orogens

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

Industry Collaborator: Minerals Targeting International (PI G. Begg)

CIs: Griffin, O'Reilly, Pearson, Belousova, Natapov

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

CIs: Turner, Schaefer, McConachy

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.**

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

CIs: Dr M. Fiorentini with PhD student M. Locmelis across Macquarie and UWA nodes

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 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 PGE geochemistry, including the role of sulfides (i.e. pentlandite, millerite), oxides (i.e. chromite), silicate phases (i.e. olivine, pyroxene) and platinum-group minerals (i.e. alloys, antimonides, arsenides, tellurides) in the concentration and fractionation of PGE in mineralised and barren sequences. Furthermore, the study investigates the spatial relationship between the PGE signature of mafic and ultramafic rocks and the occurrence of various types of NiS mineralisation, thus optimising the use of the PGEs as vectors towards mineralised environments.** **See *Research highlight p. 80.***

PaleoplateGIS quantification of the latitude and tectonic triggers for CD deposits in ancient passive margins

Industry Collaborators: Minerals and Metals Group (MMG)

CIs: D. Leach, Z.-X. Li, S. Pisarevsky and S. Gardoll

Summary: **This pilot project commenced in 2011, aimed at a better understanding of the spatiotemporal and tectonic controls on the distribution of clastic-dominated (CD) lead-zinc deposits. We will compare the distribution of the known deposits with the latest plate-tectonic models, which will aid in understanding and testing some of the fundamental questions and hypotheses.**

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

CIs: Griffin, O'Reilly, Pearson

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.

Four-dimensional lithospheric evolution and controls on mineral system distribution in Neoarchaen to Paleoproterozoic terranes

Supported by ARC Linkage Project

Industry Collaborator: WA Department of Mines and Petroleum

CIs: McCuaig, Barley, Fiorentini, Kemp, Belousova, Jessell, Hein, Begg, Tunjic, Bagas, Said, Bagas

Summary: This project will obtain a better understanding of the evolution, architecture and preservation of continents and their links to mineral deposits between 2.7 and 1.8 billion years ago (a period in Earth history that is endowed with mineral deposits and reflects a very important transition in the evolution of our planet and its biosphere-hydrosphere-atmosphere). By producing and integrating new high quality geophysical and geochemical data and making a major contribution to training students and researchers, the project aims to develop a superior model to help understanding Earth's evolution and target areas of high prospectivity for important mineral deposits. The results will be applicable to exploration in Australia and world-wide.

Tectonic evolution and lode gold mineralisation in the Southern Cross district, Yilgarn Craton (Western Australia): a study of the meso- to Neoarchaean missing link

Supported by ARC Linkage Project

Industry Collaborators: Geological Survey of Western Australia

CIs: Barley, McCuaig, Gessner, Miller, Thebaud, Tohver, Doublier, Romano, Wyche, Partner Organisations

Summary: In the December quarter 2008, Gold export earnings increased by 2 per cent to $3.9 billion. despite an increase in exploration expenditure to around $50 million per year, the discovery rates have been declining. Although the easy targets have been found, there remains considerable potential for future major discoveries. This project addresses the pressing need for new data and improved exploration techniques to enable industry to target new discoveries. As the Southern Cross district is located in remote communities such discoveries also have major benefits for regional Australia.

Multiscale dynamics of ore body formation

Supported by ARC Linkage Project

Industry Collaborator: Geocrust Pty Ltd, Geological Survey of Western Australia, Golden Phoenix International Pty Ltd, Mineral Mapping Pty Ltd, Primary Industries and Resources South Australia (PIRSA), Silver Swan Group Ltd, Swiss Federal Institute of Technology Zurich, Vearncombe & Associates Pty Ltd, Western Mining Services (Australia) Pty Ltd

CIs: Gessner, McCuaig, Hobbs, Cawood, Gorczyk, Connolly, Gerya, O'Neill, Lester

Summary: **Future discoveries of giant ore-bodies will undoubtedly be under surface cover. Modelling of new data from South Australia and Western Australia will define targeting criteria for new major ore-bodies, thus exploiting Australia's deep earth resource potential. New understanding of controls on mineralisation decreases exploration risk. Ore-bodies such as Olympic Dam have made major contributions to Australia's economy over past decades and promise to add increased value over future decades. This project enhances the probability that at least one other ore-body of this type will be discovered. Such discoveries contribute directly to the wealth of Australia through export earnings and accelerate the development of regional infrastructure and new technological development.**

Hydrothermal remobilisation of base metals and platinum group elements in magmatic nickel deposits

Supported by ARC Linkage Project

Industry Collaborator: WA Department of Mines and Petroleum

CIs: Fiorentini, Brugger, Barnes, Perring

Summary: **This study combines new observations about the remobilisation of base metals, gold and PGE around known nickel-sulphide deposits, with compilation of the thermodynamic data and critical experiments aimed at answering fundamental questions about the geochemistry of nickel, cobalt and the PGE in hydrothermal systems. An essential component of this work will be in unravelling the multiple episodes of alteration and deformation, which have affected many deposits in greenstone terrains. Among other approaches, this will require understanding of the geochemistry of hydrothermal circulation systems operating before, during and after deformation. The behaviour of critical elements such as nickel, cobalt and the PGE in hydrothermal solution is relatively poorly understood; we will use recent developments in experimental geochemistry to decipher, in particular, the role of sulphur and chloride in the development of alterations halos around these deposits.**

International links in CCFS

BACKGROUND

International links in CCFS provide leverage of intellectual and financial resources on a global scale, and an international network for postgraduate experience. International Partners provide the core of such collaboration. Other 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 2011 INCLUDE:

Macquarie

Zdislav Spetsius, Bill Griffin and Ekaterina Rubanova discussing Ekaterina's PhD project.

- A formal MOU was signed with the China University of Geosciences (CUG), Wuhan, to promote collaborative research and exchange of postgraduate students. Professors Sue O'Reilly and Bill Griffin were invested as Guest Professors at CUG (Wuhan) and participated in a 2-day postgraduate seminar workshop. Formal visits of high-level University delegates took place between Wuhan and Macquarie University. The first cotutelle student (Mr Qing Xiang) commenced at GEMOC/CCFS in October 2011, and Dr Chunmei Yu undertook research during a 6-month stay at Macquarie. Ongoing research continued in collaboration with Professor Jianping Zheng and his group, and with seismologist Professor Yinhe Luo (e.g. see *CCFS Publications #18, 44, 95, 97*). Areas of geochemical research include the evolution of the lithosphere beneath several parts of China, crustal evolution in the North China Block, the Yangtze Block and southeastern China, the UHP metamorphism of Dabie-Sulu peridotites and ultramafic rocks and ophiolites in Tibet. Geophysical research includes shallow and deep seismology in western and southeastern China and Tibet.

- Following the signing of a formal MOU in 2011 with the China Academy of Science, (Beijing) involving the Institutes of Geology and Geophysics, collaboration expanded in 2011 with exchange of personnel, a new cotutelle PhD project (Ms Yuya Gao), and joint access to the complementary analytical equipment at each institution. In the first exchange, Dr Chuanzhou Liu completed a 6-month stay at GEMOC aimed at transfer of GEMOC's technology for *in situ* analysis of Os isotopes. Collaboration on technology development remains a focus, capitalising on complementary strengths at each institution.

- 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). This was originally funded by an ARC Discovery Project, which was relinquished, with the funding now provided from a CCFS allocation. This includes the PhD project of Ms Ekaterina Rubanova. Dr Zdislav Spetsius (Mirny, Siberia) visited GEMOC as an external advisor to this PhD, and for analytical work connected with the diamond project, on which Dan Howell is the postdoctoral Research Fellow.

- 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 Minerals Targeting International, BHP Billiton and Professor Steve Grand (University of Texas at Austin).
- 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.
- 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 Institute for Tibetan Plateau Research, Beijing.

Discussions at Montpellier for FAST DIISR project (Norman Pearson, Jennifer Chauffaud, Sue O'Reilly and Sylvie Demouchy.

- The nature of the lithosphere in Mongolia, Vietnam and Russia, with Dr Kuo-Lung Wang (Institute of Earth Sciences, Academia Sinica, Taiwan).
- Development of methodology for lithium-isotope signatures in ultramafic and mafic rocks continued with Dr Mei-Fei Chu (National University of Taiwan).
- Collaboration with colleagues at the University of Jean Monnet, St Etienne, including Professor Jean-Yves Cottin, Dr Bertrand Moine and Dr Marie-Christine Gerbe (with reciprocal funding from both sides) expanded. A formal agreement between the two universities includes PhD exchange, academic exchange and research collaboration relevant to the nature of the lithosphere in the Kerguelen Archipelago, Crozet Islands and the Hoggar region of Algeria.
- Collaboration with colleagues at the University of Montpellier continued with the cotutelle PhD project of Yoann Gréau (graduated 2011) and projects on the mantle budget of platinum group elements, microstructures of meteorites and mantle rocks, and ophiolites. A collaboration funded by the DIISR Grant "Probing the composition of the early Solar System and planetary evolution processes" continued. Exchange visits of Dr Olivier Alard and two postgraduate students from Montpellier (Jennifer Chaufard and Valerie Migeon) to CCFS/GEMOC in January 2011, Drs Olivier Alard and Sylvie Demouchy, and Professors O'Reilly and Griffin and Associate Professor Norman Pearson to Montpellier, advanced the research on this project.
- 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). Cotutelle PhD student Yao Yu from Nanjing undertook research at CCFS/GEMOC, 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), including economic and subeconomic PGE (platinum-group element)-Cu-Ni sulfide deposits; (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 the Witwatersrand grains) represent the oldest terrestrial platinum-group minerals known so far.

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

Olivier Alard, CI on FAST DIISR MQ-Montpellier project.

- A collaborative project with Alexander Kremenetsky, Director of the Institute of Mineralogy, Geochemistry and Crystal Chemistry of Rare Elements (IMGRE), Moscow, Russia, utilised the *TerraneChron*® approach to look at the sources of giant heavy-mineral placer deposits in Australia and Russia.
- Studies on Cathaysia's place in Rodinia, the crustal evolution of southeast China, and the crustal evolution of the Yangtze Block with Professor Jinhai Yu and Ms Lijuan Wang (collaborative project with Nanjing University and cotutelle program); Lijuan's PhD was accepted in 2011 and she will graduate in 2012.
- Studies continued with Dr Rendeng Shi (Institute of Tibetan 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 (Professor 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 on the region around the giant Olympic Dam deposit.
- GEMOC continued 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 Professor 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, Geology and Geochemical Institutes; China University of Geosciences (Beijing, Wuhan) and Hong Kong University.

- 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.

José María González-Jiménez and Monica Escayola in the GAU, GEMOC.

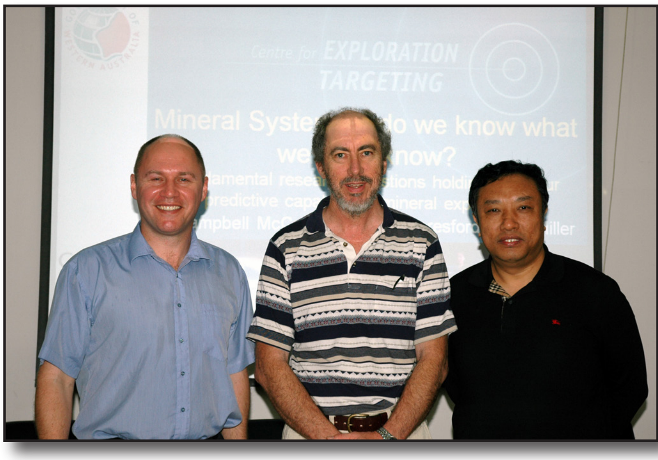
- A collaboration with Dr Nada Vaskovic, of Belgrade University, on the geochronology of the Balkan ophiolites of Serbia and related rocks continued.
- Collaboration started with Dr Monica Escayola on the Os-isotope compositions of sulfides and alloys from ultramafic complexes in the Yukon; this will continue with Dr Escayola's 6-month visit (funding from an Australian Endeavour Award) to carry out similar studies on rocks from the Andes.
- Collaboration continued with Dr Carlos J. Garrido (University of Granada, Spain), Dr Isabel Fanlo (University of Zaragoza, Spain) and Dr Antoni Camprubí (National University of Mexico) on the origins of chromitite deposits in ophiolites, including Os-isotope analysis of Platinum Group Minerals.
- Collaboration continued with Dr Vlad Malkovets (Novosibirsk) on the origins and modification of the lithospheric mantle beneath cratonic areas, using the compositions (including Os-isotope compositions) of sulfide phases included in mantle-derived minerals.

José María González-Jiménez, Csaba Szabo and Bill Griffin at Macquarie.

- A cotutelle agreement was signed with EOTVOS University (Prague), based on our continuing collaboration with Professor Csaba Szabo, who is investigating sulfide phases in xenoliths from around the Pannonian Basin.
- Dr Juan Carlos Afonso collaborated with Professors Ivone Jimenez-Munt, M. Fernandez, J. Verges and D. Garcia-Castellanos from Institute of Earth Sciences 'Jaume Almera', CSIC, Barcelona, Spain on a project "*Characterisation of the lithospheric mantle beneath the Alpine orogenic belt from numerical modeling: a comparison between Atlas, Tibet, and Zagros*" funded by the National Research Council of Spain.
- Dr Craig O'Neill continued collaborations with Adrian Lenardic (Rice University) and Shijie Zhong (University of Colorado, Boulder) as part of the Flat Subduction Geodynamics CCFS project (Two-phase flow within Earth's mantle: modelling, imaging and application to flat subduction settings).
- Professor Yinhe Luo from China University of Geosciences visited CCFS/GEMOC for three months to work with Dr Yingjie Yang on a project: "*Imaging detailed crustal structures of the Dabie Orogenic Belt using ambient noise tomography*."

University of Western Australia

- Professor Cam McCuaig was invited by Professor Zeng-qian Hou, Director of the Institute of Geology, Chinese Academy of Geological Sciences (CAGS), to participate in the international project of IGCP/SIDA 600 "*Metallogenesis of collisional orogens in the East Tethyside domain*". This project (2011-2014) is jointly funded by UNESCO and the Swedish International Development Cooperation Agency (SIDA) and lead by Professor Hou. The Centre for Exploration Targeting (CET), UWA was invited to be a partner institute and Professor Marco Fiorentini and Mr Yongjun Lu from CET are actively collaborating with CAGS under this IGCP framework. This collaboration between CET and CAGS will expand from studying potassic intrusions in the western Yangtze Craton to experimental and field studies of adakites and associated porphyry Cu systems in Tibet.



Cam and Peter with Professor Zeng-qian Houat CAGS (Chinese Academy of Geological Sciences). Professors McCuaig and Cawood were invited by Professor Zengqian Hou to CAGS, Beijing for collaboration.

- Researchers at UWA have an ongoing collaboration with Professor Robert Kerrich from University of Saskatchewan, Canada, which ranges from studying potassic intrusions in SW China and porphyry magmatism in the Philippines, to greenstone belts in the Yilgarn Craton and western Africa.
- Professor Cam McCuaig continued collaboration with Dr David Leach from the U.S. Geological Survey (USGS), leading to a paper "*Banded Iron Formation to Iron Ore: Implications for the Evolution of Earth Environments*".
- A new collaborative project between Dr David Wacey and Martin Brasier (Oxford University, UK) commenced, investigating the geology and biodiversity of the 1900 Ma Gunflint Formation of Canada, in particular sulfur-based metabolisms.
- Dr David Wacey commenced a collaborative project with Nicola McLoughlin, Harald Furnes, Ingunn Thorseth from University of Bergen, Norway, investigating the emergence of life on Earth 3+ billion years ago funded by the Bergen Research Foundation and the University of Bergen.
- Professor Mark Barley continued his collaborations with international leaders in multiple sulfur isotope geochemistry (James Farquar, Boz Wing, Shuhei Ono, Doug Rumble, Sue Golding, Jay Kaufman etc.) to determine how the range of methods fits together.
- Dr Matt Kilburn continued a collaboration begun in 2009 with Bernard Wood and Jon Wade (University of Oxford, UK), to investigate the isotopic fractionation of elements between metal and silicate melts at high pressures and temperatures.

GSWA

- Dr Klaus Gessner maintains international research collaboration links with a number of international researchers. Within the ARC Linkage Project "*Multiscale Dynamics of orebody formation*" he has collaborated with Professor Jamie Connolly and Professor Taras Gerya

(ETH, Zurich, Switzerland) on simulating the dynamics of lithosphere-scale fluid and melt transport, and with Peter Cawood (St Andrews University, UK), on the tectonic evolution of Australia.

- Klaus has carried out field work in New Zealand with Dr Virginia Toy (Otago University, Dunedin) and with Associate Professor Uwe Ring (Canterbury University, Christchurch), within the UWA Research Collaboration Grant "*The Active Alpine Fault as an Analog for Fluid Dynamics in Archaean Mineral Systems".*
- As part of the International Synchrotron Access Program-funded project on "*Three dimensional characterisation of brittle fault rocks*" Klaus has collaborated with Professor Achim Kopf (Bremen University, Germany), Dr Virginia Toy (Otago University, Dunedin), and Dr Xianghui Xiao and Dr Francesco de Carlo at the Advanced Photon Source's 2-BM-B beamline (Argonne National Laboratories, USA).
- Martin van Kranendonk is tracing the geochemical origin and evolution of granitoid rocks in the Ancient Gneiss Complex of Swaziland, with the help of Professor Alfred Kroner (University of Mainz), Dr Elis Hoffman (University of Bonn) and Professor Carsten Munker (University of Cologne). He is collaborating with Dr Steven Shirey (Geophysical Lab., Washington, D.C.) on the onset of subduction on Earth at ca 3.0 Ga, and working with Professor John Valley, Professor Clark Johnson, and Dr K. Williford (University of Wisconsin) on collaborative projects including: *in situ* investigation of kerogen of microfossils from the 2.3 Ga Turee Creek Group; Fe-isotope investigation of 2.75 Ga BIF from the Murchison Domain of the Yilgarn Craton; U-Th-Pb dating of jaspilite from the ca 3.5 Ga Marble Bar Chert Member of the Duffer Formation, Pilbara Craton; oxygen isotope studies of cherts from the Pilbara Craton.

Curtin University

- Dr Xuan-Ce Wang is collaborating with Dr Jie Li (Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou, China) on the petrogenesis of the Leiqiong flood basalts, with the aim of understanding the links between mantle plumes and subduction.
- Dr Sergei Pisarevsky is Paleomagnetic Coordinator on the International project "*Reconstruction of supercontinents back to 2.7 Ga using the Large Igneous Province (LIP) record*", in collaboration with Dr Richard Ernst (Carleton University, Canada) and Dr Wouter Bleeker (Geol. Surv. of Canada). He also is Team Leader in the IGCP-SIDA Project 599 "*The Changing Early Earth*", in collaboration with Dr Jaana Halla (University of Helsinki, Finland).
- Dr Zheng-Xiang Li has an ongoing collaborative project with a large group of researchers from around the world, including Dr D.A.D. Evans (Yale University), Dr S. Zhang (China University of Geosciences, Beijing) and the Nordic Paleomagnetic Working Group, aiming to establish the configuration and evolution of a pre-Rodinia supercontinent Nuna (Columbia) that probably existed between 1.8-1.4 Ga.
- Dr Zheng-Xiang's work on the Phanerozoic magmatism and tectonics of South China is part of an ongoing collaborative project with Dr X.H. Li (Chinese Academy of Sciences (CAS), Beijing), Dr W.X. Li (CAS, Guangzhou), Professor X. Xu (Nanjing University), and Professor S.L. Chung and Dr Q.H. Lo (National Taiwan University).
- An ARC-CAS jointly-funded project on Mesozoic vertical tectonic movements in South China and subduction dynamics involves collaboration with Dr Y.G. Xu and and Dr W.X. Li (CAS-Guangzhou), and Dr M. Danisik (Univ of Waikato, NZ). A project on the tectonic evolution of Tibet and NW China is a collaboration with Dr Q. Wang (CAS–Guangzhou) and

Dr C.L. Zhang (China Geological Survey–Nanjing). A newly funded NSF-China project to work on the development and evolution of the Red River Fault System involves a collaboration with Professor X.D. Jiang (China Ocean University).

Jian-Bo Zhou of Jilin University examining a sample from the Mohe Complex of the Erguna Block, NE China, as part of a study of the Central Asian Orogenic Belt in China.

- Professor Simon Wilde continues to work with Professors Jian-Bo Zhou and Xing-Zhou Zhang of Jilin University on the evolution of the NE China segment of the Central Asian Orogenic Belt. Collaboration with Professor Xiao-Long Huang from the Guangzhou Institute of Geochemistry has led to the characterisation of the TTG gneisses in the Taihua complex at the extreme south of the North China Craton. Professor Xiao-Long Huang spent 12 months at Curtin working with Simon, supported by the Chinese Science Council and the Chinese Academy of Sciences.
- Simon's ongoing collaboration with Dr Guochun Zhao of the University of Hong Kong has led to the recognition of two high-grade metamorphic events in rocks of the Huaian complex near the junction between two Proterozoic mobile belts: the Khondalite Belt and the Trans-North China Orogen. Collaborative work on the Central Indian Tectonic Zone with Professor Santanu Bhowmik of the Indian Institute of Technology at Kharagpur has focused on the application of U-Pb and Lu-Hf isotopic work on zircon and dating of monazite in high-grade metamorphic rocks.
- Simon's long-standing collaboration with Professors Fuyuan Wu and Jinhui Yang at the Institute of Geology and Geophysics at the Chinese Academy of Sciences (CAS) in Beijing has led to compilation of an extensive geochronological data base for the Chinese part of the Central Asian Orogenic Belt and continued investigation of the isotopic signature of magma mixing in the North China Craton. Ongoing collaboration with Profs Dunyi Liu and Yusheng Wan and their students at the Institute of Geology at the Chinese Academy of Geological Sciences (CAGS) in Beijing has recently focused on examining events that straddle the Archean/Proterozoic boundary in the Western Block of the North China Craton. Collaboration with Dr Yuruo Shi of CAGS has concentrated on Precambrian rocks close to Beijing.

CCFS funding

Financial accounting for allocated funds is carried out at each node, with MQ responsible for the final reporting to ARC through the DVC Research.

Strategy for CCFS funding leverage

ARC anticipates that Centres of Excellence will develop a profile of basic and strategic research outcomes that provides an attractor for leveraging resources. Active strategies within CCFS include:

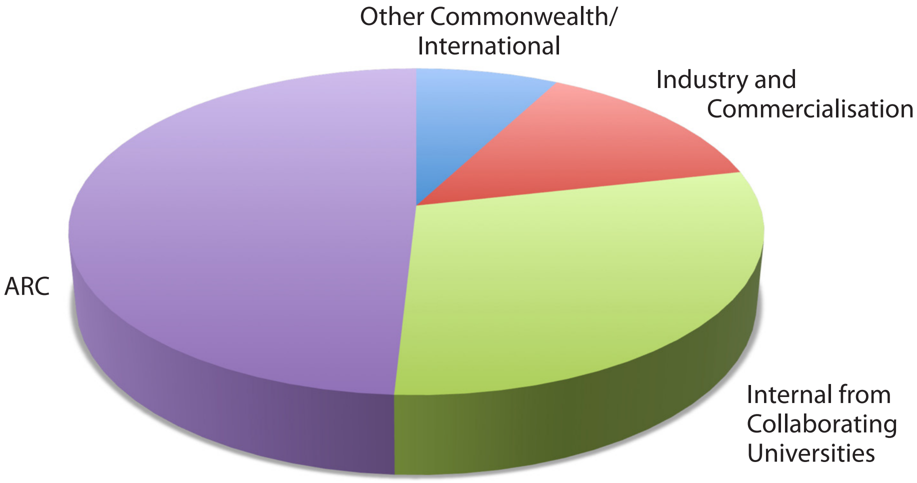
- Collaborative project building with industry partners
- Technology development to deliver new and improved methodologies and tools for enhanced research collaboration and for the exploration industry
- Diversification of the funding portfolio to include other Government schemes, industry and participation in international research programs
- Applications to funding schemes for matching funds for new infrastucture purchases and partner co-investment
- Providing input into future NCRIS (especially AuScope) policies, using CCFS research concentration and leading directions to inform national priorities.

This is an unaudited summary of 2011 income. A full, audited statement of detailed expenditure and income is prepared by Macquarie University. No in-kind support is included here.

CCFS INCOME 2011

	$K
ARC	
CoE CCFS	1,800
ARC Post-Award Early Career Research Support	1,250
Discovery (including Fellowships), Linkage (Project and International)	1,969
LIEF	1,280
Other Commonwealth/International	
NCRIS	150
SLF	500
Aust. Antarctic Div., Aust-India Grant, MERIWA, DIISR, HKRG, ISAP, NSFC	340
Industry and Commercialisation	
Collaborative research projects and commercial contracts (e.g. GLITTER) via Access MQ	310
Industry contributions to ARC Linkage and internal collaborative research projects	1,455
Internal from Collaborating Universities	
Fellowships	175
Matching to other commonwealth/state	50
Matching to ARC schemes	2,000
Research grants	225
Postgraduate awards	1,162
Postgraduate research grants	23
Infrastructure (RIBG)	100
Other	30
TOTAL	**12,819**

PIE CHART OF INCOME SOURCES 2011



National Benefit

- Scientific innovation relevant to National Priority Areas

  Research Priority 1: An Environmentally Sustainable Australia

  Goal 1: Water – a Critical Resource

  Goal 2: Transforming existing industries

  Goal 6: Developing Deep Earth Resources

  Research Priority 3: Frontier Technologies for Building and Transforming Australian Industries

  Goal 1: Breakthrough Sciences

  Goal 2: Frontier Technologies

- Implementation of recommendations (relevant to CCFS) from the Theo Murphy Think Tank endorsed by Minister Martin Ferguson, April, 2011 (http://www.science.org.au/events/thinktank/thinktank2010/index.html)
- 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: Foundation Project summaries, progress 2011 and plans for 2012

1. THE TARDIS PROJECT: TRACKING ANCIENT RESIDUES DISTRIBUTED IN THE SILICATE EARTH

Aims: Platinum Group Minerals in chromite-rich rocks from ophiolites and komatiites can provide a faithful and robust record of the osmium-isotope composition of Earth's convecting mantle through time; this record contains vital information on Earth's origins and the overall evolution of its core-mantle system. In this project an international team of leading mantle researchers will use a unique combination of geochemical and isotopic techniques to decode this information and provide new insights into deep-Earth processes. Specific objectives are:

- To define the initial composition and long-term evolution of Earth's convecting mantle, using the isotopic systematics of platinum-group minerals and sulfides from ophiolites and komatiites
- To understand the origins of ophiolitic chromitites and the processes that concentrate the platinum-group elements in these and other samples of the convective mantle to help unravel Earth's geochemical evolution
- To understand the Os-isotope heterogeneity observed in samples from the convective mantle, and how this heterogeneity may reflect major events in Earth's evolution
- To evaluate the evidence for the preservation of large volumes of ancient continental mantle within the ocean basins

Progress during 2011:

During 2011 we acquired a large collection of chromitites from ophiolite localities worldwide; this collection will continue to grow, especially through our active collaboration with groups at the Universities of Barcelona and Granada. The chromites (and in some cases the associated silicates, where preserved) were analysed for major- and trace-elements, and were surveyed petrographically to locate and identify any platinum-group minerals (PGM) or base-metal sulfides (BMS) residing in them. Those that were found were then analysed by LA-MC-ICPMS to determine their Os-isotope compositions. Approximately 500 Os-isotope analyses of PGM have been carried out; a larger number (>2000) of BMS analyses was carried out, with ca 20% containing enough Os to give reliable results.

One major finding has been the common appearance of ancient PGM and sulfides preserved in the mantle section of young ophiolites. These point to the involvement of ancient (continental?) lithospheric mantle in the ocean basins, and their entrainment in ophiolites. Many of the ophiolite sections also retain evidence of multiple sulfide-forming events in the mantle. A second major finding, based on detailed studies of PGM in the metamorphosed ophiolites of Bulgaria, is that Os is far more mobile in the mantle system than currently believed, at least at high temperatures. This has implications for the stability of Os-isotope systems even in Os-rich PGM, and emphasises the need for *in situ* analysis and very detailed petrographic study. A paper on this has been accepted by *Geology*.

To provide comparative material for the ophiolite work, we have continued studies of PGM and BMS in xenoliths from the subcontinental mantle, both as xenoliths and in exposed massifs such as Ronda and Ojen. We hosted visits by Professor Carlos Villaseca (Univ of Madrid) and Dr Monica Escayola (Canadian Geological Survey) who carried out studies of the mantle beneath central Spain and the North American Cordillera, respectively. We also completed a study of BMS in xenoliths from beneath Arkansas, showing the presence of an Archean continental fragment beneath the Proterozoic orogenic belt.

Near the end of the year Dr José María González-Jiménez and Dr Marek Locmelis (both ECRs) started an extensive review of the accumulated chromite data (major + trace elements), integrated with a database derived from an earlier PhD thesis at GEMOC. This has suggested a new approach to the treatment of such data, allowing the inference of tectonic setting and petrological evolution. This work is in progress. Dr Locmelis also worked for several months with Dr Mei-Fei Zhou (independently funded ECR) for transfer of knowledge about the methodologies she developed for analysis of Li isotopes in ultramafic and mafic systems relevant to fluid flow in lithospheric mantle domains.

In mid-2011 Dr José María González-Jiménez was awarded independent ECSTAR funding from ARC Post-award funds. His position was filled by Dr Jin-Xiang Huang, whose work is focusing on the application of the Mg stable-isotope system to tracking the evolution of lithospheric mantle.

Two PhD students have joined the project: Mr Qing Xiong is a cotutelle student with the China University of Geosciences, Wuhan and began in November. He is working on ophiolites and ultramafic complexes in two parts of Tibet. Ms Nicole McGowan, having completed an Honours degree in Analytical Chemistry at University of Technology, Sydney, will start a multi-isotopic study of chromitites and their host rocks in 2012. This will involve direct collaboration with Dr Rendeng Shi (Institute for Tibetan Research, Chinese Academy of Sciences) who will provide her with key samples from three Tibetan ophiolites. Ms McGowan also will collaborate with Dr José María González-Jiménez on the study of ophiolites in Spain and Turkey.

Melange complex enclosing red cherts overlying the green peridotite massif in the Zedang ophiolite, South Tibet.

Fresh harzburgite in the Zedang ophiolite.

Published outputs:

CCFS Publications #1, 65, 71, 75, 95 (*Research Highlights pp. 44, 48, 52*)

Aims and work plan for 2012:

The aims of the project remain unchanged for 2012. Further field work will be done in Spain and Turkey, and more extensive collections of ophiolite material will be provided by PI Arai. The work on these will follow the template developed in 2011. The chromite database will be expanded significantly, to test the synthesis achieved late in 2011; this work will be prepared for publication and presentation in international fora.

Mr Xiong will continue his PhD studies of Tibetan ophiolites, and Ms McGowan will begin her project on the ophiolites of Tibet, Spain and Turkey, working together with Dr José María González-Jiménez and Dr Shi. Dr Villaseca and Dr Escayola, each with independent external funding, will return to carry out further investigations of the Spanish continental lithosphere, and the mantle beneath the Cordilleras of both North and South America. Dr Huang will work on the development of techniques for the analysis of Mg isotopes in mantle rocks, and will apply them to both eclogites and peridotites. She also is developing standards for the analysis of O isotopes in mantle-derived, Cr-bearing garnets.

2A. METAL SOURCES AND TRANSPORT MECHANISMS IN THE DEEP LITHOSPHERE

This project is designed to (1) provide new knowledge of the character and behaviour of Earth fluids, such as silicate and sulfide melts, brines, vapours, hydrocarbons, supercritical fluids, in mantle rocks at the P-T conditions of the lower lithosphere and asthenosphere, and (2) unravel the complex transport and concentration mechanisms of siderophile-chalcophile elements such as Ni, Cu and PGE in the deep lithosphere.

Despite the significance attributed to mantle-derived fluids as key elements in the transport and concentration of metals within the crust, we lack a robust understanding of the processes through which the mantle evolves and interacts with fluids at sub-crustal depths, in the lithospheric mantle and asthenosphere. The rationale of this multi-scale integrated study is to address this void in our understanding through (1) a set of key experiments to evaluate the chemical behaviour of fluid systems at lithospheric mantle-asthenospheric conditions, and (2) parameterising and testing these experiments through the measurement of rock samples collected from two key areas: (a) the Ivrea-Verbano Zone in northern Italy and (b) the granulite facies terrains of southeastern Greenland.

As well as representing direct exposure of continental lithospheric mantle rocks, these zones host unusual nickel-sulfide occurrences that offer rare insights into how metallogenic fluids behave at such depths. Most known world-class nickel-sulfide deposits were formed far from their primary mantle metal sources, at the surface or in the uppermost levels of the lithosphere. The nickel-sulfide systems in the Ivrea-Verbano Zone and in the granulite terrains of Eastern Greenland, however, were formed in the mid-to-lower crust and upper lithospheric mantle. These systems display petrological, mineralogical and geochemical features that are anomalous in relation to typical orthomagmatic systems. They display pipe-like geometries and contain abundant accessory mineral phases, which are anomalously enriched in large-ion lithophile and highly-incompatible elements, with a strong alkaline affinity and a unique metal paragenesis.

Fieldwork in the areas of interest will be carried out in close association with (1) researchers from the University of Leoben (Austria), where research is currently active (Zaccarini, PhD student) applying a multi-technique mineralogical, petrological and geochemical approach to unravel the origin of ore mineralisation in the mafic-ultramafic rocks of the Ivrea-Verbano Zone, and (2) researchers from GEUS, who are currently focusing on Greenland's nickel resource potential. These areas thus offer critical insights into the deeper behaviour of mantle-sourced metallogenic fluids that is not currently incorporated into models of deposit evolution and exploration.

As a corollary to these two key research streams, this study will also investigate the optimisation and integration of analytical techniques to constrain the behaviour of fluids and melts at relevant P-T conditions. This approach will provide improved insight into the meaning and significance of the geochemical signature of deep mineral systems. The experimental results from the proposed study will generate new parameters that can be integrated into the predictive modelling of metal reservoirs, contributing to improved exploration models and opening up new exploration search space for nickel-sulfide systems in the deeper portions of the lithosphere.

Progress during 2011:

In 2011, the work was concentrated on southeastern Greenland (Fig. 1), where two UWA Honours students joined a large team of geoscientists from the Geological Survey of Denmark and Greenland in a two-month field expedition. In the area, laterally extensive mafic bands hosting nickel-sulfide mineralisation can be found within orthogneiss lithologies, which largely dominate the relatively unexplored region between Graah Fjord and Bernstorff Isfjord. The mafic bands are dominantly gabbroic in composition and contain a large proportion of volatile-rich phases, ranging locally from gabbros to pyroxene hornblende norites. The mafic bands display some similarities with the mafic complex of the Ivrea-Verbano Zone in Italy, which is thought to represent lower crustal material.

Amphibole-bearing ultramafic bodies occur locally within the mafic bands. The ultramafic rocks are dominantly peridotites with a smaller volume of pegmatitic pyroxenites. It seems most likely that the mafic bands in the study area represent lower crustal material intruded by mantle-sourced ultramafic magmas.

Preliminary observations indicate that the ultramafic rocks can be subdivided into two generations based on their trace-element geochemistry. One generation probably was sourced from a deep, relatively undepleted mantle source, while the other was sourced from a depleted shallow mantle source. The shallow-sourced ultramafic rocks host most of the mineralisation and display evidence for having interacted with a volatile-rich fluid, rich in incompatible elements, S, Cu and Ni. This fluid is interpreted as a key factor in the formation of the mineralisation.

Work on samples from the Ivrea-Verbano zone also started in 2011 by evaluating an existing sample set from the Valmaggia pipe and selecting samples for major-, trace-, and isotope-analysis. Electron-microprobe analysis and laser ablation ICP-MS were used to analyse primary magmatic minerals (olivine, pyroxene) and metasomatic phases (amphibole, phlogopite) to determine the magma composition and the nature of the metasomatic fluid that is inferred to play an important role in the pipe's genetic history. Sulfide phases were analysed to determine the major- and trace-element composition of the sulfide liquid that formed the nickel-sulfide deposits in the Valmaggia pipe.

Preliminary results show that the Valmaggia pipe was emplaced at a depth of at least 20-25 km and a temperature around 900 °C, close to the water-saturated peridotite solidus. Phlogopite and amphibole data suggest that the metasomatic fluid was mantle-derived and carbonate-rich. The sulfides appear to be mantle-derived and predominantly consist of pyrrhotite from which the nickel-sulfide pentlandite and the copper-sulfides chalcopyrite and cubanite exsolved during cooling.

Concurrent work on selected samples from the neighbouring Ivrea-Verbano Zone pipes was carried out to determine their age of crystallisation. Peter Kollegger (PhD student at University of Leoben, Austria) visited UWA in late 2011 and separated a large number of zircon grains, which were subsequently analysed by SHRIMP. Preliminary data indicate that all pipes were emplaced coevally in the Permian, at a time consistent with metasomatism taking place in the underlying subcontinental mantle. Work is in progress to further establish the link between mantle metasomatism and the genesis of mineralised pipes.

Preparatory work for the experimental program has included the manufacture of specialised capsules and furnace assemblies that will be suitable for the sulfide-bearing systems to be investigated.

Aims and work plan for 2012:

In 2012, fieldwork will be done in the Ivrea-Verbano Zone (IVZ) and in southeastern Greenland. In May 2012 Marek Locmelis and Marco Fiorentini will join a team of geoscientists from the University of Leoben (Austria) to carry out a comprehensive mapping and sampling campaign in selected areas of the IVZ. In July 2012, John Owen (PhD student) and Brendan Lally (Honours student) will join a large team of geoscientists from the Geological Survey of Denmark and Greenland in a one-month field expedition in the area where reconnaissance was done in 2011.

In 2012, laboratory work on previously and newly collected material will steam ahead. Ultra-pure mineral separates (olivine, pyroxene, amphibole, phlogopite), which are currently being prepared for lithium isotope analysis, will be analysed for the lithium isotopic composition of the magma source where the pipes originated, and to address the link between mantle metasomatism, pipe genesis and metal transfer. Together with lithium isotopes, the research team will carry out a wide range of analyses, including *in situ* and whole-rock major- and trace-element geochemistry, sulfur isotopes and selected radiogenic isotopes.

High-pressure, high-temperature experiments have been planned for 2012. Specifically, a series of experiments at variable pressures and temperatures (1-3.5 GPa and 1000-1300 °C) will be used to establish how chalcophile metals partition between sulfide melts (modelled on the Ivrea sulfides) and coexisting hydrous alkaline basalt melts. These will provide constraints on both the compositional characteristics of the melts involved in ore deposition and the role of physical gradients (pressure and temperature) during melt transport, in controlling ore deposition. The study will employ basaltic compositions that have already been well-studied at Macquarie University and for which partitioning data are already available for a wide range of elements and peridotite minerals. This will generate a well-integrated data set for both silicate and sulfide phases that will be applicable to the upper mantle/lower crustal conditions of the Ivrea-Verbano Zone.

2B. DYNAMICS OF EARTH'S MANTLE: ASSESSING THE RELATIVES ROLES OF DEFORMATION AND MAGMATISM

Understanding the evolution of continental mantle in rifting environments is one key to understanding plate tectonics. How and why divergence is initiated in extensional zones, and how a continental rift evolves to become an oceanic accretion centre, are poorly constrained processes but fundamental to our understanding of the processes structuring the lithosphere. This project explores the upper mantle beneath the East-African Rift (Marsabit, Kenya) to constrain how the deformation has been initiated, localised and evolved in such geological settings. We characterise the microtextures and the deformation mechanisms recorded by mantle minerals such as olivine and pyroxenes, using EBSD techniques. With this information, we can determine the evolution of the deformation related to the rifting.

Progress during 2011:

We obtained a series of mantle xenoliths from the East-African Rift (Marsabit, Kenya) from Neuchatel University (Switzerland). The xenoliths are spinel peridotite and they display granular, porphyroclastic, mylonitic and ultra-mylonitic textures. We characterised both inter- and intra-crystalline deformation for all samples with EBSD. Results indicate that olivine from the granular peridotites displays a strong alignment of (010) axes, indicating the activation of the (100)[010] glide-system. This glide system is unusual and rarely described but not reported as anomalous. Our microtextural observations combined with thermometry (Kaeser et al. 2006) indicate that this glide-system should be active at high temperature and low strain. The principal glide direction changes from [010] in the granular peridotites to [100] in porphyroclastic and mylonitic peridotites, with a dominant activation of the (010)[100] glide system. This glide system is common in the upper mantle and also occurs at high temperature and low strain (e.g. Ben Ismail and Mainprice, 1998; Nicolas et al. 1971). A further inspection of intra-crystalline deformation of olivine porphyroclasts in the mylonite and ultra-mylonite peridotites indicates a range of active glide systems in the same rock. For instance the E-type (001)[100] is the more active slip system in the mylonite, whereas in the higher-strain ultra-mylonite sample, the C-type (100)[001] slip system is more active (e.g. Karato, 1995; Jung and Karato 2001). A decrease in temperature should result in a change in the dominant slip direction in olivine from [100] to [001] (Durham and Goetze, 1977; Bai et al., 1991, Tommasi et al., 2009), which is consistent with the decompression and cooling recorded by Marsabit xenoliths (from 1200˚C at 2.5-2.7 GPa to <850˚C at 1.5 GPa; Kaeser et al. 2006).

These new observations reflect the textural heterogeneity of the mantle beneath the East African Rift, related to the extensional setting. The mantle is composed of layers or lenses that are more deformed where the decrease in temperature and grain size acted as principal parameters to localise the deformation.

Aims and work plan for 2012:

In 2012, we will complete the imaging of all phases, including EBSD data on primary minerals and acquisition of EBSD data and cathodoluminescent images on carbonate phases. We will start chemical analyses to fully characterise all the mantle phases (including secondary) using the electron microprobe. Raman spectroscopy will be used to analyse fluid inclusions. Isotope analyses by ion microprobe on carbonates will then follow. These data should provide the composition of the fluids that formed the secondary phases.

3. GENERATING AND STABILISING THE EARLIEST CONTINENTAL LITHOSPHERE - LARGE GRANITE BLOOMS

The project aims to understand the genesis of the earliest continental lithosphere, including the processes of fluid/melt extraction that stabilise, and thus preserve, Archean cratonic lithosphere. This will involve isotopic studies of zircons from ancient terrains and deep-crustal xenoliths worldwide, to further constrain the nature of the oldest preserved crust, and a continued search for the oldest mantle samples beneath cratonic areas. Targeted studies involving (1) a regional characterisation of the 3.1 Ga Mpuluzi batholith (Swaziland/RSA) and (2) a similar characterisation of the end-Archean granites of the North China Craton, will provide a basis for static and dynamic modelling of the rheology of the crust before, during and after melt extraction.

This project has close linkages with the research of Future Fellow Dr Elena Belousova (*Research Highlight p. 54*). This will involve regional surveys (*TerraneChron®* approach) of zircons (U-Pb, Hf isotopes, O isotopes) from old continental areas, in an attempt to pick up the signatures of the oldest crust. The project also will study zircons from deep-crustal and mantle xenoliths in basaltic and kimberlitic rocks, to look deeper into the lithosphere. This work will be integrated with Os-isotope analysis of sulfides in the mantle xenoliths (see *TARDIS project*) to define the origins of the subcontinental lithospheric mantle beneath the old areas where ancient crust is identified, and constrain the role of the SCLM in stabilising ancient crust.

Two targeted areas will be investigated to look at some of the processes of crustal stabilisation. The Barberton Greenstone Belt and Ancient Gneiss Complex in Swaziland and adjacent RSA represent some of best-preserved and most-studied Early- to Mid-Archean (3.6 to 3.2 Ga) crustal remnants. There are several models for their formation, ranging from oceanic to continental settings; all may need revision in light of Sm-Nd data and unpublished zircon-Hf data (A. Kroener, pers. comm.) that indicate the participation of older crust (model ages ≥3.8 Ga). However, it is clear that the tectonic and magmatic processes that produced the greenstones, associated TTG magmatism, sedimentation and (locally high-grade) metamorphism ended abruptly at ca 3.1 Ga, with the emplacement of regionally extensive granitic magmas (Mpuluzi granodiorite, Nelspruit potassic granite, Boesmanskop syenite, Salisbury Kop granodiorite). These form thick sheets extending over at least 10,000 km^2. This intrusive episode marks the final cratonisation of the crust in this area; little happened thereafter until ca 2.5 Ga. The sheer volume of these magmas raises several fundamental questions relevant to the generation and stabilisation of ancient crust in general. (1) What sort of materials were melted to produce the magmas? (2) Where did the heat come from? (3) What controlled the formation of regionally extensive sheets, rather than deep-rooted batholiths? (4) How many different pulses of magma were involved, and over what time span?

Collaborators include Professor Alfred Kroener (Mainz, and Beijing), a world-recognised expert on Precambrian geology and in particular that of southern Africa. This incorporates the PhD project of Ms Rosanna Murphy, who began in 2011 with Professor Alfred Kroener as an external supervisor.

The second area to be investigated will be the southern part of the North China Craton, where a similar "granite bloom" at the end of the Archean appears to have been the defining event that stabilised the crust, although studies of deep-crustal xenoliths have already shown that felsic-intermediate crust was already in place by 3.4 Ga.

Progress during 2011:

Dr Belousova starts her Future Fellowship in 2012, but during 2011 she carried out field work to collect samples for the project. We await the identification of an appropriate cotutelle student to undertake the Chinese strand of the project.

In a separate development, new PhD student Yuya Gao (cotutelle with CAS, Beijing, a CCFS Partner) began a thesis analysing Li isotopes in A-type granites, following from the success of Dr Xian-Hua Zhou in establishing this technique during 2011. These granites are typically the latest components in "granite blooms" and this work will be directly relevant, as an analogue, to the aims of the project.

Ms Murphy took part in an international conference in Johannesburg in January 2011; this was followed by a field trip that introduced her to the area and allowed her to carry out a sampling program, assisted by personnel from CCFS and the Swaziland Geological Survey. The samples she returned were partly processed during 2011. She has carried out petrographic studies, whole-rock analysis of major- and trace-elements, and separation of zircons from a large number of selected samples. The zircons have been analysed for U-Pb ages and Hf-isotope composition, and in some cases for trace elements. The results so far show that the degree of compositional homogeneity in the batholith has been somewhat overstated. They have confirmed the narrow spread of intrusion ages around 3.1 Ga, but they also have shown that most samples contain a scattering of older inherited zircons, stretching back to 3.5-3.6 Ga. This is consistent with the Hf isotopes, which give model ages in the same range. There is, thus far, little evidence of a Hadean crust in the area.

Published outcomes 2011:

CCFS Publications #12, 97

Aims and work plan for 2012:

The aims of the project will remain unchanged. Dr Belousova and Ms Gao will begin their analytical work in 2012. Professor Griffin will start a program of analysis of sulfide and alloy phases in the most depleted xenoliths from the Kaapvaal Craton, aimed to test if there are remnants of lithospheric mantle older than previously known

Ms Murphy plans another field trip to Swaziland for supplementary sampling, together with a French group who have overlapping interests in the area. The field trip will be preceded by a conference, in which she plans to present her results so far. This will be an excellent chance to develop more international connections, and to interact with a very active group with similar interests. Through the first 2/3 of the year, her analytical program will be completed, expanding it to include the new samples. She will analyse O-isotopes in the zircons by SIMS. She also will obtain whole-rock isotopic data on selected samples, for comparison with the data gained from the zircons. With these results in hand, she will begin a program of thermal/compositional/dynamic modelling (with Dr Craig O'Neill) to constrain the processes that produced these huge volumes of magma in such a short time. One alternative is the *in situ* heat generated by a K-U-Th-rich deep crust blanketed by a refractory upper crust; another is a deep-seated source such as a mantle overturn.

Rosanna Murphy collecting samples in Swaziland.

4. TWO-PHASE FLOW WITHIN EARTH'S MANTLE: MODELLING, IMAGING AND APPLICATION TO FLAT SUBDUCTION SETTINGS

The overarching goal of this project is the development and application of in-house state-of-the-art computational tools to simulate and image complex geochemical-geodynamic processes involving two-phase reactive flow in multi-component deformable media. These tools, in combination with advanced seismic imaging techniques, will be applied to the problem of fluid transport from shallow-dipping to flat subduction settings, in both the western USA and South China in the past.

Progress during 2011:

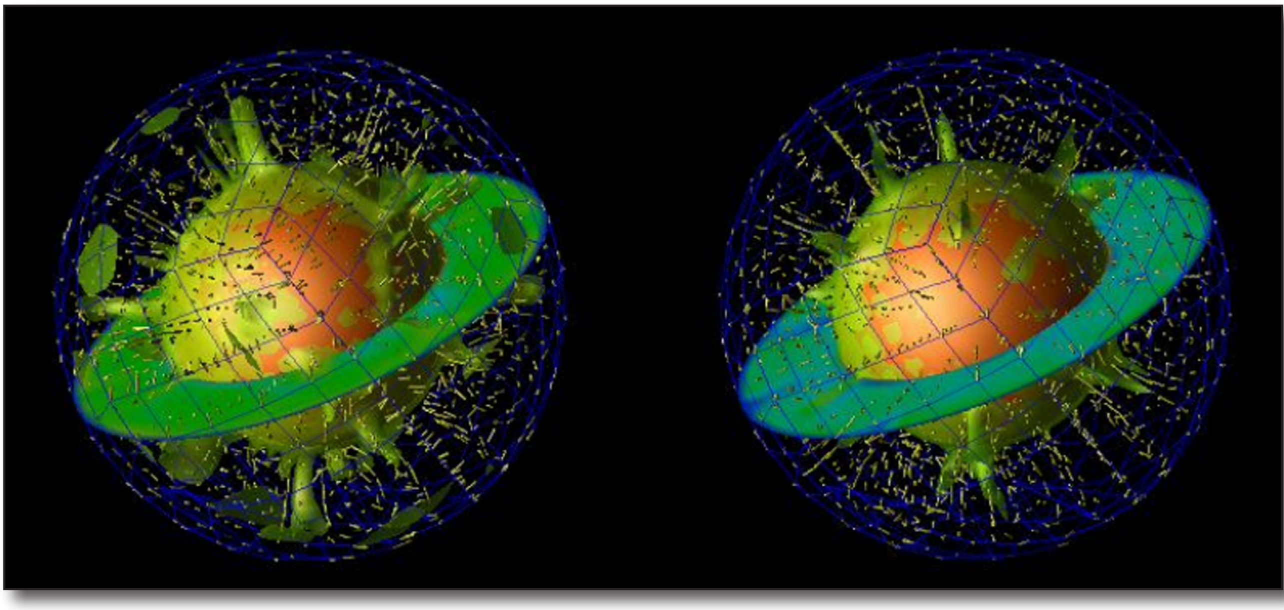
The project started in mid 2011. Work has included collating a shortlist of candidates for the Postdoctoral and technician positions. The work roles have been filled by casual employment of computer technicians over 2011-2012. A fulltime employee will be appointed in early 2012 for the technician position. A formal advertisement for the postdoctoral position is currently being finalised for printing in Eos.

Visualisation pathways for modelling subduction zones settings have been developed, and code to process existing plate data into input format for geodynamic models has been written and debugged. Preliminary models of global plate-driven subduction in 3D have been finished. High-resolution modelling of these zones, with vizualisation, is currently underway. This modelling will be combined with coding on CitcomS to incorporate fluid hydration and dehydration during the subduction cycle.

Aims and work plan for 2012:

The aim in 2012 is to complete coding for a CitcomS module to track hydration and dehydration of subducting lithosphere, and to begin work on the first phase of a coupled finite-element implementation of a two-phase flow code.

The CitcomS module will enable the rapid development of models for global slab dewatering, which will have immediate science outcomes in the latter half of 2012. The FE code development is part of a larger implementation of MPMCRF that will continue over 2012-2014 with development, benchmarking and testing.



Whole mantle convection for an Earth-like planet. Shown are hot upwellings (yellow) and an equatorial temperature cross section.

5. EARLY EVOLUTION OF THE EARTH SYSTEM AND THE FIRST LIFE FROM MULTIPLE SULFUR ISOTOPES

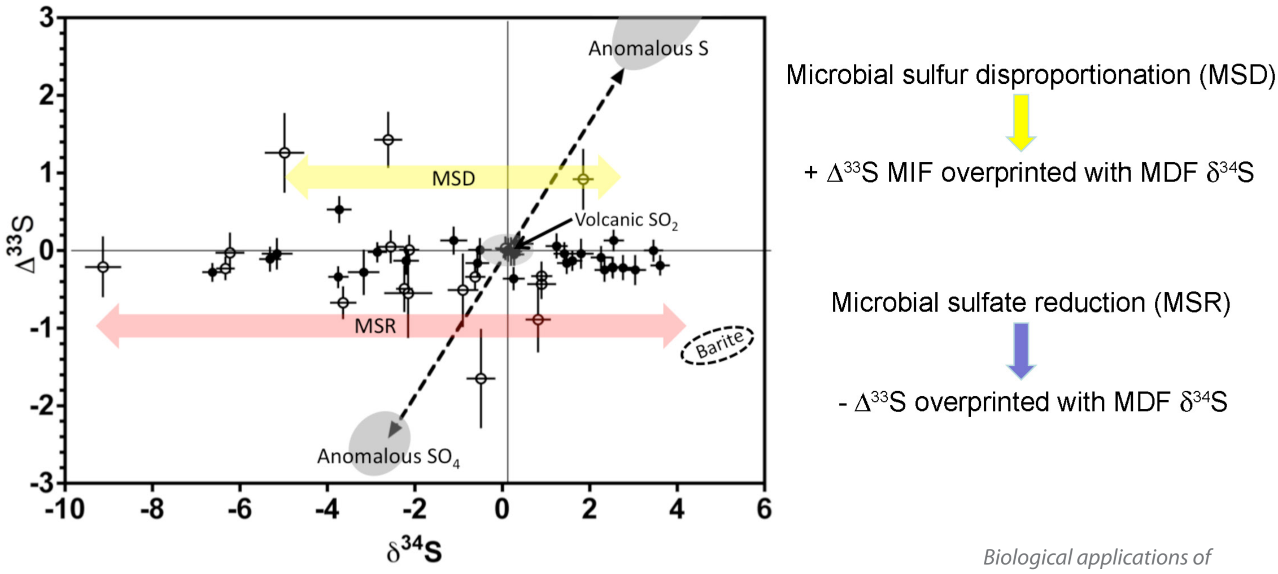
Aims:

1. To define the nature of the first life in the early Archean and links between the early evolution of life and the rise of atmospheric oxygen in the Neoarchean
2. To understand the evolution of the Earth's oceanic and atmospheric composition during the Archean and Paleoproterozoic
3. To evaluate the links between the evolution of the sulfur cycle and the formation of important Archean submarine ore deposits

Context and rationale: Mass-independent fractionation (MIF) of multiple sulfur isotopes $\delta^{34}S$, $\Delta^{33}S$ and $\Delta^{36}S$ in rocks older than 2.45 Ga provides the best evidence for changes in Earth's early atmosphere and ocean due to the evolution of the sulfur cycle. Recent work indicates that variations in the MIF record have important implications for understanding changing environmental conditions in the evolving Archean Earth system. Prior to 3.1 Ga the MIF record is characterised by significant MIF, with reduced variation between 3.1 and 2.8 Ga and increased variation from 2.75 to 2.5 Ga followed by reduction during the Great Oxidation Event (2.45 and 2.32 Ga). We have the potential to analyse samples that may resolve how these changes may have been linked to tectonic events (e.g. a fluctuating sulfur cycle linked to increased subaerial volcanic gas as continents grew) and the evolution of life. Multiple sulfur isotopes are important for the investigation of biological processes on the early Earth. They have the potential to elucidate the types of life present in Earth's earliest sedimentary environments, as well as to trace the transfer of sulfur in fluids and gases from the interior of the Earth, via the atmosphere and hydrosphere into the biosphere.

Although compilations of sulfur isotope data from Archean sedimentary rocks indicate the sulfur content of the oceans was very low, Archean greenstone successions contain some of the world's largest submarine metal sulfide deposits and these commonly have non-zero $\Delta^{33}S$ values. A better understanding of the role of different sulfur sources in Archean mineral systems will provide important insights into the evolution of the early sulfur cycle as well as keys for mineral exploration. The analysis of multiple sulfur isotopes in sulfide inclusions in mantle-derived diamonds and eclogites from kimberlites has the potential to indicate details of recycling of Archean sulfur to depth in the crust and mantle, and sulfide inclusions in Hadean zircons and meteorites have the potential for understanding very early Earth fluids.

One problem that has held back research in the biological field is the spatial resolution at which multiple sulfur



Biological applications of multiple sulfur isotopes.

Example from Wacey et al., 2010. (Geology 38 (12), 115-1118). Analyses made using CAMECA IMS 1280 isotopes can be analysed. Bulk analyses can lead to artificial homogenisation of sulfur-isotope signals in a sample, and a lack of understanding of processes on the micron scale, where microbial mediation may be observed. For example, recent Nano SIMS sulfur isotope studies have revealed large variations in $\delta^{34}S$ in both modern and ancient microenvironments. These small-scale heterogeneities in sulfur isotope composition cannot be detected by bulk techniques, emphasising the growing need to study sulfur-isotopes on a spatial scale relevant to microbial processes. Hence, as an extension to studying multiple sulfur isotopes in Archean sediments and mineral deposits we will also investigate the biogeochemistry of sulfur using samples from key times in Earth history (e.g. early Archean to investigate Earth's earliest life; late Archean to investigate the interplay between sulfur metabolisms and the rise of atmospheric oxygen), and will incorporate new technology available at the CMCA. An increased understanding of the biological S-cycle is important not only for studies of life in the Archean, but also for elucidating the composition of the early atmosphere, the mechanisms for cycling of these elements between the lithosphere, biosphere and atmosphere, and the cycling of other elements essential for life.

Methods/methodologies:

The major aims of the project require analysis of multiple sulfur isotopes from relevant samples, some that we already have and others to be collected soon.

The most appropriate method for bulk multiple sulfur isotope analyses is use of the EA-CF-IRMS at the University of Queensland (key analyses in the 2009 DP) this will be used to see which sedimentary and mineral deposit samples require more detailed spatial analyses. The CAMECA IMS 1280 ion microprobe is capable of measuring $\delta^{34}S$ and $\Delta^{33}S$ with precisions of better than 0.2‰ and from samples as small as ca15 mm. For $\Delta^{36}S$ it can achieve precisions of better than 0.3‰ from samples as small as ca 40 mm. The CAMECA Nano SIMS 50 extends this capability to samples as small as 2-3mm for $\delta^{34}S$. This will allow us for the first time to analyse $\delta^{34}S$, $\Delta^{33}S$ and $\Delta^{36}S$ from individual sulfides and sulfates at the correct scale to identify individual microbial processes.

Innovation: This is the first time all three analytical methodologies for multiple sulfur isotopes have been available in Australia and will provide the chance of very important high-impact results and one of the best global databases.

Progress during 2011:

The research plans for this project are to obtain appropriate samples and undertake the analyses to meet our objectives. In this context we have been able to get appropriate sets of samples from Mesoarchean (3.3 to 2.8 Ga) greenstone belts and volcanic-hydrothermal massive sulfide deposits and komatiite-hosted Ni sulfide deposits. Australia is the only place with a wide variety of samples of this key age, which has been a gap in the existing global database. We have got the first excellent results from the 2.9 Ga Lake Johnston Belt and Murchison showing key evidence for variations in the sulfur cycle through this period of time rather than just minor oxygen fugacity variations before the great oxidation event (key data shown in diagrams). These data show that the strongest variations in the Mesoarchean S MIF record are linked to the only preserved evidence for major volcanic events with some subaerial volcanism producing the key volcanic gas. The largest 2.95 Ga deep submarine volcanic massive sulfide deposit, Golden Grove, is evidence for major sulphur recycling after plate tectonics started. These are important results and we will submit manuscripts to key journals in the next few months. The CIs have given invited talks at conferences and the PhD students have given posters. PhD student Carissa Isaac (started 2010), whose initial analytical work was partly supported by the Discovery Grant (VMS and sedimentary S isotopes in the North Eastern Yilgarn), has gotten a large, very appropriate batch of samples for ongoing research in this project.

Completing the planned collection of key samples and their analyses plus putting together a good batch of publications will be the milestones for the next year. We have large batches of samples collected in 2011; some are already analysed and the rest will be analysed in the future in the CoE. We are aware of other key areas and important mineral deposits in the Murchison and West Pilbara that can provide more important samples and there are three good PhD students working on this with us. We thus have the potential for some more important milestones in getting a much better understanding of the variations of the sulfur cycle and its links to tectonics, life and mineral deposits in the early Earth between 3.5 and 2.4 Ga.

Using these different methods has given us the first strong data for how the methods fit together for this important work. We are also collaborating with international leaders in multiple sulfur isotope geochemistry (James Farquar, Boz Wing, Shuhei Ono, Doug Rumble, Sue Golding, Jay Kaufman etc.) in 2011 and 2012. We also plan to convene a 2 to 3 days MIF Work Shop in Australia (Sydney) with these international leaders.

Aims and work plan for 2012:

David Wacey has just taken up his CCFS Research Associate position. He is the CMCA person with expertise in early life and related biogeochemistry and astrobiology. He will continue collecting an excellent set of samples and examining them by Nano SIMS and IMS1280 to study early life in 2012. The samples sets include the following

3490 Ma Dresser Formation – putative pyritised microbial mats and microbially- induced sedimentary structures in a MIF world. We will conduct multiple sulfur isotope analysis of microbial-like laminations (putative tufted mats) that have been heavily pyritised (March/April 2012). Are the data consistent with microbially-mediated pyrite – if so, what type of metabolismwas involved? How do the data compare with previous data from other environments (e.g. Dresser barite lithology and Strelley Pool Fm sandstone lithology) at this time? Or are the data more consistent with hydrothermal pyritisation? The data also may provide additional insights into the composition of the atmosphere at this time.

1900 Ma Gunflint chert – pyritised microbial communities in a post-MIF environment. We will conduct multiple sulfur isotope analysis of pyritised microfossils (March/April 2012). Was pyritisation induced by microbial sulfate reduction, a combination of metabolisms, or was it hydrothermal? Focused ion beam and TEM techniques (April 2012) will be used to track the conversion of organic fossil material into pyrite (and later into hematite) at the nano-scale in order to understand more about the mechanisms of fossilization in these different materials. These are also excellent analogues for Archean silicified microfossil assemblages, which will provide a baseline for comparison with Archean data.

Experimentally produced modern microbes (Winter/Spring 2012). We will obtain in situ multiple sulfur isotope data at the micron scale from sulfides precipitated by cultures of the sulfate-reducing Archaea Archaeaglobus fulgidus. This will be the first multiple sulfur isotope data set obtained from individual micron-sized sulfides precipitated in controlled microbial experiments. The results will aid in the interpretation of similar micron-scale sulfur-isotope data obtained from the Archean rock record.

We also will do more field work in other key areas, including mineral deposits in the Murchison and West Pilbara, to find important samples and analyse them for S MIF data with the appropriate techniques. It is likely we will start a new international PhD student working in specific areas of multiple S isotope data.

We plan to hold a Workshop on Mass-Independent Fractionation processes in Sydney, involving the international leaders in multiple sulphur isotope geochemistry with whom we collaborate. This will be the first major meeting about this important scientific development and the different analytical approaches and will be a high-impact international CCFS event. We plan to produce a benchmark publication from this for Reviews in Mineralogy and Geochemistry.

We also will do more field work in other key areas and mineral deposits in the Murchison and West Pilbara to find important samples and analyse them for S MIF data. It is likely we will start a new international PhD student working in specific areas of multiple S isotope data.

A Workshop on Mass-Independent Fractionation processes is being planned to be held in Australia (Sydney). This will be the first major meeting about this important science and the different analytical facilities and will be a high-impact international CCFS event. We plan to produce a benchmark publication from this for Reviews in Mineralogy and Geochemistry (see *Research Highlight p. 42)*.

6. DETECTING EARTH'S RHYTHMS: AUSTRALIA'S PROTEROZOIC RECORD IN A GLOBAL CONTEXT

The main goals of this project are (1) testing a groundbreaking hypothesis that the birth and death of a supercontinent on Earth's surface is intimately linked to the spatial and temporal location of superplumes, and that cyclic supercontinent-superplume events and associated fluid events dominate Earth's evolution; (2) pushing our knowledge of the Earth's palaeogeographic and geodynamic history back to the Archaean.

Context and rationale:

How plate tectonics on the Earth's outer shell interacts with its mantle, and what drives plate tectonics, remain a challenge to the 21st century geoscience community.

Does plate tectonics drive mantle convection, or vice versa? What determines the formation, positions and lifespan of hot mantle plumes and superplumes deep in the mantle, and how do plumes/superplumes interact with plate dynamics? Are mantle plumes and superplumes fixed relative to the Earth's rotation axis? Are the formation and breakup of supercontinents in Earth's history accidental events, or more regular events determined by some internal mechanisms?

While working on the evolution of Rodinia, Z.-X. Li and co-workers noticed that the assembly of Rodinia was followed by a >100 million years (Ma) episode of worldwide plume activity that is temporally linked to the breakup of the supercontinent. The sequence of events resembles that during Pangaean time both in its lateral scale and its duration, including a time lag of tens of millions of years between the final assembly of the supercontinent and the onset of plume breakout. More intriguingly, Neoproterozoic palaeomagnetic data suggest that Rodinia and the mantle plumes beneath it may have rotated rapidly between ca 0.81 and 0.75 Ga, confirming that mantle plumes and supercontinents are probably coupled. Did such coupling occur during Earth's earlier history?

In this project we will test the hypothesis further by analysing global palaeogeography back to the Neoarchaean era. Primary data gathering in the first three years will focus on numerous Paleo- to Mesoproterozoic Australian igneous complexes with studies of palaeomagnetism and geochemistry. We will compare the Australian records with those of the entire world through international collaborations.

Kong-Yang Zhu ready to take core samples of mafic dykes in the Ravensthorpe region of southeastern Yilgarn Craton.

Progress during 2011:

We made progress on two fronts in this project during the start-up year of CCFS. First, we appointed two key personnel for the project. Dr Sergei Pisarevsky, a world leading palaeomagnetist with much experience in making global palaeogeographic reconstructions, joined the Curtin Node in late March 2011 as a half-time Senior Research Fellow. He is leading part of the palaeomagnetic investigations in the project. We also secured the continuation of Dr Xuan-Ce Wang, a Senior Research Fellow specialising in geochemistry of mafic rocks and mantle evolution. Xuan-Ce was later awarded one of the CCFS's ECSTAR fellowships, but will continue to lead the geochemical and petrological aspects of the project as well as carrying out his ECSTAR project. We are still seeking new PhD students to be involved in this project. Key collaborators are Professor D.A.D. Evans (Yale University), Dr R. Ernest (Ernestgeosciences) and Associate Professor E. Tohver (University of Western Australia).

On the scientific front, we carried out the first sampling trip to the southeastern Yilgarn Craton (the Ravensthorpe region) in June, targeting the ca 1.2 Ga and possibly younger dykes for palaeomagnetic, geochronological and geochemical/petrological investigations. The palaeomagnetic analysis is nearly complete; geochronological and geochemical/petrological investigations are ongoing.

Aims and work plan for 2012:

In 2012 we aim to complete all analyses of the Ravensthorpe dykes, and write up the results for publication. We also plan to carry out targeted sampling trips to key parts of Western Australia, and to northern Australia if PhD students become available in time.

Palaeomagnetic sampling trip to mafic dykes in the Ravensthorpe region of southeastern Yilgarn Craton.

7. FLUID REGIMES AND THE COMPOSITION OF THE EARLY EARTH

Earth was assembled from solar and planetary debris, and the heat generated during this process would have expelled volatile elements into space. Several models suggest that Earth's current inventory of water and other volatiles was added by a "late bombardment" of cometary material. However, the scarcity of water on the Moon, and our recent discovery that Earth may have had surface water 4.2-4.4 billion years ago, raise key issues about the sources and role of water during Earth's early evolution.

Geochemical and micro-structural studies of lunar samples, meteorites, and Earth's oldest rocks and minerals can tell us how and when Earth became "wet", and link the geochemical evolution and deformation histories of proto-planetary bodies. The isotopic composition of meteorites will be used to define the types of material that went into the construction of Earth and other terrestrial planets, and to give a better baseline for comparison with Earth. We will use a variety of techniques, including synchrotron-based spectroscopy and high-precision stable-isotope analysis of oxidation/reduction-sensitive elements such as Cr, Fe, O, C and S in minerals from Earth, the Moon and meteorites, to assess planetary oxidation states and give new clues as to how the planets formed. Some of these elements have short-lived isotopes (e.g. $^{53}Mn \rightarrow {}^{53}Cr$, half-life 3.5 Ma) and can be used to investigate how oxidation states changed during the accretion and very early evolution of Earth.

Mars is the only planetary body in the Solar System where surface conditions similar to those observed on the Earth (i) may have existed in the past and (ii) can be studied directly via samples of Martian meteorites. As such, Mars provides a unique opportunity to test models of atmospheric, hydrospheric and biospheric evolution, as well as climate variations possibly similar to those developed on Earth. It appears that a relatively early record of this evolution, which is very incomplete on Earth, is preserved in Martian samples. We can potentially utilise information obtained from Martian meteorites to apply new constraints on the initial state of Earth's atmosphere and hydrosphere. Information about the Martian surface environment can be extracted through analysis of a suite of low temperature minerals, including carbonates, preserved in several of these meteorites. On Earth, these minerals are commonly associated with sedimentation, diagenesis, and precipitation from either surface or groundwater. However, carbonates that occur in several Martian meteorites are included in magmatic rocks and their origin is poorly understood, with models ranging from formation in high temperature hydrothermal solutions to precipitation from low-temperature surface water.

We will utilise information obtained from extra-terrestrial sources with ongoing analysis of Earth's oldest zircons in order to provide new constraints on the nature, evolution and weathering of Earth's earliest crustal remnants. Several outstanding questions remain: 1) what is the significance of the inclusion suite in ancient zircons which, where amenable to dating, are always younger than their host; 2) were the earliest zircons derived through melting of a solidified magma ocean or do they require extensive continental crust and oceans; and 3) when was the onset of some form of plate tectonics on Earth that led to transfer of material back into the mantle? These and other related questions provide the inspiration for this project.

The aims are twofold:

Part 1: Characterising the earliest crust on Earth: The primary research objective is to characterise the nature and origin of the earliest crust on Earth. This will be achieved by comparing information already acquired from the 4.4-3.5 Ga detrital zircon suite at Jack Hills with comparable new data obtained from the earliest known rocks on Earth, preserved in Antarctica, Canada, China, Greenland, India and Western Australia. We will document the changes that took place from the formation of the earliest zircons (4.4 Ga) to the time when crust was widely preserved (~3.5 Ga) and evaluate why so few Hadean rocks survived on Earth.

Part 2: Characterisation of minerals and related fluids phases in Extraterrestrial samples: The aim of this study is to compare conditions in the early solar system with those on the early Earth and extends the scope of the original project description. Initial work will focus on the Martian meteorites with the aims of (1) characterising the presence of fluid and its interaction with minerals and (2) obtaining information on primitive mantle deformation mechanisms and processes. This will be done by combining geochemical and microstructural techniques such as SEM imaging, electron and ion microprobes, EBSD and Raman.

Progress during 2011:

Part 1: Zircon from the Napier Complex in Antarctica was recognised in earlier studies as having high U contents and structural complexities. Analysed zircons are typically dark in CL and yield $^{207}Pb/^{206}Pb$ ages up to 3.9 Ga; some of the oldest grains are reversely discordant. Zircon grains have also been ion imaged by SIMS using a single collector for Ti, Y, Hf, Pb, Th and U and a multicollector for the Pb isotopes. Patchy distribution of Pb and Ti does not correspond to either zonation or crystal imperfections and appears to confirm redistribution of radiogenic Pb (now unsupported).

Preliminary work in the Dharwar Craton of India indicates TTG components as old as 3.3 Ga in the eastern part. However, the major events occurred in the Neoarchean with magmatism at ~2.55 and ~2.15 Ga.

Part 2: We have received 5 thin sections of Martian samples (Zagami, Nakhla and ALH84001) from the Smithsonian Institute, the Johnson Space Centre Curation Office and the WA Museum. We have completed initial work on microstructure characterisation on the Zagami and Nakhla samples using Secondary Electron Microscopy (SEM) and SEM coupled with an Electron Backscatter Diffraction (EBSD) system to determine the crystallographic preferred orientation (CPO) of minerals. The Zagami sample corresponds to the "Normal Zone" (NZ) composed of pyroxenes exhibiting a foliated texture interpreted as mantle deformation prior to shock. The NZ portion is cross-cut by glass veins of shock-melt that seem to follow the alignment of pyroxenes. Our preliminary CPO results indicate that clinopyroxenes in the Nakhla sample are randomly oriented whereas clinopyroxenes in the Zagami sample indicate two different orientations. These orientations are still not well constrained, but might be the result of mantle flow. The major part of this study, related to microtextures, is to characterise the internal features and textural relationships between minerals present in the samples. Preliminary EBSD maps of minerals including pyroxene, olivine, feldspar and apatite indicate weak internal deformation with subgrain formation, and the deformation is apparently independent of the orientation of polysynthetic twinning, which has been caused by shock (Fig. 1). We have also completed initial work aiming to characterise fluid inclusions and secondary phases (carbonates) in some of these samples. In particular, we have identified a number of carbonates in our thin sections of sample ALH84001 and characterised their internal features and textural relationships with other rock forming minerals, using optical microscopy, SEM imaging and x-ray analyses. These are Fe-Mg-Mn-Ca carbonates that are globular and growing in small vesicles (Fig. 2). They are strongly zoned with Mn- and Ca-rich cores and Fe- and Mg-rich rims.

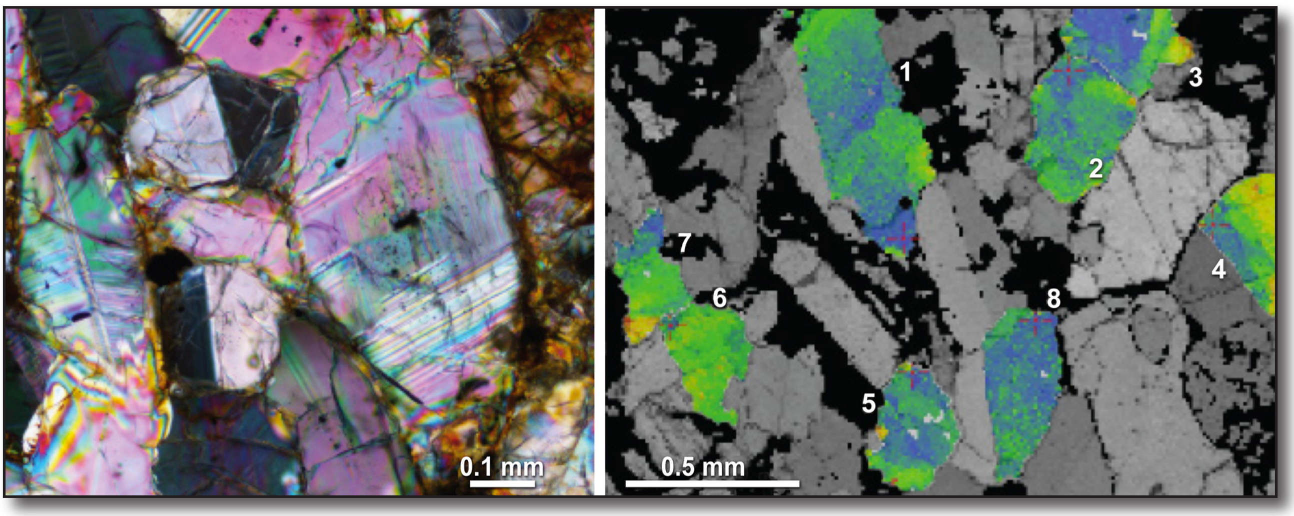


Figure 1. Photomicrograph and EBSD map of clinopyroxenes in Nakhla sample. (a) Cross polarised picture of clinopyroxenes with polysynthetic twinning. (b) Cumulative misorientation maps derived from EBSD data showing internal texture of 7 clinopyroxene grains, from a reference point (red cross) in the blue area to a maximum represented by the red area (up to 7˚).

Aims and work plan for 2012:

Part 1: Work will continue on the Antarctic samples with special emphasis on ion imaging of zircons to determine variations in the elemental and isotopic distribution. For comparative purposes, similar studies will be undertaken on the oldest zircons from Jack Hills. Work will commence on zircons extracted from the oldest rocks in Canada and Greenland, with a possible field excursion to obtain additional samples from key localities. The acquisition and interpretation of oxygen, lithium and lutetium-hafnium data from zircons extracted from the most ancient terrestrial rocks in Antarctica, Canada and Greenland will enable us to make a preliminary evaluation of what changes, if any, took place on Earth between consolidation of a magma ocean and the extensive development of continental crust.

Part 2: We will finish the imaging of all mineral phases, in particular complete EBSD on primary minerals and acquire EBSD and cathodoluminescence images on carbonate phases. We will also undertake chemical analyses to fully characterise the mantle phases as well as the secondary phases, using the electron microprobe. Raman spectrometry will be used to analyse fluid inclusions. Once this is completed we will be able to start isotope analyses on carbonates using the ion microprobe. These data should provide the composition of the fluids that permitted the secondary phases to crystallise.

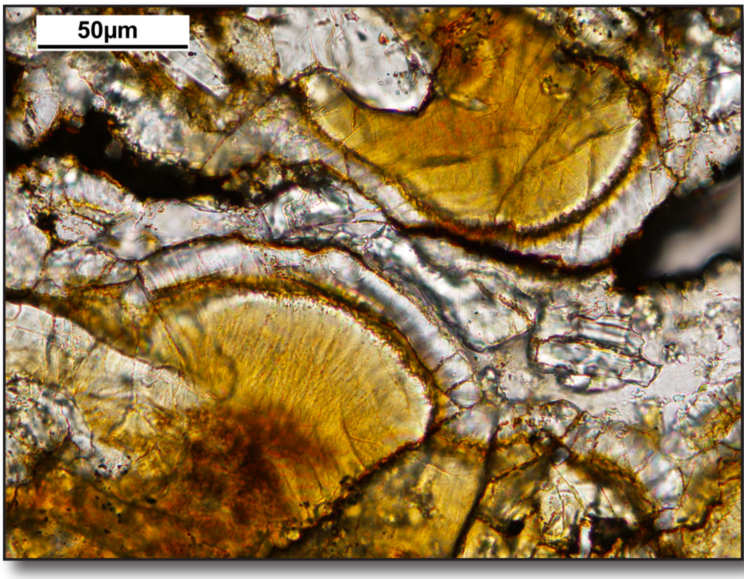


Figure 2. Optical photomicrograph of carbonate phases (orange) in ALH84001.

8. DIAMOND GENESIS: CRACKING THE CODE FOR DEEP-EARTH PROCESSES

The aims of the project are:

- To combine LAM-ICPMS analysis of diamonds, developed at Macquarie, with other types of *in situ* data to define the nature and evolution of diamond-forming fluids
- To constrain the causes of isotopic variability of carbon, oxygen and nitrogen in diamond-forming fluids; are these primary signatures, or do they reflect isotopic fractionation during diamond growth?
- To understand the links between diamond formation and the redox state of the lithospheric and asthenospheric mantle
- To develop a new exploration/evaluation methodology for application to kimberlites, by defining the trace-element signatures of mantle minerals that have been exposed to diamond-bearing fluids
- To better characterise different types of mantle fluids and their interactions with mantle rocks

This project engages Postdoctoral Researcher Daniel Howell, and PhD students Ms Ekaterina Rubanova and Ms Yao Yu.

Progress during 2011:

The aims of the project were expanded somewhat during 2011, to characterise other types of fluids in the lithospheric mantle. PhD student Yao Yu (cotutelle with Nanjing University) is carrying out an FTIR-based study of the distribution of water in different types of lithospheric mantle, using xenoliths from basalts and kimberlites. The first phase of her study, involving spinel peridotites from the North China Craton, was accepted for publication, and she has begun preparing samples of a range of previously-studied xenoliths from the kimberlites of the Kaapvaal Craton.

O'Reilly and Griffin wrote up a review and synthesis of metasomatic processes in the mantle, for an online review volume and teaching resource that will be launched at the Montreal Goldschmidt conference in 2012 (*CCFS Publication #5*).

Dr Howell, working together with Dr Craig O'Neill, completed the development of a software package (DiaMap). This allows the construction of maps derived from the reduction of the huge volumes of FTIR data collected by our state-of-the-art FTIR spectrometer. A full description of the program has been submitted to a journal; once the paper is accepted, the software will be put on the CCFS website as freeware. Dr Howell also completed a study of a unique suite of centre-cross diamonds, revealing new information about the processes of diamond growth; a manuscript on this work is in review, along with another on the development of platelets in cuboid diamond growth. Dr Howell initiated a detailed study of a large parcel of diamonds from the Diavik kimberlites (Lac de Gras, Canada), many of which show several stages of growth, of varying habit. Imaging of these stones is progressing, and some have been analysed for C-isotopes. He also carried out a long series of experiments designed to greatly improve the detection limits for the LAM-ICPMS analysis of diamonds; at year's end, the preliminary results were exciting. Finally, he has written and submitted a long series of articles on his results from 2010 and 2011 (this is a relinquished project).

Another important development in 2011 was the start of carbon-isotope analysis in diamonds, using the SIMS lab at University of Western Australia. CCFS has provided a position for a technical person in this lab (not filled in 2011) and the laboratory has allocated a significant proportion of its capacity to CCFS projects. Dr Howell and Ms Rubanova have both benefited from this in 2011, making trips to carry out analyses that were previously done in Edmonton (Canada). The results show excellent agreement between the two laboratories, and similar internal precision. The remaining challenge will be to improve the homogeneity of our available standards, which at present constrain the external precision.

Ms Rubanova is studying the relationships between diamonds and silicates in suites of diamondiferous eclogites and polycrystalline diamond-silicate intergrowths. In 2011 she carried out both C-isotope analyses of her diamonds, and O-isotope analyses of the coexisting silicates, to investigate possible covariations of these two systems in the fluids that deposit diamonds. Mentored by Research Associate, Associate Professor Sandra Piazolo, she also has adopted a new technique, Electron Backscatter Diffraction (EBSD) to look at the microstructures of the polycrystalline diamonds. This revealed that, rather than being deposited as fine-grained aggregates, the "diamondites" were originally quite coarse-grained and that the grain size has been reduced by deformation and recrystallisation. A paper on this work is under review.

We continued our collaborations with Russian and Israeli colleagues on the nature of diamond-related fluids, which is directly relevant to questions of diamond growth.

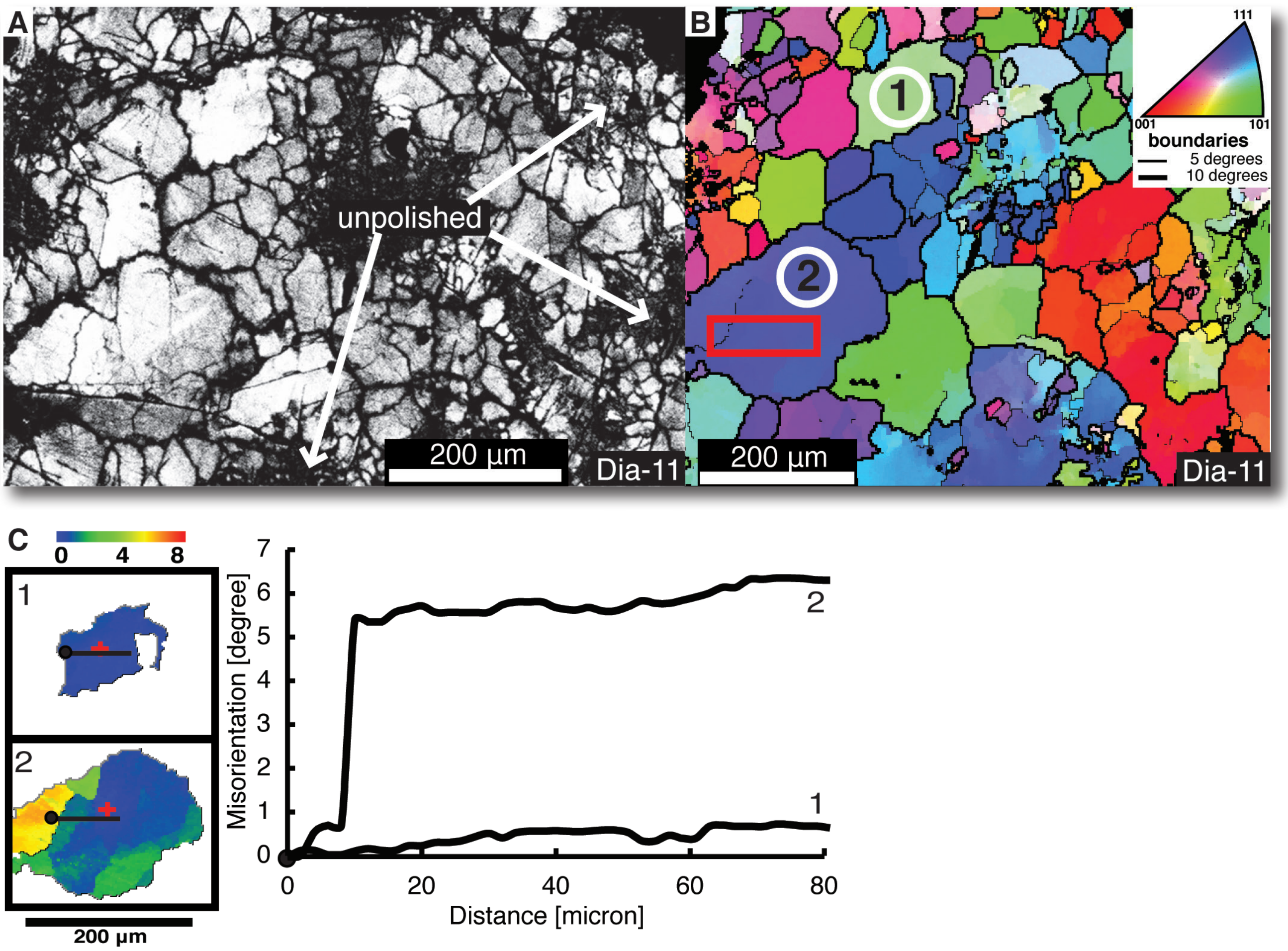
Published outputs:

CCFS Publications #2, 52, 135

Aims and work plan for 2012:

The aims of the project, as expanded in 2011, will be followed in 2012.

A new eximer laser will be installed early in 2012, for use with the quadrupole ICPMS. Dr Howell will use this system to carry out ultra-trace analyses of diamonds showing multiple stages of growth and/or mixed-habit growth, to quantify the trace-element characteristics of the fluids from which such diamonds grow. This will then be cross-compared with our extensive database of fluid compositions in fibrous diamonds. The new techniques also will



Photomicrograph (A) of a polished diamondite; (B) EBSD map of the area in (A); (C) and (D) traverses showing gradual (1) amd abroupt (2) changes in crystallographic orientation in single diamond grain.

be used to re-evaluate our older data on gem-quality diamonds, where many analyses were near the detection limits available at the time. C-isotope analyses will be done on the same diamonds, to correlate trace-element patterns with isotopic characteristics. Dr Howell also will complete his C-isotope studies on zoned and centre-cross diamonds.

Ms Rubanova will complete the planned program of chemical, isotopic and microstructural analysis of her collection of diamonds, diamondites and diamondiferous xenoliths, and prepare papers for publication as well as the first parts of her PhD thesis. She will present some of this work at the 10th International Kimberlite Conference in India (February 2011).

Dr Piazolo has been awarded a Future Fellowship, and will be building up an EBSD capability at Macquarie-CCFS in 2012, which will facilitate further studies of diamonds and their host rocks.

Ms Yu will carry out FTIR studies of the Kaapvaal xenoliths; samples are now being prepared in Nanjing. This is expected to result in at least one paper.

9. 4D LITHOSPHERIC EVOLUTION AND CONTROLS ON MINERAL SYSTEM DISTRIBUTION: THE WESTERN SUPERIOR-YILGARN COMPARISON

The project will provide a very well-constrained case study in an Archaean craton outside of the Yilgarn to (1) apply multi-isotopic (U-Pb, Lu-Hf, O) analyses of zircon to map lithospheric architecture in space and time, (2) determine if the distribution of mineral systems (VMS, Fe, NiS, Au) shows strong control by this architecture, as it appears to in the Eastern Goldfields Superterrane of the Yilgarn Craton, and (3) generate mappable exploration criteria for targeting exploration for various Archaean mineral systems at the craton to terrane scale.

Context and rationale:

Recent studies (Champion and Cassidy, 2007; McCuaig et al., 2010; Mole et al., 2010; Begg et al., in press) have demonstrated in the Yilgarn Craton of Western Australia that multi-isotopic maps (Lu-Hf and U-Pb *in situ* analyses of zircon combined with whole-rock Sm-Nd data) are a powerful tool to map crustal growth and image lithospheric blocks of different age (putative paleocraton margins). Moreover, these studies have pointed to a strong spatial correlation between these lithospheric block edges and the location of large concentrations of several styles of mineral deposits. The interpretation is that these isotopic boundaries mark lithosphere-scale structures that control the flux of mass and energy (and thus the location of large mineral systems) through time.

The western Superior Province of Canada is the perfect place to undertake a comparative study to complement the Yilgarn example. The western Superior is host to major deposits of gold (Red Lake Camp, Musselwhite mine, Hemlo), VMS (Kidd Creek) and diamonds (Victor Mine) as well as the recent discoveries of the world-class chromite and nickel deposits in the Ring of Fire. However, the western Superior Province has important contrasts to the Yilgarn in that it is relatively VMS-rich, and NiS-poor. Moreover, the Western Superior is an exceptionally well-constrained Archaean craton, with well-defined stratigraphy, an abundance of high-precision geochronology to constrain its evolution, and abundant high-quality geophysical data including crustal seismic and potential field datasets. Current thinking is that the southwestern Superior Province comprises largely juvenile lithosphere at ca 2.75-2.65, growing by combinations of arc-plume interactions and accretion of terranes. This contrasts with the Yilgarn Craton, comprising largely evolved lithosphere at that time, and tectonic models that range from intracratonic rifting through to assembly of accretionary terranes. Systematic delineation of lithospheric blocks of different character would radically change the views on assembly of these ancient cratons.

Methodologies:

This project will investigate the U-Pb-Lu-Hf-O isotope characteristics of zircons from key units in the Wabigoon subprovince of the western Superior Province, in order to obtain a better understanding of the evolution, architecture and preservation of this complex 3.0-2.7 Ga Archaean terrane and the mineral deposits that formed within it.

Progress during 2011:

Yongjun Lu was appointed as a research associate in October 2011 to undertake this project. The access to zircon samples allows a value-add on well-constrained samples. Collaboration with Peter Hollings at Lakehead University, Don Davis and Kirsty Tomlinson at Ontario Geological Survey have given us access to zircon samples that have already been characterised in terms of location and context, whole rock geochemistry, U-Pb geochronology and, in many cases, whole rock Sm-Nd.

Regarding the task of analysing 70 samples in the first year, there have been ca 50 samples available for SHRIMP U-Pb dating and Hf-O isotopic analysis. All available zircon samples have been sent to Minsep in Denmark, WA for preparation of zircon mounts. The first two mounts (6 samples) have been returned and are scheduled for SHRIMP dating on March 2nd and 9th 2012. Other mounts are expected to be finished by mid-March. Subsequent oxygen and hafnium analysis will be scheduled once SHRIMP dating is done.

Aims and work plan for 2012:

One aim is to obtain SHRIMP U-Pb ages, oxygen and hafnium isotopes of ca 50 samples which are already in preparation by August 2012.

A field trip is scheduled in mid-2012 for additional selective sampling of critical units across interpreted terrane boundaries in order to ascertain the location of these boundaries in a whole-lithospheric context.

One manuscript is expected to be submitted on the first batch of SHRIMP U-Pb and Hf-O isotopes by the end of 2012.

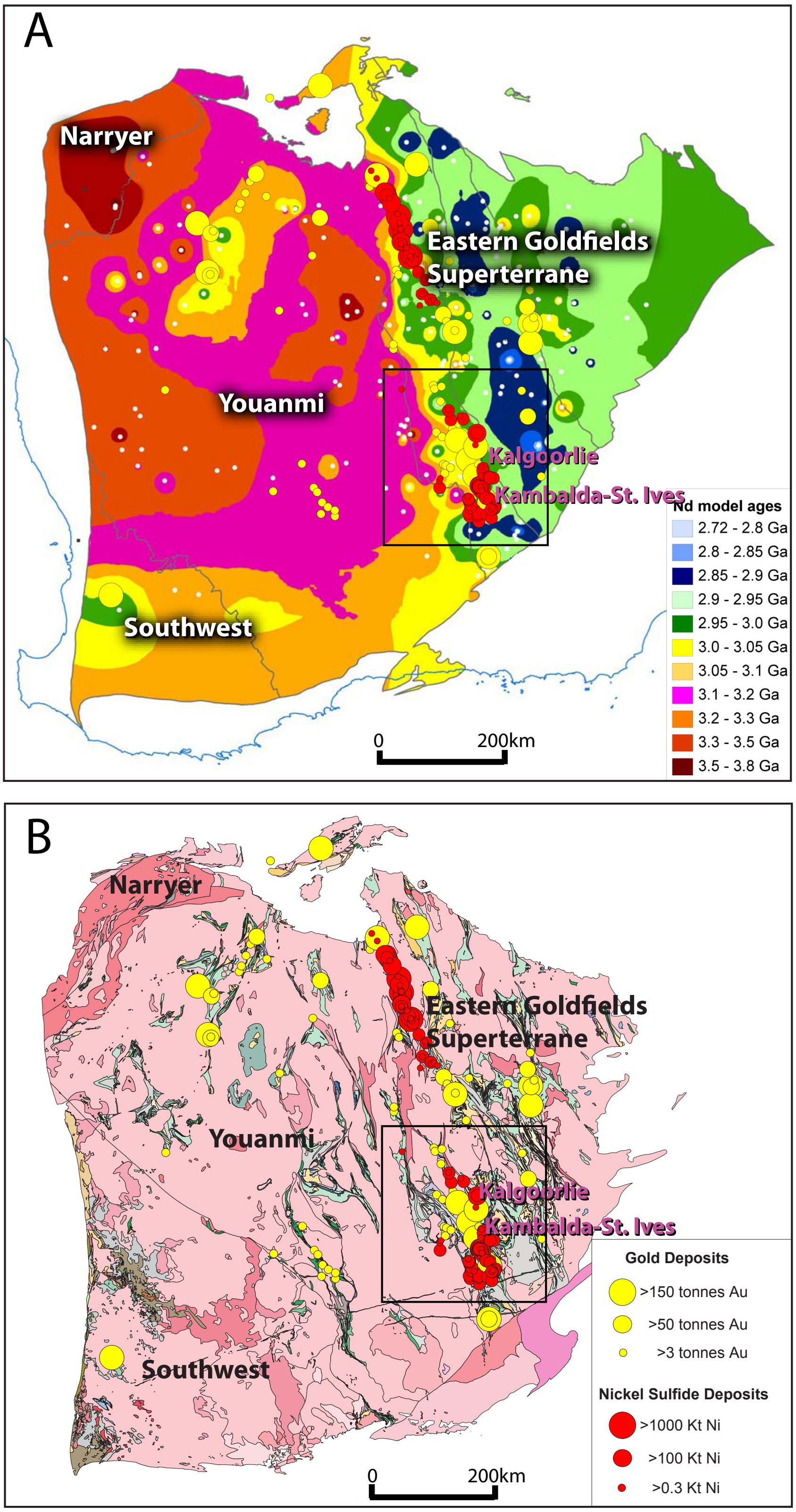


Figure 1. Nd model ages with Au (yellow) and Ni (red) deposits in Yilgarn Craton (After Cassidy and Champion, 2007).

10A. 3D ARCHITECTURE OF THE WESTERN YILGARN CRATON

This project is a major initiative by the Geological Survey of Western Australia (GSWA) to integrate the results of 1:100,000 scale regional mapping, geochronology and geochemistry with newly acquired high-quality geophysical data, including gravity and aeromagnetic data, and deep seismic and magnetotelluric surveys.

Aims:

The aims of the project are to integrate the data into a 4-dimensional, integrated model of crustal evolution for the western Yilgarn Craton, and to derive a better understanding of the mineralisation processes for this region, how the crust links to underlying lithospheric mantle, and what relationships this piece of lithosphere has with the more highly endowed, eastern part of the craton (Eastern Goldfields Superterrane (EGS)).

Context and rationale:

The Yilgarn Craton of Western Australia is a large and highly complex piece of Archean crust with a long history extending from 4.4–2.6 Ga. It is locally well endowed with a variety of mineral deposits, particularly gold and nickel in the EGS. Previous work has identified a number of lithostratigraphic terranes interpreted to have had distinct crustal histories prior to tectonic amalgamation at ca 2.65 Ga. However, recent work by the GSWA in the northwestern part of the craton has identified a long-lived, autochthonous history of crustal development there, including episodes of volcanism, granitic magmatism, shearing and gold mineralisation that are similar in composition and temporal development to those further east, in what has been interpreted as the accreted, younger part of the craton (EGS). This, together with a number of other features of the surface geology, suggests there are significant problems with current models of crustal development through arc-accretion tectonics.

This project incorporates 2-D and 3-D imaging, modelling and analysis of newly acquired deep seismic, magnetotelluric, gravity, and aeromagnetic data along three linked transects totalling 700 km in length across the northwestern part of the Archean Yilgarn Craton, Australia. These geophysical data will be synthesised in conjunction with new geological data to develop an integrated lithospheric model of the Narryer and Youanmi terranes, and their relation to the Eastern Goldfields Superterrane. Additional studies will include integrated analysis of Lu-Hf in zircons from dated surface samples in order to better understand the roles of juvenile mantle additions to the crust and crustal recycling, and when these different, but possibly linked, factors occurred. The project involves close collaboration between staff of the Geological Survey of WA and researchers at Macquarie and UWA.

The proposed research project will apply well-established, existing research technologies to the previously poorly studied, and underexplored, northwestern part of the Yilgarn Craton: it is the first study of this kind to cover over more than half of the craton. The project is further innovative in developing an integrated research framework from mantle through to crust, involving a team of researchers with different expertise at a variety of scales.

Progress during 2011:

The project will commence in 2012.

Aims and work plan for 2012:

The aims for 2012 are to develop a preliminary 3D model of key areas along the Youanmi seismic reflection lines YU1, YU2 and YU3. This will be achieved by collaborative research between GSWA (Gessner), UWA (Gorczyk), UNSW (van Kranendonk) and Macquarie University (TBA, Belousova, Yang, Afonso, O'Neill). A new Research Associate (employed through Macquarie) will be appointed and based in the Centre for Exploration Targeting at The University of Western Australia in Perth. This researcher will, in collaboration with Macquarie geophysicists, conduct 2-D and 3-D imaging, modelling and analysis of newly acquired deep seismic, magnetotelluric, gravity, and aeromagnetic data along three linked transects totalling 700 km in length across the northwestern part of the Archean Yilgarn Craton, Australia. These geophysical data sets will be used in conjunction with newly acquired geological data with the aim to develop an integrated lithospheric model of the Narryer and Youanmi terranes, and their relation to the Eastern Goldfields Superterrane (see *Research Highlight p. 58*).

10B. ZIRCON LU–HF CONSTRAINTS ON PRECAMBRIAN CRUSTAL EVOLUTION IN WESTERN AUSTRALIA

Modern geochronology has led to substantial advances in understanding the Precambrian geological evolution of Western Australia. However, in many cases it is unclear how rocks or terranes of similar age might be related. This project will obtain and integrate zircon Lu–Hf isotope data with other geological, geochemical and geophysical information to understand the evolution of continental crust in specific areas of Western Australia.

Zircon Lu–Hf analyses provide insight into the relative contributions of juvenile sources and recycled crust to the continental crust through time, and 'Event Signature' curves permit the evolution of different crustal domains to be visually compared. Integrating these constraints with other isotopic and geochemical information, geological mapping, and recently acquired geophysical datasets will advance our understanding of geodynamics and test hypotheses of tectonic evolution. Efforts will be aimed at addressing specific geological questions in key areas, particularly along the new geophysical transects, as well as in underexplored regions (e.g. the Albany–Fraser and Capricorn Orogens) where the new information will also improve the targeting of mineral exploration.

Measurement of hafnium isotopes in zircon crystals allows determination of the Hf isotope ratio at the time of zircon crystallisation. The ability to generate large amounts of data for zircons of a range of ages (within single crystals, single samples, and by compiling data from several samples) means that time-space variations in crustal evolution can be readily evaluated. The project will include analysis of detrital zircons in sedimentary rocks as well as zircons with multiple growth stages in both igneous and metamorphic rocks. In collaboration with GEMOC, isotope analyses will be performed by laser-ablation ICPMS on zircons selected from the GSWA archive of >1000 samples dated using SHRIMP. This is the first time in Western Australia that Lu–Hf isotope data obtained on this scale can be integrated with geological and geochemical data and newly acquired gravity, aeromagnetic, seismic and magnetotelluric datasets.

Progress during 2011:

Samples for Lu–Hf were chosen from the Gascoyne and Musgrave Provinces, the Albany–Fraser Orogen, the Pilbara Craton, the Murchison and Southern Cross Domains and Eastern Goldfields Superterrane of the Yilgarn Craton, and the Edmund, Officer, Ashburton and Bresnahan Basins. The results were integrated with existing isotope data acquired by GSWA, and used in refereed journal articles and GSWA Publications.

The results have already demonstrated the considerable value of this program in understanding geological evolution in key areas of Western Australia. Data for the Albany–Fraser orogen indicate that the earliest Biranup Zone magmas represent reworked Archean crust, and show progressive addition of juvenile mantle through time. This isotopic evolution is compatible with the Biranup Zone representing a Mesoproterozoic active back-arc rift on the Yilgarn margin, rather than being an exotic terrane. Lu–Hf data have confirmed that the Glenburgh Terrane, which forms basement to the Gascoyne Province, has a distinctly different crustal history to the Yilgarn and Pilbara Cratons. Data from the Yilgarn Craton reveal an overlap of the most juvenile Hf values for the Southern Cross Domain with those of the Eastern Goldfields Superterrane. This could suggest a shared crustal source, and that the Eastern Goldfields Superterrane may not be exotic to the western Yilgarn Craton, as previously suggested. Hf isotope data from zircons in intrusive rocks of the west Musgrave Province indicate apparent crustal reworking following juvenile input events at ca 1900 and 1600–1550 Ma.

Aims and work plan for 2012:

The project will continue to generate Lu–Hf isotope data, and integrate them with geological and geochemical data as well as geophysical datasets. The research will be focused in 'greenfields' areas where little information presently exists. Based on results obtained, it is likely that new samples will be collected during the normal course of GSWA fieldwork to address specific geological problems.

Foundation Centre Technology Development projects (Whole-of-Centre projects)

1. CAMECA ION MICROPROBE DEVELOPMENT: MAXIMISING THE QUALITY AND EFFICIENCY OF CCFS ACTIVITIES WITHIN THE UWA ION PROBE FACILITY

The Centre for Microscopy, Characterisation and Analysis at UWA is home to two state-of-the-art Secondary Ion Mass Spectrometers: the CAMECA IMS 1280 large-radius ion microprobe, for the high-precision analysis of stable isotopes in minerals, and the CAMECA NanoSIMS 50 for imaging mass spectrometry at the sub-micron scale. In addition to the analytical capabilities located at the other nodes, the CCFS is poised to become a world-leader in *in situ* stable isotope analysis, and it is therefore essential that the data and interpretations be of the highest quality.

This project provides a dedicated Research Associate for the development of CCFS activities utilising the CAMECA Ion Microprobes at UWA, thereby increasing the capacity of the facility, enabling a higher degree of interaction and participation on projects, and allowing greater synergy with other CCFS node facilities. The Research Associate will play an integral role in experimental design, planning, sample preparation, and the acquisition, processing and interpretation of data. The complex nature of the Ion Microprobes demands a high-degree of technical ability, while an understanding of the aims of the individual projects requires a deep understanding of geological and geochemical processes. This position is fundamental to the generation of high-quality, *in situ*, elemental and isotopic data for a diverse range of projects and, as such, represents a significant investment into the overall success of the CCFS.

Progress during 2011:

The recruitment process began in September 2011, when funds became available. An offer has been made as this Report is being prepared.

Aims and work plan for 2012:

Training for the appointee will commence when the appointment is taken up (estimated mid 2012). Active participation in relevant Centre projects and targeted technique and method development will follow training.

2. FRONTIERS IN INTEGRATED LASER-SAMPLED TRACE-ELEMENT AND ISOTOPIC GEOANALYSIS

The project aims to enhance the world-class facility for *in situ* isotopic and elemental analysis in the Geochemical Analytical Unit (GAU) at GEMOC (see *section on Technology Development, p. 91*), in order to maintain Australia's LAM-ICP-MS capabilities at international standards, and to advance beyond it in some aspects. The advances will be based on femto-second laser sampling and the coupling of instruments for simultaneous analysis.

Research in CCFS depends critically on world-class geochemical and high-pressure experimental infrastructure. The ongoing improvement and refinement of the geochemical methodologies and techniques is driven by the CCFS research program and the acquisition of new instrumentation. In 2010 GEMOC was awarded a $1.5M LIEF grant, to purchase a femto-second laser sampling system, a new quadrupole (Q-)ICP-MS and a single collector sector-field (SF-)ICP-MS. This project uses this infrastructure boost to advance the capabilities of the GEMOC GAU. The current project aims to investigate ways of linking these new instruments in different combinations with laser sampling, to achieve simultaneous analysis of two isotopic systems or of trace-element data together with isotopic data. Combinations of instruments can be achieved by splitting the ablation gas into two lines downstream from the ablation chamber, and using different instruments to analyse the two gas fractions. This will allow a range of innovative analytical approaches, including (but not restricted to):

1. U-Pb dating of zircon and other U-bearing minerals + Hf-isotope analysis
2. Os-isotopes of sulfide grains + trace elements (Q-ICP-MS) or S-isotopes (SF-ICP-MS)
3. Sr-isotopes (MC-ICP-MS) + Pb isotopes (SF-ICP-MS) in feldspars
4. "Non-conventional" stable isotopes (e.g. Li, Si, Mg, Ca, Fe, Ga, Cu, Zn, Mo, Se, Tl and other still unexplored systems; MC-ICP-MS) + trace elements (Q-ICP-MS)

With this enhanced capability, the plan is to expand the stable-isotope program, including:

- Mg, Fe, Si and Li isotopes in olivine from mantle-derived rocks as tracers of mantle processes: melting, metasomatism and the recycling of crustal material
- Mg, Ca and Si isotopes in chondrules, Ca-Al inclusions and other silicate phases in meteorites, as tracers of cosmogenic processes and their timescales
- Mg and Li isotopes in speleothems and microfossils to constrain past climate change
- Si isotopes in quartz from crustal rocks to study hydrothermal processes, and in SiC from kimberlites, to understand the fractionation of Si and C in mantle processes
- Cu, Fe, Zn, Mo, Se, S isotopes in ore systems, including sea-floor "black smoker" chimneys, to investigate biological and other low-T fractionation processes

In each case the collection of trace-element and isotopic data from the same analytical spot will provide better constraints on each type of data than if they were collected from different spots.

The development of new methodologies and applications in this project will provide more analytical options for CCFS researchers and create new research opportunities across all CCFS themes. This facility and the innovation that it represents will help maintain the high profile that Australian geoscience has enjoyed internationally, making it easier to attract high-quality researchers, postgraduate students and industry-related research funding.

Progress during 2011:

Planned innovations in the Geochemical Analysis Unit (GAU) at Macquarie University in the first term of the Centre of Excellence Core to Crust Fluid Systems are based on new instruments purchased with the recent LIEF funding. This equipment allows the development of the 'split-system' techniques in which two mass spectrometers (a MC-ICP-MS and an ICPMS) will be connected to a common laser source for novel simultaneous measurement of geochemical parameters. The current status of this new instrumentation is as follows:

Q-ICP-MS: An Agilent 7700cx Q-ICP-MS has been installed, joining the existing stable of Q-ICPMS (3) and MC-ICPMS (2) instruments. The second instrument has arrived and awaits installation.

Femtosecond Laser Microprobe: At the time of the LIEF application Photon Machines (California) manufactured the only commercially available femtosecond laser ablation microprobe system. In 2010 New Wave Research (UK) released a femtosecond system, which incorporated a new design of their universal platform (UP) beam delivery system. Our assessment of the two laser systems extended into 2011 and following extended negotiations to obtain our required performance specifications an order was placed for a Photon Machines fs198 laser system. This instrument is scheduled for delivery in April-May 2012.

SF-ICP-MS: Following the order of the femtosecond laser, an order was placed for the Nu Attom high-resolution SF-ICP-MS. The features of this instrument include continuously variable high-resolution capabilities, fast electrostatic scanning/jumping and a fully laminated, high-scan-speed magnet. Fast data acquisition is critical in the measurement of the transient signals produced by laser ablation and the performance and operation of the magnet in fast scanning mode during evaluation of the Nu Attom proved to be critical for the types of applications for which it is to be used. The Nu Attom is due for delivery in July-August 2012.

In addition to the new laser systems on order, two of the existing New Wave UP-213 laser ablation microprobes underwent upgrades in 2011 to enhance the system capabilities. The modifications incorporated refurbishment of laser sources and new sample cell designs. These produced improved stability, sensitivity and sample throughput, all of which resulted in increased efficiency and data quality.

While the new instruments are being built, several parallel method development programs for the measurement of Li and Mg isotopes have been underway. These programs have led to significant advances in the separation of these elements from complex rock and mineral matrices, as well as in the mass spectrometer measurements. This work is also contributing to the development of well-characterised reference materials that are essential for *in situ* analysis by laser ablation ICP-MS or SIMS.

Lithium isotopes

Advances have been made in the application of lithium isotopes as a potential tracer of fluid-rock interaction in the deep Earth. These advances have centred on the extraction and purification of lithium isotopes from a range of different rock types and the development of analytical procedures to determine high precision isotope ratios by plasma source mass spectrometry. Specific developments include:

- the refinement of methods for basaltic rocks;
- the adaptation of these procedures to ultramafic rocks from the Earth's mantle that have extremely low Li abundances;
- the analysis of Li isotopes in zircon (in collaboration with Partner Institution CAS (Beijing));
- the analysis of Li from corals (collaboration with Dr Mei-Fei Chu, National Taiwan University).

The method development program has been undertaken by a postdoctoral researcher (supported by the NSW SLF) and protocols have been established to enable the transfer of the methodology to other researchers. To date two higher degree research students (both international cotutelle) and one postdoctoral fellow have commenced programs in CCFS to apply and enhance the methods in their specific projects.

Magnesium isotopes

The pioneering work on the high-precision measurement of Mg isotopes in mantle olivine by Pearson et al. (2006) demonstrated how mass-dependent isotopic fractionation at high temperature could be used as a tracer of deep earth processes. The extension of this approach to other mantle minerals is complicated by more complex chemical compositions. In 2011 a project was initiated to analyse the Mg isotopic composition of mantle-derived garnets from a suite of eclogites from the Roberts Victor kimberlite in South Africa. So far the work has involved the development of new extraction and purification techniques specifically for Ca-Mg-Fe garnet compositions and preliminary measurements indicate the robustness of the new chemical procedures.

Aims and work plan 2012:

- Delivery, installation and commissioning of femtosecond laser system (due April-May, 2012).
- The appointment of a Research Associate (Postdoctoral position) with existing expertise in laser sampling and ICP-MS analysis to undertake method development on the femtosecond laser system.
- Establish and undertake the first phase of an experimental program to investigate fundamental properties of femtosecond ablation processes in geological materials, focusing on laser-induced isotopic fractionation.
- Delivery, installation and commissioning of Nu Attom high resolution SF-ICP-MS (due July-August, 2012).
- Transfer of *in situ* methodologies for trace-element analysis and U-Pb isotope measurements from Q-ICP-MS to Nu Attom.
- Refinement of Li isotope methodologies and expansion to other applications.
- On-going development of the procedures for the measurement of Mg isotope composition of garnet.

3. OPTIMISING MINERAL PROCESSING PROCEDURES: FROM ROCK TO MICRO-GRAINS

Aims:

Liberation and recovery of accessory mineral components of any type of rock, for geochemical and geochronological analysis.

The aims of the CCFS projects require the separation of accessory minerals from a range of different rock types. There are several major issues with these processes: breakage of grains, potential laboratory contamination, and the concentration and separation of extremely fine-grained phases. These problems can now be reduced if not eliminated by using new technology and newly developed procedures: (1) electrostatic pulse disaggregation (EPD); (2) the use of disposable sieves; (3) hydroseparation procedures for ultrafine material.

The first selFrag instrument in Australia was installed in GEMOC in May 2010. The selFrag uses EPD to break rock samples into their component phases and produces better liberation of mineral phases, especially accessory minerals, than conventional crushing procedures. Because disaggregation proceeds along grain boundaries, it greatly increases the proportion of unbroken grains. Disaggregation takes place inside a large Teflon-lined container, which is easily cleaned to prevent cross-contamination.

Examples:

- **Zircon separation:** Increasing the yield of zircon crystals for geochronology. The liberated zircon crystals are virtually unbroken and the surfaces are very clean. In contrast to mechanically crushed samples, no remnants of other minerals such as biotite have been found on the zircon surfaces.
- **Separation of Platinum Group Minerals from chromite ores:** Conventional mechanical crushing of compact chromite samples produces multi-mineral grains and excessive amounts of dust. The recovery of PGMs is very difficult. Selective fragmentation using the selFrag, on the other hand, produces only small amounts of fines and no dust. Breakage occurs preferentially along grain boundaries and inclusions, thus liberating the platinum minerals.
- **Separation of minor components from complex rocks:** e.g. kimberlites and diamondites

Progress during 2011:

Since its installation the selFrag has been used for a range of applications including zircon separation, the analysis of grain size and shape of phenocrysts in volcanic rocks, and the liberation of trace minerals from a range of mantle-derived and crustal rocks. In 2011 the selFrag was used to process more than 160 samples for 30 different research projects, including CCFS research projects (TARDIS; PhD projects; Honours), *TerraneChron®* and users from other institutions (e.g. ANU, Wollongong University, NSW Geological Survey). Users are trained in the operation of selFrag and mineral separation procedures, and the training program is an important aspect of the facility's operations and achievements.

Each new sample processed on selFrag requires the development and refinement of experimental procedures depending on grain size, mineralogy and the amount of sample. As experience is gained through the processing of different rock types, a handbook of experimental conditions is being compiled, benefiting all users and improving the efficiency of the facility.

A facility for mineral separation is being established at GEMOC to process the products of the selFrag and in 2011 the following separation methods were developed and/or refined:

- sample sieving using disposable plastic/nylon sieves to prevent (cross-) contamination of samples
- heavy liquid mineral separation using aqueous solutions of the nontoxic chemical sodium polytungstate (SPT) for heavy-mineral separation

- magnetic/paramagnetic separation using a Frantz® Magnetic Barrier Laboratory Separator for separation of dry materials according to magnetic susceptibility, exploiting either paramagnetic or diamagnetic properties => output fractions: magnetic, paramagnetic and non-magnetic
- micropanning equipment is available for further concentration of phases with densities slightly different from their matrix – best suited to grains >200 microns

A hydroseparator (CNT-HS-11, manufactured by CNT Corporation, Canada) was purchased in 2011 and is currently being installed. This device processes samples of extremely fine-grained (down to a few microns) water-insoluble particles/grains to produce "heavy-mineral concentrates" from material of similar physical properties. The aim is to take disaggregated material from the selFrag and process theses using the hydroseparator to concentrate rare accessory phases (e.g. alloys in mantle peridotites, platinum group minerals in chromitites). Dr José María González-Jiménez visited the University of Barcelona in September 2011 to undertake training in the use of the hydroseparator and this experience is helping to set up the equipment and establish the technique.

Other ancillary equipment purchased in 2011 for the mineral separation facility included a large-volume drying oven, binocular microscope, top-loading balance and glassware for heavy liquid separation.

Aims and work plan for 2012:

The principal objectives for 2012 are to continue to produce high-purity mineral separates for CCFS research programs and to train users in the latest mineral separation procedures.

Planned development and refinement of procedures and protocols for selFrag include:

- Expansion to new rock types
- Use of small volume cell to extract mineral inclusions
- Improve zircon yield from ultra-fine materials

A priority in 2012 is to finalise the installation and commissioning of the hydroseparator, and initial method development will focus on the separation of PGMs from chromitite.

ECSTAR projects

The following projects are supported by ARC Post-Award funds allocated mid 2011 for early-career researchers. These are ARC ECSTAR Fellowships (Early Career Startup Awards for Research). The two appointees in 2011 are Dr José María González Jiménez and Xuan-Ce Wang.

ECSTAR PROJECT 1. PLATINUM-GROUP MINERALS: MONITORS OF DEEP EARTH PROCESSES

José María González-Jiménez: Supported by ARC CCFS ECSTAR (commenced 2011)

This project interfaces with Foundation Project 1, The TARDIS-E Project: Tracking Ancient Residual Domains in the Silicate-Earth. The Re-Os isotopic system in Platinum-Group Minerals (PGM) from Earth's mantle potentially provides the most robust record of long-term interactions between distinct regions of Earth's interior. However, the reliability of this approach needs further testing, because the chemistry of many PGM hosted in mantle-derived rocks has been modified by hydrothermal alteration or metamorphism during excavation of the mantle rocks from deep Earth to surface. The fact that PGM of different suites of mantle rocks exhibit variable scales of heterogeneity of Os suggests that post-magmatic alteration could also disturb the Re-Os compositions of these minerals. This project uses a combination of classical mineralogical methods and novel micro-analytical techniques for isotopic measurements to test the robustness of the Re-Os system in PGM from mantle-derived rocks affected by variable degrees of hydrothermal alteration and metamorphism, and thus to constrain the interpretation and applications of Os-isotope data.

Progress during 2011:

We have found significant differences in $^{187}Os/^{188}Os$ between primary and secondary PGM from metamorphosed ophiolite chromitites of the Dobromirtsi Ultramafic Massif, in the Central Rhodope Metamorphic Core Complex of southeastern Bulgaria. Primary (magmatic) PGM hosted in unaltered chromite cores have $^{187}Os/^{188}Os$ from 0.1231 to 0.1270 and $^{187}Re/^{188}Os \leq 0.002$. T_{MA} and T_{RD} model ages, calculated relative to the Enstatite Chondrite Reservoir cluster around three main peaks: ~ 0.3, 0.4 and 0.6 Ga. Secondary PGM, produced by alteration of magmatic PGM, have a wider range of variation ($^{187}Os/^{188}Os$ = 0.1124-0.1398, $^{187}Re/^{188}Os \leq 0.024$); these grains yield T_{MA} and T_{RD} model ages from -1.7 up to 2.2 Ga. The larger range in $^{187}Os/^{188}Os$ in the secondary PGM is interpreted as due to reactions between the primary PGM and infiltrating metamorphic-hydrothermal fluids with a range of Os-isotope compositions. This redistribution of Os in PGM during metamorphism has significant implications for the interpretation of both whole-rock and *in situ* Os-isotope data in mantle-derived rocks since Os-isotope compositions of Platinum-Group Minerals (PGM) in ophiolite chromitites have been commonly regarded as resistant to fluid-related processes. Thus, the fact that secondary PGM in the metamorphosed chromitites of Dobromirtsi yield $^{187}Os/^{188}Os$ within the range of depleted to enriched mantle sources suggests that much of the Os-isotopic variability previously reported for PGM taken out of their microstructural setting (e.g. mineral concentrates or detrital grains collected from streams), and interpreted as a magmatic feature, may instead be related to secondary alteration processes. Therefore, interpretations of mantle events based on the analysis of PGM nuggets from placers may be need to be re-considered. On a more positive note, the Os-isotope data from the secondary Os-bearing phases in ophiolites can give a wider perspective on the sources and evolution of the host mantle peridotite (Geology, *CCFS Publication # 42*).

Aims and work plan for 2012

The basic approach of the ECSTAR I project requires obtaining a statistically useful number of Os-isotope analyses of PGM from a large number of sample localities with a range of types and degrees of alteration. The strategic planning for 2012 aims to expand the set of PGM analysable for *in situ* Re-Os isotopes by sampling PGM-bearing rocks from ultramafic bodies with well-established P-T conditions of post-magmatic alteration. It will involve visiting ophiolite sequences exposed in the Coolac Serpentinite Belt in southern Australia (low-temperature oceanfloor serpentinisation), the Vizcaino Peninsula in northern Mexico (mid-grade metamorphism) and the Jakovitsa, Avren and Golyamo Kamenyane Ultramafic Massifs in southern Bulgaria (mid-to-high grade metamorphism). Another set of PGM-bearing rocks from ophiolites and other ultramafic complexes with different settings and with potential for finding PGM will be provided by overseas collaborators: ophiolite of Tehuitzingo (central Mexico) to be supplied by Dr Joaquín Proenza (University of Barcelona Spain), transitional ophiolite-subcontinental mantle Kohistan paleo-Arc (Pakistan) to be supplied by Dr Carlos Garrido (Consejo Superior de Investigaciones Científicas, Granada, Spain) and Dharwar Craton (India) to be supplied by Dr Sisir K. Mondal (Jadavpur University, Kolkata, India).

It also is planned in 2012 to expand the set of PGM potentially useful for Re-Os isotopes by obtaining concentrates of PGM from whole-rock samples using the combination of selFrag electrostatic rock disaggregation plus hydroseparation, both facilities being currently developed at the Geochemical Analysis Unit at CCFS/GEMOC. The new development of hydroseparation at CCFS/GEMOC will be carried out in collaboration with two Spanish labs from the University of Barcelona and Granada which already have experience in the use of this technique. With the aim to constraint better constrain the Re-Os isotopic data obtained from the PGM it is also hoped that this technique will assist in searching for zircons in PGM-bearing rocks. Thus it is aimed to determine distributions of major, minor and trace elements as well as radiogenic isotopes (U-Th-Pb and Lu-Hf series). This new research line in the project will be carried out in close collaboration with CCFS/GEMOC and overseas collaborators. The project aims for 2012 mesh with current research projects of undergraduate, post-graduate and PhD students under the supervision of the project leader. These include students from different Earth Sciences departments of overseas Universities: National University of Mexico (UNAM, Mexico), Universities of Zaragoza and Barcelona (Spain) and the Geological Institute of the Bulgarian Academy of Science (BAS, Bulgaria). Communication of results is planned to be mainly through international scientific journals (e.g. *Chemical Geology, Contributions to Mineralogy and Petrology, Lithos*) and presentations in high-profile international geoscience conferences: Cordilleran Section, Geological Society of America 108th Annual Meeting, to be held 29-31 March 2012 in Querétaro City (Mexico); XXXII Reunión Cientifica de la Sociedad Española de Mineralogía to be held 27-30 June 2012 at Bilbao (Spain); 22nd Goldschmidt conference to be held 24-29 June 2012 at Montréal (Canada); 34th International Geological Congress to be held 5-10 August at Brisbane (Australia); International Earth Science Colloquium on the Aegean Region 2012, to be held 1-5 October 2012 in Izmir (Turkey).

José María González Jiménez and Carlos Villaseca (Universidad Complutense de Madrid) in the field.

ECSTAR POJECT 2. ESTABLISHING THE LINKS BETWEEN PLATE TECTONICS AND MANTLE PLUME DYNAMICS: MESSAGE FROM THE LATE CENOZOIC LEIQIONG BASALTS IN SE ASIA

Xuan-Ce Wang: Supported by ARC CCFS ECSTAR funding and NSFC (National Science Foundation of China) Project grant (commenced 2011)

Whether mantle plumes and plate subduction are genetically linked is a fundamental geoscience question that impinges on our understanding of how the Earth works. Late Cenozoic basalts in Southeastern Asia are globally unique in relation to this question because they occur above a seismically-detected thermal plume adjacent to major deep subducted slabs. The main goal of this project is to examine the petrogenesis of late Cenozoic continental flood basalts (CFBs) that are located directly above a plume-like mantle seismic structure, and spatially close to major subduction zones in southeastern Asia. We will take a multidisciplinary approach, determining the chemical composition of the primary melts of the basalts, characterising the chemical compositions of their mantle source, and examining the temporal-spatial variations in the geochemical characteristics of the Leiqiong CFB. We will also test the geological and thermochronological evidence for lithosphere uplift. The results will be employed for testing major predictions of plume models as well as other end-member geodynamic models for such unique CFBs. This study will advance our understanding of (1) the thermochemical state of the deep Earth where a lower-mantle-rooted plume-like seismic structure exists unusually close to subducted slabs; (2) relationships between geophysical and geological manifestations of mantle plume activities at mantle downwellings; (3) the nature and origin of enriched mantle source regions; and (4) the behaviour of mantle plumes at plate boundaries and inter-relationships between mantle plume dynamics and plate tectonic processes. Knowledge obtained in this project will help to address one of the most fundamental questions in geodynamics: how the two major processes of whole-mantle convection, i.e., deep subduction that drives mantle downwelling, and mantle plumes that drive mantle upwelling, relate to and interact with each other.

Progress during 2011:

We have established the mantle thermal state beneath Hainan Island, based on the estimated primary melt compositions. The estimated mantle potential temperature varies from about 1500 to 1580° C with a weighted average of 1541 ± 10° C (Wang et al., *Journal of Petrology, 2012*). This provides independent support for the Hainan plume model that has previously been proposed largely based on geophysical observations. Pb-isotope analyses demonstrate that the basalts were derived mainly from an ancient (4.5–4.4 Ga) primitive mantle reservoir preserved near the core-mantle boundary (CMB). Their Nd- and Os-isotope compositions also suggest a lower-mantle origin. These new findings, along with existing evidence for high melting temperatures, confirm that the plume-like mantle seismic velocity structure indeed represents a plume from the lower mantle fuelled by an ancient reservoir at the CMB. The fact that this young plume is surrounded by deep subduction zones further suggests that they are genetically linked to each other, thus providing the first observational support for dynamic linkages between deep subduction and mantle plume generation.

Aims and work plan for 2012:

1) In-depth characterisation of the mantle heterogeneity beneath the Leiqiong flood basalt by examining geochemical and petrological variation with increasing depth of the lava plateau. This analysis is based on drill core samples.
2) To conduct He isotope analysis of olivine in order to examine the relationship between He isotopes and other elements and isotopes
3) Construction of a 3-D model of the geometry of the Hainan Plume within the upper mantle to evaluate the effect of later subduction-driven mantle flow; this is important for understanding the potential relationship between plate tectonics and mantle plumes
4) To undertake an in-depth analysis of the effect of dehydration of stagnated Pacific slabs on the generation of the Cenozoic intraplate volcanism in eastern Asia

Appendix 2: Independently funded basic research projects

Independently funded research projects within CCFS contribute to the long-term, large-scale strategic goals and play an important role in determining the shorter-term research plans. Research goals for each year are thus linked to the aims of funded projects. Summaries of the current independently funded CCFS-related projects are given below.

Multiple vertical tectonic movements in a continental interior: consequences of flat-subduction and foundering of an oceanic plateau?

Z.X. Li, M. Danisik, Y. Xu: Supported by ARC Discovery

Summary: **This project will investigate how the subduction of particularly thick oceanic crust impacts on the landscape, climate, structure and composition of the adjacent continent. It will help in understanding the history and distribution of mineral and hydrocarbon resources of similar provinces in Australia.**

What lies beneath: Unveiling the fine-scale 3D compositional and thermal structure of the subcontinental lithosphere and upper mantle

J.C. Afonso, Y. Yang, N. Rawlinson, A.G. Jones, J.A.D. Connolly, S. Lebedev: Supported by ARC Discovery (commencing 2012)

Summary: **Characterising the compositional and thermal structure of the lithosphere and upper mantle is one of the most important goals of Geoscience. Yet, a method capable of providing robust estimates of these two fields in 3D has still not been achieved. This limitation is the focus of this project, which will develop the first full 3D method that integrates multiple geophysical and petrological datasets. We will apply our methodology to image the fine-scale thermochemical structure of the lithosphere beneath Australia, South Africa, and western USA. This project will not only help us understand the evolution of continental lithosphere but its outcomes will be translatable into predictive exploration methods for Australia's Deep Earth Resources.**

The application of very short-lived Uranium-series isotopes to constraining Earth system processes

S. Turner, T. Dosseto, M. 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.**

The effective strength of oceanic plate bounding faults

C. O'Neill, J.-C. Afonso: Supported by ARC Discovery and MQ (commenced 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

T. Rushmer, S. Turner: Supported by ARC Discovery (commenced 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.**

Partial melting in natural metal-silicate and silicate systems: rheological and geochemical implications for the Earth and other planets

T. 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.**

Oxygenating the Earth: using innovative techniques to resolve the timing of the origin of oxygen-producing photosynthesis in cyanobacteria

M.R. Walter, B.A. Neilan, S.C. George, R.E. Summons, J.W. Schopf: Supported by ARC Discovery

Summary: **The early Earth was a hostile place with little oxygen in the atmosphere. Then cyanobacteria ('blue green algae') invented oxygen releasing photosynthesis. That profound event affected many fundamental processes, from the course of evolution to the formation of ore deposits. However, estimates of when these bacteria originated are disputed with uncertainties of hundreds of millions of years. We will resolve those uncertainties. We have developed new analytical techniques that we will apply to well preserved 2.7-2.8 billion year old rocks in Western Australia. We will couple that approach to the use of the latest genetic techniques to reveal the origins of living cyanobacteria.**

Investigation of the early history of the Moon: implications for the understanding of evolution of Earth and Solar System

A. Nemchin, M.L. Grange: Supported by ARC Discovery (commencing 2012)

Summary: **The goal of the project is to characterise the chemistry and timing of processes that shaped the specific evolutionary path followed by the Moon during the early history of the Solar System. This is not only vital for evaluation of lunar history, but is also essential for a better understanding of early evolution of the Earth, where the record of the first 500 m.y. of history has been erased by the continuous activity of the planet. The project will test existing models of lunar evolution describing initial global differentiation, early plutonic magmatism, impact history and volcanic activity, shedding new light on the processes driving these major events on the Moon and determining the ability of these models to describe the early history of the Earth.**

Supercells and the supercontinent cycle

W.J. Collins, J.B. Murphy, E. Belousova, M. Hand: Supported by ARC Discovery (commencing 2012)

Summary: **Phanerozoic plate motions can be explained by westerly and northerly migration of continental blocks toward Laurentia during protracted (~500 Ma) northerly mantle flow, confined within a hemispheric supercell. The other supercell on Earth encompasses the oceanic Pacific realm, characterised by E-W mantle flow diverging from the East Pacific Rise. We aim to determine if similar supercells and mantle flow patterns existed during the Proterozoic, by characterising contrasting orogenic systems within different supercells through tectonostratigraphic review, isotopic fingerprinting using Lu-Hf isotopes in zircon, and by paleomagnetic analysis. This is a new holistic approach to solving Precambrian geodynamics and continental reconstructions.**

Investigating the fundamental link between deformation, fluids and the rates of reactions in minerals

S. Piazolo, N.R. Daczko, A. Putnis, M.W. Jessell: Supported by ARC Discovery (commencing 2012)

Summary: **In Earth's crust and mantle, minerals are constantly undergoing chemical changes while simultaneously being deformed. In this project we use a novel combination of techniques in order to advance our understanding of how deformation influences these chemical changes.**

Dating Down Under: Resolving Earth's crust - mantle relationships

E. Belousova: Supported by ARC Future Fellowship and MQ (commencing 2012)

Summary: **How the continental crust has grown is a first-order problem in understanding the nature of the surface on which we live. Was most of the crust formed early in Earth's history or did it grow episodically? Was its growth related to underlying mantle processes? The project will use in situ isotopic and trace-element microanalysis of the mineral zircon (a geological "time capsule"), extracted from rocks and sediments worldwide, to answer these fundamental questions. It will develop a new model for the timing of crustal formation and the tectonic and genetic links between Earth's crust and mantle. The results will be relevant to the localisation of a wide range of mineral resources.**

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

C. O'Neill: Supported by ARC Future Fellowship and MQ (commenced 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.**

Flow characteristics of lower crustal rocks: developing a toolbox to improve geodynamic models

S. Piazolo: Supported by ARC Future Fellowship and MQ (commencing 2012)

Summary: **This project will investigate in detail how rocks flow in the lowest part of the Earth's crust. The results will be used to improve sophisticated computer simulations of large-scale geological processes, allowing a better understanding of earthquakes, the formation of volcanic areas and location of energy resources.**

From Core to Ore: emplacement dynamics of deep-seated nickel sulphide systems

M. Fiorentini: Supported by ARC Future Fellowship (commencing 2012)

Summary: **Unlike most mineral resources, which are generally concentrated in a wide range of crustal reservoirs, nickel and platinum are concentrated either in the core or in the mantle of our planet. In punctuated events throughout Earth history, large cataclysmic magmatic events have had the capacity to transport and concentrate these metals from their deep source to upper crustal levels. This project aims to unravel the complex emplacement mechanism of these magmas and constrain the role that volatiles such as water and carbon dioxide played in the emplacement and metal endowment of these systems.**

Events through time: eruptions, extinctions, impacts, ore-bodies and orogenies - upgrading the national argon geochronology network

G.S Lister, F. Jourdan, M.A Forster, B.I McInnes, P.M Vasconcelos, G. Rosenbaum, D.R Cooke, A.C. Harris, D. Giles, A.S. Collins, J. Aitchison, N.R. Daczko, W.J. Collins, S.M. Reddy, Z.-X. Li, T.C. McCuaig, J.M. Miller, B.J. Pillans, R. Grun, H. Zwingmann, N.J. Evans, M.O. McWilliams (ARC LIEF, 2011)

Summary: **Nine universities and the CSIRO will replace aged and obsolete equipment with new mass spectrometers which will be strategically placed at opposite ends of our continent to improve access for Australian researchers to these instruments for which there is high demand. These instruments will allow more exact dating of events such as eruptions, impacts, climate change, biological extinctions, mineral deposits and mountain building.**

Nanoscale Characterisation Centre WA analytical electron microscope facility (UWA)

D. Sampson, M. Fiorentini, Y. Liu, R.J. Gilkes, B. Rasmussen, Z. Rengel, N.J. McNaughton, C. Kirkland, S.A. Wilde, M.T. Wingate, Z. Xie, R.C. Thompson: Supported by ARC LIEF

Partner/Collaborating Organisation(s): Geological Survey of Western Australia, Curtin University of Technology, Edith Cowan University, Murdoch University

Summary: **This analytical facility for Western Australia will provide researchers with much needed access to new electron microscope instrumentation. The facility will support major research efforts in key disciplines, including minerals and mining, energy, engineering, nanotechnology, medical science, forensics, agriculture and animal science.**

Tectonic evolution and lode gold mineralisation in the Southern Cross district, Yilgarn Craton (WA): a study of the meso- to Neoarchaean missing link

Barley, McCuaig, Gessner, Miller, Tohver, Doublier, Romano, Doublier: Supported by ARC Linkage

Summary: **The primary objective of this study is to develop a superior tectono-metamorphic model to capture the geological evolution of the gold-endowed Youanmi Terrane in the Yilgarn Craton of Western Australia. The structural relationship between Archean (i.e. > 2,500 million years ago) greenstone belts and adjacent granitoids is critical to unravel the crustal evolution of the Early Earth and understand the formation of gold deposits. Based on a multidisciplinary approach, this project will generate an improved metallogenic model to help target areas of high prospectivity for gold mineralisation in Western Australia and world-wide.**

A novel approach for economic uranium deposit exploration and environmental studies

S. Turner, B. Schaefer, G. 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.**

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

W.L. Griffin, S. O'Reilly, N. Pearson: Supported by ARC Linkage and De Beers Group Services (commenced 2009)

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.

The first Australian high pressure Synchrotron facility for geoscience research

T. Rushmer, H.S. O'Neill, A.R. Cruden, S.P. Turner (ARC LIEF 2012)

Summary: **In high-pressure mineral physics and chemistry, mineral properties, stress-strain relationships and processes like partial melting are applied to geophysical research about the deep Earth. This project will provide a large volume, high pressure capability at the Australian Synchrotron which will allow these mineral properties to be measured under conditions which simulate the deep earth.**

Flexible architecture high-performance computing facility for the intersect consortium of New South Wales

L. Radom, I.H. Cairns, J.W. Crawford, L. Shen, C.M. Wade, M.R. Wilkins, H.A. Abbass, A.S. Dzurak, J.P. Evans, W. Wen, C.G. Poulton, M.D. Arnold, L.C. Botten, M.J. Ford, A. Rahmani, C.J. O'Neill, K.K. Cheung, M.E, F.A. Henskens, J.M. Borwein, T.R. Marchant, M. Hagenbuchner, K.A. Tieu, A.L. Rose, S.A. Gillies, P.L. Harrison, D.L. Waters, G. Leedham, R.D. Murison (ARC LIEF 2011)

Partner/Collaborating Organisation(s): ***Macquarie University, Southern Cross University, The University of Newcastle, The University of New England, The University of New South Wales, University of Technology, Sydney, University of Wollongong***

Summary: **This new supercomputing facility is an important addition to the nation's research infrastructure and will enable world-leading, New South Wales researchers to continue their ground breaking work in increasingly competitive environments. Much of the research to be undertaken at the facility lies in areas of national priority, including frontier technologies and environmental sustainability.**

How does the continental crust get so hot?

C. Clark: Supported by ARC DECRA (commencing 2012)

Summary: **This project is aimed at constraining the tectonic drivers of high geothermal gradient crustal regimes. The key outcomes of this project are better constraints on the tectonic drivers of high geothermal gradient metamorphism and the development of quantitative tools to assess the evolution of heat within areas of mountain building.**

Tectonic setting and evolution of the Paleoproterozoic Jiao-Liao-Ji Belt in the Eastern Block of the North China Craton

G. Zhao, S.A. Wilde, S. Li, and X. Li: Supported by HK RGC GRF (Project code: HKU7057/08P); (commenced 2009)

Summary: **The Jiao-Liao-Ji belt is one of three Paleoproterozoic mobile belts in the North China Craton. Previous studies have suggested it formed in an extensional regime, in contrast to the collisional origin proposed for the Khondalite Belt and the Trans-North China Orogen. The well-exposed central part contains the Liaoji Granitoids and the North and South Liaohe Groups. The Liaoji granitoids record two ages: 2.2–2.1 Ga from monzogranitic gneisses and 1.88–1.85 Ga from porphyritic monzogranites and alkaline syenites. The North and South Liaohe Groups consist of volcano-sedimentary sequences metamorphosed from greenschist to lower amphibolite facies. Zircons from both groups have magmatic cores that define two age populations: at 2.5 Ga and 2.2–2.0 Ga, indicating provenance from late Archean basement rocks and the Liaoji Granitoids. Zircon rims in both groups yield ages of ~1.95 Ga, interpreted as defining peak metamorphism. Metamorphism was thus coeval with that in the Khondalite Belt in the Western Block of the North China Craton. Protoliths of both groups appear to have been deposited coevally between 2.1–1.9 Ga and similar Hf model ages and εHf values confirm this conclusion.**

Facility for long term preservation and storage of biological, chemical, environmental and geological samples

Nevalainen, Packer, Karuso, Jamie, Molloy, Brown, Liu, Herbert, George, Vemulpad: Supported by Macquarie University Research Infrastructure Block Grants (RIBG)

Summary**:** **Funds will be used to establish an integrated facility for safe preparation and preservation (freeze drying) and long term (-80 °C) storage of precious biological, environmental, geological and chemical samples. These materials are the result of longstanding and recently established research of biological, medical and environmental significance, and form the basis for future research and new IP. In recent years, we have lost various precious samples due to lack of and breakdown of freeze driers and freezers. The need for cryo-preparation and storage facilities is therefore acute, especially with the recent appointment of CORE researchers and concurrent significant increase in research activity.**

Hydrothermal footprints of magmatic nickel sulfide deposits

M. Fiorentini, S. Barnes, Miller: Supported by MERIWA, WA State Gov.

Summary: **(MERIWA M413) This study focuses on the mineralogical and lithogeochemical footprints around syngenetic magmatic nickel-sulphide deposits, which arise from the interaction of these deposits with later hydrothermal fluids. Hydrothermal footprints are in common use in gold and Cu-Zn exploration, but have so far received little attention from nickel explorers, mainly because the nature and the scale of the alteration halo are largely unconstrained. This study addresses this window of opportunity: The new knowledge acquired from this study will aid exploration for nickel-sulphide systems at multiple scales, and will be applied in the interpretation of isolated "orphan" drill holes under cover in greenfields terranes, as well as in more data-rich mine-scale environments.**

Nature of the lower continental crust

N. 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.**

Laser ablation microprobe sample cell

S.Y. O'Reilly: Supported by MQRIBG O'Reilly (commencing 2011)

Summary: **Funds are requested for a new-design large-format sample-cell to upgrade one of the existing laser microprobes that is used in the microanalysis of trace elements and isotope ratios in minerals. These types of data are fundamental to the majority of the current ARC Discovery and Linkage projects in GEMOC, the new CoE and the EAPE CoRE. The new sample-cell will provide significant benefits for data quality, spatial resolution and increased sample throughput. The combination of these factors will enable significant improvement in current methods, sensitivity and productivity, and development of new analytical procedures that will enhance future research capabilities.**

Understanding the growth of the Tibetan Plateau: Unveiling the final-scale 3D structure of the crust and upper mantle beneath the Tibetan Plateau

Y. Yang: Supported by MU New Staff Scheme

Summary: **The Tibetan Plateau is the highest and largest plateau in the world with an average elevation of about 4-5 km, and it is still growing vertically and laterally. How such a broad and highly elevated plateau formed and persisted, however, is still not well understood. This project investigates the fine-scale 3D structures of the crust and upper mantle beneath the Tibetan Plateau using innovative tomography methods and extensive and dense coverage of seismic stations. The outcomes of this project will shed new insights on fundamental questions regarding the growth of the Tibetan Plateau.**

Resurrecting Rodinia? The role of east Antarctica in supercontinent assembly

N. 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.**

AuScope Australian Geophysical Observing System - Geophysical Education Observatory

C. O'Neill: Supported by EIF

Summary: **AuScope Australian Geophysical Observing System is designed to augment existing NCRIS AuScope infrastructure with new capability that focuses particularly on emerging geophysical energy issues. It will build the integrated infrastructure that facilitates maximum scientific return from the massive geo-engineering projects that are now being considered – such a deep geothermal drilling – in effect building the platform for treating these as mega geophysical science experiments. AuScope AGOS infrastructure will enable collection of new baseline data including surface geospatial and subsurface imaging and monitoring data, thereby providing for better long-term management of crustal services, particularly in our energy-rich sedimentary basins. The Geophysical Education Observatory – comprising the development of digital real-time connection to existing teaching laboratories, will use the national observatory to provide a unique opportunity for integrating scientific research and education by engaging students, teachers, and the public in a national experiment that is going on in their own backyard.**

The thermal evolution of Peninsula India: Past behaviours and future potential

A. Collins, M. Hand, D. Kelsey, G. Baines, G. Backe, G. Halverson, (McGill Uni, Canada), C. Clark, S. Reddy, P. Kinny, N. Timms (Curtin Uni), Chetty, Sukanta Roy, Babu, Rajendra-Prasad, Singh, Harinarayana, Bhaskar Rao (National Geophysical Research Institute, India), Gupta, Mumtani, Panigrahi (Indian Institute of Technology, Kharagpur), Bhattacharya, Saha, Patranabis-Deb (Indian Statistical Intitute, Kolkata): Supported by Department of Innovation, Industry, Science and Research – Australia – and Department of Science and Technology – India – Strategic Research Fund Award (Commenced 2009)

Summary: **The roots of southern Indian mountain belts (orogens) have experienced extremely high crustal temperatures (>900°C) in the geological past that are at least in part due to the presence of detrital U, Th and K (i.e. radioactive heat-producing elements) caught up in sedimentary rocks deposited before the orogens formed. If equivalent-aged sedimentary rocks that occur outside of the orogens have the same sources, or deposits eroded from these orogens can be identified, southern India will have the potential for a significant geothermal 'hot-fractured rock' resource.**

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

S. O'Reilly, W. Griffin, N. Pearson, O. Alard, B. Ildefonse, S. 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)).

Petrogenesis of Leiqiong flood basalts: constrain the potential linkage between mantle plume and subduction

J. Li, PI: X.-C. Wang: Supported by NSFC (commenced 2011)

Summary: Whether mantle plumes and plate subduction are genetically linked is a fundamental geoscience question that impinges on our understanding of how the Earth works. Late Cenozoic basalts in Southeastern Asia are globally unique in relation to this question because they occur above a seismically detected thermal plume adjacent to deep subducted slabs. This project will address a geodynamic model that links these two fundamental geotectonic processes.

Three-dimensional characterisation of brittle fault rocks

Gessner, Hough, Toy, Thebaud, Liu, Dellepiane, Zwingmann, Kopf: Supported by The International Synchrotron Access Program (ISAP)

Summary: Understanding the microstructure of fault rocks is highly relevant to geological applications such as carbon storage, hydrocarbon and geothermal reservoir characterisation, earthquake mechanics and mineral exploration. We propose to obtain micro-tomographic images of cataclasite and gouge samples from active natural faults in different settings and experimental samples using the XOR 2-BM at the Advanced Photon Source. Particles and porosity are analysed in three dimensions. This project will advance the understanding of fault rupture during earthquakes, and of the role that fault rocks play in the flow of fluids within Earth's crust.

Archean subduction in the Kaapvaal Craton

M.J. van Kranendonk: Supported by UNSW SPF01 (commencing 2012)

Summary: This project will investigate claims of a fossil Archean subduction zone (ca. 3.2 Ga) within the Kaapvaal Craton of Southern Africa. Previous work has suggested the presence of such a structure based on interpreted metamorphic conditions preserved in amphibolites, but no convincing map of the area has been presented in which to place this claim in context. This project will map the area and determine the nature of the metamorphism within a regional structural and lithological framework.

The Archean-Proterozoic boundary in Western Australia

M.J. van Kranendonk: Supported by UNSW SPF01 (commencing 2012)

Summary: This project is aimed at investigating the changes wrought across the Archean-Proterozoic boundary in Western Australia, marking the transition from juvenile, reducing, early Earth to more modern, oxidised, adolescent Earth. Details of stratigraphy, stable isotope geochemistry, and paleontology will be examined and integrated into global events.

The Active Alpine Fault Zone as an analogy for fluid dynamics in Archaean mineral systems

K. Gessner, Thebaud, Toy, Ring: Supported by UWA Collaborative Research Fund

Summary: The circulation of hydrothermal fluids and their capacity to transport heat and solutes controls heat and mass transfer in the Earth's crust. The genetic and spatial link between fault zones, fluid flow, and mineral deposits has been known for a long time, but there has been little systematic investigation into how deformation fabrics and chemical alteration of rocks interact in active fault zones. We propose to address this shortcoming by applying state of the art mineral mapping and x-ray tomography methods to characterise deformed and chemically altered rocks from the Alpine fault in New Zealand and from the Eastern Goldfields in Western Australia.

Geobiology of the 1900 Ma Gunflint Formation

D. Wacey, M. Brasier (international collaborator): Supported by UWA RCA

Using newly developed analytical capabilities we will increase our understanding of the most iconic Precambrian microfossil assemblage (The Gunflint Biota). In particular, SIMS, NanoSIMS and the use of the Focused Ion Beam in combination with Scanning and Transmission Electron Microscopy will enable us to study the microfossils and newly discovered phosphate minerals in situ, at higher resolution than previously possible, and in 3D. This work is essential if the Gunflint microfossils are to continue to serve as a useful baseline for future studies of putative Archean and extraterrestrial microfossils.

Petrogenesis of Cenozoic Inner Mongolia flood basalts: detecting the dehydration of stagnated Pacific slabs

X.-C. Wang: Supported by NSFC (commenced 2009)

Summary: **Central and Eastern Asia has the largest and most poorly understood diffusive intraplate large igneous provinces (DLIPs). This project is designed to construct the primary melt compositions based on the published data and our new analysis and then to investigate the source, thermochemical state and water contents. This study showed that the central and eastern Asian Cenozoic basalts were produced by hydrated mantle source with about 0.2 wt.% H_2O in the continental interior, and an increase up to about 0.5 wt.% in the margin of the Pacific back arc basin. The Cenozoic mantle beneath this region has a mantle potential temperature similar to MORB-type mantle. Thus, dehydration of stagnated slabs atop the mantle transition zone played an important role in producing the intraplate DLIPs.**

Australian Drilling Program: Biomarkers, oxygen and geobiology

George, Dutkiewicz, Webb: Supported by Agouron Institute Research Grant (commenced 2010)

Summary: **The project aims...**

- **To resolve whether Archean hydrocarbon biomarker molecules are indigenous or not,**
- **To obtain geobiological and redox-indicator samples in environmental and temporal context,**
- **From drill-cores of strata that are too weathered at the surface for reliable preservation of hydrocarbon biomarkers and other redox-sensitive biosignatures and environmental indicators,**
- **From rocks dating from before the ecological dominance of animals,**
- **With particular emphasis on time intervals and rock types relevant to the rise of oxygen,**
- **To complement and extend the environmental and stratigraphic range of samples obtained from the Agouron South African drilling program.**

Appendix 3: Participants list

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Appendix 4: Publications 2011/2012

A FULL LIST OF CCFS PUBLICATIONS IS UPDATED AT: http://www.ccfs.mq.edu.au/

1. **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, 49, 1549-1570.*

2. Yu, Y., Xu, X.-S., **Griffin, W.L.**, **O'Reilly, S.Y.** and Xia, Q.-K. 2011. H_2O contents and their modification in the Cenozoic subcontinental lithospheric mantle beneath the Cathaysia block, SE China. *Lithos, 26, 3-4, p182-197.* doi: 10.1016/j.lithos.2011.07.009

3. **Gréau, Y.**, Huang, J., **Griffin, W.L.**, Renac, C., **Alard, O.**, **O'Reilly, S.Y.** 2011. Type I eclogites from Roberts Victor kimberlites: Products of extensive mantle metasomatism. *Geochimica et Cosmochica Acta, 75, 22, 6927-6954.* doi:10.1016/j.gca.2011.08.035

4. Wang, K.L., **O'Reilly, S.Y.**, Kovach, V., **Griffin, W.L.**, **Pearson, N.J.**, Yarmolyuk, V., Kuzmin, M.I., Chieh, C. and Shellnutt, J.G. 2012. Microcontinents among the accretionary complexes of the Central Asia Orogenic Belt (CAOB): *in situ* Re-Os evidence. *Journal of Asian Earth Sciences.* (corrected proof online doi:10.1016/j.jseaes.2011.09.016)

5. **O'Reilly, S.Y.** and **Griffin, W.L.** 2012. Mantle metasomatism. In (D. Harlov and H. Austrheim, eds.) *Metasomatism (Lecture Notes in the Earth Sciences).* (in press 9/2011)

6. **Howell, D.**, Wood, I.G., Nestola, F., Nimis, P. and Nasdala, L. 2012. Inclusions under remnant pressure in diamond: A multi-technique approach. *European Journal of Mineralogy, 42, 2.* (in press).

7. **Danis, C.**, **O'Neill, C.** and Lackie, M. 2012. Building 3D geological knowledge through regional scale gravity modelling for the Bowen Basin. *Exploration Geophysics.* (in press)

8. Wang, X.-L., Jiang, S-Y., Dai, B-Z., **Griffin, W.L.**, Dai, M-N. and Yang, Y-H. 2011. Age, geochemistry and tectonic setting of the Neoproterozoic (ca 830 Ma) gabbros on the southern margin of the North China Craton. *Precambrian Research, 190, 1-4, 35-47.*

9. Godinho, J.R.A., **Piazolo, S.**, Stennett, M.C. and Hyatt, N.C. 2011. Sintering of CaF_2 pellets as nuclear fuel analogue for surface stability experiments. *Journal of Nuclear Materials, 419, 1-3, 46-51.*

10. **O'Neill, C.J.** 2012. Tectonothermal evolution of solid bodies: terrestrial planets, exoplanets, and moons. *Australian Journal of Earth Sciences, 59, 2, 189-198.*

11. **Howell, D.** 2012. "Birefringence in Diamond. *European Journal of Mineralogy*. (in press)

12. Andersson, U.B., Begg, G., **Griffin, W.L.** and Hàgdah, K. 2012. Ancient and juvenile components in the continental crust and mantle: Hf isotopes in zircon from Svecofennian magmatic rocks and rapakivi granites in Sweden. *Lithosphere.* (in press)

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Appendix 5: CCFS visitors & GAU users

CCFS VISITORS 2011 (Excluding Participants in Conferences and Workshops)

MACQUARIE

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

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

Dr Christoph Beier (GeoZentrum Nordbayern, Universtitaet Erlangen-Nuernberg Erlangen, Germany)

Dr Brittany Brand (University of Washington)

Dr Rosalba Bonaccorsi (NASA Ames Research Center/SETI Institute, Space Science & Astrobiology Division, California, USA)

Professor John Burrows (University of Bremen, Institute of Environmental Physics, Bremen, Germany)

Ms Grisel Carreira (Business Analyst, University of Technology, Sydney)

Ms Jennifer Chauffard (Geosciences, UMR 5243-CC60, University of Montpellier 2, Montpellier, France)

Dr Bin Chen (University of Michigan Geological Sciences, MI, USA)

Dr Simon Clark (Earth and Planetary Sciences, University of California, Berkeley)

Professor Bill Collins (School of Environmental and Life Sciences, University of Newcastle)

Dr Louis Coney (MINTEK, Randburg, South Africa)

Dr Sylvie Demouchy (Geosciences, UMR 5243-CC60, University of Montpellier 2, Montpellier, France)

Professor John Dewey (Department of Geology, University of California, Davis, USA)

Professor Leonid Dubrovinsky (Bavarian Research Institute of Experimental Geochemistry and Geophysics University of Bayreuth, Germany)

Dr Monica Escayola (Instituto de Estudios Andinos, Universidad de Buenos Aires, Ciudad de Buenos Aires, Argentina)

Dr Dan Fay (Director Earth, Energy and Environment, Microsoft Research)

Dr Marnie Foster (Research School of Earth Sciences, Australian National University)

Ms Yuya Gao (Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing PR China)

Dr Dick Glen (Geological Survey of NSW)

Professor Marc Hirschmann (Department of Earth Sciences, Geology and Geophysics, Minneapolis, MA, USA)

Dr Harold Javid (Microsoft Research)

Professor Chen Jianfa (Stable isotopic geochemistry and gas geology. China University of Petroleum)

Dr Fred Jourdan (Department of Applied Geology, Faculty of Science and Engineering, West Australian School of Mines)

Dr K Paul Kirkbride (Chief Scientist Forensic and Data Centres, Australian Federal Police)

Dr Chris Kirkland (Geological Survey of Western Australia)

Ms Lucinda Land (Education and Outreach Team, NASA Ames Research Centre, California, USA)

Professor Gordon Lister (Structural Geology and Tectonics, Research School of Earth Sciences, Australian National University ACT)

Dr Chuan-Zhou Liu (Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing PR China)

Dr Marc-Antoine Longpré (McGill University)

Associate Professor Yinhe Luo (Institute of Geophysics and Geomatics, China University of Geosciences, Wuhun, China)

Dr Vladimir Malkovets (Laboratory of Diamond Deposits Institute of Geology and Mineralogy Siberian Branch, Russian Academy of Sciences, Novosibirsk, RUSSIA)

Ms Valerie Migeon (Geosciences, UMR 5243-CC60, University of Montpellier 2, Montpellier, France)

Dr Martha Navarro (Vice-Provost for International Affairs, Universidad Nacional Autonoma de Mexico)

Professor Qiu Nansheng (China University of Petroleum)

Dr Nick Rawlinson (Earth Physics, Research School of Earth Sciences, Australian National University)

Dr Michel de Saint Blanquat (Chercheur au CNRS Geosciences Environment Toulouse, Observatoire Midi-Pyrenees, Toulouse, France)

Dr Inga Sevastjanova (Department of Earth Sciences, Royal Holloway University of London, UK)

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

Professor Csaba Szabo (Department of Petrology and Geochemistry, Institute of Geography and Earth Sciences, Eötvös University, Budapest)

Professor Lawrence Taylor (Petrology and Geochemistry, Department of Earth and Planetary Sciences, Knoxville, TN, USA)

Dr Patrick Trimby (Australian Centre for Microscpy and Microanalysis, University of Sydney)

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

Mr John Warren (Manager, ANZ Programs Microsoft Research Connections, North Ryde)

Dr Chunmei Yu (China University of Geosciences, Wuhan, Hubei, PR China)

Professor Jiang Zhenxue (General petroleum geology and resource assessment. China University of Petroleum)

Professor Ningning Zong (Organic petrography and organic geochemistry, leader of the group. China University of Petroleum)

UWA

Mr Ed Baltis (Chief Geologist, Gold Fields Australia Pty Ltd)

Dr Steve Barnes (Principal Research Scientist, Ore Systems, CSIRO)

Dr Graeme Begg (Director, Minerals Targeting International PL)

Dr Steve Beresford (Chief Geologist and Nickel Commodity Leader, Minerals and Metals Group)

Mr Chris Bonwick (Managing Director, Independence Group NL)

Dr Patrice de Caritat (Principal Research Scientist, Geoscience Australia)

Mr Stefano Caruso (PhD Student, University of Milano, Italy)

Dr Jon Claoué-Long (Geoscience Australia)

Professor Sandy Cruden (Professor of Tectonics and Geodynamics and Head of the School of Geosciences, Monash University)

Dr Hilke Dalstra (Principal geologist, Rio Tinto)

Mr Thomas Dittrich (PhD Student, Technical University Bergakademie Freiberg, Germany)

Dr Rosa Figueiredo e Silva (Universidade Federal Minas Gerais)

Dr Louise Fisher (Geochemist, CSIRO)

Dr Ana Fogliata (University of Tucuman/Lillo)

Mr Steve Garwin (Consultant, Steven L Garwin Pty Ltd)

Ms Belinda Godel (CSIRO Earth Science and Resource Engineering)

Mr Ignacio Gonzalez-Alvarez (Australian Resources Research Centre, CSIRO)

Mr Barry Goss (Barry Goss, General Manager, Ivanhoe Australia)

Professor Bill Griffin (CCFS Macquarie University/GEMOC)

Mr Sebastian Grignola (PhD Student, University of Tucuman, Argentina)

Dr Brian Hoal (Executive Director, Society of Economic Geologists)

Dr Jon Hronsky (Director, Western Mining Services)

Professor Mark Jessell (Research Director, Institute de Recherche pour le Dévéloppement, Toulouse, France)

Professor Rob Kerrich (University of Saskatchewan, Canada)

Mr Peter Kolleger (PhD Student, University of Leoben, Austria)

Professor Ross Large (Director, CODES, University of Tasmania)

Ms Tina Larson (PhD Student, University of Tromso, Norway)

Dr David Leach (U.S. Geological Survey (USGS))

Dr Peter Lightfoot (Chief geologist - sulphide Ni, VALE)

Dr Lydia Lobato (Universidade Federal Minas Gerais)

Mr Martin Paesold (MSc Student, Swiss Federal Institute of Technology, Zurich, Switzerland)

Professor Edward M. Ripley (Professor of Geochemistry, Indiana University, USA)

Dr Andy Tomkins (Senior Lecturer, Monash University)

Mr Asinne Tshibubudze (PhD Student, University of Witwatersrand, South Africa)

Dr John Walshe (Chief Research Scientist, CSIRO)

Mr Ken Witherly (President, Condor Consulting USA)

Dr Roy Woodall (Non-executive director, Western Mining Services)

Adjunct Professor Dan Wood (W.H. Bryan Mining and Geology Research Centre, Australia)

Dr Chris Yeats (Program Leader, Mineral System Science, CSIRO)

Ms Lijuan Ying (PhD Student, Chinese Academy of Geosciences, China)

Mr Dayu Zhang (PhD Student, Hefei University of Technology, China)

CURTIN

Dr Ana Despaigne-Diaz (University of Pina del Rio, Cuba)

Professor Thorsten Geisler (University of Bonn, Germany)

Dr Ron Frost (University of Wyoming, USA)

Dr Xiao-Long Huang (Guangzhou Institute of Geochemistry, China)

Professor Matt Jackson (BHP Billiton, Australia)

Mark Jessell (University Paul Sabatier, Toulouse, France)

Professor Xiaodian Jiang (Ocean University, Qingdao, China)

Wang Jie (Sinopec, China)

Mr Mike Kammerman (North Australian Diamonds, Australia)

Dr Tony Kemp (James Cook University, Townsville)

Dr Paul Mahaffy (Chief, Atmospheric Experiments Laboratory, NASA, USA)

Professor Craig Manning (Department of Earth and Space Sciences, UCLA, USA)

Dr David Martin (BHP Billiton, Australia)

Lifeng Meng (Zhejiang University, China - PhD Student)

Ms Martina Menneken (University of Bonn, Germany - PhD Student)

Dr Renaud Merle (University of Padua, Italy)

Associate Professor David Moecher (University of Kentucky, USA)

Dr Stephanie Moore (University of Austin, Texas, USA)

Dr Marc Norman (ANU, Canberra, Australia)

Dr Henning Prommer (CSIRO)

Mr Tom Reddicliffe (North Australian Diamonds, Australia)

Chris Salt (BHP Billiton, Australia)

Catherine Spaggiari (Geological Survey of WA)

Dr Pieter Visscher (University of Connecticut, USA)

Caifu Xiang (China University of Petroleum, Beijing, China)

Dr Fengqi Zhang (Zhejiang University, China)

EXTERNAL USERS OF THE GEOCHEMICAL ANALYSIS UNIT FACILITIES IN 2011

(Note: this does not include contract work)

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

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

Mr Adam Baker (School of Geosciences, University of Sydney)

Dr Sol Buckman (School of Earth and Environmental Science, University of Wollongong)

Ms Jennifer Chaufard (Geosciences, UMR 5243-CC60, University of Montpellier 2, Montpellier, France)

Dr Louis Coney (MINTEK, Randburg, South Africa)

Dr Monica Escayola (Instituto de Estudios Andinos, Universidad de Buenos Aires, Ciudad de Buenos Aires, Argentina)

Mr Leam Gatehouse (School of Geosciences, University of Sydney)

Ms Eva Goesch (School of Earth and Environmental Science, University of Wollongong)

Mr Bob Ilitch (Copperchem Ltd, Sydney)

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

Dr Chuan-Zhou Liu (Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, PR China)

Ms Yuya Gao (Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, PR China)

Dr Vladimir Malkovets (Laboratory of Diamond Deposits, Institute of Geology and Mineralagy Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia)

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

Mr Andrew Mesthos (School of Geosciences, University of Sydney)

Ms Valerie Migeon (Geosciences, UMR 5243-CC60, University of Montpellier 2, Montpellier, France)

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

Ms Christina Neudorf (School of Earth and Environmental Science, University of Wollongong)

Professor Allen Nutman (School of Earth and Environmental Science, University of Wollongong)

Mr Daniel Page (School of Earth and Environmental Science, University of Wollongong)

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

Dr Michel de Saint Blanquat (Chercheur au CNRS Geosciences Environment Toulouse, Observatoire Midi-Pyrenees, Toulouse, France)

Dr Inga Sevastjanova (Department of Earth Sciences, Royal Holloway University of London, UK)

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

Professor Csaba Szabo (Department of Petrology and Geochemistry, Institute of Geography and Earth Sciences, Eötvös University, Budapest)

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

Dr Chunmei Yu (China University of Geosciences, Wuhan Hubei, PR China)

Appendix 6: Abstract titles

TITLES OF ABSTRACTS FOR CONFERENCE PRESENTATIONS IN 2011

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

23RD COLLOQUIUM OF AFRICAN GEOLOGY UNIVERSITY OF JOHANNESBURG, JOHANNESBURG, SOUTH AFRICA, 8-14 JANUARY 2011

Kimberlites from D.R. Congo: mantle structure and diamond potential
J.M. Batumike, **W.L. Griffin** and **S.Y. O'Reilly**

Relations between East African (740-600 Ma) and Kuunga (570-530 Ma) orogenies in NE Mozambique
B. Bingen, G. Viola, I.H.C. Henderson, **E.A. Belousova**, A.K. Engvik and M. Smethurst

GORDON RESEARCH CONFERENCE ON GEOBIOLOGY OF PRECAMBRIAN EARTH, 30 JANUARY - 4 FEBRUARY 2011

The early evolution of Earth's atmosphere, links to tectonics and life
M. Barley **Invited**

DGG/EAGE 2011, COLOGNE, GERMANY, 25 FEBRUARY 2011

Structure of the lithosphere in Central Europe based on the CELEBRATION 2000 experiment and integrated modeling
Z. Alasonati-Tasarova, M. Bielik, J. Fullea, H-J. Götze and **J.C. Afonso**

PROSPECTORS AND DEVELOPERS ASSOCIATION OF CANADA (PDAC): TORONTO, CANADA, 6-9 MARCH 2011

Integrated interpretation and targeting under cover
T.C. McCuaig **Invited**

Exploration Targeting in a Business Context
T.C. McCuaig and J.M.A. Hronsky
Keynote

Managing success - Strategies for keeping the leadership edge: Exploration Targeting
T.C. McCuaig **Invited**

42ND LUNAR AND PLANETARY SCIENCE CONFERENCE, THE WOODLANDS, USA, 7-11 MARCH 2011

Tectonic modes and atmospheric Argon on Venus and Earth
T. Höink, **C. O'Neill** and A. Lenardic

WEST AUSTRALIAN GEOTHERMAL ENERGY SYMPOSIUM, PERTH, AUSTRALIA, 21-22 MARCH 2011

From mantle instabilities to fault scarps: structural controls on geothermal systems in the Menderes Massif, western Turkey
K. Gessner and V. Markwitz

Characterization of fault damage zones in the North Perth Basin
H. Olierook, N.E. Timms, P.J. Hamilton and **S.M. Reddy**

EUROPEAN GEOSCIENCES UNION, GENERAL ASSEMBLY 2011, VIENNA, AUSTRIA, 3-8 APRIL 2011

Paleogeography of the Early Earth and paleomagnetic data
S.A. Pisarevsky

Neoproterozoic paleogeography: paleomagnetic perspective
S.A. Pisarevsky **Invited**

Neoproterozoic sedimentation and orogenesis in NE Laurentia
P. Cawood, R. Strachan and **S.A. Pisarevsky**

Analysis of single Precambrian oil-bearing fluid inclusions as a way of constraining evolution of eukaryotes.
S. Siljeström, J. Lausmaa, H. Volk, **S.C. George**, P. Sjövall, A. Dutkiewicz and T. Hode

A 3D multi-observable probabilistic inversion method for the compositional and thermal structure of the lithosphere and sublithospheric upper mantle
J.C. Afonso, **Y. Yang**, J. Fullea, S. Lebedev and S. Zlotnik

The lithosphere-sublithospheric upper mantle system beneath the Atlantic-Mediterranean Transition Region: advances and limitations from recent multidisciplinary approaches
J.C. Afonso, J. Fullea, M. Fernández, J. Vergés and H. Zeyen **Invited**

Decoupled crust-mantle accommodation of Africa-Eurasia convergence in the NW-Moroccan margin
M. Fernàndez, I. Jiménez-Munt, J. Vergés, D. Garcia-Castellanos, J. Fullea, M. Pérez-Gussinyé and **J.C. Afonso**

Imaging the lithosphere-asthenosphere boundary of southern Africa integrating elevation, surface heat flow, magnetotelluric and petrological data
J. Fullea, M. Muller, A. Jones, **J.C. Afonso** and S. Zlotnik

Alteration mechanism of chromite in podiform chromitites from two metamorphosed ophiolitic complexes: Golyamo Kamenyane (Bulgaria) and Tapo (Peru)
F. Gervilla, I. Fanlo, T. Kerestedjian, R.Castroviejo, **J.M. González-Jiménez**, J.A. Padron and J.F. Feliciano-Rodriques
Keynote

Lu-Hf evolution patterns and implications for palaeotectonic settings
C. Kirkland, S. Daly, S. Johnson and **E. Belousova**

Geophysical-petrological modelling of the lithosphere beneath the Cantabrian Mountains and North-Iberian margin: mantle wedge hydration triggered by eclogitization reactions?
D. Pedreira, J.A. Pulgar and **J.C. Afonso**

IV CUBAN EARTH SCIENCE CONVENTION, HAVANA, CUBA, 4-8 APRIL 2011

Unravelling the first 500 million years of Earth history
S.A. Wilde **Invited**

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS 2011, ANNUAL CONVENTION & EXHIBITION, 10-13 APRIL 2011

Stylolites; Their origin and impact on reservoir quality
J. Hamilton, **S. Reddy**, H. Olierook and N. Timms

"MINERALS AT EXTREME CONDITIONS: INTEGRATING THEORY AND EXPERIMENT" ELIZABETH AND FREDERICK WHITE CONFERENCE, CANBERRA, AUSTRALIA (AUSTRALIAN ACADEMY OF SCIENCE), 13-15 APRIL 2011

Fluids in diamonds: samples from the deep lithosphere
W.L. Griffin and **S.Y. O'Reilly** **Invited**

Tracking Earth's plumbing system in time and space: an interdisciplinary strategy towards understanding Earth's evolution
S.Y. O'Reilly **Invited**

The effect of D" and post-perovskite on the dynamics of plumes
C. O'Neill and T. Jones **Invited**

Evaluating the validity of 2D experiments: New insights from 3D XRD analysis during *in situ* heating of rocksalt
S. Piazolo, V. Borthwick and S. Schmidt

Direct evidence for the nature and timing of sub-arc mantle metasomatism
S. Turner, J. Caulfield, **M. Turner**, P. van Keken, R. Maury, M. Sandiford and G. Prouteau **Invited**

INTERNATIONAL CONFERENCE ON CRATON FORMATION AND DESTRUCTION, BEIJING, CHINA, 25-29 APRIL 2011

Paleomagnetic constraints for the building blocks of Nuna
S.A. Pisarevsky, D.P. Gladkochub and T.V. Donskaya

Deep and ancient lithosphere rules supreme: a 3.6 Ga story of persistence, transformation, dispersal and re-assembly
S.Y. O'Reilly, **W.L. Griffin**, M. Zhang, **N.J. Pearson**, J. Zheng, X. Xu, J. Yu and **J.-H. Yang** **Keynote**

Coupling, decoupling and metasomatism: Crust-mantle relationships beneath NW Spitsbergen
W.L. Griffin, N. Nikolic, **S.Y. O'Reilly** and **N.J. Pearson** **Invited**

Tracking cratonic mantle evolution using highly siderophile elements in mantle sulfides
M. Zhang, **S.Y. O'Reilly**, **W.L. Griffin**, K.-L. Wang and J. Hronsky

Making, keeping and potentially losing cratonic lithosphere
A. Lenardic, C.M. Cooper, **C.J. O'Neill**, L. Moresi, C. Sandu, C.T. Lee and A. Levander

Continental accretion and reworking beneath the North China Craton: Evidence from deep-seated xenoliths
J. Zheng, **W.L. Griffin**, C. Yu, **S.Y. O'Reilly**, H. Tang, Q. Ma, Q. Xiong and M. Zhang **Invited**

SCLM of the Siberian Craton and subduction
Z.V. Spetsius, L.A. Taylor, **W.L. Griffin** and O.V. Tarskhix

Phanerozoic crustal growth: Sorting out facts from fiction
S.A. Wilde **Keynote**

FRONTIERS IN MINERAL SYSTEMS: THE INAUGRAL SOLOMON MEETING, YALLINGUP, WESTERN AUSTRALIA, 8-13 MAY 2011

Multiple sulphur isotopes in magmatic systems
M.L. Fiorentini **Invited**

Mineral system deposition and timing: Constraints from quantitative microanalysis
S. Reddy **Keynote**

OPPORTUNITIES IN RESEARCH OF METALS AND MINERALS, DEAKIN UNIVERSITY, 12 MAY 2011

Integrating in-situ experiments with numerical simulations
S. Piazolo **Invited**

GAC - MAC - SEG - SGA ANNUAL MEETING, OTTAWA, ONTARIO, CANADA, 25-27 MAY 2011

Reassessment of isobaric and molecular interferences in LA-MC-ICP-MS Hf isotope analysis
J.L. Payne, **N.J. Pearson**, K. Grant, M. Hand and G.P. Halverson

Microstructural control on pentlandite exsolutions from monosulphide solid solution in komatiite hosted Ni sulphides from the Yilgarn Craton, Western Australia
Z. Vukmanovic, S.J. Barnes, **S.M. Reddy** and **M.L. Fiorentini**

EARTHSCOPE NATIONAL MEETING, TEXAS, USA, 17-20 MAY 2011

Compositional variations in the mantle, and their velocity and density effects
D. Schutt, **J.C. Afonso** and C. Lesher

THE 6TH INTERNATIONAL CONFERENCE ON ARCTIC MARGINS (ICAM VI), UNIVERSITY OF ALASKA, FAIRBANKS, USA, 31 MAY - 2 JUNE 2011

U-Pb ages and Hf systematic of Detrital zircon from quartzite of Mesoproterozoic Gulliksenfjellet Formation (SW-Svalbard)
N. Kuznetsov, J. Majka, A. Ladenberger, **L. Natapov** and **E. Belousova**

CONFERENCE - ECLOGITE AND GRANULITE COMPLEXES IN THE EARTH HISTORY, PETROZAVODSK, RUSSIA, 16-18 JUNE 2011

The high-pressure pseudobasement of the Northern Caucasus Fore Range
M.L. Somin, A.N. Konilov, **L.M. Natapov**, **E.A. Belousova**, V.A. Kamzolkin and K.A. Dokukina

THE EVOLUTION OF PHOTOSYNTHESIS AND OXYGENATION OF THE EARTH SYMPOSIUM, UNSW, SYDNEY, AUSTRALIA, 28-29 JUNE 2011

New biomarker results from the 2.7 Ga Tumbiana Formation, Pilbara region
S.C. George, J. M. Coffey and M.R Walter

Contingent events leading to an oxygenated environment
M.J. van Kranendonk **Keynote**

IUGG 2011 GENERAL ASSEMBLY, EARTH ON THE EDGE: SCIENCE FOR A SUSTAINABLE PLANET, MELBOURNE, AUSTRALIA, 28 JUNE - 7 JULY 2011

Precambrian supercontinents and paleomagnetic data, or how "super" are supercontinents?
S.A. Pisarevsky **Invited**

Unravelling the driving forces behind recent changes in the eruptive behaviour of Merapi Volcano, Indonesia
R. Gertisser, J. Barclay, K. Berlo, **H. Handley**, R. Herd, K. Preece and M. Reagan

Relationship between mantle events and crustal magmatism in northeast Australia: evidence from *in situ* sulfide and zircon isotope data
V. Murgulov, **W.L. Griffin** and **S.Y. O'Reilly**

Growth and Recrystallization of Diamond in the Upper Mantle
E. Rubanova, **S. Piazolo**, **W. Griffin** and **S. O'Reilly**

3D isotropic and anisotropic structures of crust and uppermost mantle in Tibet and surrounding regions from ambient noise tomography
Y. Yang, Y. Zheng and M. Ritzwoller

The structure of the crust and uppermost mantle beneath the western US revealed by ambient noise and earthquake tomography
Y. Yang, W. Shen and M. Ritzwoller

THE XVII INTERNATIONAL CONGRESS ON THE CARBONIFEROUS AND PERMIAN: PERTH, WESTERN AUSTRALIA, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA, 3-8 JULY 2011

Timing of opening and subduction of the paleo-Tethys at Jinshajiang (SW China): perspectives from zircon U-Pb and Hf-O systematics of ophiolitic plagiogranites
J.W. Zi, P.A. Cawood, W.M. Fan, E. Tohver and **T.C. McCuaig**

SEVENTH HUTTON SYMPOSIUM ON GRANITES AND RELATED ROCKS, AVILA, SPAIN, 4-9 JULY 2011

Recycled meta-igneous crustal sources for S- and I-type Variscan granitoids from the Spanish Central System batholith: constraints from Hf isotope zircon composition
C. Villaseca, D. Orejana and **E.A. Belousova**

AUSTRALIAN MARS EXPLORATION CONFERENCE, THE UNIVERSITY OF WA, PERTH, AUSTRALIA, 22-23 JULY 2011

New biomarker results from the 2.7 Ga Tumbiana Formation, Pilbara region
S.C. George, J. M. Coffey and M.R Walter

9TH INTERNATIONAL ECLOGITE CONFERENCE, 2011, MARIÁNSKÉ LÁZNE, CZECH REPUBLIC, 6-9 AUGUST 2011

The evolution of prograde-type orogenic peridotites from Liverpool Land, a HP terrane in the eastern Greenland Caledonides
R. Bubbico, H.K. Brueckner, E.H. Hartz, S.M. Johnston and **W.L. Griffin**

Decompression melting of composite mafic-felsic crust (Archean Belomorian eclogite province, Gridino area, Russia)
K. Dokukina, A. Konilov, **L. Natapov** and **E. Belousova**

Metasomatic hide and seek: The origins of Roberts Victor eclogites
W.L. Griffin, J. Huang, **Y. Gréau**, **S.Y. O'Reilly** and **N.J. Pearson**

High-pressure (eclogite facies) complex of the Northern Caucasus
A. Konilov, M. Somin, **L. Natapov**, **E. Belousova,** A. Kröner, V. Kamzolkin, K. Dokukina and A. Mukhanova

THE 8TH ANNUAL MEETING OF THE ASIA OCEANIA GEOSCIENCES SOCIETY (AOGS), TAIPEI, TAIWAN, 8-12 AUGUST 2011

Involvement of heterogeneous crustal sources in the generation of granitoid rocks in the Central Asian Orogenic Belt: Evidence from zircon ages and Hf isotopes
A. Kröner, **E. Belousova**, R. Seltmann, J. Wong, E. Hegner, K. Cai, R. Armstrong, A. Dolgopolova, M. Sun and D. Liu

GOLDSCHMIDT 2011, PRAGUE, CZECH REPUBLIC, AUGUST 14-19, 2011

Hadean greenstones and the origin of the Earth's early continental crust
J. Adam, **T. Rushmer**, J. O'Neil and D. Francis

The first multiple sulfur isotope evidence for a 2.9 Ga Mesoarchean sulfate reservoir
M. Barley, S.E. Golding, G.J. Heggie and **M.L. Fiorentini**

Chalcophile elements in magmas and magmatic sulfide deposits: Can we see the mantle signals?
S.J. Barnes, **M.L. Fiorentini** and W.D. Maier

Sr-Nd-Hf-Pb isotope systematics of the Oyu Tolgoi Cu-Au deposit (Mongolia)
A. Dolgopolova, R. Seltmann, R. Armstrong, **E. Belousova** and R. Pankhurst

Evidence of water degassing in Archean komatiites
M.L. Fiorentini, S.W. Beresford, W.E. Stone and E. Deloule

Plume-ridge interaction: constraints on melting dynamics from the Azores and Iceland
F.S. Genske, C. Beier, **S.P. Turner**, K.M. Haase and **B.F. Schaefer**

Geodynamic implications of >1 Ga Re-Os model ages in PGM from the Dobromirtsi Ultramafic Massif, Central Rhodope, Bulgaria
J.M. González-Jiménez, **W.L. Griffin**, F. Gervilla, T. Kerestedjian, **S.Y. O'Reilly** and **N.J. Pearson**

Deciphering mafic and felsic lunar magmatic events: Insight from zircon
M.L. Grange, **A.A. Nemchin**, N. Timms, **R.T. Pidgeon** and C. Meyer

Ore deposits and the SCLM
W.L Griffin, G. Begg, **S.Y. O'Reilly** and **N.J. Pearson** **Keynote**

Insights into the Galápagos plume from Uranium-series isotopes of recently erupted basalts
H.K. Handley, K. Berlo, C. Beier, **S. Turner** and A.E. Sy

Mixed-habit diamonds: Evidence of a specific mantle fluid chemistry?
D. Howel, **W.L. Griffin**, **S.Y. O'Reilly**, **C. O'Neill**, **N. Pearson**, **S. Piazolo,** T. Stachel, R. Stern and L. Nasdala

Fluid microinclusions in octahedral diamonds
I. Kiflawi, Y. Weiss, **W.L. Griffin** and O. Navon

Late metasomatic addition of garnet to the SCLM: Os-isotope evidence
V.G. Malkovets, **W.L. Griffin**, **N.J. Pearson**, D.I. Rezvukhin, **S.Y. O'Reilly**, N.P. Pokhilenko, V.K. Garanin, Z.V. Spetsius and K.D. Litasov

Monogenetic, but not monotonous: basaltic eruptions in the Auckland Volcanic Field, New Zealand
L.E. McGee, I.E.M. Smith, M.-A. Millet, C. Beier, J.M. Lindsay and **H.K. Handley**

Long-distance transport of north Gondwana Cambro-Ordovician sandstones: Evidence from detrital zircon Hf isotopic composition
N. Morag, D. Avigad, A. Gerdes, **E. Belousova** and Y. Harlavan

U-Series disequilibrium in groundwater as a vector for U mineralisation
M.J. Murphy, A. Dosseto, **S.P. Turner** and **B.F. Schaefer**

"Table" vs "Bench": trace elements in fibrous diamonds
O. Navon, **W.L. Griffin** and Y. Weiss

The punctuated evolution of the Earth: Geodynamic constraints and model predictions.
C. O'Neill, A. Lenardic and K. Condie

Coupling, decoupling and metasomatism: a saga of crust-mantle relationships beneath NW Spitsbergen (Arctic Norway)
S.Y. O'Reilly, N. Nikolic, **W.L Griffin** and **N.J. Pearson**

Matrix effects and Hf isotope analysis of zircon by laser ablation MC-ICP-MS
N.J. Pearson, J.L. Payne and **K.J. Grant**

The legacy of plastic deformation and pre-existing microstructures during olivine serpentinization
O. Plümper, H. Austrheim, **S. Piazolo** and H. Jung

A complex network analysis of growth and mixing dynamics in natural metal-silicate systems
T. Rushmer, A. Tordesillas and D.M. Walker

Gold mobility in the mantle: Constraints from sulfides in pyroxenites and lherzolites
J.E.J. Saunders, **N.J. Pearson** and **S.Y. O'Reilly**

A new Br isotope analytical protocol: constraints on the global Br cycle
B.F. Schaefer

Deep crust of the Siberian craton: evidence from xenoliths
V.S. Shatsky, V.G. Malkovets, L. Buzlukova, **W.L. Griffin**, **E.A. Belousova** and **S.Y. O'Reilly**

3 Ga onset of the supercontinent cycle: SCLM and crustal evidence
S.B. Shirey, S.H. Richardson and **M.J. van Kranendonk**

Zircon from kimberlites of the Nyurbinskaya pipe as indicator of kimberlite emplacement and Lithosphere evolution
Z.V. Spetsius, **E.A. Belousova**, **W.L. Griffin**, **S.Y. O'Reilly** and A.S. Ivanov

Evolution of andesite magma systems; Egmont Volcano, New Zealand
R.B. Stewart, A.V Zernack, **M.B. Turner,** R.C. Price, I.E.M. Smith and S.J. Cronin

Direct evidence for the nature and timing of sub-arc mantle metasomatism
S. Turner, J. Caulfield, **M. Turner**, P. Van Keken, R. Maury, M. Sandiford and G. Proteau **invited**

Geology, age and origin of the oldest terrestrial rocks and minerals
M.J. van Kranendonk **Keynote**

Freeze-fry cycles in the Paleoproterozoic Turee Creek Group of Western Australia
M.J. van Kranendonk, A. Lepland and K.E. Yamaguchi

Origin of isotopically heavy Fe in pyrite from 2.75 Ga Wilgie Mia BIF, Western Australia
M.J. van Kranendonk and M.J. Whitehouse

Os isotopes in sulfides from xenoliths of the Campos de Calatrava Volcanic Field, Central Spain
C. Villaseca, **J.M González-Jiménez**, **W.L. Griffin**, E. Ancochea, F. Gervilla, **S.Y O'Reilly**, **N.J. Pearson** and **E. Belousova**

Primordial ages of lithospheric mantle vs ancient relicts in the asthenospheric mantle: *in situ* Os perspective
K.-L. Wang, **S.Y. O'Reilly**, **W.L. Griffin**, **N.J. Pearson**, V. Kovach and V. Yarmolyuk

High-Mg carbonatitic HDFs, kimberlites and the SCLM
Y. Weiss, **W.L. Griffin**, D.R. Bell and O. Navon

Transitional oxygenation recorded in the Paleoproterozoic Turee Creek Group, Western Australia
K.H. Williford, **M.J. van Kranendonk**, T. Ushikubo, R. Kozdon and J.W. Valley

Formation of the oldest rocks in the Cathaysia Block, Southern China
J.-H. Yu, **S.Y. O'Reilly**, L. Wang and **W.L. Griffin**

Water contents in the Cenozoic subcontinental lithospheric mantle beneath the Cathaysia block, SE China
Y. Yu, X.S. Xu, **W.L. Griffin** and **S.Y. O'Reilly**

Evidence for evolution of growth media in superdeep diamonds from Sao-Luis (Brasil)
D.A. Zedgenizov, A.L. Ragozin, V.S. Shatsky, H. Kagi, S. Odake, **W.L. Griffin**, D. Araujo and O.P. Yuryeva

7TH INTERNATIONAL SYMPOSIUM ON DIGITAL EARTH, PERTH, AUSTRALIA, 23-25 AUGUST 2011

3D mineral map of Australia
T. Cudahy, M. Caccetta, J. Chia, R. Fraser, **K. Gessner**, M. Haest, I. Lau, C. Laukamp, C. Ong and A. Rodger

DEFORMATION MECHANISMS, RHEOLOGY AND TECTONICS, DRT CONFERENCE, OVIEDO, SPAIN, 31 AUGUST - 2 SEPTEMBER 2011

Compaction related microstructure in chromitites from the Merensky Reef, Bushveld Complex, South Africa
Z. Vukmanovic, **S.M. Reddy**, S.J. Barnes, B. Godel and **M.L. Fiorentini**

PENROSE CONFERENCE ON "COMPARATIVE EVOLUTION OF PAST AND PRESENT ACCRETIONARY OROGENS: CENTRAL ASIA AND THE CIRCUM-PACIFIC", URUMQI, XINJIANG UYGUR AUTONOMOUS REGION, CHINA, 4-10 SEPTEMBER 2011

Hf isotopes in zircons from the CAOB: Crustal evolution history and tectonic significance
E. Belousova, R. Seltmann, **W.L. Griffin** and **S.Y. O'Reilly** **Invited**

Tectonic evolution of the CAOB in NE China
S.A. Wilde and J.-B. Zhou **Invited**

GEOLOGICAL PROCESSES FROM GLOBAL TO LOCAL SCALES, ASSOCIATED HAZARDS & RESOURCES: MUNICH, 4-7 SEPTEMBER 2011

Is the Menderes Massif in Turkey one big Neogene shear zone?
K. Gessner, V. Markwitz, L.A. Gallardo and U. Ring

FERMOR 2011 - ORE DEPOSITS IN AN EVOLVING EARTH, BURLINGTON HOUSE, PICCADILLY, LONDON, 7-9 SEPTEMBER 2011

High temperature deformation in magmatic chromites from the Merensky Reef (Bushveld Complex, South Africa)
Z. Vukmanovic, S.J. Barnes, **S.M. Reddy**, B. Godel and **M.L. Fiorentini**

3D structural model of Southwest Turkey reveals lithosphere-scale control on hydrothermal fluid flow
K. Gessner, L.A. Gallardo and L.A. Markwitz

Mapping the intra-cratonic framework of an Archean Craton: implications for camp-scale mineralization
D.R. Mole, **M.L. Fiorentini**, N. Thebaud, **T.C. McCuaig**, K.F. Cassidy, C.L. Kirkland, **M.T.D. Wingate**, S.S. Romano, M.P. Doublier, **E.A. Belousova** and S. Barnes

Komatiite volcanism: Lithospheric controls on the Earth's hottest melts and implications for associated Ni-Cu-PGE deposits
D.R. Mole, **M.L. Fiorentini**, N. Thebaud, **T.C. McCuaig**, K.F. Cassidy, C.L. Kirkland, M.T.D. Wingate, S.S. Romano, M.P. Doublier, **E.A. Belousova** and S. Barnes

XXXI REUNION DE LA SOCIEDAD ESPAÑOLOA DE MINERALOGÍA, BARCELONA, SPAIN, 7-10 SEPTEMBER 2011

Discriminación de cromititas ofiolíticas a partir de elementos menores y trazas: un estudio mediante LA-ICPMS
J.A. Proenza, M. Escayola, **J.M. González-Jiménez** and **S. Jackson**

Re-Os isotope evidences of multiple melting event in the Ojén Ultramafic Massif
J.M. González-Jiménez, R. Gutiérrez-Narbona, **W.L. Griffin**, F. Gervilla, **S.Y. O'Reilly**, **N.J. Pearson** and J.P. Lorand

18TH INTERNATIONAL CONFERENCE ON SECONDARY ION MASS SPECTROMETRY (SIMS XVIII), RIVA DEL GARDA, ITALY, 18-23 SEPTEMBER 2011

Chemistry at the sub-µm scale with NanoSIMS
M. Kilburn **Invited**

INTERNATIONAL FIELD WORKSHOP ON THE PRECAMBRIAN EVOLUTION OF KOREA, AND EAST ASIAN TECTONICS, KBSI OCHANG CENTER, SOUTH KOREA, 19-24 SEPTEMBER 2011.

A >1300 km-long Late Pan-African Khondalite Belt along the southern margin of the CAOB
S.A. Wilde and J.-B. Zhou **Invited**

GEOLOGICAL SURVEY OF NORWAY, TRONDHEIM, NORWAY, 23 SEPTEMBER 2011

A chronostratigraphic division of the Precambrian: possibilities and challenges
M.J. van Kranendonk **Invited**

GONDWANA 14, BUZIOS, BRAZIL, 25-30 SEPTEMBER 2011

Siberia and Baltica in Nuna and Rodinia
S.A. Pisarevsky, D.P. Gladkochub and T.V. Donskaya

A Precambrian continental margin arc in the southern Thomson Orogen, eastern Australia: implications for the evolution of Gondwana
R.A. Glen, A. Saeed, **E. Belousova** and **W.L. Griffin**

11TH BIENNIAL SGA MEETING, ANTOFAGASTA, CHILE, 26-29 SEPTEMBER 2011

Identification of optimal conditions for komatiite-hosted nickel sulfide formation: non-mass dependent S isotopes from various reservoirs of the north Eastern Goldfields, Western Australia
C. Isaac, **M. Barley**, **M.L. Fiorentini** and S. Golding

New types of porphyry Cu (Au-Mo) mineral systems of Eastern Tibetan Plateau in western Yunnan: compositional characteristics, sources, and exploration implications for continental collision metallogeny
Y.J. Lu, **C.T. McCuaig**, **R. Kerrich**, C.J.R. Hart, P.A. Cawood, A.I.S. Kemp, **Z.X. Li** and Z.Q. Hou

Origin of Ferrian Chromite in metamorphosed podiform chromitites: a two-stage process
F. Gervilla, I. Fanlo, T. Kerestedjian, R. Castroviejo, J.A. Padrón, J.F. Rodrigues and **J.M. González-Jiménez**

Chromite deposits at Loma Baya: petrogenesis and clues for the origin of the coastal Guerrero Composite Terrane in Mexico
J.M. González-Jiménez, J.A. Proenza, A. Camprubí, E. Centeno-García, E. González-Partida, **W.L. Griffin**, **S.Y. O'Reilly** and **N.J. Pearson**

Re-Os systematics in chromite deposits from the Bulgarian Rhodopes: preliminary results
J.M. González-Jiménez, **W.L. Griffin**, T. Kerestedjian, F. Gervilla, **S. Y. O´Reilly**, J.A. Proenza and **N.J. Pearson**

Lithospheric controls on mineral systems
D. Mole, **M. Fiorentini**, N. Thebaud, **C. McCuaig**, K. Cassidy, C. Kirkland, S. Romano, M. Doublier, **E. Belousova** and S. Barnes

4D imaging of an Archean craton: Implications for the localisation of komatiite-hosted nickel camps
D. Mole, **M. Fiorentini**, N. Thebaud, **C. McCuaig**, K. Cassidy, C. Kirkland, S. Romano, M. Doublier, **E. Belousova** and S. Barnes

New types of porphyry Cu (Au-Mo) mineral systems of Eastern Tibetan Plateau in western Yunnan: compositional characteristics, sources, and exploration implications for continental collision metallogeny
Y.-J. Lu, **T.C. McCuaig**, **R. Kerrich**, C.J.R. Hart, P. Cawood, A.I.S. Kemp, **Z.-X Li** and Z.-Q. Hou

11TH AUSTRALIAN SPACE SCIENCE CONFERENCE 2011, CANBERRA, AUSTRALIA, 26-29 SEPTEMBER 2011

Constraining weathering processes on Venus from particle size distributions and Magellan Synthetic Aperture Radar (SAR)
E. Schinella and **C. O'Neill**

GSA ANNUAL MEETING, MINNEAPOLIS, MINNESOTA, USA, 9-12 OCTOBER 2011

Two contrasting Phanerozoic orogenic systems on Earth revealed by Hf isotope data from zircon
W.J. Collins, **E.A. Belousova**, A.I.S. Kemp and J.B. Murphy

Tectonic controls on magmatic-hydrothermal gold mineralization in the magmatic arcs of SE Asia and the SW Pacific
M. Barley

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA, PERTH, AUSTRALIA, 17 OCTOBER 2011

Romance in Geology: The marriage and breakup of continents
M.J. van Kranendonk **Invited**

JORDANIAN-EGYPTIAN BASEMENT EVOLUTION (JEBEL) WORKSHOP AND FIELD EXCURSION "BASEMENT COMPLEX OF SOUTHWEST JORDAN", UNIVERSITY OF AMMAN, AMMAN, JORDAN, 23-27 OCTOBER 2011

Hafnium isotope results from Wadi Allaqi, Egypt
K. Ali, **S.A. Wilde** and R.J. Stern

ICE DEFORMATION; FROM THE MODEL MATERIAL TO ICE IN NATURAL ENVIRONMENTS, GRENOBLE, FRANCE, 7-9 NOVEMBER 2011

Strain heterogeneities and recrystallization in polycrystalline materials: Characterization and Interpretation
S. Piazolo **Invited**

2011 SPRIGG SYMPOSIUM: UNRAVELLING THE NORTHERN FLINDERS AND BEYOND, MAWSON LECTURE THEATRE, UNIVERSITY OF ADELAIDE, 1 DECEMBER 2011

Application of U-series isotopes in understanding sandstone-hosted uranium mineralisation in the Frome Embayment, South Australia
M.J. Murphy, A. Dosseto, **B.F. Schaefer**, **S.P. Turner** and **N.J. Pearson**

AGU'S 2011 FALL MEETING, SAN FRANCISCO, CALIFORNIA, USA, 5-9 DECEMBER 2011

The distribution of intraplate volcanism and controls on the generation of intraplate magmatism
J. Adam, **T.A. Rushmer** and I.E. Smith

Ubiquitous old depleted mantle in the Oceanic mantle
O. Alard **Invited**

3D multi-observable probabilistic inversion for the compositional and thermal structure of the lithosphere and sublithospheric upper mantle
J.C. Afonso, J. Fullea, **Y. Yang**, **W.L. Griffin**, A.G. Jones, J. Connolly, S. Lebedev and **S.Y. O'Reilly**

The subductability of the continental lithosphere: results from coupled thermodynamic-thermomechanical numerical modeling
J.C. Afonso and S. Zlotnik **Invited**

The Australian Seismometers in Schools Project: Building relationships between scientists, schools and local enthusiasts
N. Balfour, M. Sambridge and **C. O'Neill**

Links between tectonics and life in the Archean to early Paleoproterozoic
M. Barley

Water behaviour during mantle melt percolation-reaction: a case study from the Borée peridotite xenoliths (Massif Central, France)
J. Chaufaud, **O. Alard**, S. Demouchy, J.-M. Dautria and **S.Y. O'Reilly**

Dy/Dy*; a tool for resolving petrogenetic processes from REE data
J.P. Davidson, **S. Turner** and T. Plank

Reappraisal of magma genesis under the Kamchatka arc with uranium-series isotopes
A. Dosseto and **S. Turner** **Invited**

SimLAB: Evaluating geophysical proxies for the lithosphere-asthenosphere boundary
d.W.S. Eaton, C.M. Hogan, **J.C. Afonso** A.G. Jones, J. Tromp, M.S. Miller and T.W. Becker

Petrogenetic constraints on the origin and evolution of the volcanic rocks on Solander Island, New Zealand
F.V. Foley, **N.J. Pearson**, **T.A. Rushmer**, **J. Adam** and **S. Turner**

Source symmetry in the Azores mantle plume: new constraints from Li-B-O isotopes
F.S. Genske, C. Beier, **S. Turner** and **B.F. Schaefer**

Uranium-series isotopic constraints on recent changes in the eruptive behaviour of Merapi Volcano, Java, Indonesia
R. Gertisser, **H.K. Handley**, M.K. Reagan, K. Berlo, J. Barclay, K. Preece and R. Herd

Redistribution of trace elements during refertilization of oceanic mantle: A LA-HR-ICPMS study of ODP Site 1274 peridotites
M. Godard, **O. Alard** and **Y. Gréau**

Uranium-series disequilibria in Vanuatu arc volcanic rocks: constraints on pre-eruptive processes in contrasting volcanic systems
H.K. Handley, **S. Turner**, M.K. Reagan, G. Girard, S.J. Cronin and C. Firth

Imaging 3D crustal and upper mantle structures of the Dabie orogenic belt using ambient noise and teleseismic surface wave data
Y. Luo, **Y. Yang** and Y. Xu

Lithospheric controls on Earth evolution
D.R. Mole, **M.L. Fiorentini**, N. Thebaud, **T.C. McCuaig**, K.F. Cassidy, C.L. Kirkland and **E.A. Belousova**

A window of opportunity for plate tectonics in evolution of Earth-like planets?
C. O'Neill

Systematic and extreme rare earth element variation within a single zircon population; implications for granite redox state and petrogenesis
M.J. Pankhurst, **B. Schaefer** and **S. Turner**

Underworld and multi-basin heat flow
S.M. Quenette, **C. O'Neill**, L.N. Moresi, **C.R. Danis** and J. Mansour

Crustal and uppermost mantle anisotropy in the western US and China inferred from surface wave dispersion
M.H. Ritzwoller, F.-C. Lin, W. Shen, J. Xie, **Y. Yang**, Y. Zheng and Z.L. Quan **Invited**

Lithospheric modeling over Atla Regio, Venus
E. Schinella, **J.C. Afonso** and **C. O'Neill**

Compositional variations in the mantle and their velocity and density effects
D. Schutt, **J.C. Afonso** and C. Lesher

The effect of grain orientation on SIMS U-Pb analysis of rutile
R.Taylor, **C. Clark** and **S. Reddy**

Estimating variations of H_2O in andesitic magmas – implications to eruption variability and associated hazards
M.B Turner, **S. Turner**, **J. Adam** and H.S. O'Neill

Azimuthal anisotropy within the crust and uppermost mantle of southeastern China from both ambient noise and teleseismic earthquake Rayleigh wave tomography
J. Xie, Z.L. Quan, F.-C. Lin, W. Shen, Y. Zheng, **Y. Yang** and M.H. Ritzwoller

A synoptic view of the distribution and connectivity of the mid-crustal low velocity zone beneath Tibet
Y. Yang, Y. Zheng, Z. Xie and M.H. Ritzwoller

Surface wave tomography on large-scale seismic arrays combining ambient noise and teleseismic earthquake data
Y. Yang, M.H. Ritzwoller, W. Shen, Y. Zheng and Z.L. Quan **Invited**

Ambient noise tomography of East China
Y. Zheng, W. Shen, Z.L. Quan, **Y. Yang** and M.H. Ritzwoller

Appendix 7: Research funding

GRANTS AND OTHER INCOME FOR 2011

Investigators	2011 Funding Source	Project Title	Amount
O'Reilly	ARC CoE	Core to Crust Fluid Systems	$1,800,000
O'Reilly	ARC CoE (MQ contribution)	Core to Crust Fluid Systems	$875,000
UWA Node	ARC CoE (UWA)	Core to Crust Fluid Systems	$415,000
Curtin Node	ARC CoE (Curtin)	Core to Crust Fluid Systems	$500,000
GSWA	ARC CoE (GSWA)	Core to Crust Fluid Systems	$150,000
O'Reilly	ARC Post-Award Early Career Research Support	ARC Post-Award Early Career Research Support	$1,250,000
O'Reilly	Science Leveraging Fund (SLF)	Centre of Excellence for Core to Crust Fluid Systems	$500,000
Li, Danisik, Xu	ARC Discovery Grant	Multiple vertical tectonic movements in a continental interior: consequences of flat-subduction and foundering of an oceanic plateau?	$70,000
Barley, Golding, Fiorentini	ARC Discovery Project	The early evolution of the Earth system from multiple sulfur isotope records of sediments and seafloor mineral systems	$70,000
Turner, Dosseto, Reagan	ARC Discovery Project	The application of short-lived uranium-series isotopes to constraining Earth system Processes	$98,000
O'Neill, Afonso	ARC Discovery Project	The effective strength of oceanic plate bounding faults	$65,000
Rushmer, Turner	ARC Discovery Project	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
Rushmer	ARC Discovery Project	Partial melting in natural metal-silicate systems: rheological and geochemical implications for the Earth and other planets	$60,000
Walter, Neilan, George, Summons, Schopf	ARC Discovery Project	Oxygenating the Earth: using innovative techniques to resolve the timing of the origin of oxygen-producing photosynthesis in cyanobacteria	$30,000

Investigators	2011 Funding Source	Project Title	Amount
O’Neill	ARC Future Fellowship	Strength and resistance along oceanic megathrust faults: implications for subduction initiation	$88,831
O’Neill	MQ Academic Non-Discretionary Fund	Start-up funds for Future Fellowship FT100100717	$100,000
Belousova	ARC Future Fellowship	Dating down under: Resolving Earth’s crust - mantle relationships	$156,530
Fiorentini	ARC Future Fellowship	From core to ore: emplacement dynamics of deep-seated nickel sulphide systems	$85,616
Piazolo	ARC Future Fellowship	Flow characteristics of lower crustal rocks: developing a toolbox to improve geodynamic models	$101,787
Lister, Jourdan, Forster, McInnes, Vasconcelos, Rosenbaum, Cooke, Harris, Collins (A), Aitchison, Daczko, Collins (W), Reddy, Li, McCuaig, Miller, Pillans, Grun, Zwingmann, Evans, McWilliams	ARC LIEF	Events through time: eruptions, extinctions, impacts, ore-bodies and orogenies - upgrading the national argon geochronology network	$420,000
Sampson, Fiorentini, Liu, Gilkes, Rasmussen, Rengel, McNaughton, Kirkland, Wilde, Wingate, Xie, Thompson	ARC LIEF	Nanoscale Characterisation Centre WA analytical electron microscope facility (UWA)	$360,000
Random, O’Neill et al.	ARC LIEF	Flexible architecture high-performance computing facility for the intersect consortium of New South Wales	$500,000
Random, O’Neill et al.	ARC LIEF	Flexible architecture high-performance computing facility for the intersect consortium of New South Wales (MQ contribution)	$60,000
Gessner, McCuaig, Hobbs, Cawood, Gorczyk, Connolly, Gerya, O'Neill, Lester	ARC Linkage	Multiscale dynamics of ore body formation	$180,000

Investigators	2011 Funding Source	Project Title	Amount
Gessner, McCuaig, Hobbs, Cawood, Gorczyk, Connolly, Gerya, O'Neill, Lester	ARC Linkage	Multiscale dynamics of ore body formation (WA state contribution)	$50,000
Barley, McCuaig, Gessner, Miller, Tohver, Doublier, Romano, Wyche	ARC Linkage Project	Tectonic evolution and lode gold mineralisation in the Southern Cross district, Yilgarn Craton (Western Australia): a study of the meso- to Neoarchaean missing link	$90,000
Barley, McCuaig, Gessner, Miller, Tohver, Doublier, Romano, Wyche	ARC Linkage WA state contribution	Tectonic evolution and lode gold mineralisation in the Southern Cross district, Yilgarn Craton (Western Australia): a study of the meso- to Neoarchaean missing link	$95,000
Turner, Schaefer, McConachy	ARC Linkage Project	A novel approach for economic uranium deposit exploration and environmental studies	$118,500
Turner, Schaefer, McConachy	ARC Linkage Project	A novel approach for economic uranium deposit exploration and environmental studies (Heathgate Resources contribution)	$45,000
Griffin, O'Reilly, Pearson	ARC Linkage Project	Composition, structure and evolution of the lithospheric mantle beneath Southern Africa: improving area selection criteria for diamond exploration (De Beers Group Services contribution)	$60,000
McCuaig, Barley, Fiorentini, Kemp, Miller, Belousova, Jessell, Hein, Begg, Tunjic, Said, Bagas	ARC Linkage Project	Four dimensional lithospheric evolution and controls on mineral system distribution in Neoarchean to Paleoproterozoic terranes	$540,000
McCuaig, Barley, Fiorentini, Kemp, Miller, Belousova, Jessell, Hein, Begg, Tunjic, Said, Bagas	ARC Linkage Project	Four dimensional lithospheric evolution and controls on mineral system distribution in Neoarchean to Paleoproterozoic terranes (AMIRA International Ltd, AngloGold Ashanti, Gold Fields contribution)	$1,129,386
Fiorentini, Brugger, Perring, Liu, Barnes	ARC Linkage Project	Hydrothermal remobilisation of base metals and platinum group elements in magmatic nickel deposits	$65,000
Fiorentini, Brugger, Perring, Liu, Barnes	ARC Linkage Project	Hydrothermal remobilisation of base metals and platinum group elements in magmatic nickel deposits (Department of Mines and Petroleum)	$63,000
GAU, GEMOC MQ	Department of Earth and Planetary Sciences	GAU maintenance contribution	$30,000

Investigators	2011 Funding Source	Project Title	Amount
Zhao, Wilde, Li Sanzhong, Li Xuping	Hong Kong Research Grants Scheme	Tectonic setting and evolution of the Paleoproterozoic Jiao-Liao-Ji Belt in the Eastern Block of the North China Craton	$18,000
Nevalainen, Packer, Karuso, Jamie, Molloy, Brown, Liu, Herbert, George, Vemulpad	Macquarie University Research Infrastructure Block Grants (RIBG)	Facility for long term preservation and storage of biological, chemical, environmental and geological samples	$60,000
Fiorentini, Barnes, Miller	MERIWA M413	Hydrothermal footprints of magmatic nickel sulphide deposits	$120,000
Griffin, O'Reilly, Pearson, Belousova	MQ Enterprise Partnership Pilot Research Grant	Lithospheric architecture mapping in Phanerozoic orogens	$50,000
Griffin, O'Reilly, Pearson, Belousova	MQ Enterprise Partnership Pilot Research Grant (Minerals Targetting International Pty Ltd)	Lithospheric architecture mapping in Phanerozoic orogens	$60,000
Daczko	MQ Safety Net Scheme	Nature of the lower continental crust	$16,519
O'Reilly	Macquarie University Research Infrastructure Block Grants (RIBG)	Laser ablation microprobe sample cell	$40,000
Clark	Curtin University Research Fellowship	The thermal evolution of continental crust	$95,000
Turner M	MU Fellowship	Research supplement for NZ S&T Fellowship	$30,000
Yang	MU New Staff Scheme	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
Daczko	MURDG	Resurrecting Rodinia? The role of east Antarctica in supercontinent assembly	$19,545
O'Reilly	NCRIS Auscope	A4.45; Macquarie University Project - Earth composition and evolution	$100,000

Investigators	2011 Funding Source	Project Title	Amount
O'Reilly	NCRIS MQ Contribution	AuScope (www.auscope.org.au)	$50,000
O'Neill	AuScope/ MQ Education Investment Fund Project	AuScope Australian Geophysical Observing System - Geophysical Education Observatory	$50,000
Clark, Reddy, Timms, Kinny	Australia-India Strategic Research Fund node. (ST030046)	The thermal evolution of Peninsular India: Past behaviours and future potential	$115,000
O'Reilly, Griffin, Pearson, Alard, Ildefonse, Demouchy	DIISR French-Australian Science and Technology Program	Probing the composition of the early Solar System and planetary evolution processes	$11,000
George, Christensen, King, McIntyre, McRae, Snape, Stark	Australian Antarctic Division	Rates of depletion of lubricant and fuel contaminants from Antarctic regions during natural attenuation and remediation procedures	$14,000
Harrison, George, King, Lane	Australian Antarctic Division	Ecological risks associated with the use of fuels in Antarctica: characterising hydrocarbon behaviour and assessing toxicity on sensitive early life stages of Antarctic marine invertebrates	$12,000
Gessner, Hough, Toy, Thebaud, Liu, Dellepiane, Zwingmann, Kopf	The International Synchrotron Access Program (ISAP)	Three-dimensional characterization of brittle fault rocks	$10,100
Reddy	Office of Research and Development, Curtin University	Support for research	$50,000
Gessner, Thebaud, Toy, Ring	UWA Collaborative Research Fund	The Active Alpine Fault Zone as an analogy for fluid dynamics in Archaean mineral systems	$7,500
Wacey, Brasier (international collaborator)	UWA RCA	Geobiology of the 1900 Ma Gunflint Formation	$12,000
Wang	NSFC	Petrogenesis of Cenozoic Inner Mongolia flood basalts: detecting the dehydration of stagnated Pacific slabs.	$40,000
George, Dutkiewicz, Webb	Agouron Institute Research Grant	Australian drilling program: Biomarkers, oxygen and geobiology	$76,000

Investigators	2011 Funding Source	Project Title	Amount
Yu	PGRF	The evolution, dynamics and water inventory of the subcontinental lithospheric mantle, SE China	$5,000
Schinella	PGRF	Processes shaping the surface of Venus	$4,064
Saunders	PGRF	Geochemical mobility of gold within the mantle and its significance to crustal endowment	$4,064
Genske	PGRF	Assessing the heterogeneous source of the Azores mantle plume	$4,711
Pankhurst	PGRF	Investigating post-orogenic collapse through magmatic records	$5,417
Huang	Cotutelle iMQRES + CSC	Origin of eclogite and pyroxenite xenoliths in kimberlites and basalts	$22,860
Xiong	Cotutelle iMQRES + CSC	Shenglikou and Zedang peridotite massifs, Tibet: Upper mantle processes and geodynamic significance	$22,860
Yu	Cotutelle iMQRES + CSC	The evolution and tectonic dynamics of the subcontinental lithospheric mantle, SE China	$22,860
Abbassi	MQRES	Mass balancing of generation and escape of methane on the North West Shelf of Australia in the Tertiary	$22,860
Foley	iMQRES	Generation of continental crust during subduction initiation	$52,355
Grose	iMQRES	Geodynamics of the oceanic lithosphere	$52,355
Pankhurst	MQRES	Geodynamic significance of shoshonitic magmatism within the Andean Altiplano	$22,860
Dunkley	MQRES	Hf Isotopic behaviour in turbidites, migmatites and granites at Mount Stafford, Central Australia	$22,860
Genske	iMQRES	Assessing the heterogeneous source of the Azores mantle plume	$52,355
Gaildry	iMQRES	Island arc processes as seen through Vanuatu volcanism and geochemistry.	$52,355
Rubanova	iMQRES	Fluid processes in the deep mantle: Geochemical studies of diamonds and related minerals	$52,355
Taneja	iMQRES	Origin of intraplate volcanism in the east Indian Ocean	$52,355
Murphy	APA	Stabilising a craton: origin and emplacement of the 3.1 Ga Mpuluzi batholith (Swaziland/RSA)	$22,860

Investigators	2011 Funding Source	Project Title	Amount
Saunders	APA	Gold distribution and mobility within the mantle and its significance to mineralised provinces	$22,860
Schinella	APA	Processes shaping the Venusian landscape	$22,860
Firth	APA	Integrating the volcanological and magmatic record of a young Arc volcano: Yasur Vanuatu	$22,860
Lu	UWA IPRS	Tectonic setting, magmatic evolution and metallogeny of Paleogene potassic instrusions in western Yunnan, southeastern Tibetan Plateau	$50,000
Zi	UWA IPRS	Indosinian tectono-magnetic evolution of the Yidun Arc in the Sanjiang Region, southwestern China	$50,000
Isaac	UWA IPRS	4D architecture of the Eastern Goldfields Superterrane in the Yilgarn Craton of Western Australia, in order to constrain the role of the lithospheric structure at 2.7 Ga in the localization of nickel mineral systems	$50,000
LeVaillant	MERIWA/UWA SIRF	Hydrothermal footprints of magmatic nickel sulfide deposits	$5,000
Parra	SIRF/UIS/Safety-Net Top-Up Scholarship	Four dimensional evolution of the Paleoproterozoic West African Craton	$50,000
Schindler	UWA IPRS, Industry Funding	Petrogenesis of intrusive rocks in the Telfer region, Patterson orogen, Western Australia: implications for gold mineralisation	$50,000
Mole	UWA IPRS	Quantifying melt-lithosphere interaction in space and time: understanding nickel mineral systems in the Archaean Yilgarn craton UWA	$50,000
Zeng	CSC/UWA SIRF	Geology, geochronology and genesis of gold deposits in the West Qinling Orogenic Belt, central China	$50,000
Huang (H)	CUPS	Ranges of South China and tectonic Implications	$50,000
Liu (Y)	APRA	Recognising gold mineralisation zones using GIS-based modelling of multiple ground and airborne datasets	$50,000
Liu (L)	CSC + CUPS	Timing and kinematics of Mesozoic-Cenozoic mountain building and cratonic thinning in Eastern North China: a Combined structural and thermochronological study	$22,860
Niu	CUPS	Neoproterozoic paleomagnetism of South China and Implication to global geodynamics	$50,000

Investigators	2011 Funding Source	Project Title	Amount
Pang	CSC + CUPS	Basin record of Mesozoic tectonic events in South China	$22,860
Tao	CSC + CUPS	Thermochronological record of vertical tectonic movements in Mesozoic-Cenozoic South China	$22,860
Yao	CSC + CUPS	Lower Palaeozoic basin record in southern South China- nature of the Cathaysia Basement and evolution of the Wuyi-Yunkai Orogeny	$22,860
Zhu	CSC + CUPS	Petrogenesis and tectonic setting of Phanerozoic granitic rocks in eastern South China	$22,860

GRANTS AND OTHER INCOME FOR 2012

Investigators	2012 Funding Source	Project Title	Amount
O'Reilly	ARC CoE	Core to Crust Fluid Systems	$1,900,000
O'Reilly	ARC CoE (MQ contribution)	Core to Crust Fluid Systems	$875,000
UWA Node	ARC CoE (UWA)	Core to Crust Fluid Systems	$415,000
Curtin Node	ARC CoE (Curtin)	Core to Crust Fluid Systems	$500,000
GSWA	ARC CoE (GSWA)	Core to Crust Fluid Systems	$150,000
Afonso, Yang, Rawlinson, Jones, Connolly, Lebedev	ARC Discovery Project	What lies beneath: Unveiling the fine-scale 3D compositional and thermal structure of the subcontinental lithosphere and upper mantle	$95,000
Li, Danisik, Xu	ARC Discovery Grant	Multiple vertical tectonic movements in a continental interior: consequences of flat-subduction and foundering of an oceanic plateau?	$70,000
Turner, Dosseto, Reagan	ARC Discovery Project	The application of short-lived uranium-series isotopes to constraining Earth system processes	$103,000
O'Neill, Afonso	ARC Discovery Project	The effective strength of oceanic plate bounding faults	$65,000
Rushmer, Turner	ARC Discovery Project	Origin of silicic magmas in a primitive island arc: the first integrated experimental and short-lived isotope study of the Tongan-Kermadec system	$80,000

Investigators	2012 Funding Source	Project Title	Amount
Walter, Neilan, George, Summons, Schopf	ARC Discovery Project	Oxygenating the Earth: using innovative techniques to resolve the timing of the origin of oxygen-producing photosynthesis in cyanobacteria	$30,000
Piazolo, Daczko, Putnis, Jessell	ARC Discovery Project	Investigating the fundamental link between deformation, fluids and the rates of reactions in minerals	$90,000
Nemchin, Grange	ARC Discovery Project	Investigation of the early history of the Moon	$70,000
Collins, Belousova, Murphy, Hand	ARC Discovery Project	Supercells and the supercontinent cycle	$90,000
O'Neill	ARC Future Fellowship	Strength and resistance along oceanic megathrust faults: implications for subduction initiation	$177,797
Belousova	ARC Future Fellowship	Dating down under: Resolving Earth's crust - mantle relationships	$153,938
Fiorentini	ARC Future Fellowship	From core to ore: emplacement dynamics of deep-seated nickel sulphide systems	$169,523
Piazolo	ARC Future Fellowship	Flow characteristics of lower crustal rocks: developing a toolbox to improve geodynamic models	$204,247
Belousova	MQ Academic Non-Discretionary Fund	Start-up funds for Future Fellowship FT110100685	$130,000
Piazolo	MQ Academic Non-Discretionary Fund	Start-up funds for Future Fellowship FT110100070	$150,000
Rushmer, O'Neill, Cruden, Turner	ARC LIEF	The first Australian high pressure Synchrotron facility for geoscience research	$155,000
Roberts, Heslop, Pillans, De Deckker, Lister, Li, Rosenbaum, Vasconcelos, Aitchison, Pisarevsky, Tohver, Schmidt, McWilliams	ARC LIEF	A world-class rock magnetic facility to support Australian palaeomagnetic and environmental research	$254,078
Gessner, McCuaig, Hobbs, Cawood, Gorczyk, Connolly, Gerya, O'Neill, Lester	ARC Linkage	Multiscale dynamics of ore body formation	$180,000

Investigators	2012 Funding Source	Project Title	Amount
Gessner, McCuaig, Hobbs, Cawood, Gorczyk, Connolly, Gerya, O'Neill, Lester	ARC Linkage	Multiscale dynamics of ore body formation (WA state contribution)	$50,000
Turner, Schaefer, McConachy	ARC Linkage Project	A novel approach for economic uranium deposit exploration and environmental studies	$118,500
Turner, Schaefer, McConachy	ARC Linkage Project	A novel approach for economic uranium deposit exploration and environmental studies (Heathgate Resources contribution)	$45,000
McCuaig, Barley, Fiorentini, Kemp, Miller, Belousova, Jessell, Hein, Begg, Tunjic, Said, Bagas	ARC Linkage Project	Four dimensional lithospheric evolution and controls on mineral system distribution in Neoarchean to Paleoproterozoic terranes	$520,000
McCuaig, Barley, Fiorentini, Kemp, Miller, Belousova, Jessell, Hein, Begg, Tunjic, Said, Bagas	ARC Linkage Project	Four dimensional lithospheric evolution and controls on mineral system distribution in Neoarchean to Paleoproterozoic terranes (AMIRA International Ltd, AngloGold Ashanti, Gold Fields contribution)	$1,080,208
Fiorentini, Brugger, Perring, Liu, Barnes,	ARC Linkage Project	Hydrothermal remobilisation of base metals and platinum group elements in magmatic nickel deposits	$65,000
Fiorentini, Brugger, Perring, Liu, Barnes,	ARC Linkage Project	Hydrothermal remobilisation of base metals and platinum group elements in magmatic nickel deposits (Department of Mines and Petroleum contribution)	$62,000
Clark	DECRA	How does the continental crust get so hot?	$125,000
George, Turner, Rushmer, Schaefer, Brock	RIBG	Precision saw for finely cutting and slicing geological samples	$33,000
GAU, GEMOC MQ	Department of Earth and Planetary Sciences	GAU maintenance contribution	$30,000
Griffin, O'Reilly, Pearson, Belousova	MQ Enterprise Partnership Pilot Research Grant	Lithospheric architecture mapping in phanerozoic orogens	$50,000
Griffin, O'Reilly, Pearson, Belousova	MQ Enterprise Partnership Pilot Research Grant	Lithospheric architecture mapping in phanerozoic orogens (Minerals Targetting International Pty Ltd contribution)	$60,000

Investigators	2012 Funding Source	Project Title	Amount
van Kranendonk	UNSW SPF	Archean subduction in the Kaapvaal Craton	$20,000
van Kranendonk	UNSW SPF	The Archean-Proterozoic boundary in Western Australia	$30,000
O'Reilly	NCRIS AuScope	A4.45; Macquarie University Project - Earth composition and evolution	$55,000
O'Reilly	NCRIS MQ Contribution	AuScope (www.auscope.org.au)	$50,000
O'Neill	AuScope/ MQ Education Investment Fund	AuScope Australian Geophysical Observing System - Geophysical Education Observatory	$50,000
George, Dutkiewicz, Webb	Agouron Institute Research Grant	Australian drilling program: Biomarkers, oxygen and geobiology	$76,000
Rubanova	PGRF	Fluid processes in the deep mantle: Geochemical studies of diamonds and related minerals	$2,750
Xiong	Cotutelle iMQRES + CSC	Shenglikou and Zedang peridotite massifs, Tibet: Upper mantle processes and geodynamic significance	$23,728
Yu	Cotutelle iMQRES + CSC	The evolution and tectonic dynamics of the subcontinental lithospheric mantle, SE China	$23,728
Abbassi	MQRES	Mass balancing of generation and escape of methane on the North West Shelf of Australia in the Tertiary	$23,728
Foley	iMQRES	Generation of continental crust during subduction initiation	$54,993
Grose	iMQRES	Geodynamics of the oceanic lithosphere	$54,993
Pankhurst	MQRES	Geodynamic significance of shoshonitic magmatism within the Andean Altiplano	$23,728
Dunkley	MQRES	Hf Isotopic behaviour in turbidites, migmatites and granites at Mount Stafford, Central Australia	$23,728
Genske	iMQRES	Assessing the heterogeneous source of the Azores mantle plume	$54,993
Gaildry	iMQRES	Island arc processes as seen through Vanuatu volcanism and geochemistry.	$54,993
Rubanova	iMQRES	Fluid processes in the deep mantle: Geochemical studies of diamonds and related minerals	$54,993
Taneja	iMQRES	Origin of intraplate volcanism in the east Indian Ocean	$54,993

Investigators	2012 Funding Source	Project Title	Amount
Murphy	APA	Stabilising a craton: origin and emplacement of the 3.1 Ga Mpuluzi batholith (Swaziland/RSA)	$23,728
Saunders	APA	Gold distribution and mobility within the mantle and its significance to mineralised provinces	$23,728
Schinella	APA	Processes shaping the Venusian landscape	$23,728
Firth	APA	Integrating the volcanological and magmatic record of a young Arc volcano: Yasur Vanuatu	$23,728
Isaac	UWA IPRS	4D architecture of the Eastern Goldfields Superterrane in the Yilgarn Craton of Western Australia, in order to constrain the role of the lithospheric structure at 2.7 Ga in the localization of nickel mineral systems	$50,000
Parra	SIRF/UIS/Safety-Net Top-Up Scholarship	Four dimensional evolution of the Paleoproterozoic West African Craton	$54,993
Schindler	UWA IPRS, Industry Funding	Petrogenesis of intrusive rocks in the Telfer region, Patterson orogen, Western Australia: implications for gold mineralisation	$50,000
Huang	CUPS	Ranges of South China and tectonic implications	$50,000
Liu (Y)	APRA	Recognising gold mineralisation zones using GIS-based modelling of multiple ground and airborne datasets	$50,000
Liu (L)	CSC + CUPS	Timing and kinematics of Mesozoic-Cenozoic mountain building and cratonic thinning in eastern North China: a combined structural and thermochronological study	$23,728
Pang	CSC + CUPS	Basin record of Mesozoic tectonic events in South China	$23,728
Tao	CSC + CUPS	Thermochronological record of vertical tectonic movements in Mesozoic-Cenozoic South China	$23,728
Yao	CSC + CUPS	Lower Palaeozoic basin record in southern South China-nature of the Cathaysia basement and evolution of the Wuyi-Yunkai Orogeny	$23,728
Zhu	CSC + CUPS	Petrogenesis and tectonic setting of Phanerozoic granitic rocks in eastern South China	$23,728

Appendix 8: Standard performance indicators

Performance Measure	Reporting Frequency	Target 2011	Outcome
Research findings			
Number of research outputs	Annually	*10*	94
Quality of research outputs • Journals with Impact Factor >2.5 • Journals with Impact Factor >3 • Journals with specific target audience (e.g. Aust J Earth Sciences) • Book chapters/ international conference proceedings	Annually	*>70%* *50%* *20%* *10%*	*69%* 64% 22% 5.6%
Number of invited talks/papers/ keynote lectures given at major international meetings	Annually	*>4 out of a total of all (>15) presentations including other esteem factors e.g. organising sessions*	35 out of a total of 62 consisting of 27 invited and 8 keynote talks
Number and nature of commentaries about the Centre's achievements In general/specialist publications, electronic postings or equivalent	Annually	*>2*	8 See the Communication section of the Annual report for full details
Citation data for publications	At review	*A census of publications and citations related to Centre core business by Centre researchers will be undertaken annually to establish base-line and progress levels*	To be assessed at review
Research training and professional education			
Number of attended professional training courses for staff and postgraduate students Includes Centre workshops for postgraduates and training courses (e.g. field, geochemistry, GIS etc.)	Annually	*10*	12
Number of Centre attendees at all professional training courses	Annually	*20*	Varied from 8-20 attendees depending on the nature of the training
Number of new postgraduate students working on core Centre research and supervised by Centre staff (include PhD, Masters by research and Masters by coursework)	Annually	*6*	10

Performance Measure	Reporting Frequency	Target 2011	Outcome
Number of new postdoctoral researchers recruited to the Centre working on core Centre research Number of new positions depends on length of each postdoctoral term (e.g. a 3-year term will yield 1 new position, 3x1-year terms yield 3 new but same cumulative number for same funding	Annually	*4*	9
Number of new Honours students working on core Centre research and supervised by Centre staff	Annually	*6*	6
Number of postgraduate completions and completion times, by students working on core Centre research and supervised by Centre staff	Annually	*6*	5
Number of Early Career Researchers (within five years of completing PhD) working on core Centre research	Annually	*6*	9
Number of students mentored	Annually	*12 Honours + postgrad*	43
Number of mentoring programs • Formal • Informal	Annually	*3*	2 Formal 4 Informal
International, national and regional links and networks			
Number of international visitors and visiting fellows	Annually	*20*	67
Number of national and international workshops held/organised by the Centre • National • International	Annually	*1 of each*	4 National 2 International
Number of visits to overseas laboratories and facilities Centre Investigators & researchers for collaboration, technology /research exchange	Annually	*>10*	16

Performance Measure	Reporting Frequency	Target 2011	Outcome
Examples of relevant interdisciplinary research supported by the Centre Geochemistry/ geophysics, tectonics/ geochemistry, tectonics/ geodynamics, geochemistry /technology development	Annually	*At least 50% of projects*	93% i.e. 12 out of 13 Foundation Projects
End-user links			
Number of government, industry and business community briefings	Annually	*4*	6
Number and nature of public awareness programs School programs, visits, public lectures, media interviews	Annually	*5*	12
Currency of information on the Centre's website	Annually	*Establish website first 3 months 2011*	Completed
Number of website hits Year 1 target will be re-assessed at end 2011 following pilot study in 2011 and subsequent years targets adjusted	Annually	*1000*	1100
Number of public talks given by Centre staff	Annually	*2*	7
Organisational support			
Annual cash contributions from Collaborating Organisations	Annually	*Macquarie University: $875,000* *University of Western Australia: $415,000* *Curtin University: $500,000*	Macquarie University: $875,000 University of Western Australia: $415,000 Curtin University: $500,000
Annual in-kind contributions from Collaborating Organisations	Annually	*Macquarie University: $8,318,100* *University of Western Australia: $1,500,000* *Curtin University: $2,600,000*	Macquarie University: $8,318,100 University of Western Australia: $1,500,000 Curtin University: $2,600,000
Annual cash contributions from Partner Organisations	Annually	*Geological Survey of Western Australia $150,000*	Geological Survey of Western Australia $150,000

Performance Measure	Reporting Frequency	Target 2011	Outcome
Annual in-kind contributions from Partner Organisations	Annually	*Geological Survey of Western Australia: $541,800 Geochemical Institute, Chinese Academy of Sciences: $375,000 University of Saskatchewan: $190,000 University of Maryland: $34,500 University of Montpellier: $75,000 Bayreuth University: $13,000*	Geological Survey of Western Australia: $541,800 Geochemical Institute, Chinese Academy of Sciences: $375,000 University of Saskatchewan: $190,000 University of Maryland: $34,500 University of Montpellier: $75,000 Bayreuth University: $13,000
Other research income secured by Centre staff (list research income from ARC grants, other Australian competitive grants, grants from the public sector, industry and CRCs and other research income separately)	Annually	*$140,000 requested from NSW Government Funding to be requested from WA Government, level not negotiated at this stage. Levels of other ARC funding and industry income will be assessed after Centre Core Business has been defined before Centre commencement in early 2011*	See funding table p. 180

Postgraduate students and staff at Macquarie during a professional training course.

Performance Measure	Reporting Frequency	Target 2011	Outcome
Number of new organisations collaborating with, or involved in, the Centre	Annually	*5*	8
Level and quality of infrastructure provided to the Centre	*As per agreement with collaborating and partner institutions for access to machine and laboratory time, and itemised below. The Geological Survey of Western Australia will provide seismic data.* *Specifically:* • *Macquarie University – GAU laboratories and instruments: 50%* • *Macquarie University – GAU staff: 25% of salaries of 3 staff* • *Curtin University – laboratories and Instruments* • *Curtin University – staff in SHRIMP lab: 30% of salaries* • *University of Western Australia – 20%* • *University of Western Australia – staff currently with NanoSIMS and Cameca 1280 ion microprobes: 20%* *Other Partners' laboratory and instrument time to the value of:* • *Chinese Academy of Sciences: $350,000* • *University of Saskatchewan: $180,000* • *University of Montpellier: $40,000 (ion probe, SEM, EBSD)* • *Bayreuth University: $8,000 (Mossbauer)* • *University of Wisconsin: $75,000* *Geological Survey of Western Australia will carry out geophysical traverses across the Yilgarn craton, with a budget of $3.8M. These surveys will be available to CoE researchers, who will be actively engaged in the interpretation of the results, for the life of the Centre. We have taken 10% ($380,000) of the cost of the seismic traverses as a minimum estimate. This program, and collaboration with the CoE, is intended to extend beyond Year 3, but the GSWA is not able to commit themselves formally, so far in advance.* *Macquarie University will provide appropriate identified Centre space for admin, research and academic staff and for postgraduates and Honours students in 2011. Macquarie University will move into designated space early 2012.* *Year 3 – ensure space has been provided as outlined by each node - To be assessed at review*		To be assessed at review

Performance Measure	Reporting Frequency	Target 2011	Outcome
Governance			
Breadth, balance and experience of the members of the Advisory Committee	At review	*Members with high level of research, administrative and end-user credentials including government, academia and industry*	To be assessed at review
Frequency, attendance and value added by Advisory Committee meetings	At review	*5 full meetings in first 3 years with intermediate interaction by teleconference/email. Value-added includes access to end-user networks, project advice and managerial experience*	To be assessed at review
Vision and usefulness of the Centre strategic plan	At review	*Develop strategic plan by end 2011*	Postponed due to late start of CCFS
The adequacy of the Centre's performance measure targets	At review	*Evaluation by Advisory Board*	To be assessed at review
Effectiveness of the Centre in bringing researchers together to form an interactive and effective research team	At review	*Internode and collaborator connections measured by jointly authored presentations, publications and co-supervision of postgraduates within University organisational frameworks*	To be assessed at review
Capacity building of the Centre through scale and outcomes	At review	*Attraction of high-quality researchers: Fellows/continuing staff; postdocs, research partner visitors*	To be assessed at review
National benefit			
Contribution to the National Research Priorities and the National Innovation Priorities	Annually	*Industry seminars held relevant to National Research Priority Areas 1 and 2. Number of industry/end-user collaborations*	4
Measures of expansion of Australia's capability in the priority area(s)	At review	• *2 postgraduate units established by end year 3, extending host University postgraduate activities* • *Number of honours and postgraduate students*	To be assessed at review

Performance Measure	Reporting Frequency	Target 2011	Outcome
Centre-specific Performance Indicators for the ARC Centre of Excellence for Core to Crust Fluid Systems			
Research			
Linkage of geochemical/petrologic/ geological data with geophysical datasets/modelling	Review	*Initiate relevant research projects*	7 Relevant projects initiated
Technology and method development related to NCRIS infrastructure (mineral separation, LA-ICPMS and Cameca ion probe)	At review (and annual appraisal)	• *Initiate methodologies for C, O, S stable isotope analysis;* • *development of simultaneous techniques on LA-ICPMS* • *Develop SelFrag separation techniques*	• Completed • Postponed due to the delayed arrival of ordered equipment • Completed
Research Training			
Establish formal postgraduate units and training within host and Collaborating University frameworks	At review	*To be assessed at review*	To be assessed at review
End-user links			
Establish Linkage and collaborative projects(s) with end-users relevant but external to core business of the Centre	At Review (and annual appraisal)	*Presentations to end-users and scoping of potential projects; input from Advisory Board* *Minerals Targetting industry* *CET Meetings* *Linkage projects listed in annual report*	Minerals Targetting Industry CET Meetings Linkage Projects

Appendix 9: CCFS postgraduate opportunities

POSTGRADUATE OPPORTUNITIES

CCFS 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 at all universities.
- **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. CCFS/GEMOC). These include cotutelle programs with international universities (http://www.international.mq.edu.au/research/cotutelles)
- **International Postgraduate Research Scholarships (E-IPRS Endeavour Scholarships):** available to overseas students to cover tuition fees with a closing date in late August annually (http://www.deewr.gov.au/International/EndeavourAwards/Pages/Home.aspx)

Macquarie University also provides research funding through a competitive internal scheme; CCFS and externally funded projects provide further resources to support postgraduate research projects; and some CCFS support is available for approved postgraduate research support.

Postgraduate projects are tailored to your expertise and interests within the framework of CCFS research goals. CCFS carries out interdisciplinary research across the boundaries of petrology, geochemistry, tectonics, metallogenesis, geodynamics and geophysics to explore the nature and evolution of the Earth and global geodynamics. Current funded projects are based in Australia, Antarctica, Canada, China, Taiwan, Italy, France, Spain, Siberia, Norway, North America, South America, Africa, Kerguelen Islands, Greenland and other locations globally (see the map on p. 25 of this Report).

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

Examples of broad PhD project areas include (but are not limited to):

- 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

Initial inquiries can be sent to: ccfs.admin@mq.edu.au; or to any CCFS staff.

Contact details

- **CCFS information is accessible at:**

  http://www.ccfs.mq.edu.au/

- **Contact CCFS via email at:**

  ccfs.admin@mq.edu.au

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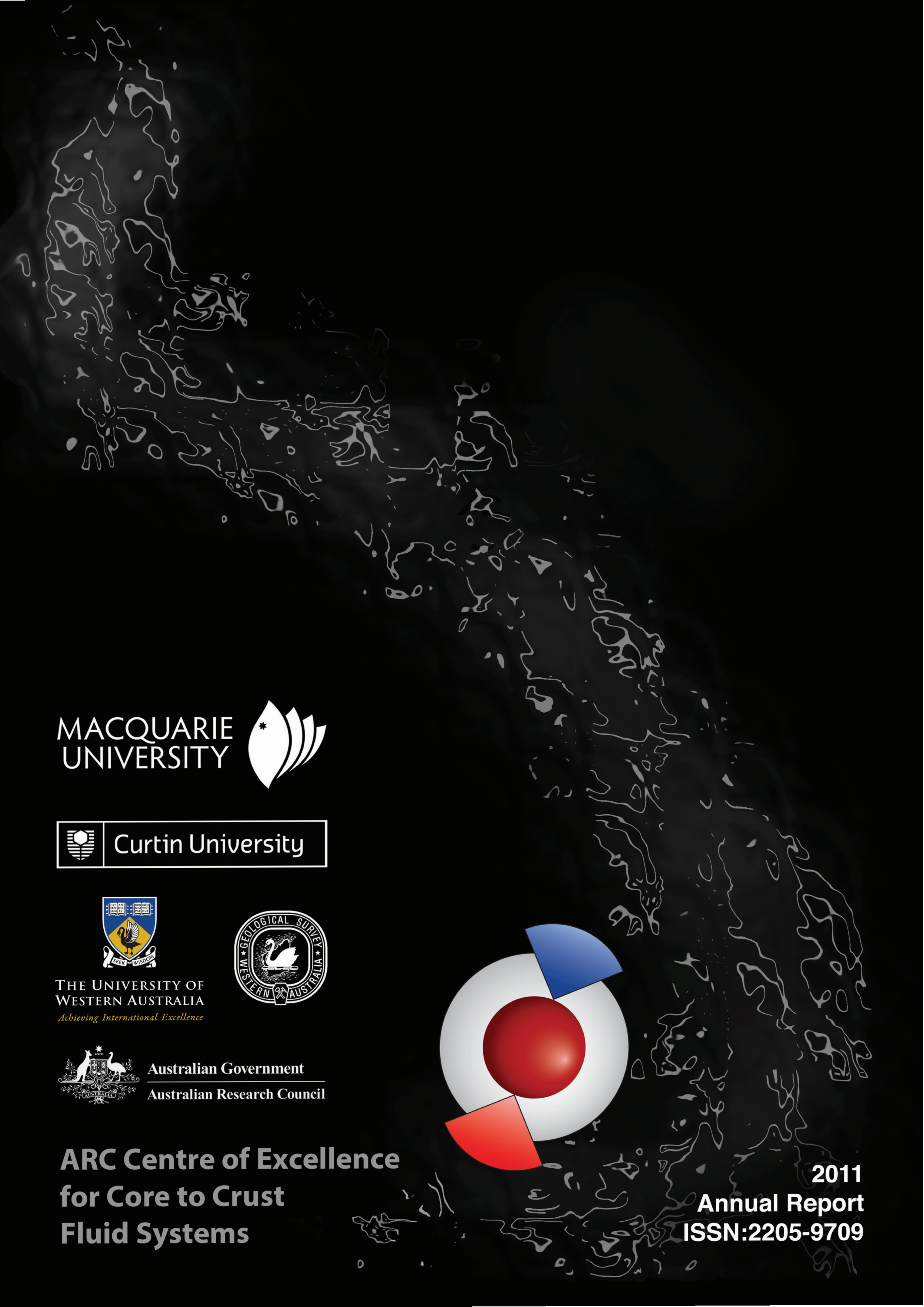
Australian Government
Australian Research Council

Glossary

AMIRA	Australian Mineral Industry Research Association
AMMRF	Australian Microscopy and Microanalysis Research Facility
ANU	Australian National University
APA (I)	Australian Postgraduate Award (Industry)
ARC(-APD)	Australian Research Council - (Australian Postdoctoral Fellowship)
BSE	Backscattered Electrons
CAS	Chinese Academy of Sciences
CAGS	Chinese Academy of Geological Sciences
CCFS	Core to Crust Fluid Systems
CET	Centre for Exploration Targeting
CMCA	Centre for Microscopy, Characterisation and Analysis (UWA)
CNRS	French National Research Foundation
CoE	Centre of Excellence
COO	Chief Operating Officer
CSC	China Scholarship Council
CSIRO	Commonwealth Scientific Industrial Research Organisation
CU(PS)	Curtin University (Postgraduate scholarship)
DECRA	Discovery Early Career Researcher Award
DEST	Department of Education, Science and Training (from 2002)
DIATREEM	Consulting company within Access MQ Limited
DIISR	Department of Innovation, Industry, Science and Research
DP	Discovery Project
EAPE CoRE	Earth and Planetary Evolution Concentration of Research Excellence
EBSD	Electron Backscatter Diffraction
ECR	Early Career Researcher
ECSTAR	Early Career Start-up Awards for Research
EIS	Exploration Incentive Scheme
(D)EPS	(Department of) Earth and Planetary Sciences
EMP	Electron Microprobe
GA	Geoscience Australia (formerly AGSO)
GAU	Geochemical Analysis Unit (DEPS, Macquarie University)
GEMOC	Geochemical Evolution of Metallogeny of Continents
GIS	Geographic Information System
GLAM	Global Lithospheric Architecture Mapping
GLITTER	GEMOC Laser ICPMS Total Trace Element Reduction software
GPS	Global Positioning System
GSWA	Geological Survey of Western Australia
ERA	Excellence in Research for Australia
FIM	Facility for Integrated Microanalysis
FTIR	Fourier Transfer Infrared Spectroscopy
ICPMS	Inductively Coupled Plasma Mass Spectrometer
iMURS	International Macquarie University Research Scheme
IPRS	International Postgraduate Research Scholarship
LAM-ICPMS	Laser Ablation Microprobe - ICPMS
LIEF	Linkage Infrastructure, Equipment and Facilities
MC-ICPMS	Multi-Collector - ICPMS
MERIWA	The Minerals and Energy Research Institute of Western Australia
MQNS	Macquarie University New Staff Research Grants Scheme
MQRDG	Macquarie University Research Development Grant
(i)MQRES	(International) Macquarie University Research Excellence Scholarships
MQRF	Macquarie University Research Fellowship (formerly MURF)
NCRIS	National Collaborative Research Infrastructure Scheme
PGE	Platinum Group Element
PIRSA	Primary Industries and Resources, South Australia
RIBG	Research Infrastructure Block Grant
RSES	Research School of Earth Sciences at ANU
SAC	Science Advisory Committee
SEM	Scanning Electron Microscope
SIRF	Scholarship for International Research Fees
UWA	University of Western Australia



MACQUARIE UNIVERSITY

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Achieving International Excellence

GEOLOGICAL SURVEY WESTERN AUSTRALIA

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