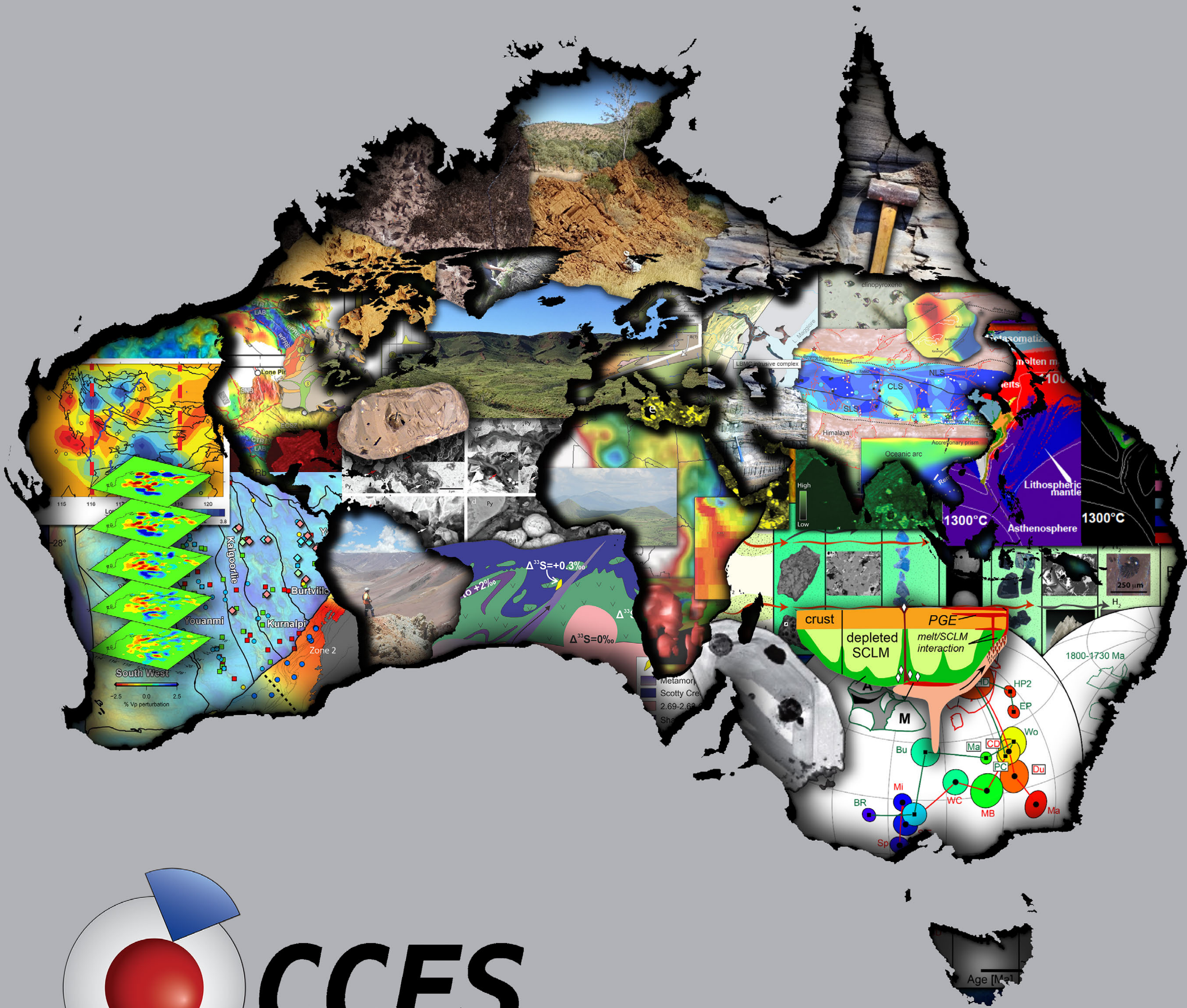
2017

Annual Report



CCFS

The Australian Research Council Centre of Excellence for Core to Crust Fluid Systems

CCFS information is accessible on WWW at:

http://www.ccfs.mq.edu.au/

Contact CCFS via email at:

ccfs.admin@mq.edu.au

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 gives a snapshot of images from the 2017 Research Highlights (p. 36-74).

Cover and Report design by Sally-Ann Hodgekiss.

Contents

Australian Government
Australian Research Council

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

Director's preface

This report summarises the activities and achievements of the Australian Research Council Centre of Excellence for Core to Crust Fluid Systems (CCFS) in 2017 (formally commenced mid 2011). Activities include research, technology development, stakeholder engagement, 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.

The CCFS Vision "*Delivering the fundamental science needed to sustain Australia's resource base*" has been more than fulfilled over the last six and a half years. CCFS became a significant thought-leader in national geoscience, both in new initiatives for, and contributions to, the national research and geoscience agenda. CCFS Chief and Associate Investigators, collaborating researchers and Board members have been instrumental in shaping UNCOVER Australia (https://www.uncoveraustralia.org.au/) and the 2017 AMIRA "*Undercover Roadmap*" (http://www.amirainternational.com/WEB/site.asp?section=activities&page=ExplorationUnderCover-STAGE2-RegistrationForm). Indeed the 4-D Lithosphere Mapping approach (established by GEMOC and CCFS with industry partners) forms the robust conceptual basis for UNCOVER, contributed significantly to the AMIRA Roadmap process, and has become part of the vernacular in smart exploration strategies. CCFS CIs and Board members were members (and Chair) of the Australian Academy of Science National Committee for Earth Science (NCES) in 2017. In that capacity, they contributed submissions to the Chief Scientist on the continuing issue of research infrastructure funding and the future of NCRIS. They also played a key role in producing the Decadal Plan for Earth Science in Australia, *Our Planet, Australia's Future: A decade of transition in Geoscience* which will be published and distributed in mid 2018.

CCFS has truly delivered transformational scientific outcomes. A few examples include: the development of regional isotopic mapping, which is revealing unprecedented information about Earth's crustal evolution and has paved the way for mapping the whole Australian continent in this way; presentation of complex geochemical data as meaningful images (as geophysicists have done for decades) instead of less accessible plots and diagrams; refining paleomagnetic reconstructions to better understand tectonic evolution; recognising ultra-reduced domains and their significance in the lithosphere and below; providing new knowledge of the carbon cycle from the deep mantle to the surface; innovative geodynamic modelling to probe the nature of the early Earth and huge advances towards the holy grail of theoretical multi-observable probabilistic prediction of the composition of the lithospheric mantle and beyond; and new adjoint methodologies for processing seismic data.

CCFS' huge and rapidly growing international network, developed across the globe, has forged collaborations that bring complementary expertise, hugely funded resource leverage, access to an unsurpassed virtual laboratory for geochemical analysis and imaging, experimental capabilities, geophysical instruments and techniques, and for global natural laboratories that provide analogues to understand the Australian continent where its geological clues are hidden beneath cover. Just one example from 2017 is the new collaboration with the Institute of Geology and Geophysics, China Academy of Science, Beijing, (IGG CAS), CCFS, Geoscience Australia, and ANSIR (Australian facilities for Earth sounding) that has resulted in a 4-year passive seismological deployment along a 900 km profile across NW Australia from Port Hedland to the southwestern border of the ancient Kimberley Craton in a dense array (station spacing of 10-15 km) extended beyond the continent margin using ocean-bottom seismometers.

The 2017 Whole-of-Centre Meeting in Cairns in November was inspirational with over 120 participants. The transformational, interdisciplinary research presented clearly demonstrated the significant scientific advances that can be made with the timescale provided by Centre funding. It was striking to see the lecture theatre dominated by early- to mid-career researchers, fulfilling the original goal of delivering the next generation of frontline geoscientists.

83 PhD students undertook research aligned with CCFS in 2017. CCFS postgraduates are producing world-class research with authorship of 42 publications (28 first-authored) in high-impact journals in 2017 and 73 presentations at peak international workshops and conferences. Participation of early-career researchers reached 21.

Eleven Future Fellowships have been awarded across CCFS and show good gender balance, with five women recipients. The CCFS Future Fellows continue to make significant contributions to CCFS, either directly or as external collaborators and formal associates. Those of this outstanding cohort who have completed their Fellowship, have now transitioned to continuing high-level positions and have become international research leaders both nationally and abroad. Those in CCFS nodes now lead research programs, have initiated new strategic directions, and some have initiated new University Centres, springboarding from CCFS in new directions.

CCFS has exceeded its original goals and has delivered transformational outcomes for geoscience relevant to Earth's composition, evolution, geodynamics and structure. These fundamental advances have indeed resulted in heightened understanding of Earth's processes and changes through time, as well as providing powerful methodologies for smart exploration targeting, national benefit and the fundamental science needed to sustain Australia's resource base.

S.Y. O'Reilly

Professor S.Y. O'Reilly

CCFS participants at the 2017 Whole-of-Centre Meeting (Photo: Will Powell).

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

Vision

Delivering the fundamental science needed to sustain Australia's resource base

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, the biosphere, and the development of giant ore deposits.

Subduction - the descent of oceanic plates into the mantle - carries water down into Earth's interior; dehydration of the subducting crustal slabs at high pressure and temperature releases these fluids into the mantle, causing melting and controlling the strength, viscosity, melting temperature and density of rocks in the deep Earth, as well as 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 only in its developmental stages. 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.

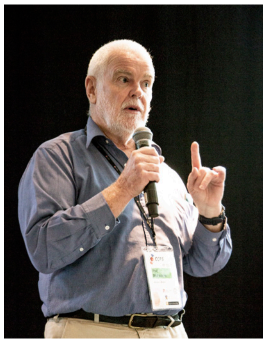
2017 WHOLE-OF-CENTRE RESEARCH MEETING

A successful and productive CCFS research meeting was held in Cairns, 27-29 November 2017. The meeting provided the opportunity for participants, as well as members of the CCFS Board, to hear research presentations from CCFS researchers, including postgraduates and ECRs.

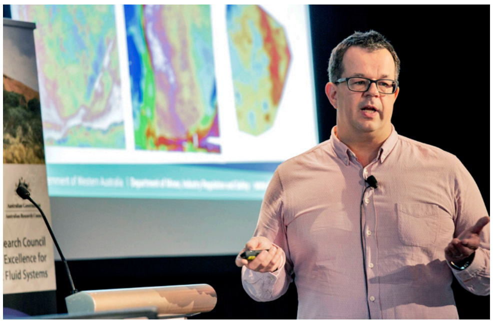
The forum was a catalyst for new, exciting ideas and cemented collaboration among researchers of the Centre's nodes and partner institutions.

The CCFS Whole-of-Centre Meeting Abstract Volume ISSN:2209-1351 (Online) is available for download http://ccfs.mq.edu.au/WoCMeeting17/2017WoCMAbstractVolume.pdf

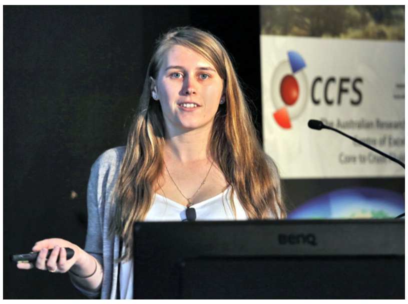
L-R, T-B: Phil McFadden, Hava Zhang, Anna Wan, Sally-Ann Hodgekiss, Magdalene Wong-Borgefjord, Keng Chai Ng, Summer Luo, Klaus Gessner, Yoann Gréau, Weronika Gorczyk, Christoph Lenz, Cait Stuart, Beñat Oliveira, Louise Goode, Sarah Gain, Georgia Soares.



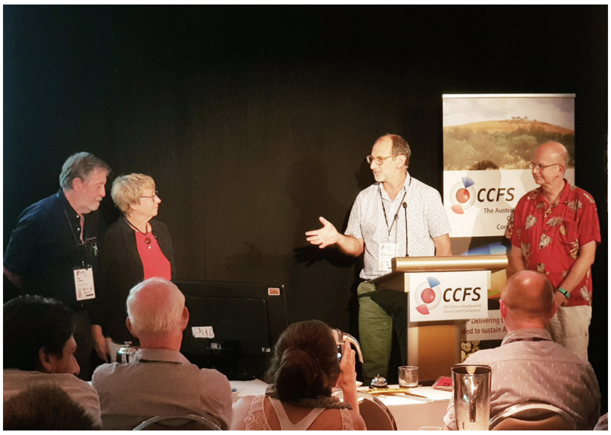
The CCFS admin team.

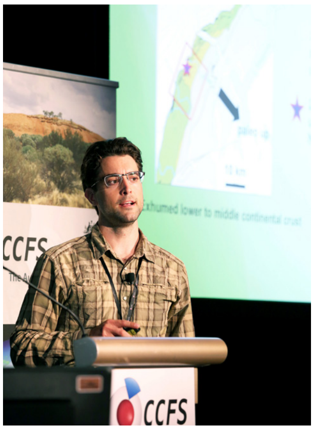


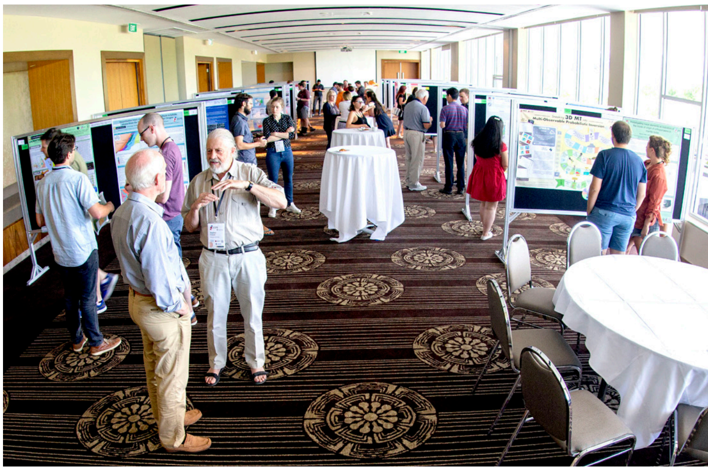
The CCFS Advisory Board.



The CCFS Board Meeting, 27 November 2017 - Front L-R: Sally-Ann Hodgekiss, Magdalene Wong-Borgefjord, Cam McCuaig, Ian Gould, Sue O'Reilly, Simon Wilde, Marco Fiorentini. Rear L-R: Zheng-Xiang Li, Craig O'Neill, Steve Foley, Dorrit Jacob, Phil McFadden, Andy Barnicoat, Ian Tyler.







L-R, T-B: Weihua Yao, Amaury Pourteau, Laure Martin, Jinxiang Huang, Bill Griffin, Irina Tretiakova, Michael Etheridge, Sue O'Reilly and Bill Griffin being thanked for their contribution to CCFS by Martin Van Kranendonk and Steve Foley, Greg Dering, Chris Kirkland, Jianggu Lu, Anqi Zhang, Andrea Giuliani, Poster Session, Ian Tyler, Steve Foley.

CENTRE RESEARCH

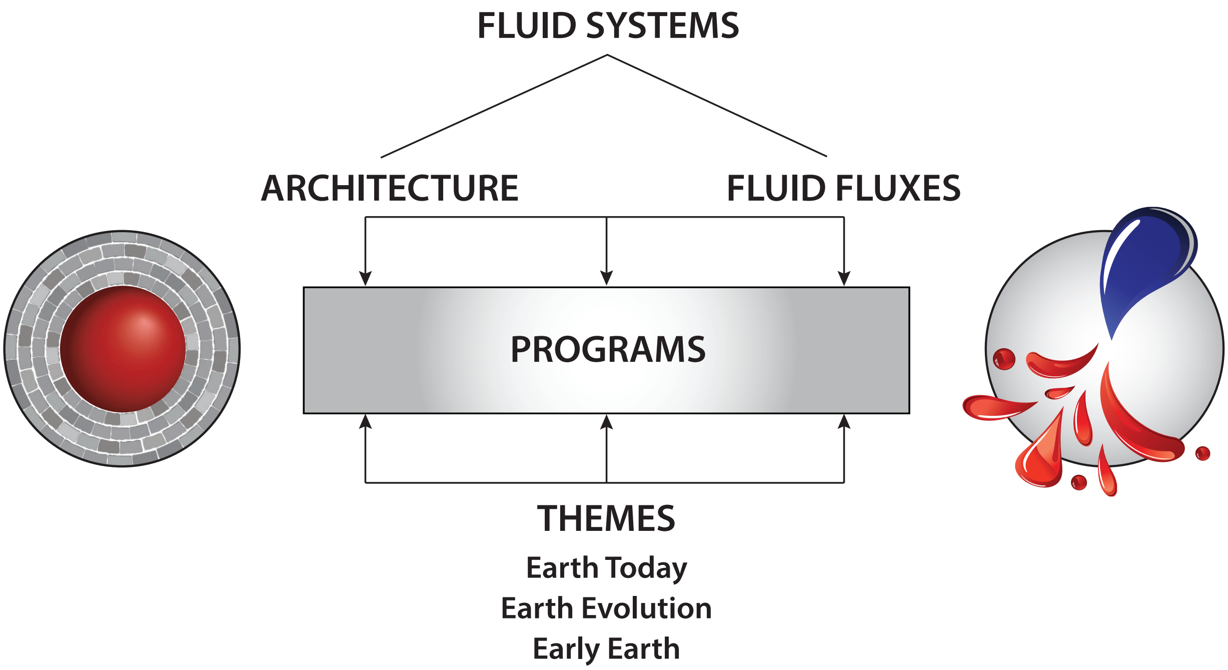
Research programs within the Centre are focused to provide maximum synergy for the scope enabled by the resource base. As it is not possible to encompass the full range of research about the Earth's fluid cycle and deep Earth dynamics, all applied and mature strategic research is carried out in parallel, supported by other funding sources. The Research Program structure was revised in 2014 to ensure the overarching goals were being fulfilled. The resulting Flagship Programs (see *p. 20*) were put in place as cross-node streams contributing to the three global Themes (Early Earth, Earth's Evolution and Earth Today).

These are structured to capitalise on the people and resource context of the Centre in a way not possible with a shorter timeframe, or without the critical mass of research expertise, depth and breadth. More detailed information is given in *"The CCFS research program"* and *"Research highlights"*.

In order to track the input of coalescing strands, the concept of programs contributing to understanding ***Earth Architecture*** and/or ***Fluid Fluxes*** helps track the pieces of the giant 4-dimensional Earth puzzle being solved by CCFS and encapsulates the relationship of all the CCFS programs to Earth *'fluids'*.

> ***"Architecture" is the 'roadmap' for fluids***
> ***"Fluid Fluxes" represents the 'traffic report'***

All Research highlights and Programs are now keyed to this framework shown diagrammatically below:



THEMES

THEME 1: EARLY EARTH

The Early Earth - Its formation and fluid budget. This theme focuses on the nature of Earth's early differentiation and the role of fluids. 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

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 Earth's cooling; 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

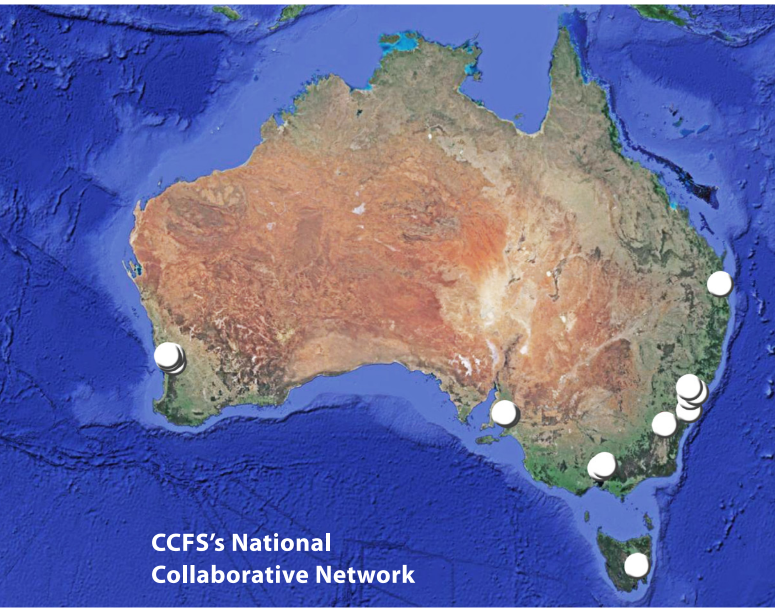
Earth Today - Dynamics, decoding geophysical imaging, and Earth resources. Geophysical imagery gives us a snapshot of the current status of the deep Earth but also carries the imprints of past processes. Realistic interpretation of these data will give us new insights into Earth's internal dynamics and 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. These codes 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.

Field trip to the mantle section of the Trinity ophiolite, California; the legendary, snow covered Mount Shasta, in the background. L-R: Romain Tilhac, Garazi Gil Azpitarte, Mary-Alix Kaczmarek (CCFS, GET), Hadrien Henry and Georges Ceuleneer (GET).

Structure

CCFS builds on a world-class infrastructure base, and multiplies the capabilities of three internationally recognised centres of research excellence: Macquarie University (Administering Institution), Curtin University and the University of Western Australia. The Geological Survey of Western Australia is a Partner Institution and researchers from Melbourne University and the University of New South Wales are formally affiliated. The overseas nodes led by Partner Investigators in France, China, Germany and the USA are contributing resources and provide access to a wide variety of expertise and instrumental capabilities. Memoranda of Understanding (MOU) for research collaboration and postgraduate exchange and joint programs, provide formal affiliations with six additional global institutions with leading reputations in the field. CCFS also has formal Cotutelle MOU with a further fourteen global institutions (see *p. 98*). 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.

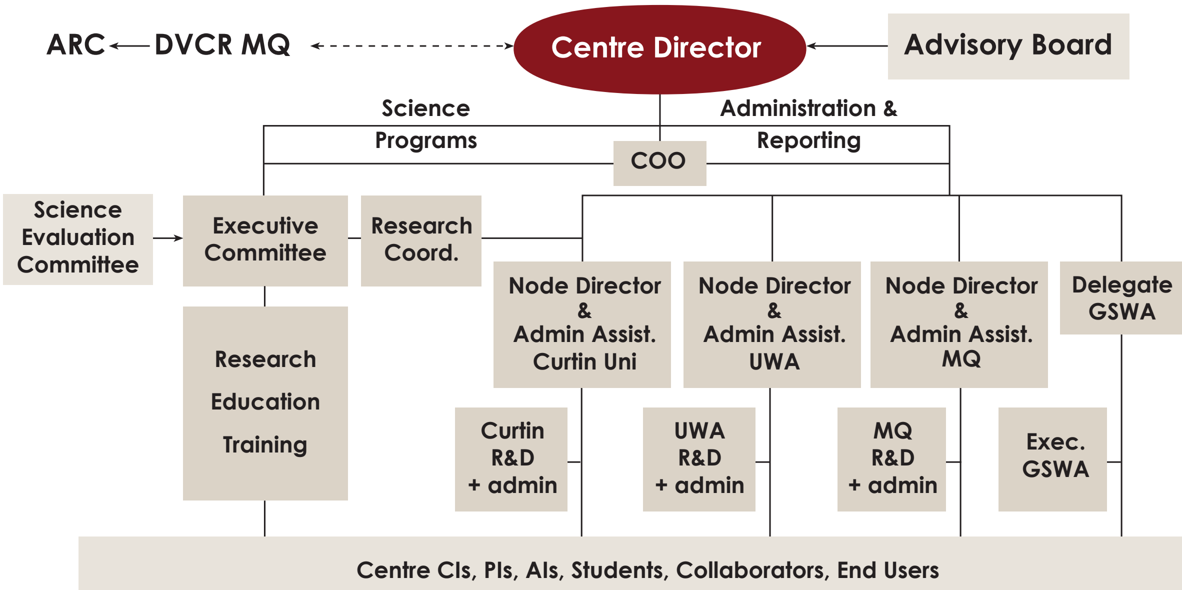

CCFS's National Collaborative Network

There is active national collaboration with state Geological Surveys, Geoscience Australia (GA), CSIRO, the Australian National University (RSES), University of Newcastle, 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 programs related to the CCFS strategic goals. A distinctive feature of CCFS is the high level of active international collaborations and reciprocal links (see the section on *International links*).

MACQUARIE University

THE UNIVERSITY OF WESTERN AUSTRALIA

Curtin University



Governance & management

Centre Director Professor Suzanne O'Reilly is supported by a Chief Operating Officer and a Reporting and Communications Manager. Professor O'Reilly provides scientific leadership and strategic direction for the Centre. Node Directors administer the CU and UWA nodes and 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 which guides the Advisory Board and Centre Director on the appropriateness of the research strategies, reports on progress in achieving aims as well as structure and general operating principles, and identifies and protects the Centre IP. A new Executive position of Centre Research Coordinator was introduced in 2013, taken on by the targeted MQ appointment of Professor Stephen Foley.

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 at least annually to provide advice on the research program and governance, and any other matters relevant to CCFS. The six external members of the Advisory Board are actively engaged and supportive of CCFS (87.5% attendance at meetings) and extensively workshopped the new vision statement to reflect the national benefit deriving from the fundamental research in CCFS.

The Science Advisory Committee has a rotating membership and primarily evaluates the Centre's research, in particular its research strategies, structure and outcomes.

Executive Committee

Professor Suzanne Y. O'Reilly - Director
Department of Earth and Planetary Sciences
Macquarie University

Professor William L. Griffin
Department of Earth and Planetary Sciences
Macquarie University

Associate Professor Craig O'Neill
Department of Earth and Planetary Sciences
Macquarie University

Professor Simon Wilde - Node Director
Department of Applied Geology,
Curtin University

Professor Zheng-Xiang Li
Department of Applied Geology,
Curtin University

Associate Professor Marco Fiorentini - Node Director
School of Earth and Environment
University of Western Australia

Associate Professor Matthew Kilburn
Deputy Director, CMCA
University of Western Australia

(Ex Officio)
Professor Stephen Foley - Research Coordinator
Department of Earth and Planetary Sciences
Macquarie University

Dr Ian Tyler - GSWA
Assistant Director Geoscience Mapping
Geological Survey of Western Australia

Magdalene Wong-Borgefjord - COO
Department of Earth and Planetary Sciences
Macquarie University

Advisory Board

Dr Ian Gould
Former Chancellor, University of South Australia

Dr Andy Barnicoat
Chief, Community Safety & Earth Monitoring Division, Geoscience Australia

Dr Paul Heithersay
Chief Executive, Olympic Dam Task Force, and Deputy Chief Executive, Resources and Energy Group, Department of State Development

Dr Jon Hronsky
Principal, Western Mining Services

Dr Phil McFadden
Treasurer and Executive Committee,
Fellow, Australian Academy of Science;
driver of the UNCOVER initiative

Dr Roric Smith
Consulting Geologist
Evolution Mining

(Ex Officio)
Dr Campbell McCuaig
Principal Geoscientist
Geoscience Centre of Excellence
BHP Billiton

plus the Executive Committee

Participants

Organisations

Administering Organisation

Macquarie University (MQ)

Collaborating Organisations

Curtin University (CU)

University of Western Australia (UWA)

Partners

Australian Partner

Geological Survey of Western Australia (GSWA)
Dr Ian Tyler - CCFS Leader GSWA

International Partners

CNRS and Université de 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

Dr Elena Belousova - MQ

Professor Simon Clark - MQ

Associate Professor Marco Fiorentini,
Node Leader - UWA

Professor Stephen Foley, Research Coordinator - MQ

Professor William Griffin - MQ

Associate Professor Matthew Kilburn - CMCA/UWA

Professor Zheng-Xiang Li - CU

Associate Professor Alexander Nemchin - CU

Associate Professor Craig O'Neill - MQ

Professor Suzanne Y. O'Reilly, Director - MQ

Associate Professor Norman Pearson - MQ *until July 2017*

Professor Martin Van Kranendonk - UNSW

Professor Simon Wilde, Node Leader - CU

Associate Professor Yingjie Yang - MQ

A full list of CCFS participants is given in *Appendix 4* and at http://www.ccfs.mq.edu.au/

Partner Investigators

Australian Partner Investigator

Dr Klaus Gessner - GSWA

Dr T. Campbell McCuaig - BHP Billiton

International Lead Partner Investigators

Professor Michael Brown - University of Maryland

Dr David Mainprice - Université de Montpellier

Professor Catherine McCammon - Bayreuth University

Professor Fuyuan Wu - CAS Beijing

Associate Investigators

Associate Professor Juan Carlos Afonso - MQ

Dr Olivier Alard - MQ

Associate Professor Nathan Daczko - MQ

Professor Simon George - MQ

Dr Richard Glen - MQ Adjunct Professor

Dr Masahiko Honda - Australian National University

Professor Dorrit Jacob - MQ

Associate Professor Mary-Alix Kaczmarek - University
Paul Sabatier Toulouse III

Associate Professor Christopher Kirkland - CU

Professor Jochen Kolb - GEUS

Dr Yongjun Lu - GSWA

Professor Louis-Noel Moresi - University of Melbourne

Professor Steven Reddy - CU

Associate Professor Tracy Rushmer - MQ

Associate Professor Bruce Schaefer - MQ

Professor Paul Smith - MQ

Professor Simon Turner - MQ

Dr Michael Wingate - GSWA

Professor Shijie Zhong - University of Colorado,
Boulder, USA

Early Career Researchers

Dr Raphael Baumgartner - UWA

Dr Montgarri Castillo-Oliver - MQ

Dr Denis Fougerouse - CU

Dr Rongfeng Ge - CU

Dr Andrea Giuliani - DECRA - MQ at UM

Dr Christopher Gonzalez - UWA

Dr Johannes Hammerli - UWA

Dr Heejin Jeon - CMCA, UWA

Dr Uwe Kirscher - CU

Early Career Researchers *cont...*

Dr Crystal LaFlamme - UWA
Dr Erwann Lebrun - UWA
Dr Yongjun Lu - GSWA
Dr Ross Mitchell - CU
Dr Rosanna Murphy - MQ
Dr Hugo Olierook - CU
Dr Beñat Oliveira Bravo - MQ
Dr Luis Parra-Avila - UWA
Dr Romain Tilhac - MQ
Dr Irina Tretiakova - UWA
Dr Qing Xiong - MQ
Dr Weihua Yao - CU

NEW STAFF

Dr Kate Selway

ECRs *(featured on pp. 11-13 of our ECR section)*

Dr Raphael Baumgartner - UWA
Dr Beñat Oliveira Bravo - MQ
Dr Romain Tilhac - MQ
Dr Irina Tretiakova - UWA

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 ARC Future Fellow rounds emphasises this role of our Centre in recruiting high-flyers at early to mid-career levels. Ten Future Fellows; Dr Elena Belousova, Associate Professor Marco Fiorentini, Dr Heather Handley, Professor Dorrit Jacob, Associate Professor Craig O'Neill, Professor Sandra Piazolo, Associate Professor Yingjie Yang, Dr Xuan-Ce Wang, Dr David Wacey and Dr Olivier Alard have completed or are working on projects relevant to CCFS goals. The CCFS Future Fellows all continue to make significant contributions to CCFS, either directly or as external collaborators and Associates. Those of this outstanding cohort who have completed their Fellowship, have now transitioned to permanent high-level positions and become international research leaders both nationally and abroad. Those in CCFS nodes now lead research programs, have initiated new strategic directions, some with new University Centres, springboarding from CCFS in new directions. Their profiles can be accessed from the "*Participants*" section of our previous reports (http://www.ccfs.mq.edu.au/AnnualReport/Index.html). The 11th CCFS Future Fellow, Dr Kate Selway, commenced her fellowship in 2017.

Dr Kate Selway is a geophysicist with a specialty in magnetotellurics (or MT). She is particularly interested in using MT to discover new properties of the Earth's mantle. Kate completed her PhD at Adelaide University in 2007 and continued to work there in postdoctoral positions, including an ARC APD fellowship, until 2012. She then spent several years pursuing

postdoctoral research abroad at Yale University, Lamont-Doherty Earth Observatory of Columbia University, and the Centre for Earth Evolution and Dynamics at the University of Oslo. Kate returned to Australia in early 2017 after being awarded a Future Fellowship at Macquarie University.

In her Future Fellowship, Kate aims to constrain the level of hydration of the lithospheric mantle. Mantle hydration is important because it is a strong control of viscosity and is, therefore, a major factor controlling continental evolution. Hydrated pathways are also likely to be formed during mantle fluid-flow events, including those that form significant mineral deposits. MT is unique in being able to image mantle hydration, and Kate aims to produce the first systematic study of hydration of the continental lithosphere from MT data. These results will be used to improve models of mantle viscosity, cratonic survival and ore deposit formation.

EARLY CAREER RESEARCHERS (ECR)

The second primary goal of CCFS (see *p. 3*) concerns the recruitment, development and mentoring of Early Career Research (ECR) staff "*for the development of the next generation of Australia's geoscientists*".

These CCFS ECRs have all achieved high positions, both nationally and abroad, and are having significant impact across many countries including Japan, Spain, Chile, USA, Europe and Asia. They are contributing in diverse areas that include: the nuclear science and environmental sector, CSIRO, Geological Surveys, international Research Centres, Government instrumentalities, the exploration industry and in consultancies in the private sector.

The following profiles present 2017 ECRs and summarise their expertise and research areas.

NEW 2017

Dr Raphael Baumgartner received his MSc in Economic Geology from the University of Leoben (Austria). He joined CCFS/CET at UWA in June 2013, as a PhD candidate, seeking to unravel the potential of martian igneous systems to host precious metal-enriched sulfide mineralisation. His work provided important insights into the behaviours of (highly) siderophile and chalcophile elements in martian mantle reservoirs and derived igneous systems through mineral-scale analytical experiments on sulfide and oxide phases from shergottite and chassignite meteorites - a rare group of meteorites that are thought to represent samples of the volcanic martian crust.

At the completion of his PhD, Raphael was employed as a Research Associate at CET. His research focuses on the 3.5 Ga old stromatolites at North Pole Dome, Dresser Formation, Pilbara (WA) and their link to hydrothermal fluids. He is examining whether such fluids have delivered transition metals such as Zn, Mo and Ni, known to be key ingredients for bacterial metabolism and thus likely catalysts for the origin of life on Earth. For this research, Raphael aims at the micron- to nano-scale textural examination and trace metal characterisation of associated Fe- and Zn-sulfide laminate using systematic *in situ* multiple sulfur-isotope analyses to unveil the potential microbial component of sulfide precipitation. Raphael's research contributes to CCFS Flagship program 4. See *Research highlight p. 58-60.*

Dr Beñat Oliveira completed his Bachelor and Master degrees in Civil Engineering at Universitat Politecnica de Catalunya. In February 2013, he joined CCFS-MG3 as a PhD student, where he developed an internally-consistent numerical platform for multiphase reactive transport modelling. The numerical model is based on two main ingredients: 1) a general and scalable multi-phase approach, coupled with 2) a sound chemical thermodynamic framework for the reactive and chemical transport phenomena. He continues with his research as a Research Associate in CCFS. In his current role, he has expanded his code to quantitatively assess the origin and evolution of transcrustal magmatic systems, including both disequilibrium trace-element and isotopic modelling. In April 2018, he received his PhD from Macquarie University. This research contributes to CCFS Flagship Program 3. See *Research highlight p. 51.*

Dr Romain Tilhac completed his BSc and MSc in Earth and Planetary Sciences at Paul Sabatier University in Toulouse, France. He joined CCFS in 2013 as a cotutelle PhD student between Macquarie University and Paul Sabatier University. Romain's thesis focused on the petrology, geochemistry and isotope geochemistry (Sr, Nd, Hf and Os) of arc-related mantle pyroxenites exposed in the Cabo Ortegal Complex, Spain. After graduating from both universities in 2016 and 2017, he took up a

Research Associate position in CCFS at Macquarie University. His current research relates to the compositional evolution of the Earth's mantle and the genesis of mantle-derived magmas, and associated tectonics and geodynamics. He uses petrology, *in situ* and solution geochemistry and geochronology of mafic and ultramafic terranes to understand the sources and differentiation processes of arc magmatism with the aim to better understand elemental mobility and isotopic fractionation associated with pyroxenite petrogenesis and the role of fluid-melt-rock interaction in subduction zones. This research contributes to CCFS Flagship Program 1 (TARDIS II).

Romain also works in collaboration with Beñat Oliveira on the numerical modelling of reactive transport associated with melt generation, migration and differentiation, melt-rock interaction and metamorphic reactions as part of the Flagship Program 3.

In October 2017, he became the manager of the *TerraneChron®* team at CCFS. *TerraneChron®* integrates *in situ* analysis of U-Pb ages, Hf-isotopes, and trace-element concentrations of zircons and fosters collaboration with industry and geological survey partners. See *Research highlights pp. 47, 51.*

Dr Irina Tretiakova completed her Bachelor and Master degrees in Geology at Novosibirsk State University in Russia. In April 2013, she joined CCFS to undertake a PhD project focused on studying the age, nature and evolution of the subcontinental lithospheric mantle and the lower crust under the Siberian Craton. Irina based her thesis on geochemical and isotopic analyses of various minerals from kimberlitic pipes of the Siberian diamond-bearing province. After submitting the thesis in October 2016 she joined CET, WA to continue the Siberian mantle study using advanced analytical technologies available in the CMCA. Irina focused on tiny sulfide inclusions in silicate minerals which record the age and composition of the mantle.

In December 2017 Irina moved back to Russia to take up the position of Deputy head of Department in the Central Research Institution of Geological Prospecting for Base and Precious Metals (TsNIGRI), Moscow. Currently, she is working on the genetic models of Ni-Cu and platinum-group element deposits. One of her primary goals is the application of new scientific approaches to geological prospecting and exploration.

CONTINUING

Dr Montgarri Castillo-Oliver completed her Bachelor and Master degrees in Geology at Universitat de Barcelona. In November 2014, she joined CCFS as a cotutelle PhD student, carrying out her research both at Universitat de Barcelona and Macquarie University. Montgarri's thesis focused on the characterisation of the structure and metasomatic evolution of the subcontinental lithospheric mantle in NE Angola, based on the study of mantle xenoliths and their host kimberlites.

In September 2016, she officially graduated with a PhD from both universities.

Her current role as Research Associate in CCFS involves the textural, compositional and isotopic (C, O and Sr) characterisation of kimberlitic carbonates, using *in situ* techniques [(MC-)LA-ICPMS and SIMS]. Primary carbonates in hypabyssal kimberlites are considered CO_2 traps; therefore, their study provides new insights into the isotopic composition of the parental kimberlite melt. The integrated approach of her research also aims to discriminate the different processes that led to carbonate formation in kimberlites (i.e., magmatic crystallisation, deuteric crystallisation, degassing, weathering, etc.). Montgarri also aims to enlarge the current understanding of the deep Earth's carbon cycle in cratonic roots by studying the C isotope variation of the deep mantle with space and time. This research contributes to CCFS Flagship Program 1.

Dr Denis Fougerouse completed his BSc at the university of Saint-Etienne (France). His MSc, at the University of Nancy (France), focused on the timing of mineralisation events in the West Africa Craton using Re-Os dating. In 2012, Denis commenced his PhD at the University of Western Australia in the Centre for Exploration Targeting (CET). Completed in 2015, his PhD focused on the mineralisation processes occurring in the giant Obuasi gold deposit.

Denis is currently a Postdoctoral Research Associate at Curtin University in the Geoscience Atom Probe group. He has worked on developing the geological applications of atom probe microscopy to a wide range of minerals including zircon, monazite, titanite, plagioclase and sulfides. In particular, Denis is investigating the mobility of trace elements and their implications for geochemistry and geochronology. His research contributes to CCFS Flagship Program 2.

Dr Rongfeng Ge completed his undergraduate and MSc studies at Nanjing University (China) and joined CCFS in 2012 as a cotutelle PhD candidate. He received his PhD degrees from Nanjing University in December 2014 and from Curtin University in August 2015 and is now a Research Associate at Curtin University.

Rongfeng's study interests include the origin and evolution of continental crust, the reconstruction of Precambrian supercontinents, and the tectonic evolution of orogenic belts. His primary focus is on the Tarim Craton, NW China, and the Central Asian Orogenic Belt. Through multiple laboratory techniques and field-based work, his study has revealed the oldest rocks and crustal components from the Tarim Craton, a Tarim - North China connection in the Columbia/Nuna supercontinent, and a long-lived subduction - accretionary orogenic system at the circum-Rodinia subduction zone.

Rongfeng's current research focuses on the Hadean detrital zircons from Jack Hills. Using cutting-edge techniques, including ion imaging and the atom probe, Rongfeng will revisit the isotopic and elemental distributions and compositions of these ancient and complex zircon grains. This study will provide new insights into the origin of continental crust and the geodynamic setting in the early Earth. This research contributes to CCFS Flagship Program 6.

Dr Andrea Giuliani joined CCFS in June 2015 as an ARC DECRA (Discovery Early Career Research Award) Fellow. Andrea completed his PhD in mantle geochemistry at the University of Melbourne in 2013 where he then undertook a year of post-doctoral research in 2014 before becoming a lecturer in Igneous Petrology in January 2015.

Andrea's research focuses on the composition and sources of deep Earth fluids and melts - including kimberlites, which are the primary source of terrestrial diamonds. Kimberlites represent the deepest melts that reach the Earth's surface and therefore provide a unique probe into the deepest realms of our planet.

At CCFS, Andrea is working closely with Professors Sue O'Reilly, Bill Griffin and Steve Foley to improve current understanding of the evolution of the Earth's interior and the melting processes affecting it, with particular attention to the role of volatiles and recycled crustal and surface material that trigger deep melting events. His research contributes to CCFS Flagship Program 1. See *Research highlight pp. 44-45.*

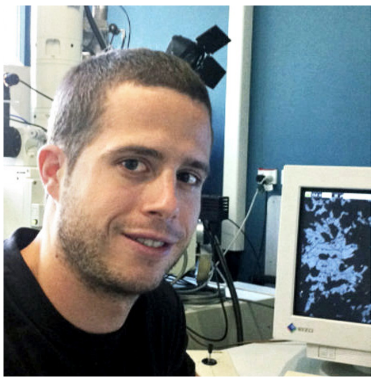
Dr Christopher Gonzalez joined the CET and CCFS team, first as a PhD student in 2012, and now as a Research Associate. Chris graduated from the University of Minnesota – Twin Cities with Bachelor of Science degrees in Geology and Geophysics (2011).

Chris undertook PhD studies at CET as part of an Arc Linkage project *"Multiscale Dynamics of Ore Body Formation"*.

His research includes numerical modelling of geodynamic processes with a focus on H_2O-CO_2 fluids. Using a thermomechanical numerical modelling code (I2VIS), new (de) carbonation routines and carbonated lithologies were coded into I2VIS during his thesis to gain a better understanding of the two most abundant recycled volatiles on Earth (H_2O and CO_2).

As a Research Associate, he aims to apply this code to quantitatively assess metasomatism and melting processes ongoing during continental collision using the Ivrea–Verbano zone as a natural laboratory. Specifically, sulfur-rich carbonate bearing *'pods'* have been observed, and are thought to be a direct consequence of slab derived carbonic fluids interacting with the mantle wedge. To examine this hypothesis, Chris will use his code to numerically constrain the sequence of events that led to the formation of the sulfur-rich carbonate pods. This research aligns with CCFS Flagship Program 2.

Dr Johannes Hammerli completed his MSc in Earth Sciences at the University of Bern, Switzerland, before moving to Townsville, Australia. He received his PhD from James Cook University



in 2014, where he studied element mobility during metamorphism and the identification of hydrothermal fluids by microanalysis. In late 2014 Johannes joined CET on a Swiss National Science Foundation

Fellowship. During this time he focused on studying crustal differentiation and evolution. In May 2016, Johannes joined the CCFS research group where he uses the microanalysis of accessory minerals, in particular apatite from magmatic systems, to unravel processes which lead to the fertile systems feeding ore deposits. His research contributes to CCFS Flagship Program 2.

Dr Heejin Jeon received her Bachelor and Master degrees at the School of Earth and Environmental Sciences, Seoul National University. She was awarded a PhD at the Research School of Earth Sciences, Australian National University in 2012. Her PhD project focused on continental crust evolution and crustal recycling in southeastern Australia (Carboniferous-Permian granites across the Lachlan Fold Belt and New England Orogen). During her time at ANU, Heejin worked extensively on zircon for U-Th-Pb dating, O and Hf isotope measurements (SHRIMP II and LA-MC-ICPMS). She then had two years of postdoc experience in the NORDSIM ion probe lab, Swedish Museum of Natural History, where she expanded her ion probe expertise with the CAMECA IMS1280 and contributed to a wide variety of collaborative projects. Heejin also carried out a project in the Neoproterozoic Arabian Shield and studied how much older crustal materials have contaminated this apparently juvenile crust. Heejin has worked at the Ion Probe Facility, CMCA, University of Western Australia, with CCFS participants Matt Kilburn and Laure Martin, to improve widely used isotope applications and also to develop new applications during 2015-2017. Her research contributed to CCFS's Technology Development Program at CMCA. From early 2018, Heejin started a new research position in NORDSIM. See *Research highlights pp. 43, 49-50*.

Dr Uwe Kirscher completed his PhD in geophysics at the Ludwig-Maximilians University in Munich in 2015 working on the Paleozoic paleogeography of the Central Asian Orogenic Belt using paleomagnetism. In early 2016, he joined Curtin University as a CCFS funded Research Associate as part of Professor Zheng-Xiang Li's Laureate team.

His research interests are focused on Proterozoic paleomagnetic constraints of the Australian Precambrian blocks. He aims to use several paleomagnetic approaches to constrain and more precisely understand the supercontinent cycle and its geodynamic features. His research contributes to CCFS Flagship Program 5. See *Research highlight p. 53*.

Dr Crystal LaFlamme attended Acadia University for her BSc and completed her MSc at Memorial University of Newfoundland studying the tectonostratigraphy and formation of volcanic rocks of the Makkovik Province in northern Labrador. Her PhD at the University of New Brunswick investigated the formation and geodynamic evolution of a reworked Archean high-grade terrane in the Western Churchill Province in the Canadian Arctic.

In February 2015 Crystal joined CCFS/CET as a Postdoctoral Research Associate to study the sulfur isotope record of craton margins. Her research focuses on tracing anomalous sulfur isotope signatures preserved in the Archean-Proterozoic rock record to better understand large-scale crust formation processes and small-scale thermochemical processes leading to metal occurrences. This knowledge base is building to ultimately better understand the link between fluid-driving tectonic processes and ore genesis. Crystal's research contributes to CCFS Flagship Program 2. See *Research highlight p. 43*.

Dr Erwann Lebrun received his BSc in Geology from Blaise Pascal University, France in 2008, an MSc in Economic Geology from the University of Québec in Montréal (UQAM), Canada and from the Earth Sciences Institute of Orléans (ISTO), France in 2010. Subsequently, Erwann moved to Australia to start a PhD which he completed in 2016 His PhD project focused on the 4D evolution of the orogenic gold district of Siguiri, in Guinea (West Africa). This project was funded by AngloGold Ashanti and is part of the West African eXploration Initiative (WAXI). During his PhD, Erwann used a multidisciplinary set of geological tools including structural geology, 3D modelling, geochronology,

sedimentology and geochemistry, at the micro-, deposit, district and regional scale to reconstruct the deformation and hydrothermal history of the Siguiri orogenic gold district and the tectonic evolution of the Siguiri Basin, hosting the district. This integrated study permitted the identification of the controls on gold mineralisation in the Siguiri Basin and the development of various targeting criteria for future exploration strategies.

In 2016 Erwann continued his research as a Research Associate at CET. His research interests focused on the magmatism, tectonics and mineralisation of eastern Greenland. Erwann left CCFS/CET in May 2017, to take the position of Consultant (Structural Geology) at SRK Consulting. His research has contributed to CCFS Flagship Program 2.

Dr Yongjun Lu is the Senior Geochronologist and Isotope Specialist at the GSWA, an Associate Investigator at CCFS, and an Adjunct Senior Research Fellow at the Centre for Exploration Targeting (CET), UWA. He manages the isotopic program at

GSWA such as Pb, Sm-Nd, Lu-Hf and O isotopes, which are used to tackle various scientific questions ranging from imaging the lithospheric architecture through cover to understand crustal evolution and mineral deposit formation. Yongjun is also leading a project at GSWA investigating the zircon chemistry of Archean granites, aimed at unravelling the ore fertility of these ancient granites. He is also investigating the petrology, geochemistry, isotopes and tectonics of the poorly understood Southwest Terrane of the Yilgarn Craton. Through CCFS, Dr Lu has an ongoing collaboration with Chinese Academy of Geological Sciences (CAGS) and China University of Geosciences in Beijing (CUGB) to investigate the porphyry copper systems in the Tibetan plateau and surrounding region. Yongjun serves as reviewer for prestigious international journals such as *Nature Geoscience, Geology, Earth-Science Reviews and Economic Geology.* See *Research highlights pp. 60-61, 62-63, 70-71.*

Dr Ross Mitchell is a Research Fellow in the Earth Dynamics Research Group at Curtin University. He completed his PhD in geology and geophysics at Yale University in 2013 on "*Supercontinents, the true polar wander, and the paleogeography of the Slave Craton*".

His interests centre on the supercontinent cycle, which describes not only the suturing and rifting of continents via plate tectonics but also the wholesale organisation of mantle convection patterns, which has consequences for true polar wander. Prior to Pangea, paleomagnetism is the only quantitative method for reconstructing continents. Ross conducts extended paleomagnetic sampling campaigns grounded in field geology. Synthesising newly acquired data with the global paleomagnetic database, he aims to both generate paleogeographic maps for 3 billion years of Earth history and to evaluate how such empirical constraints shape plate tectonic and true polar wander theory. He pairs these studies of ancient supercontinents with detailed magnetostratigraphic profiles of Phanerozoic time and electron-probe analyses of magnetic mineralogy in order to test the limits of paleomagnetism as a paleogeographic method. His research contributes to CCFS Flagship Program 5.

Dr Rosanna Murphy completed her PhD with CCFS/GEMOC in 2015. Her thesis examined the 3.1 Ga Mpuluzi Batholith in South Africa/Swaziland as a case study to understand the processes involved in the creation of ancient continental crust.

In December 2015, Rosanna became the manager of the *TerraneChron®* team at CCFS. This role involves integrating *in situ* analysis of U-Pb ages, Hf-isotope, and trace element concentrations in zircons and involves collaboration with a number of industry and geological survey partners. *TerraneChron®* provides valuable insight into geological mapping and exploration programs worldwide.

Dr Hugo Olierook completed his undergraduate studies at Curtin University in 2011. He continued at Curtin with a PhD examining the tectonic and stratigraphic evolution of the Western Australian margin. After completing his PhD in 2015, he moved to the University of Liverpool as an NERC postdoctoral associate studying reservoir quality in the United Kingdom and adjacent petroleum domains. In November 2016, Hugo returned to Curtin University and joined CCFS to take up a two-year postdoctoral fellowship as part of the SIEF Distal Footprints project in the Capricorn Orogen of Western Australia. Hugo is using his expertise in geochronology, geochemistry, tectonics and geodynamics to understand the 3 billion year history of the Capricorn Orogen and its mineral endowment.

Dr Luis Parra-Avila, from Caracas, Venezuela, earned his Bachelor's degree in 2007 at the University of Central Missouri, then moved to the state of Illinois to work on his Masters degree, which he earned in 2010 at Southern Illinois University-Carbondale. His Masters thesis involved Co-Ni enriched Mississippi Valley-type deposits in southeast Missouri, and was supported by the "*The Doe Run Company*".

After concluding his Masters degree, he continued his education at the CET UWA, where he earned his PhD in 2016. His PhD project focused on establishing the crustal tectonic history of the Paleoproterozoic Domain of the West African Craton across Burkina Faso, Ghana, Mali, Ivory Coast and Guinea and its links to mineral deposits. The project was funded through the ARC linkage program and was part of the AMIRA West Africa Exploration Program (P934A).

In October of 2015, Luis joined CCFS as a post-doctoral research associate with a research focus on evaluating zircon characteristics and the link to porphyry Cu deposits. The project sought to develop new pathfinders to assist with the exploration of porphyry Cu deposits and to understand the difference between fertile and unfertile tectonic environments for such deposits.

In 2017 Luis commenced a new project aimed at unravelling the geologic history of Northern Thailand. This project focuses on the tectonic history (collision and amalgamation) of continental and arc terranes, including closure of ocean basins across the Sukhothai (arc) terrane, Nan Suture zone and western Indochina terrane. It follows and expands on existing work in the Loei-Phetchabun Foldbelt and mid-Triassic intrusive magmatism associated with subduction of Paleotethys seafloor beneath western Indochina. The project is multidisciplinary and will integrate new field-based data collection with state-of-the-art geochronological techniques, as well as geochemical and isotopic fingerprinting, to substantially build on previous petrological and geochemical studies in the region. The results of this study will provide a geologically '*young*' example of continental crustal evolution to compare with Archean and Proterozoic examples in Australia and other ancient cratonic regions elsewhere, as well as a context for understanding the formation of particular mineral deposits. His research contributes to CCFS Flagship Program 2. See *Research highlights pp. 60-61, 62-63*.

Dr Qing Xiong completed his undergraduate studies at China University of Geosciences (Wuhan) and joined CCFS in 2011 as a cotutelle PhD candidate. He received PhD degrees from China University of Geosciences (Wuhan) in December 2014 and from Macquarie University in November 2015. Qing's PhD project focused on the origin and evolution of orogenic peridotites and ophiolites from Tibet (China), and revealed the detailed upper-mantle processes and subduction geodynamics during the assembly of the Tibetan-Himalayan Plateau in the Phanerozoic.

Qing commenced his employment as a Research Associate at CCFS, Macquarie University in June 2015. His research focused on the mantle rocks from the representative ophiolites in the Yarlung Zangbo Suture Zone of South Tibet as part of CCFS Flagship Program 1, TARDIS II. He systematically collected ultramafic rock samples from the Kangjinla and Dazhuka ophiolites, to carry out petrochemical and microstructural characterisation of these ophiolitic mantle sections, using petrochemical and Electron Backscattered Diffraction (EBSD). He also worked on the super-reducing mineral assemblages in the Zedang and Kangjinla ophiolites to provide new insights into 1) tectonics of the Neo-Tethyan Ocean between Eurasia and Greater India, 2) mantle recycling processes and unusual interaction between fluids/magmas and mantle rocks in subduction and collision zones, and 3) the genesis of chromitite ore deposits in ophiolites.

In September 2017, Qing moved to China University of Geosciences (Wuhan) to take up a full-time position as a Researcher fellow (Junior Professorship). His current research focuses on the origin and evolution of mantle rocks (including chromitite ores) from ophiolites in the Yarlung Zangbo Suture Zone of South Tibet and the related dynamic processes in the Tethyan regions, part of targets of CCFS Flagship Program 1, TARDIS II. He is also planning to work on the majoritic peridotites in Norway, and to reveal the crust-mantle interaction and mass transfer processes in continental subduction channels.

Dr Weihua Yao *(pictured centre, below)* completed her undergraduate study at China University of Geosciences (Wuhan), and graduated with a PhD degree from Curtin University (August 2014). She then joined CCFS as a Postdoctoral Research Associate after her graduation, working with CCFS, TIGeR, ACTER and IGCP648 at Curtin University. Her research mainly focuses on sedimentary, stratigraphic and provenance correlations between the Indian-Australian Gondwana and Asian continents (including South China and Indochina blocks), and also the Precambrian paleogeography of Hainan Island in the supercontinents Nuna and Rodinia. Two main highlights of her research suggest an Ediacaran-Cambrian collision between South China and northern India, leading to the formation of the Nanhua foreland basin and the Ordovician-Silurian Wuyi-Yunkai orogeny in South China; and Hainan Island's connection with western Laurentia during the Nuna breakup and Rodinia assembly. Weihua is also leading a China Geological Survey funded project, investigating the Ediacaran-Silurian basin on the western Yangtze margin of South China. Her research contributes to CCFS Flagship Program 5.

ECRs and Postdocs at the 2017 CCFS Whole-of Centre Meeting, Cairns (Photo: Will Powell).

The CCFS research program

The CCFS CoE builds on world-class infrastructure and world-leading research expertise and track record, and has already multiplied the capabilities of the Collaborating and Partner Institutions. The research program aims to enhance existing strengths in geology, geochemistry, geophysics, experimental petrology and petrophysical/dynamic modelling, and to integrate knowledge and datasets from 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 have 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 undertake 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 Programs described below.

The scope of the research, and thus of the research programs, are determined by the funding base allocated by ARC with strategic leverage planned to expand available resources.

FLAGSHIP RESEARCH PROGRAMS

The original Foundation Programs for 2011-2014 were funded from the ARC Centre funds allocation, and included components from the Universities' funding support. Programs were 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. The Programs were designed to be interdisciplinary, cross-nodal and to foster participation of early-career/postgraduate researchers. Research directions were designed to contribute to the overarching three major Themes identified to bring about a new level of understanding of Earth and its resource dispersion. They included three integrated projects targeted at Technology Development.

In 2014 the Flagship Programs were restructured to identify the most productive research directions relevant to fulfilling the CCFS vision of "*Delivering the fundamental science needed to sustain Australia's resource base.*" All the research programs were scrutinised, reassessed and realigned (following advice from the Science Advisory Committee).

This resulted in seven Flagship Programs (see *p. 20*) based on the benchmark outcomes of the first 3 years and extending in new directions; programs that had come to fruition in the first three years were finalised. These Flagship Programs target the research goals through to 2018, providing a new focus and realigned strategies to deliver more transformational outcomes and leave a legacy in knowledge, new technology and methodologies, and vital new knowledge about Australia's geological evolution to guide smart new mineral exploration. They are underpinned by two Technology Development Programs designed to deliver more leading-edge geochemical breakthroughs, capitalising on the outstanding geochemical instrumental infrastructure across CCFS.

Aims and progress are detailed in *Appendix 1*.

***Appendix 2* presents the 2018 workplan.**

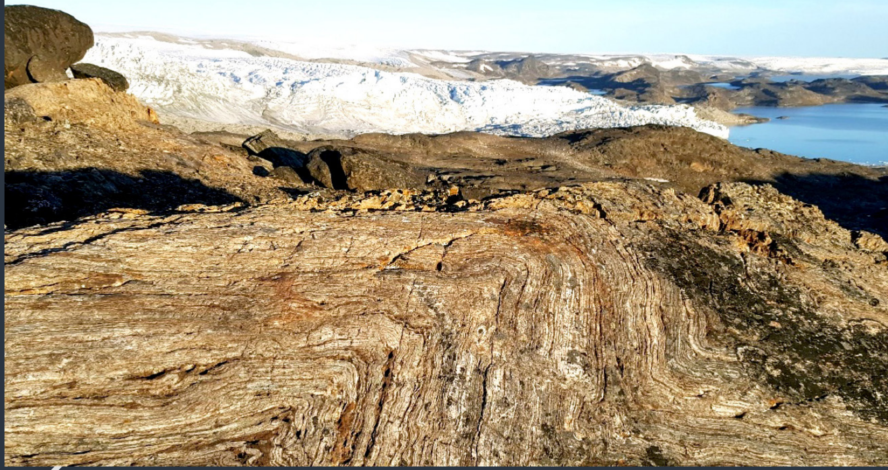
Independently funded basic research projects are listed in *Appendix 3*.

2014 FLAGSHIP PROGRAMS

Program / Theme / Framework	Coordinator and main Centre personnel
1. Deep Earth fluids in collision zones and cratonic roots (TARDIS II) Themes 1, 2, 3 Earth's Architecture and Fluid Fluxes	**O'Reilly, Griffin**, Pearson, Kilburn, Martin, Alard, Shafaii Moghadam, Huang, Giuliani, Gréau, Castillo-Oliver, Xiong (ECRs) Xu, Tilhac, Colas, Lu, Liptai, Chasse (PhDs)
2. Genesis, transfer and focus of fluids and metals Themes 2 and 3 Fluid Fluxes	**Fiorentini**, McCuaig, Foley, O'Reilly, Griffin, Reddy, Rushmer, Turner, Lu (ECR), Bagas, Gorczky, Piazolo, Kilburn, Loucks, Clarke, Lebrun (ECR) Bjorkman, Iaccheri, Davies, Dering, Poole, Bennett, Lampinen (PhDs)
3. Modelling fluid and melt flow in mantle and crust Themes 2 and 3 Earth's Architecture and Fluid Fluxes	**O'Neill**, Afonso, Yang, Li, Foley, Clark, S. Zhang (ECR), Gorczky, Smith, O'Reilly, Griffin Jiang, Oliveira, Ramzan, Wasilev, Wang, Wu (PhDs)
4. Atmospheric, environmental and biological evolution Theme 1 Earth's Architecture and Fluid Fluxes	**Van Kranendonk**, Fiorentini, Foley, Kirkland, Kilburn, Grange, Alard, LaFlamme, Baumgartner Barlow, Djokic, Nomchong, Selvaraja, Soares, Steller (PhDs), Bannister, Blake, Tadbiri (MPhils)
5. Australia's Proterozoic record in a global context Themes 2 and 3 Earth's Architecture	**Li**, Pisarevsky, Wang, Yao (ECR), Wingate, O'Reilly, Griffin, Pearson, Belousova, McCuaig, Kirscher (ECR) Stark, Y. Liu, Martin, Nordsvan, Volante (PhDs)
6. Fluid regimes and composition of early Earth Themes 1 and 3 Earth's Architecture and Fluid Fluxes	**Wilde**, Nemchin, Grange, Martin, O'Neill, Ge (ECR) Liu, K (PhD)
7. Precambrian architecture and crustal evolution in WA Themes 1, 2 and 3 Earth's Architecture	**Gessner**, Kirkland, Belousova, Gréau, Yuan, Wingate, Tyler, Lu Dering (PhD)
TECHNOLOGY DEVELOPMENT	
Cameca Ion microprobe development Themes 1, 2 and 3 Earth's Architecture and Fluid Fluxes	**Kilburn**, Martin, Jeon, Fiorentini, McCuaig, Griffin, LaFlamme, Reddy Students of CIs and ECRs utilising the Ion Probe Facility are active in the program
GAU multi-instrument development Themes 1, 2 and 3 Earth's Architecture and Fluid Fluxes	**Pearson**, Griffin, O'Reilly, Gréau (ECR), Kilburn, Martin, Alard, Huang, Xiong (ECR) Henry, Liptai (PhDs)

Where out of this world is CCFS?

As part of our quest to better understand the processes that led to the formation of the early Earth, CCFS has been investigating the early history of the Moon, Mars and Venus.



View across the Trinidad Dome in the Ecambray of Central Cuba (Photo: Simon Wilde)

West Greenland, in the Isua supracrustal belt, looking out to the edge of the Inland Ice (Photo: Martin Van Kranendonk)

WHERE IN THE WORLD IS CCFS?

The Pembroke Granulite, Fiordland New Zealand, (Photo: Nathan Daczko)

Lago San Martin, Patagonia, Argentina (Photo: Gonzolo Henriquez)

Communications 2017

CCFS web resources (http://ccfs.mq.edu.au/) 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 2017 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 2017 are given in Appendix 5.

The 183 CCFS publications that were published in 2017 are dominantly in high-impact international journals (Thomson ISI); the remainder are in outlets targeted to specific stakeholders (e.g. Australian Journal of Earth Sciences, Economic Geology).

CCFS now has a LinkedIn Group - Join the conversation at http://www.linkedin.com/groups/6969996

PARTICIPATION IN WORKSHOPS, CONFERENCES AND INTERNATIONAL MEETINGS IN 2017

CCFS Investigators, associated staff, early-career researchers and postgraduates had a high profile at 41 peak geophysical, metallogenic, geodynamic and geochemical conferences as convenors, invited speakers, or presenters, with 343 presentations including:

- XLIX (49) Tectonic meeting, Tectonics of modern and ancient oceans and their margins, Москва, Russia, January 31- 4 February 2017
- Granitoids Through Time, Monash University, Australia, 2 February 2017
- The 48th Lunar and Planetary Science Conference, The Woodlands, Texas, March 20-24 2017
- Conference of the Israeli Geology Society, Mitzpe Ramon, Israel, 21 March 2017

Dorrit Jacob catching up with Steve Shirey (Carnegie Institution, Washington DC) at the Deep Carbon Observatory Meeting in Scotland.

- 3rd Deep Carbon Observatory International Science Meeting, University of St. Andrews, Scotland, 23-25 March 2017
- International Symposium on Zircon Geochronology and Crustal Evolution, Kunming, China, 12-20 April 2017
- TARGET 2017: Innovating Now for Our Future, Perth, Western Australia, 19-21 April 2017
- European Geosciences Union General Assembly 2017, Vienna, Austria, 23-28 April 2017
- Astrobiology Science Convention (Abscicon), Mesa, USA, 24-28 April 2017
- AIG Workshop, Perth, WA, 2 May 2017
- Deformation Mechanisms, Rheology and Tectonics, Inverness, Scotland, 30 April - 7 May 2017
- EMAS-15 / IUMAS-7, Konstanz, Germany, 7-11 May 2017
- JPGU-AGU Joint Meeting 2017, Chiba, Japan, 20-25 May 2017
- GAC-MAC Annual Meeting, Kingston, Ontario, Canada, 21-23 May 2017
- 2017 GSA Cordilleran Section Annual Meeting, Honolulu, Hawaii, 23-25 May 2017
- 2017 Interior of the Earth, Gordon Research Conference, Mount Holyoke College, South Hadley, MA, USA, 4-9 June 2017
- FUTORES II (Future Understanding of Tectonics, Ores, Resources, Environment and Sustainability) Townsville, Queensland, Australia, 4-7 June 2017
- ARCF Project Workshop, Perth, Australia, 7 June 2017
- Rodinia 2017: Supercontinent Cycles and Global Geodynamics, Townsville, Queensland, Australia, 11-14 June 2017

- ECROFI 2017, Nancy, France, 23-29 June 2017
- 5th Australian Atom Probe Workshop, Magnetic Island, Australia, 27-30 June 2017
- Shock Metamorphism in Terrestrial and Extra-Terrestrial Rocks Workshop, Perth, Australia, 26 June - 2 July 2017
- 6th Augen Conference, Sydney University, 5-6 August 2017
- IAVCEI 2017 Scientific Assembly, Portland, Oregon, USA, 14-18 August 2017
- Goldschmidt 2017 Conference, Paris, France, 13-18 August 2017
- 14th SGA Biennial Meeting, Quebec, 20-23 August 2017

CCFS participants cruising the Seine during the Goldschmidt Conference dinner in Paris.

- 12th International Eclogite Conference - High- and ultrahigh-pressure rocks - Keys to lithosphere dynamics through geologic time, Åre, Sweden, 26-29 August 2017
- 24th Congress and General Assembly of the International Union of Crystallography, Hyderabad, India, 21-28 September 2017
- SIMS 21, 21st International Conference on Secondary Ion Mass Spectrometry, Krakow, Poland, 10-16 September 2017
- Comparative tectonic analysis of melanges, accretionary orogens, and arc-continent collisions through time; Wuhan, China; 16-21 September 2017
- SEG 2017. Ore Deposits of Asia: China and Beyond, Beijing, China, 17-20 September 2017

CCFS PhD student Sarath Patabendigedara snaps a selfie at the 24th Congress and General Assembly of the IUCr in Hyderabad, India.

Top: Sue O'Reilly and Bill Griffin enjoying the celebrations at the 11th International Kimberlite Conference Dinner where they were honoured with a named Conference Proceeedings volume. Right: Steve Foley joins in the traditional rendition of the "Garnet Nodules" song (Photos: IKC).

- 11th International Kimberlite Conference, Gaborone, Botswana, 18-22 September 2017
- Exploration 17: Sixth Decennial International Conference on Mineral Exploration, Toronto, Ontario, Canada, 21-25 October 2017
- FAMOS (From Arc Magmas to Ores) Conference, University of Bristol, UK, 2 November 2017
- Third Lithosphere Dynamics Workshop, CET UWA, Perth, 5-6 November 2017
- Asian Orogeny and Continental Evolution: New Advances from Geologic, Geophysical and Geochemical Perspectives, Taipei, Taiwan, 6-12 November 2017
- Specialist Group in Tectonics and Structural Geology, The Geological Society of Australia, Denmark, WA, 8-12 November 2017
- Geological Society of Australia (GSA) Earth Science Student Symposium (GESSS), Sydney, Australia, 10 November 2017
- TIGeR Conference 2017, Timescales of Geological Processes, Curtin University, Perth, 13-15 September 2017
- 17th Australian Space Research Conference, Sydney, Australia, 15-17 November 2017
- CCFS Whole-of-Centre Meeting, Cairns, Australia, 27-29 November 2017
- AGU Fall Meeting, New Orleans, USA, 11-15 December 2017
- Franco-Australian Astrobiology and Exoplanet Workshop (FAAbExo), Canberra, Australia, 16-20 December 2017

INVITED TALKS AT MAJOR CONFERENCES AND WORKSHOPS IN 2017

International Symposium on Zircon Geochronology and Crustal Evolution, Kunming, China, 12-20 April 2017	Can too much information spoil a good story? **S.A. Wilde** **Keynote**
TARGET 2017: Innovating Now for Our Future, Perth, Western Australia, 19-21 April 2017	Methods of targeting across all scales – what important elements to consider? **T.C. McCuaig** **Keynote**
European Geosciences Union General Assembly 2017, Vienna, Austria, 23-28 April 2017	Long term evolution of Earth's magnetic field strength: Supercontinent cycles and nucleation of the inner core **U. Kirscher**, **R.N. Mitchell**, G. Cox, P. Asimow, **N. Zhang** and **Z.-X. Li** **Highlight** Tracing sulfur across lithospheric boundaries **C. LaFlamme**, **M. Fiorentini** and B. Wing **Invited**
JPGU-AGU Joint Meeting 2017, Chiba, Japan, 20-25 May 2017	South China in the assembled Gondwana **W. Yao**, **Z.X. Li**, W.X. Li and X.H. Li **Invited**
2017 Interior of the Earth, Gordon Research Conference, Mount Holyoke College, South Hadley, MA, USA, 4-9 June 2017	The long legacy of deep mantle processes **C. O'Neill** **Keynote**
FUTORES II (Future Understanding of Tectonics, Ores, Resources, Environment and Sustainability) Townsville, Queensland, Australia, 4-7 June 2017	Metallogeny of the Capricorn Orogen, Western Australia S.P. Johnson, I.O.H. Fielding, B. Rasmussen, J. Zi, J.R. Muhling, **M.T.D. Wingate** and S. Sheppard **Invited**
Rodinia 2017: Supercontinent Cycles and Global Geodynamics, Townsville, Queensland, Australia, 11-14 June 2017	A full-plate global reconstruction of the Neoproterozoic: An essential step in quantifying ancient geodynamics A.S. Collins, A.S. Merdith, **S.A. Pisarevsky**, S. Williams and D.R. Müller **Keynote** Precambrian mantle plume centres and breakup margins identified using the large igneous province record R.E. Ernst, **Z.-X. Li** and **S.A. Pisarevsky** **Keynote** New Progress and Constraints on Supercontinent Reconstructions **S. Pisarevsky** **Keynote**
6th Augen Conference, Sydney University, 5-6 August 2017	Meeting tomorrow's needs: The national decadal plan for Earth Sciences, and implementing it in the classroom **C. O'Neill** **Plenary**
Goldschmidt 2017 Conference, Paris, France, 13-18 August 2017	Zircon below the micron scale: on the trail of errant elements **M.A. Kusiak** **Keynote** Chronology of the Lunar Magma Ocean **A. Nemchin**, J. Snape and M. Whitehouse **Invited** Tracing the Sources of Lunar Volcanism with Pb Isotopes J. Snape, **A. Nemchin**, J. Bellucci and M. Whitehouse **Invited**
12th International Eclogite Conference - High- and ultrahigh-pressure rocks - Keys to lithosphere dynamics through geologic time, Åre, Sweden, 26-29 August 2017	Peridotites and eclogites in the SCLM: The evolution of an understanding **W.L. Griffin** and **S.Y. O'Reilly** **Keynote**

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

INVITED TALKS *cont...*

Comparative Tectonic Analysis of Melanges, Accretionary Orogens, and Arc-Continent Collisions Through Time; Wuhan, China; 16-21 September 2017	Permo-Triassic to Cretaceous magmatism along the northern margin of the North China Craton: Implications for the junction of the Central Asian Orogenic Belt S.A. Wilde and M.L. Grant **Invited**
11th International Kimberlite Conference, Gaborone, Botswana, 18-22 September 2017	Olivine zoning and the evolution of kimberlite systems A. Giuliani, A. Soltys, E. Lim, H. Farr, D. Phillips, K. Goemann and W.L. Griffin **Keynote**
Exploration 17: Sixth Decennial International Conference on Mineral Exploration, Toronto, Canada, 21-25 October 2017	Exploration targeting T.C. McCuaig and R.L. Sherlock **Keynote**
FAMOS (From Arc Magmas to Ores) Conference, University of Bristol, UK, 2 November 2017	Applications of zircon chemistry to mineral exploration R. Loucks **Invited**
Third Lithosphere Dynamics Workshop, CET UWA, Perth, November 5-6 2017	Deep mantle processes: rheology, mixing, and how it's changed C. O'Neill **Invited**
Asian Orogeny and Continental Evolution: New Advances from Geologic, Geophysical and Geochemical Perspectives, Taipei, Taiwan, 6-12 November 2017	Extrusion-style growth of the Tibetan Plateau since 40 Ma: New insights from the Longmenshan Fault Zone Z.-X. Li **Keynote** How extensive are Microcontinents within the Chinese segment of the Central Asian Orogenic Belt? S.A. Wilde **Keynote**
Specialist Group in Tectonics and Structural Geology, The Geological Society of Australia, Denmark, WA, 8-12 November 2017	Uncovering terra incognita: new insights into the evolution of Antarctica and constraints for ice sheet models J. Halpin, J. Whittaker, N. Daczko, I. Fitzsimons, A. Reading, A. Maritati, T. Staal, S. Watson, J. Mulder, T. Noble, Z. Chase, S. Tooze and I. Sauermilch **Keynote** Advances in geodynamic modelling C. O'Neill **Keynote**
17th Australian Space Research Conference, Sydney, Australia, 15-17, November 2017	Hydrothermal systems, early life on Earth and implications for astrobiology T. Djokic **Plenary**
Franco-Australian Astrobiology and Exoplanet Workshop (FAAbExo), Canberra, Australia, 16-20 December 2017	High-pressure silicate phases in exoplanets: Implications for dynamics and thermal evolution C. O'Neill **Invited**

OTHER CONFERENCE ROLES

TARGET 2017: Innovating Now for Our Future, Perth, Western Australia, 19-21 April 2017	*Secretary:* Yongjun Lu *Workshop Coordinator:* Crystal LaFlamme
European Geosciences Union General Assembly 2017, Vienna, Austria, 23-28 April 2017	*Session Convenor / Co-Convenors:* Huaiyu Yuan / Chris Kirkland and Klaus Gessner - Session: SM4.6/GD2.6/GMPV6.5/TS9.5 *"Advances in mapping the structure of cratons, craton margins, and craton boundaries (co-organised)"*

OTHER CONFERENCE ROLES *cont...*

Astrobiology Science Conference, Mesa, Arizona, 24-28 April	*Session Co-Chair:* Martin Van Kranendonk - *"Solar system sites: Mars: habitability and preservation potential of silica-producing hydrothermal systems"*
Rodinia 2017: Supercontinent Cycles and Global Geodynamics, Townsville, Queensland, Australia, 11-14 June 2017	*Co-Convenor:* Zheng-Xiang Li CCFS *Sponsored* *Theme Co-Convenors:* Zheng-Xiang Li and Louis Moresi - Theme 5: *"Supercontinent cycles and Geodynamics"* http://geodynamics.curtin.edu.au/rodinia-2017-great-success-townsville-11-14-june-2017/
6th AUGEN Conference, Sydney University, 5-6 August, 2017	*Organiser, Co-Chair:* Nathan Daczko
Goldschmidt 2017 Conference, Paris, France, 13-18 August 2017	*Co-Convenor:* Andrea Giuliani - Theme 05D: *"The Geochemistry of Hotspots and Intraplate Magmas: Mantle Sources, Metasomatism, Magmatic Processes and Xenolith Cargoes"* *Co-Convenor:* Sue O'Reilly - Theme 05E: *"Lithosphere Evolution During Subduction and Collision"*
IAMG 2017 International Association of Mathematical Geology, 18th Annual Conference, Perth, Australia, 2-9 September 2017	*Member, Scientific Committee:* Klaus Gessner
SIMS 21, 21st International Conference on Secondary Ion Mass Spectrometry, Krakow, Poland, 10-16 September 2017	*Member, International Scientific Committee, Session Chair:* Matt Kilburn - Cosmo/Geo/Archeo
SEG 2017 Ore Deposits of Asia: China and Beyond, Beijing, China, 17-20 September 2017	*Session Chair:* Yongjun Lu - *"Mineral Deposits in Tibet"*
11th International Kimberlite Conference, Gaborone, Botswana, 18-22 September 2017	*Theme Co-Convenor:* Stephen Foley - Theme 4: *"The Origin and Evolution of Kimberlites and Related Magmas"*
Specialist Group in Tectonics and Structural Geology, The Geological Society of Australia, Denmark, WA, 8-12 November 2017	*Member, Organising Committee:* Klaus Gessner
Geological Society of Australia (GSA) Earth Science Student Symposium (GESSS), Sydney, Australia, 10 November 2017	CCFS *Sponsored* *Treasurer and Mentor:* Anthony Lanati *(pictured right)* *Sponsor:* CCFS was a *"Fire Opal Sponsor"*

OTHER CONFERENCE ROLES *cont...*

AGU Fall Meeting, New Orleans, USA, 11-15 December 2017	*Session Co-Organiser:* **Weronika Gorczyk** - *Session:* T54A: *"Beyond Rigid Plates: Investigating Mechanisms, Processes, and Products of Intraplate Deformation"*

SELECTED WORKSHOP ROLES

Activity	Details & Participant/s	Date
CET Seminar Series	**Cam McCuaig**	2017
CCFS/EPS Seminar Series	**CCFS/EPS MQ**, organised by Stefan Loehr	2017
IGCP 648 Database Workshop 1	Two-day IGCP 648 workshop. **Zheng-Xiang Li** - Organiser and co-conductor Beijing China See *International Links p. 98.*	24 February 2017
How to publish your research	CCFS co-sponsored visitor, Hadyn Williams Fellow **Professor Brendan Murphy** delivered the workshop organised by **Zheng-Xiang Li**. The workshop was well attended by 35 Early Career Researchers and PhD students	4 April 2017

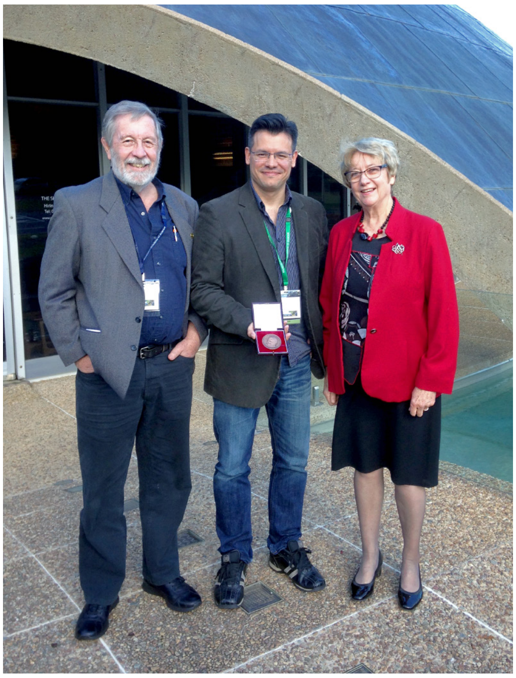
Activity	Details & Participant/s	Date
Empowering the next generation of research leaders	CCFS co-sponsored visitor, Hadyn Williams Fellow **Professor Brendan Murphy** delivered the workshop organised by **Zheng-Xiang Li**. The workshop was well attended by both Early Career Researchers and PhD students	4 May 2017
EPS HDR Conference Day	Organised by the MQ EPS and **CCFS PhD students**, featuring presentations and posters from EPS and **CCFS MQ PhD students**	15 June 2017
IGCP 648 Database Workshop 2	Two-day IGCP 648 workshop. **Zheng-Xiang Li** - Organiser and co-conductor, Townsville, Australia	9-10 June 2017
5-Lecture Short-Course on *"The Earth's Dark Ages: The Hadean and Transition to the Archean"*	Presenter - **Simon Wilde** - Attended by 50 Staff and Higher Degree students, University of Novosibirsk	25 September - 23 October 2017
Links between magma chemistry and tectonic stress	Presenter - **Bob Loucks** Rio Tinto Exploration, Reading, UK	17 October 2017

SELECTED WORKSHOP ROLES *cont...*

Activity	Details & Participant/s	Date
2017 ACTER Field Symposium	The third annual ACTER field symposium was held throughout the Lachlan Fold Belt of regional New South Wales, Australia. The field trip and symposium was led by Prof Bill Collins of Curtin University. The event was well attended, with 42 staff and graduate students from both National and International Institutions. Organised by **Zheng-Xiang Li**.	23-29 October 2017
CCFS 3rd Lithosphere Dynamics Workshop	Members of organising committee - **Weronika Gorczyk** and **Klaus Gessner** CCFS *Sponsored*	5-6 November 2017
EPS HDR Conference Day, MQ	Organised by the MQ EPS and **CCFS PhD students**, featuring presentations and posters from EPS and **CCFS MQ PhD students**	15 November 2017
Predictive Guides to Copper Discovery	Organiser and presenter - **Bob Loucks** Rio Tinto Exploration, Reading, UK	21 November 2017
CET-UWA 2017 Members' Day	Presenters included - **Crystal LaFlamme** and **Johannes Hammerli**	5 December 2017
Predictive Guides to Copper Discovery	Organiser and presenter - **Bob Loucks** BHP Exploration, Santiago, Chile	5-6 December 2017

ESTEEM

AWARDS

Participant	Activity
Juan Carlos Afonso	Presented with the 2017 Anton Hales Medal for achievements *"at the forefront of revolutionising the way that geoscientists interpret the signals they obtain from deep in the Earth by geophysical methods"* 
Crystal LaFlamme, Marco Fiorentini, Matt Kilburn	Received a Research Impact Award - UWA

AWARDS *cont...*

Participant	Activity
Richard Glen, **Elena Belousova**, **Bill Griffin**	Best Paper Award for 2016, Canadian Journal of Earth Sciences 
Zheng-Xiang Li	Finalist for Scientist of the Year - WA 2017 Premier's Science Awards
Bill Griffin	Google Scholar #1 Australian geoscience researcher in 2017 (http://www.webometrics.info/en/node/58)
Steve Foley	Google Australian #734 cited scientist in Australia (all disciplines) 2017 (http://www.webometrics.info/en/node/58)
Bill Griffin, **Sue O'Reilly**, **Zheng-Xiang Li**, **Simon Wilde**	Recognised by Clarivate Analytics (previously Thomson Reuters) as Highly-Cited Researchers (http://highlycited.com) 2017
Bob Loucks	Awarded the Benjamin Meaker Visiting Distinguished Professorship, University of Bristol
Sue O'Reilly and **Bill Griffin**	Honoured by dedication of Conference Volumes for 11th International Kimberlite Conference  
Sue O'Reilly	Google Australian #2 cited geoscientist 2017 (http://www.webometrics.info/en/node/58) Order of Australia (OAM) "*for significant service to the earth sciences as an academic and researcher, to tertiary education, and to scientific associations*" (2016)
Nanjing CCFS collaborators **Professors Zhou Xinmin**, **Xisheng Xu** and **Jinhai Yu**	State Natural Science Award (China) for "*Studies on the Mesozoic granites and crustal evolution in the Cathaysia block*"

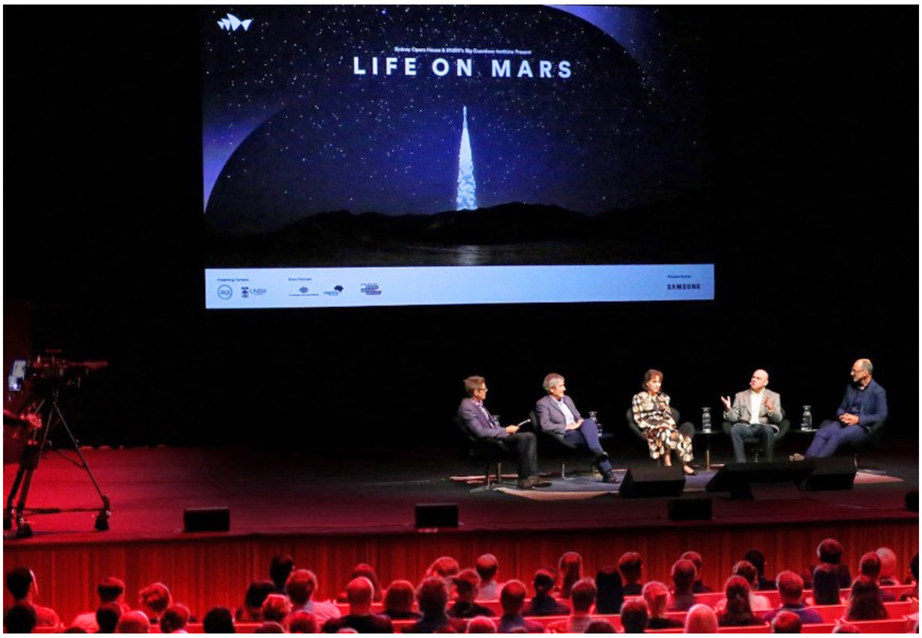
2017 NEW APPOINTMENTS AND POSITIONS

Martin Van Kranendonk	Mars2020 Sample Return team member
Anthony Lanati	Elected as NSW Division Treasurer, Geological Society of Australia
Zheng-Xiang Li	Principal Project Leader - IGCP 648: Supercontinent Cycles and Global Geodynamics Member of the Overseas Advisory Committee, China State Council
Sue O'Reilly	Project Leader – IGCP 622: Project "*Orogenic architecture and crustal growth from accretion to collision*"
Bill Griffin	Co-Editor with Sisir Mondal of "*Processes and ore deposits of ultramafic-mafic magmas through space and time*", a book published by Elsevier in 2017
Andrea Giuliani	Guest Editor - Proceedings of the 11th International Kimberlite Conference (Mineralogy and Petrology special issue)
Yongjun Lu	Appointed Councillor for Society for Geology Applied to Mineral Deposits (SGA) in 2016-2019 Appointed Secretary of the 6th International Archean Symposium (6IAS), Perth 2020
Craig O'Neill	Member of the Australian Academy of Science National Committee for Earth Sciences
Sue O'Reilly	Member Executive Committee, UNCOVER national initiative (Auspices of the Australian Academy of Science) Chair, Academy of Science National Committee for Earth Sciences, and Decadal Plan preparation Member of Council, Australian Academy of Science Elected Member of Executive Committee, Australian Academy of Sciences from 2018 Co-Chair inaugural Australian Academy of Science Task Force for "*Equity and Diversity*" from 2017 Invited Convenor – Session 5e "*Lithosphere evolution during subduction and collision*", Goldschmidt 2017 Invited Member, Scientific Committee for 3rd European Mantle Workshop (EMAW), Pavia, 2018 Australian Member, IUGG Nominations Committee

EDITORIAL APPOINTMENTS	
Acta Geologica Sinica	Li
American Journal of Science	Wilde
American Mineralogist	Handley
Cogent Geosciences	O'Neill, Moresi
Earth and Planetary Physics (EPP)	Yang
Exploration Geophysics	Selway, Yang
Geodynamics & Tectonophysics	Pisarevsky
Geology	C. Clark, Li, Van Kranendonk
Geological Society of America Bulletin	Griffin, Kirkland, Li
Geophysical Journal International	Afonso
Geosphere	Yuan
GeoResJ	George, Schaefer
Journal of Earth Sciences	Li, Wang
Journal of Jilin University - Earth Science	Wilde
Journal of Metamorphic Geology	Brown, C. Clark
Journal of Petrology	Turner
Lithos	C. Clark, Foley, Griffin
Mineralium Deposita	Fiorentini
Nature Scientific Reports	Jacob
Physics & Chemistry of Minerals	McCammon
Precambrian Research	Pisarevsky, Van Kranendonk
Solid Earth (EGU)	Afonso
Solid Earth Sciences	Griffin
Tectonophysics	Li

OUTREACH

Forum	Participant/s	Date
Numerous (daily) government briefings / Industry briefings	Chris Kirkland	2017
Filming for BBC Stargazing Live	Martin Van Kranendonk	1 January 2017
Public lecture - "*Investigating Earth's Oldest Rock*" University of Pinar Del Rio, Cuba	Simon A Wilde	13 January 2017
Public lecture - "*Direct dating hydrocarbon generation using multiple radiogenic isotope systems*" Qingdao, China	Xuan-Ce Wang	4 May 2017
Public lecture - 2017 Haydn Williams Fellowship Public Lecture: "*Why leprechauns know how mountains form*" http://geodynamics.curtin.edu.au/2017-haydn-williams-fellowship-public-lecture/	CCFS co-sponsored visitor Brendan Murphy	4 May 2017
Public lecture - Talk - Science at the Shine Dome 2017 - Anton Hales medal	Juan Carlos Afonso	24 May 2017
High School Visit - Teaching basic Astrobiology concepts	Georgia Soares	28 June 2017
School visit - East Victoria Park Primary School - 5th and 6th grades - Teacher, Mr Ranford, and students excited to have their science lesson taught by real-life scientists	Amaury Pourteau, Erin Martin, Sam Bain	9 July 2017
Panellist, Women on Mars event for female high school students - Sydney Opera House - Students heard from leading female scientists and participated in exciting scientific activities	Tara Djokic	18 August 2017
Panellist, Life on Mars: The 2020 Rover Mission - Sydney Opera House, concert hall stage	Martin Van Kranendonk	17 August 2017



CCFS Flagship Program 4 on the Concert Hall Stage of the Sydney Opera House, August 2017 for a Q&A presentation as part of National Science Week. From left to right: MC Graham Phillips, Paul Davies, Abigail Allwood, Mitch Schulte, Martin Van Kranendonk. Photo: Prudence Upton (SOH).

MQ Open day	Craig O'Neill	19 August 2017
High school outreach, Jakarta - years 8-12	Tara Djokic	1 September 2017
Public lecture in the Geology Department - Presidency University, Kolkata, India	Hindol Ghatak	12 September 2017

OUTREACH *cont...*

Forum	Participant/s	Date
ARC/STA Research Showcase event, Parliament House, Canberra - Networking with Parliamentarians and key staff - Jointly organised by ARC and Science and Technology Australia.   	Dorrit Jacob	7 September 2017
Public lecture - *"Linking Deep-Earth Volatile Cycling with Geodynamics, Magmatism, and Surface Feedback - New perspectives on the evolution of the terrestrial silica reservoirs"*, Nanjing, China	Xuan-Ce Wang	16 Sept 2017
Public lecture - *"Characterisation and Isotope Dating of Source Rocks and Hydrocarbon Generation for Exploration Targeting"* Xi'an, China	Xuan-Ce Wang	21 Sept 2017
Public lecture - Students, Russian Science Festival, Moscow  *Martin Van Kranendonk and host, Armen Mulkidjanian (far left), in front of the main building of Moscow's Lomonosov University campus.*	Martin Van Kranendonk	1 October 2017
High school outreach - Broken Hill - years 8-10	Tara Djokic	1 October 2017
	Jinxiang Huang, Romain Tilhac, Montgarri Castillo-Oliver CCFS sponsor booth manned by CCFS ECRs - Geological Society of Australia (GSA) Earth Science Student Symposium (GESSS), MQ, Sydney, Australia	10 November 2017
Years 8-12 talk for the Curious Minds program (Kelsie Dadd)	Tara Djokic	1 December 2017

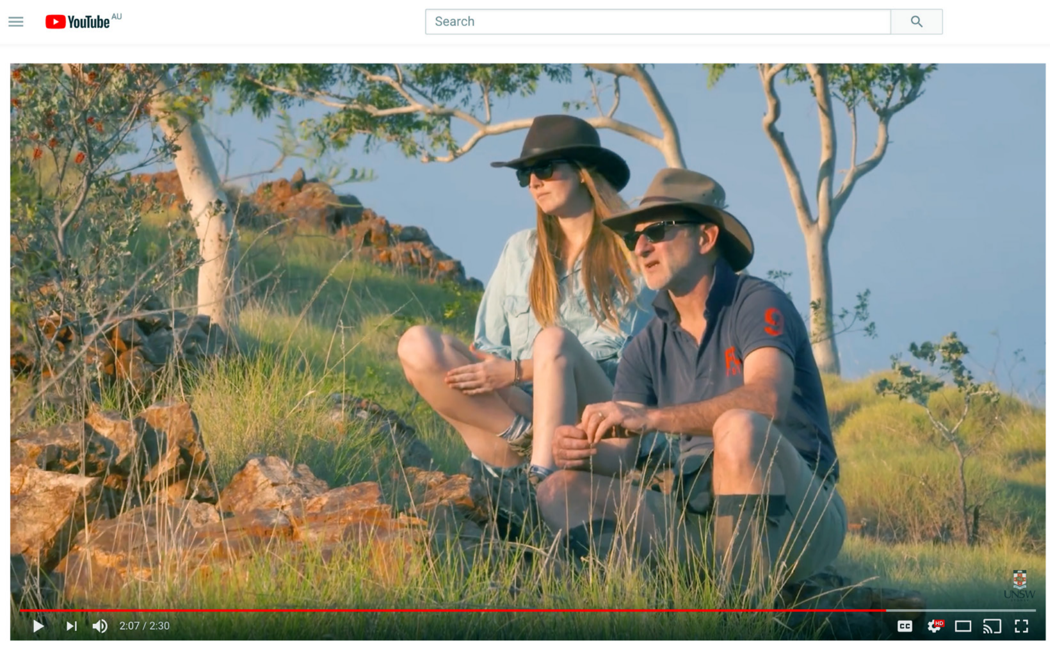
OUTREACH *cont...*

Forum	Participant/s	Date
Visit to East Victoria Park Primary School (Photo: Earth Dynamic Research Group (http://geodynamics.curtin.edu.au/east-victoria-park-primary-school-visit-2017/))	Amaury Pourteau, Erin Martin, Samuel Bain	

MEDIA

Activity	Participant/s	Date, Forum	Web address
Evidence falls into place for once and future supercontinents	Zheng-Xiang Li	11/1/17, Science News	https://www.sciencenews.org/article/evidence-falls-place-once-and-future-supercontinents
Paleomagnetic data hint at link from Earth's core to continents	Uwe Kirscher	15/6/17, Eos Earth & Space Science News	https://eos.org/articles/paleomagnetic-data-hint-at-link-from-earths-core-to-continents
Podcast - Episode 57: South American copper & Earth's evolution	Nick Gardner	1/9/17, The Northern Miner	https://soundcloud.com/northern-miner/episode-57-south-american-copper-earths-evolution
Zircons: How tiny crystals open a window into the early history of Earth	Craig O'Neill	11/9/17, Cosmos Magazine	https://cosmosmagazine.com/geoscience/zircons-how-tiny-crystals-open-a-window-into-the-early-history-of-earth
Prehistoric volcanoes to prospect for metals	Stephen Foley	20/9/17, Stories of Australian Science	http://stories.scienceinpublic.com.au/2017/prospect-metals/

CCFS on The BIG Screen: Flagship Program 4 members shot interviews for AstroMedia and continued filming for December Media's IMAX 3-D documentary "*Earth Story*" featuring CI Martin Van Kranendonk and UNSW PhD student Tara Djokic, due for release around the world in late in 2018. Filming roles also included a UNSW TV segment for the Life on Mars: The 2020 Rover Mission - Sydney Opera House, concert hall stage (*see below*).



Martin Van Kranendonk and Tara Djokic explain why research on ancient rocks with evidence of deposition in hot springs is important for the exploration of life on Mars. (https://www.youtube.com/watch?v=UdMKO2I-DzA&feature=youtu.be)

MEDIA *cont...*

Activity	Participant/s	Date, Forum	Web address
Huge space rocks could have helped start Earth's plate tectonics	Craig O'Neill	25/9/17, New Scientist	https://www.newscientist.com/article/2148366-huge-space-rocks-could-have-helped-start-earths-plate-tectonics
Did meteorites create the Earth's tectonic plates?	Craig O'Neill	26/9/17, Cosmos	https://cosmosmagazine.com/geoscience/did-meteorites-create-the-earth-s-tectonic-plates
Did giant meteorites activate our tectonic plates?	Craig O'Neill	26/9/17, NZ Herald	http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11926492
New research illuminating the dark age of geology	Craig O'Neill	28/9/17, 2SER Breakfast radio Interview	https://2ser.com/new-research-illuminating-dark-age-geology/
Astrobiology studies in the Hamersley Ranges look at early life on planet Earth - Interview with Susan Standen	Georgia Soares	12/12/17, ABC Northwest Radio and ABC online	http://www.abc.net.au/news/2017-12-08/astrobiology-study-early-life-earth-hamerlsey-ranges/9238028

MEDIA - FEATURED PAPERS

1075. **Djokic, T.**, **Van Kranendonk, M.J.**, Campbell, K.A., Walter, M.R. and Ward, C.R. 2017. Earliest signs of life on land preserved in ca. 3.5 ga hot spring deposits. *Nature Communications, 8, 15263.*

Activity	Date, Forum	Web address
World's oldest fossils unveil life 3.7 billion years ago (etc)	May 2017 various	*One of the highest ranking papers on Almetrics, in any field.* Featured in **134 news stories** from 111 outlets. (https://www.altmetric.com/details/19981498/news)

1003. **O'Neill, C.**, Marchi, S., **Zhang, S.** and Bottke, W. 2017. Impact-driven subduction on the Hadean Earth. *Nature Geoscience, 10, 793-797.*

Activity	Date, Forum	Web address
Asteroid bombardment sent the Earth's crust into meltdown 4 billion years ago	25/9/17, UK IBT	https://www.ibtimes.co.uk/asteroid-bombardment-sent-earths-crust-into-meltdown-4-billion-years-ago-1640760
Asteroid impacts 4 billion years ago transformed the Earth's crust and helped create its tectonic plates	25/9/17, Daily Mail	http://www.dailymail.co.uk/sciencetech/article-4917908/Asteroid-impacts-4-billion-years-ago-began-tectonics.html
Did giant meteorites activate our tectonic plates?	25/9/17, New Zealand Herald	http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11926492
Huge space rocks could have helped start Earth's plate tectonics	25/9/17, New Scientist	https://www.newscientist.com/article/2148366-huge-space-rocks-could-have-helped-start-earths-plate-tectonics/
Meteorite impacts may have created Earth's tectonic plates	25/9/17, Sign of the Times	https://www.sott.net/article/362866-Meteorite-impacts-may-have-created-Earths-tectonic-plates
Did meteorites create the Earth's tectonic plates?	26/9/17, Cosmos Online	https://cosmosmagazine.com/geoscience/did-meteorites-create-the-earth-s-tectonic-plates
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Large meteorite impacts drove plate-tectonic processes on the early Earth	3/10/17, Technology.org	https://www.technology.org/2017/10/03/large-meteorite-impacts-drove-plate-tectonis-processes-on-the-early-earth/

MEDIA *cont...*

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Activity	Date, Forum	Web address
Burning questions remain after discovery of recent volcanic eruptions in Angola	22/11/17, Deep Carbon Observatory Newsletter	https://deepcarbon.net/feature/burning-questions-remain-after-discovery-recent-volcanic-eruptions-angola#.WiSMYktx3Vp

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Activity	Date, Forum	Web address
Where does the gold discovered under South America come from?	29/11/17, Cooperativa	http://www.cooperativa.cl/noticias/sociedad/ciencia/geologia/de-donde-viene-el-oro-descubierto-bajo-sudamerica/2017-10-28/103551.html
An international group of scientists reveals the mystery about the origin of gold	21/11/17, Science Newsline	http://www.sciencenewsline.com/news/2017112115580075.html
An international group of scientists reveals the mystery about the origin of gold	21/11/17, EurekAlert!	https://www.eurekalert.org/pub_releases/2017-11/uog-aig112117.php
An international group of scientists reveals the mystery about the origin of gold: it comes from the Earth's mantle	16/11/17, AlphaGalileo	http://ct.moreover.com/?a=32528085118&p=1pl&v=1&x=Bpo7cBwA2yhcwnhMIAuMlg
Geologia. O ouro das estrelas foi parar ao manto da Terra	9/12/17, Publico	http://www.cooperativa.cl/noticias/sociedad/ciencia/geologia/de-donde-viene-el-oro-descubierto-bajo-sudamerica/2017-10-28/103551.html
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This new research gives new clues to the origin of gold	23/11/17, Newsweek	http://www.newsweek.com/origin-gold-chemical-factory-beneath-earth-720608

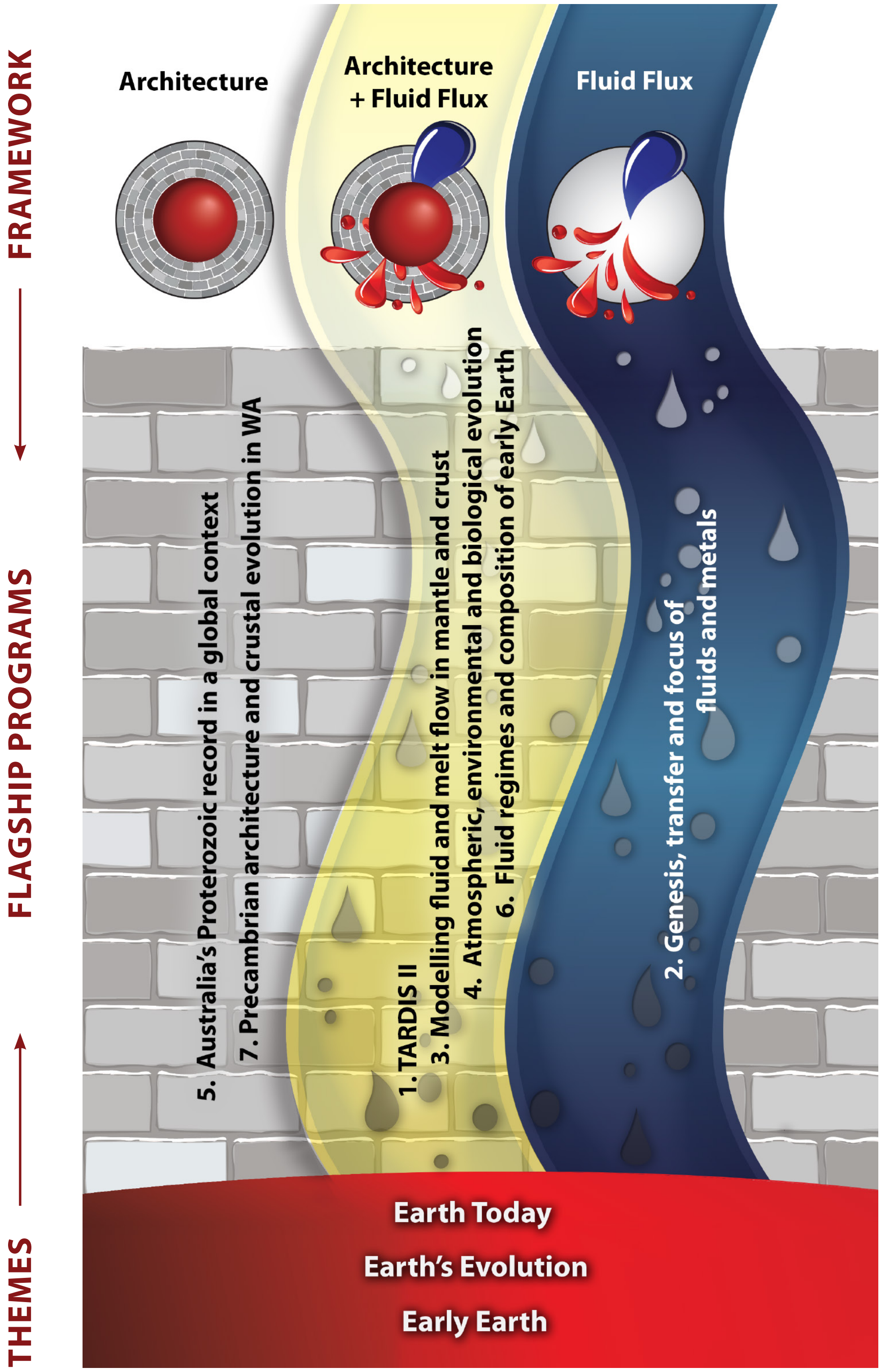
VISITORS

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.

Australian and international visitors are listed in Appendix 7. They have participated in collaborative research, technology exchange, seminars, discussions and joint publications and collaboration in postgraduate programs. For More information see the section on *International Links.*

Research highlights 2017

Following the conceptual framework outlined on *page 6*, these Research highlights are identified as contributing to understanding Earth's Architecture (the '*roadmap*' for fluids) and/or Fluid Fluxes (the '*traffic report*'), with logos for easy attribution.
For a full description of the Flagship Programs, see *Appendix 1*.



Origins of life: Insights from the Pilbara

Currently, there are two principal environments considered as sites for the origin of life. The first is that life began in the ocean in hot vents – a theory that has been favoured since the 1977 discovery of hot seafloor vents thriving with microbial life. The second, and currently gaining traction, is that life began on land in a "*warm little pond*", i.e. hot springs on land - a theory first conceived by Charles Darwin.

The Pilbara is an ancient landscape that is barren and rather desolate today, but billions of years ago things were vastly different. The Dresser Formation, located in the East Pilbara, hosts some of the earliest evidence for life on Earth. Stromatolites, i.e. rock structures built by communities of microorganisms, were discovered there in the late 1970s and the site has been a place of interest for research into the early Earth and evolution ever since. Over the past 40 years, the environmental setting has been extensively debated. Original research suggested a quite shallow-water marine environment, resembling the modern Shark Bay, on the West Australian coast. However, since the late 1990s new evidence has pointed to a much more dynamic environment, that of an ancient volcano. What was still unclear about this volcanic setting was the link between life, i.e. stromatolites, and the hot circulating fluids that typically accompany volcanoes. In modern volcanic settings, hot fluids circulate in the underground rocks and manifest either as hot vents at the bottom of the salty ocean such as the black or white smokers, or as terrestrial hot springs where fresh rainwater falls on a land, such as those in Rotorua, New Zealand. This hot circulating water is full of elements liberated from the rocks and becomes a nutrient-rich environment, fertile grounds in which microbes can thrive.

Our recent work in the Pilbara has provided new and strong evidence that terrestrial hot springs had indeed existed within this ancient volcano and, more importantly, could be linked with life. A rock type called geyserite (opaline silica) was found alongside a suite of biological textures including stromatolites. Geyserite is only found in terrestrial hot spring pools and geysers on land. The accompanying biological signatures include a newly-identified microbial texture (called palisade fabric) that represents microbes that grew on the ancient sinter terraces – the rocks that form around hot spring pools. In addition, gas bubbles are inferred to be biological because the preservation of their bubble shape indicates that a sticky substance (microbial) was present that trapped them long enough to be entombed perfectly. All of these textures are almost identical to the fossil textures observed in modern terrestrial hot spring settings today.

Biochemical studies are now showing that some of the reactions necessary to form longer-chain polymers, the more complex molecules needed as ingredients for life, can only occur where dehydration and rehydration are allowed, i.e. in hot pools exposed to air on land.

The findings in the Pilbara provide a geological perspective that lends weight to an origin of life on land, as they extend the record of life living in hot springs on land back to 3 billion years, and indicate that life inhabited the land much earlier (by up to 580 million years) than previously thought.

This project is part of CCFS theme 2, Earth's Evolution, and contributes to understanding Fluid Fluxes.

Contacts: Tara Djokic, Martin Van Kranendonk
Funded by: CCFS Flagship Program 4, UNSW

Figure 2. Cover art for Scientific American, August, 2017 issue relating to article containing Pilbara findings, CCFS publication #1070.

Figure 1. The 3.5 billion year old Dresser Formation, Pilbara, Western Australia.

Detective work on stealthy processes in Earth's mantle solves continental survival, evolution and identity issues

Serial research on, and accumulation of diverse clues about, continental formation can now solve some fundamental questions about when, how, why and where deep processes shaped Earth's lithosphere.

The lithospheric mantle, the deep part of Earth's lithospheric plates up to 300 km below the surface, holds many layers of information about the fluids that have risen up from the convecting mantle, and the huge tectonic events that have shaped the outermost part of Earth's solid shell that we inhabit. It is a palimpsest - just like ancient manuscripts that have many layers of writing superimposed on, and obscuring, earlier messages. Unravelling such repeated fluid episodes from mantle materials brought to the surface as fragments in magmas, or tectonically thrust from depth on to the surface, and remotely sensing the physical properties of the hidden lithosphere with geophysical methods can help solve this great puzzle in deep time and deep space.

Interpreting this complex record and tracking specific episodes and processes is a key to reconstructing lithosphere evolution through time and the nature of volatile fluxes from the deep Earth. Convergence between datasets of Hf isotopic model ages for zircons (e.g., *Belousova et al., 2010, Lithos*) and Re-Os model ages for mantle sulfides (*CCFS publication #344*), reinforced by other geochemical and tectonic criteria, indicate that over 75% of the subcontinental lithospheric mantle (SCLM) and its overlying crust (now mostly lower crust) formed at 3.0-3.5 Ga, probably in global overturn events that marked a change in Earth's fundamental geodynamic behaviour (*CCFS publication #344*).

Pristine Archean lithospheric mantle, the roots of the Archean cratons up to >300 km deep, is not only more depleted (low in basaltic melt components) than younger lithospheric mantle, it is differently depleted. Proterozoic and Phanerozoic lithospheric mantle (xenoliths and orogenic massifs), as well as abyssal peridotites, ophiolitic peridotites, all have one important feature in common: as Al decreases, Fe (and Cr) contents show only a very narrow range (8±1 wt% FeO). In contrast, Archean peridotites have lower Fe at low Al contents, and may show a weak positive correlation between Fe (and Cr) and Al, suggesting that no Cr-Al phase (i.e. spinel or garnet) was present on the liquidus during the melting that produced Archean lithosphere. Garnet-peridotite suite rocks in cratonic mantle are thus now interpreted as products of the metasomatic introduction of garnet and clinopyroxene into original depleted harzburgite, thus '*refertilising*' the depleted residue.

Therefore, the traditional '*oceanic melting trend*' is now interpreted as a refertilisation trend, with the compositional trend arrow reversed (*Griffin et al., 2009, J Pet*). The cratonic roots in contact with the convecting part of the mantle (the asthenosphere) and outer margins in contact with repeated fluid and melt fluxes, are the most strongly modified domains through time, so cratonic root compositions show a general increase in fertility (e.g., increasing Fe, Ti, Ca, Al content and decreasing Mg content) with increasing depth.

Integration of geochemical and geophysical datasets, groundtruthed with petrophysical measurements and modelling for different mineral compositions and modes, has enabled us to interpret global (and regional) seismic tomographic results with an increasing degree of geological reality (Fig. 1).

Stealth metasomatism and its geophysical significance

Mantle metasomatism is the process, and the results, from the interaction of fluids with mantle rocks they pass through. This affects not only the geochemical characteristics of the

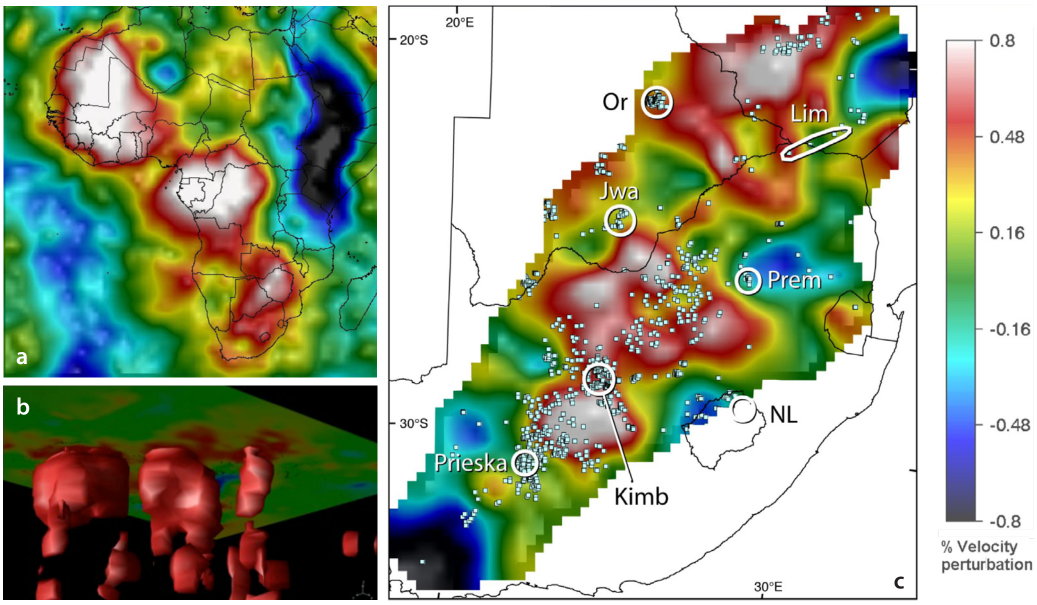
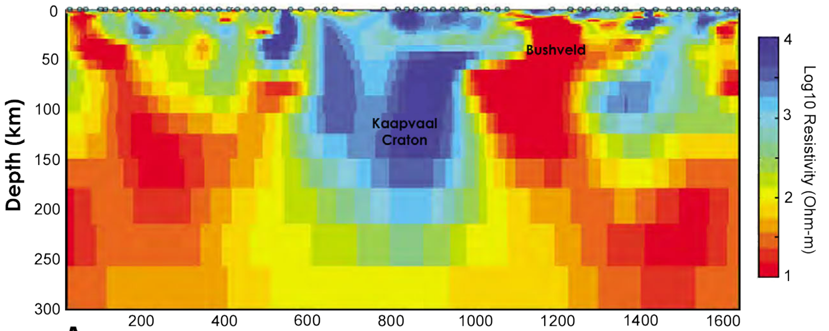
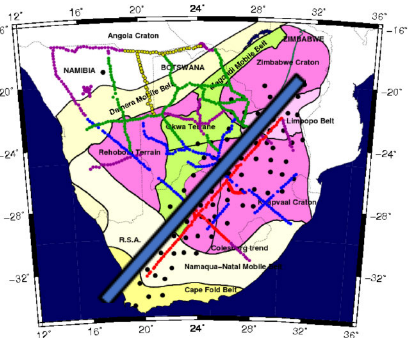


Figure 1. Vs tomography (100-150 km) of the lithospheric mantle. Red to white colours indicate high Vs; blue colours low Vs (modified from CCFS#207 and Begg et al., 2009, Geosphere). (a) Africa, showing distribution of the boundaries of high-velocity cratonic blocks with metasomatised (red) margins. (b) modelled high-Vs irregular volume of cratonic roots to ~350 km beneath each craton. (c) Detailed seismic tomography for Kaapvaal craton with kimberlites clustered at margins of high-velocity volumes. White circles show major kimberlite provinces.

lithospheric mantle, but also its physical parameters (and hence geophysical signatures) including density, seismic response and thermal and electrical characteristics. The concept of '*stealth*' metasomatism was introduced (*CCFS #5; http://ccfs.mq.edu.au/AnnualReport/12Report/ResHigh.html#Stealth*) to highlight the '*deceptive*' addition to lithospheric mantle rock-types of new minerals (e.g. garnet and/or clinopyroxene) indistinguishable mineralogically from common mantle-peridotite phase assemblages.

Recognition of stealth metasomatism reflects the increasing awareness of the importance of refertilisation (resulting in, for example, higher Fe, Ca and many minor- and trace-element contents) of ancient refractory mantle regions by deep-seated fluid fronts.





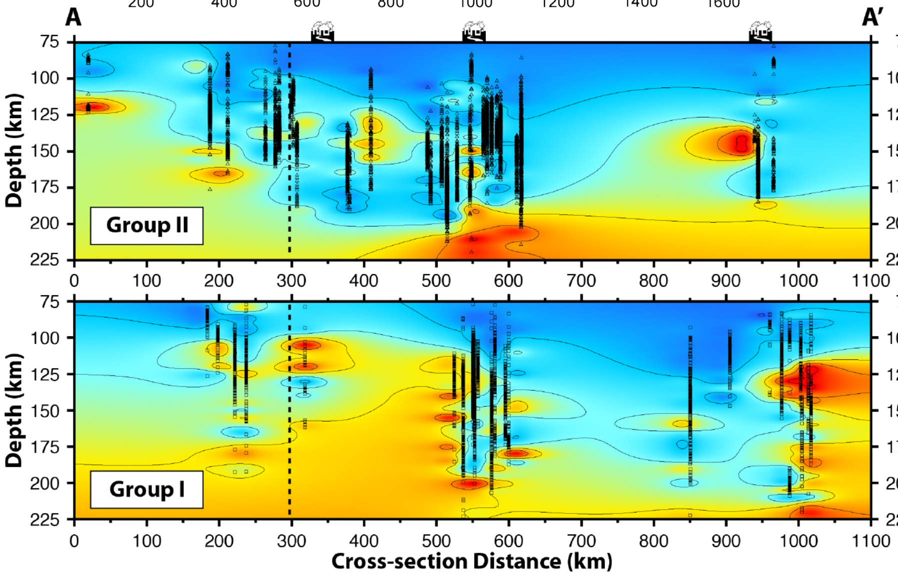


Figure 2. Upper image shows MT data for the Kaapvaal traverse from Jones et al., 2011, JGR. Inset shows traverse line. Lower images show metasomatic intensity across the same traverse at ~150 Ma (top) and 90 Ma (lower), after Kobussen et al., 2008, Geology 36.

Understanding the timing and nature of stealth metasomatism is critical to understanding the geochemical and geodynamic evolution of different regions of the lithospheric mantle and also for assessing their metallogenic fertility.

Primitive Archean lithospheric mantle is highly magnesian (~49% MgO) with lower density (~3.31 g/cm^3) than fertile mantle (~3.37 g/cm^3). The resulting contrasts in seismic response become measurable if metasomatised regions are on the scale of tens to hundreds of km. Metasomatic refertilisation of the cratonic lithospheric mantle not only increases its density, but also strongly affects its rheology. The recognition that the cratonic lithospheric mantle may in general consist of a very depleted upper layer, becoming more metasomatised (evidenced by garnet peridotites) at depth, provides a solution to some important discrepancies between geophysical data and numerical models. A deep cratonic root made up mainly of garnet peridotites would imply a lower geoid and a much greater elevation than is observed for the Kaapvaal craton, and a mismatch in Vp/Vs ratios (*Afonso et al., 2010*), but a layered model with refertilisation increasing with depth, yields numerical models that fit the geophysical data.

Thermal changes are caused by advective transfer of heat by relatively hot metasomatising fluids and by the influx of heat-producing elements (K, U, Th) that accompanies some types of metasomatism. Radioactive decay of these elements can raise the local heat flow by 50-70% over normal reduced mantle heat flow. The origins of significantly contrasting electromagnetic (MT) responses in the lithospheric mantle have not yet been satisfactorily identified. Fluid-related recrystallisation demonstrated in microstructural studies may result in significant H contents in mantle minerals and may affect electrical conductivity. The key to understanding the electromagnetic signals from the mantle lies in identifying the nature of fluids, their oxidation state, and their distribution and thus is closely connected with a full understanding of metasomatic processes, grain sizes and fabrics, and fluid compositions and movement mechanisms in the mantle. Comparisons of high-resolution MT traverses with geochemical mapping traverses show a correlation of higher conductivity with more strongly metasomatised domains.

The 2-D isotropic model of magnetotelluric response across the Kaapvaal Craton is shown in the top image, Figure 2 (*Jones et al., 2011, JGR*); the traverse locus is marked in the inset map. The lower

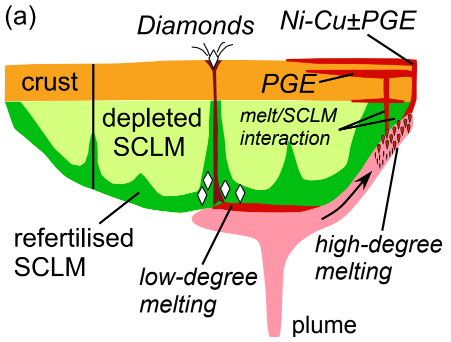


Figure 3. Interactions between magmas and the base and edges of cratonic roots. Plume magmatism triggers kimberlite formation and flows to areas of thinner SCLM where melting is focused. Variable interaction of melts with crust and SCLM influences Ni-Cu and PGE deposit genesis. Lithosphere-scale discontinuities and zones of weakness can focus the locus of kimberlite eruption. (Adapted from CCFS publication #207)

2 images show the contoured metasomatic intensity for domains beneath the same Kaapvaal traverse line in 2 time slices. This is measured using geochemical parameters of mantle-derived garnets carried to the surface in Group II kimberlites (upper panel) at around 150 Ma; the lower panel shows analogous results for garnets from Group I kimberlites (at around 90 Ma). Hotter colours show higher metasomatic intensity: the most highly metasomatised regions for the younger traverse (lower panel) coincide with regions of higher conductivity (lower resistivity).

Implications for metallogeny

Magma-related ore systems form economic deposits that underpin our human civilisation. The magmas related to metallic element redistribution derive from the asthenosphere, then traverse and interact to varying degrees with the subcontinental lithospheric mantle. The evolution of the original Archean lithospheric mantle has been the single largest influence on the formation of most of Earth's ore deposits (*CCFS publication #207*):

- the high degree of buoyancy of this ancient SCLM relative to the asthenosphere, results in the persistence today of low-density, rheologically coherent Archean domains and commonly, the preservation of old crustal (or at least lower-crustal) domains;
- the enduring (and volumetrically dominating) Archean lithospheric mantle domains are a reservoir for metasomatic enrichment over their long history, creating a potentially metallogenically-fertile mantle impregnated with critical elements (e.g., Au, Cu, Ni and PGEs; Fig. 3)
- the formation of Archean cratons provided an architectural mantle-scape of regions with contrasting rheology, composition and thickness. These cohesive Archean domains direct magma and fluid pathways around their margins and along old sutures between blocks, and may act as both sinks and sources for ore-forming elements depending on the geodynamic evolutionary stage;
- if the first stabilisation of lithospheric mantle at 3.0-3.5 Ga signalled the end of a mantle overturn regime (either uniquely, or intermittently with subduction), then this is when long-lived tectonic regimes conducive to mineralising systems (e.g., back-arc basins, passive margins, cratonic boundaries) became available (*http://ccfs.mq.edu.au/AnnualReport/13Report/ResHigh.html#GLAM*).

This project is part of CCFS theme 2, Earth's Evolution, and contributes to understanding Earth's Architecture and Fluid Fluxes.

Contact: Sue O'Reilly

Funded by: CCFS Flagship Program 1

A piece of America lingers in northern Australia: Legacy of the 1.6-billion-year-old supercontinent Nuna

Throughout Earth's 4-billion-year history, as continents have shifted around the globe, they periodically have amalgamated to form supercontinents. Most recently this occurred about 300 million years ago to form the supercontinent Pangea, in which the southern continents (Africa, South America and Australia and Antarctica) were connected to Eurasia and North America. We now recognise that an earlier supercontinent termed Nuna formed about 1.6 billion years ago. Although previous researchers have speculated that north-east Australia was near North America, Siberia, or North China within the framework of Nuna, solid evidence has been hard to find.

Approximately two thirds of the Australian continent consists of basement rocks older than 600 million years. In North Queensland, rocks 1.7 billion years old are found in Mt. Isa and 500 km away in the Georgetown region. New sedimentological field data, in conjunction with new and existing geochronological data from both regions, have revealed an unexpected component of the Australian continent. As expected, Mount Isa rocks show strong resemblances to known Australian basement rocks. However, the age spectra of zircons from sedimentary rocks in the Georgetown area (Fig. 1) revealed signatures previously unknown in Australia. Instead, they show strong resemblance to spectra from sedimentary rocks in present-day Canada, sourced from American basement rocks (Fig. 2).

The simplest explanation for our findings is that 1.7 billion years ago, when the Georgetown rocks were deposited in a shallow sea, the area was part of North America. It was then rifted away from North America, and only collided with the Mt Isa region of northern Australia at around 1.6 billion-years ago when almost

Figure 1. Current ripple laminations in fine to medium grained sandstone sedimentary rocks in Georgetown indicate ancient shallow marine environments. Our data shows these sediments were deposited off the coast of North America adjacent to present-day Canada, and later transferred to Australia.

all continents on Earth at the time assembled to form the Nuna supercontinent (Fig. 2). When Nuna broke apart some 300 million years later, the Georgetown area remained permanently stuck to Australia.

In Mount Isa we find evidence of mountains being built as Georgetown collided with the rest of Australia. Interestingly, this mountain belt, in contrast to the Himalayas, would not have been as large. To explain this, we have evoked a double-sided subduction model. Another possibility is that the Earth during this period was hotter and was unable to support the immense mountain belts we see on the modern Earth.

This project is part of CCFS theme 2, Earth's Evolution, and contributes to understanding Earth's Architecture.

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Funded by: ARC Laureate Fellowship ZX Li, Curtin University scholarship AR Nordsvan

See *CCFS publication #1043* (https://doi.org/10.1130/G39980.1)

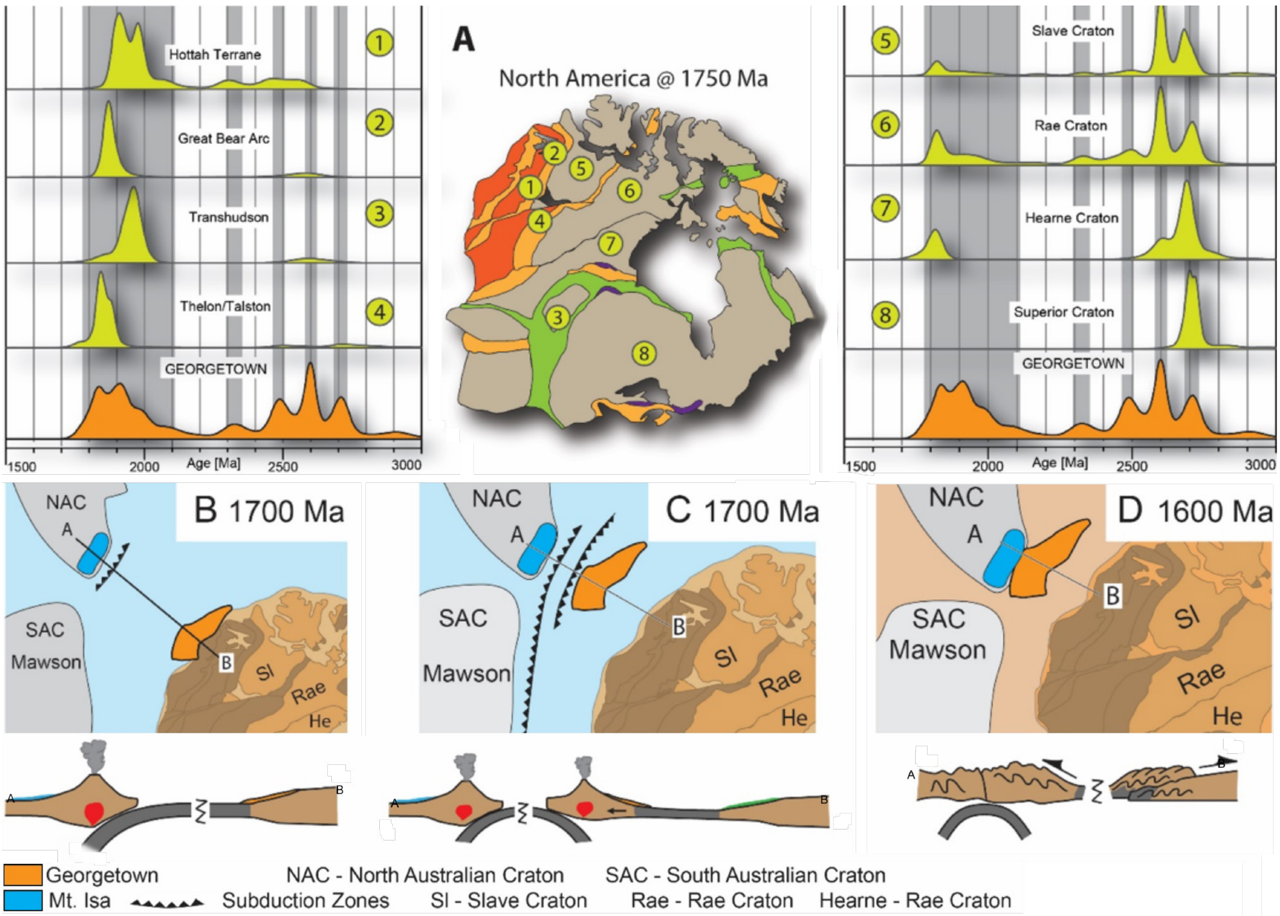

Figure 2. A) Detrital zircon spectra from the Georgetown sediments have multiple overlaps with magmatic ages from North America, suggesting an ancient link. B) Sediments now in Georgetown (orange) are believed to have been deposited off the coast of North America. C) An east-dipping subduction system caused Georgetown to be rifted away from North America about 1.7 billion years ago. D) Roughly 100 million years later, the Georgetown block was accreted to north-eastern Australia, and has stayed there ever since. This Australia-Antarctica-North America unification by ~1600 Ma signifies the completion of the assembly of Nuna.

Buoyant Ni-Cu-PGE-bearing magmas trapped deep in continental crust

The formation of magmatic Ni-Cu-PGE ore deposits depends on the ascent of high-degree partial melts from the mantle into the crust. Such deposits are commonly found along crustal-scale discontinuities that provide favourable pathways for mantle-derived magmas, such as translithospheric faults, sutures and rifts (*CCFS publication #207*). While this association has been demonstrated at the scale of tectonic plates, the mechanisms that govern magma flux within these zones of favourable structure remain poorly understood. Particularly little is known about the emplacement of ore-forming magmas in the deep crust because access to crustal roots is limited.

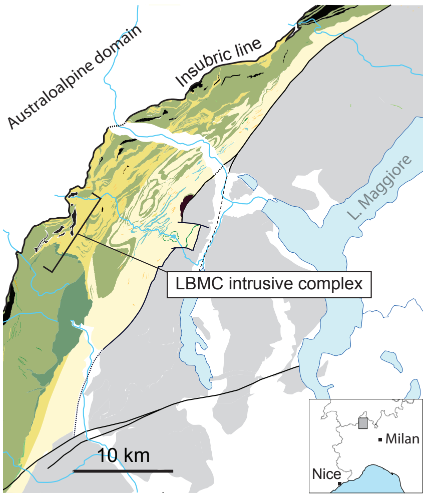

Figure 1. Generalised geologic map of the Ivrea Zone, showing the location of the LBMC intrusive complex within a section of lower continental crust that is tilted steeply SE, exposing amphibolite- to granulite-facies metasedimentary rocks (yellows) that are interleaved and intruded by mafic and minor intermediate igneous rocks (green).

The Ivrea Zone in the NW Italian Alps (Fig. 1) is a natural laboratory to examine mechanisms of magma ascent and arrest near translithospheric structures. Exhumation and tilting of continental crust has exposed a suite of mineralised mafic and ultramafic intrusions, the La Balma-Monte Capio (LBMC) intrusive complex, emplaced into host rocks at a paleodepth of 20-30 km. Collectively, these rocks preserve a continuous cross section of lower- to middle crust adjacent to a long-lived tectonic boundary between the Europe and Adria plates. The mineralised suite comprises several elongate ultramafic bodies, with a cumulative width of at least 9 km and thickness of 400 m, that are inferred to be the products of *in situ* differentiation of a high-Mg magma. Recent high-precision geochronology has revealed the mineralised bodies were emplaced at 200 Ma, overlapping with the onset of rifting at the plate boundary, and considerably later than the crystallisation of the host rocks.

A key finding is that the LBMC intrusive complex was emplaced at a rheological transition in lower continental crust, where granulite-facies gabbro is overlain by a package of paragneiss

Marco Fiorentini examines intrusive relationships between Ni-sulfide-bearing peridotite (bottom) and gabbros (centre) near the roof of the LBMC igneous complex (Photo: Greg Dering).

of similar metamorphic grade. Differences in bulk composition and mineralogy between the gabbros and overlying gneisses produce a significant density contrast at this transition. To evaluate the role of this pre-existing density contrast in trapping mafic and ultramafic magmas in the lower crust, we produced a 1D density model of the lower Ivrea Zone crust. The model incorporates published bulk densities for gabbros (n=40) and overlying granulite-facies gneisses (n=17). Densities were calculated for a range of estimated primary melt compositions (n=13) for the LBMC igneous complex, using Gibbs Free Energy minimisation and thermodynamic modelling based on empirically determined P-T parameters and the PerpleX software.

The results showed a significant range of overlapping densities at fixed P-T conditions for each of the three modelled components. Because this variation is the result of measured bulk rock compositions, it is probably representative of the natural variation in density within the lower crust. The mean calculated density of the La Balma parental melt (2810 kg/m^3) is less than the mean densities of both the footwall gabbros (3190 kg/m^3) and hanging wall felsic gneisses (2990 kg/m^3). Model results (Fig. 2) show that there is a 2.9-8.5% likelihood that estimated parental melt matches the calculated footwall

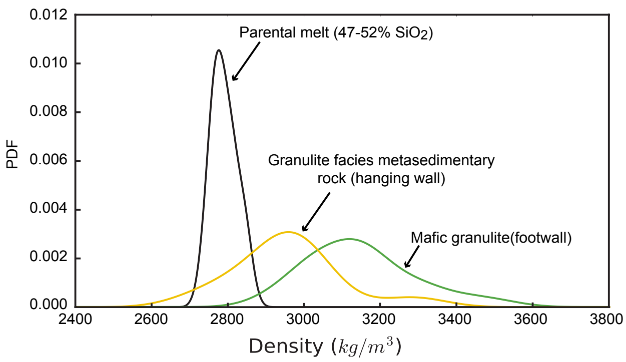

Figure 2. Kernel-density estimation for modelled physical densities of host rocks and parental melt compositions from the Ivrea Zone. The wide range of rock densities modelled for both metasedimentary and mafic granulites reflects heterogeneity in bulk composition found throughout the Ivrea Zone.

gabbro densities, and a 24.6% probability that bulk rock densities match those of the felsic wall gneisses. These results show that an emplacement scenario in which neutral buoyancy plays a role is only significant within areas characterised by particularly low-density granulite. In most scenarios covered by the model, parental melts maintain an internal vertical driving force that would be expected to carry the magma to significantly shallower crustal levels. The fact that the LBMC intrusive complex, and associated Ni-sulfide mineralisation, lies at this surprisingly deep level suggests that the internal buoyancy force of magma can be counteracted by mechanical and/or stress barriers over length scales of kilometres. Seismic velocity profiles indicate such physico-chemico transitions to be a relatively common feature of continental crust, particularly in extended terranes. Consideration of lower-crustal composition and structure should be incorporated into conceptual models of magma transport close to tectonic sutures; such models have historically emphasised sub-vertical pathways.

This project is part of CCFS theme 3, Earth Today, and contributes to understanding Earth's Architecture and Fluid Fluxes.

Contacts: Gregory Dering, Marco Fiorentini, Christopher Gonzalez, Jonathan Munnikhuis
Funded by: CCFS Flagship Program 2

Monitoring the evolution of gold-bearing fluids

$\Delta^{33}S$ anomalies ($\Delta^{33}S > \pm0.2‰$) were formed in the Archean, largely through mass independent fractionation of sulfur isotopes (MIF-S) in an oxygen-poor atmosphere, and imparted to the Archean supracrustal rock record (as MIF-S). This indelible MIF-S0 signature can be used to trace sulfur pathways to orogenic gold deposits. Through this recycling process, the original MIF-S signal ($\Delta^{33}S \neq 0‰$) may be diluted by mixing between sulfur reservoirs to such an extent that it becomes undetectable ($\Delta^{33}S = 0\pm0.5‰$). In such cases, interpretation of the geological significance of such isotopic signatures may be compromised, mass-dependent isotopic fractionation of sulfur isotopes (MDF-S, recorded as $\delta^{34}S$) can yield small $\Delta^{33}S$ values ($\pm0.2‰$), often owing to biological reactions involving sulfur.

In this project, we have reassessed the quantification of $\Delta^{33}S$ due to MDF-S from the traditionally accepted 0±0.2‰ value (*Farquhar and Wing, Earth Planet Sci Letters, 2003*), and demonstrated that its magnitude is not constant but rather is directly linked to the degree of $\delta^{34}S$ fractionation. The analysis of these results and of a data compilation from ~2.65 Ga orogenic gold deposits of the Yilgarn Craton indicates that $\Delta^{33}S$ values are too large to be the result of purely MDF-S processes; at least some of the sulfur must be derived from Archean sedimentary rocks. A compilation of >3400 $\Delta^{33}S$ measurements of Archean sedimentary rocks shows highly variable positive and negative signals, whereas the gold deposits have remarkably constant $\Delta^{33}S$ values between 0 and +0.6‰. This strongly suggests that the auriferous fluids equilibrated at depth by mixing sulfur from Archean sedimentary rocks with sulfur from a reservoir with no MIF-S signature. These outcomes significantly enhance the power of MIF-S ($\Delta^{33}S$) as a tracer of sulfur pathways through the lithosphere.

Orogenic hydrothermal gold systems often show a large spread in $\delta^{34}S$ because sulfur isotopes are sensitive to changes in pH, P, T, fO_2, fS_2. We are focusing on harnessing this variation in a spatially and temporally constrained hydrothermal architecture to understand the precipitation mechanisms of metals carried in fluids. By monitoring the isotopic evolution of a hydrothermal fluid in space and time, we can better understand the changes in thermochemistry that lead to metal precipitation from a fluid, and apply this as a vector toward mineralisation. For example, at the 6 Moz Waroonga orogenic gold deposit of the Yilgarn Craton, both $\Delta^{33}S$ and $\delta^{34}S$ have been used to document that the source of sulfur in the system remained constant. The sulfide chemistry suggests that Au precipitation was driven by an abrupt change in the redox state of the ore fluid (captured in the $\delta^{34}S$ values of the mineralisation sequence).

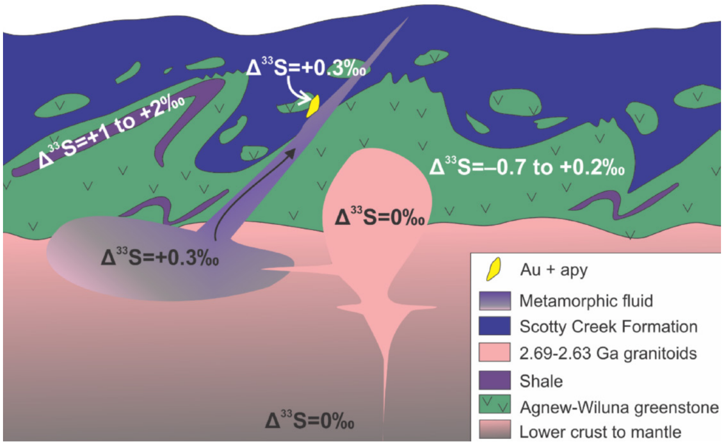

Figure 1. Schematic model demonstrating hypothesised sulfur reservoirs for Archean orogenic gold deposits in the Yilgarn Craton.

This project is part of CCFS theme 2, Earth's Evolution, and contributes to Understanding Earth's Architecture and Fluid Fluxes.

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Funded by: MRIWA

Southwestern Africa on the burner

Cenozoic volcanism is widespread in Africa; prominent examples are the Eastern African Rift System (EARS), the Cameroon Line, Darfur, Hoggar, Tibesti and the Moroccan Atlas (Fig. 1). The magmas commonly are derived from the mantle and range from carbonatitic and mafic alkaline to differentiated silica-rich magmas. A profound lithospheric control on intraplate volcanism is indicated by 1) association of volcanism with terrane boundaries and/or thin lithosphere; 2) cyclicity of magmatic activity in the same regions over >100 Myr; 3) synchronicity across the African plate; and 4) absence of clear age progression patterns. Conversely, a major role for mantle convection is supported by the coincidence of Cenozoic volcanism with regions of lithospheric uplift, positive free-air gravity anomalies and slow seismic velocities. With evidence for tectonic, lithospheric and convective controls, the ultimate trigger(s) of mantle-derived Cenozoic intraplate volcanism in Africa remains unresolved.

To improve constraints on the genesis of African volcanism, we and our colleagues at the University of Melbourne, Tasmania, Barcelona (Spain) and Luanda (Angola) have documented the age and isotopic composition of the Catanda Volcanic Complex (Figs 1 and 2), which hosts the only extrusive carbonatites in Angola. Apatite (U-Th-Sm)/He and phlogopite $^{40}Ar/^{39}Ar$ ages of Catanda lavas indicate eruption at ~500–800 ka (Fig. 3), >100 Ma after emplacement of abundant kimberlites and carbonatites in this region. The young age of the Catanda lavas is consistent

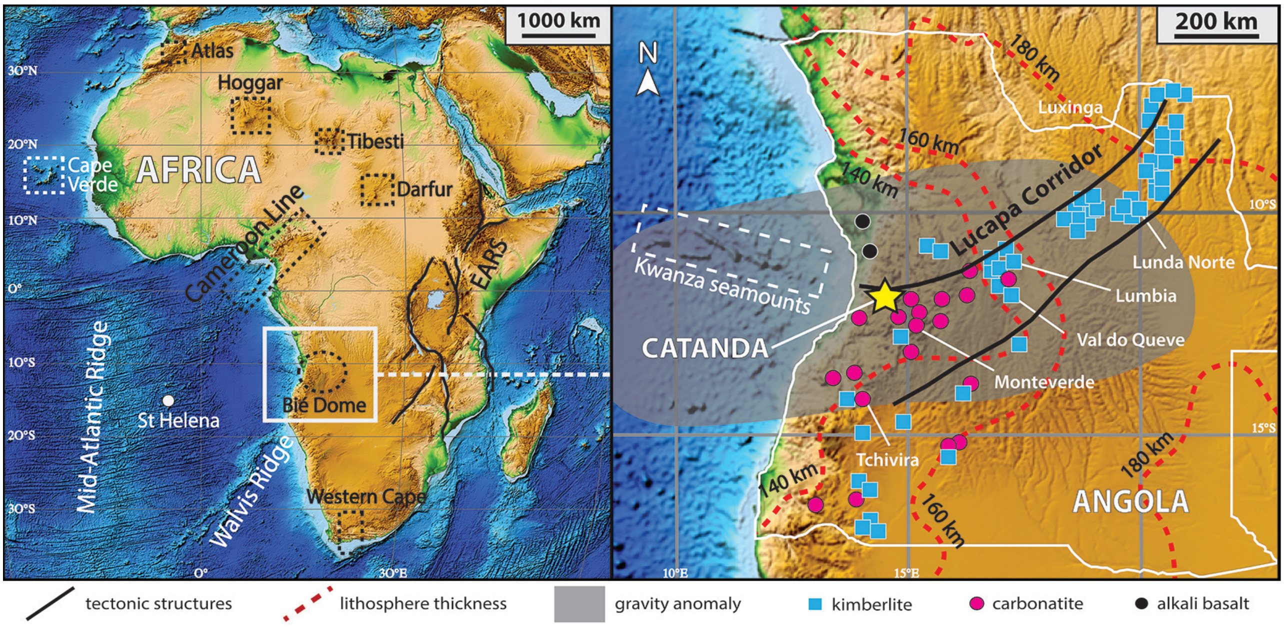

Figure 1. Elevation map of the African plate with inset showing location of the Catanda Complex and major Triassic and Cretaceous kimberlite, carbonatite and alkali basalt occurrences. Grey shaded area indicates free-air, crust-corrected gravity anomaly. Dashed red lines are estimates of the lithospheric thickness.

Figure 2. View of the Catanda Volcanic Complex (Angola).

with other evidence for recent volcanic and geothermal activity in the area, including well-preserved volcanic landforms (Fig. 2) and ongoing hydrothermal activity. These observations imply a recent resumption of volcanic activity in western Angola, some 90 Ma after emplacement of mafic alkaline dykes in the area. The lavas share HIMU-like Sr-Nd-Pb-Hf isotope compositions with other young mantle-derived volcanics from Africa (e.g., Northern Kenya Rift; Cameroon Line).

The position of the Catanda complex in the Lucapa corridor (Fig. 1), a long-lived extensional structure, coupled with recent seismic activity in the Catanda area suggests a possible tectonic trigger for the volcanism. The complex is also located on the Bié Dome (Fig. 1), a broad region (~1000 km in diameter; ~2500 m of elevation) of rapid Pleistocene uplift attributed to mantle upwelling. Seismic-tomography models indicate convection of deep hot material beneath regions of active volcanism in Africa, including Angola and northern Namibia. The rapid Pleistocene uplift, the occurrence of positive free-air gravity anomalies (Fig. 1), seismic tomography and mantle convection models all support active mantle upwelling beneath the area and make a purely tectonic trigger for mantle-derived magmatism unlikely. We suggest that rapid uplift of the Bié Dome and attendant Catanda carbonatitic volcanism in the Pleistocene might be related to a finger-like low-velocity structure, a branch of the South African Superplume that is rising beneath southwestern Africa. Thinned lithosphere beneath the Lucapa corridor and especially its western sector (Fig. 1) would provide a preferential pathway for focusing mantle upwelling.

While the Catanda complex and other expressions of late Cenozoic intraplate volcanism in Africa (e.g., EARS, Cameroon Line, Darfur, Hoggar, Tibesti, Moroccan Atlas) correlate with pre-existing lithospheric discontinuities, they also show evidence of being affected by active mantle upwelling. Therefore, intraplate carbonatitic and alkaline magmatism probably results from the complex interplay between multi-scale mantle convection and pre-existing lithospheric structures.

This project is part of CCFS theme 2, Earth's Evolution, and contributes to understanding Earth's Architecture and Fluid Fluxes.

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Funded by: ARC DECRA

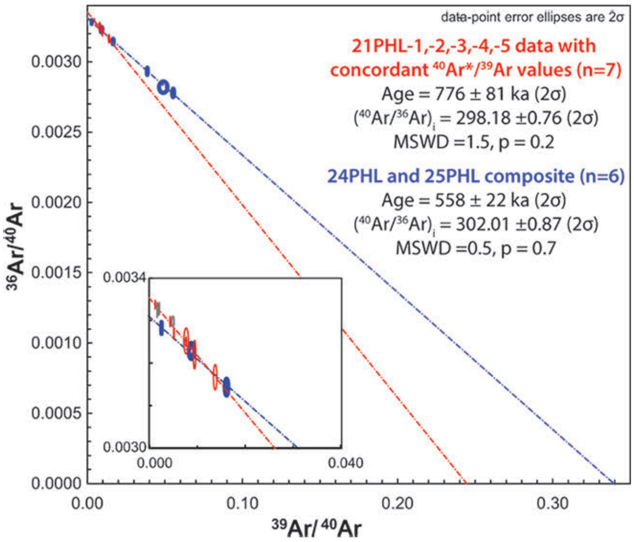


Figure 3. $^{40}Ar/^{39}Ar$ phlogopite inverse isochrons providing ages for the Catanda lavas.

A trapped fossil oceanic slab in NW China

The fate of subducted oceanic slabs can provide important clues to plate reconstruction through Earth history. However, an ancient oceanic slab, stalled in the lithosphere at the end of subduction, is unlikely to be well-preserved for long, due to the subsequent tecto-thermal events (magmatism in particular). The western Junggar region, situated in NW China (Fig. 1), is an ideal place to study the evolutionary history of the Central Asian Orogenic Belt (CAOB). This region is characterised by Paleozoic ophiolites, volcanic rocks and many valuable Cu-Au ore deposits, along with three large-scale NE-striking faults, the Hatu, Karamay-Urho and Darbut faults (Fig. 1). Particularly along the more than 200-km-long Darbut Fault and the hidden Karamay-Urho Fault, lenses of ophiolitic mélanges crop out. Extensive Late Paleozoic magmatism and deformation occurred in this region and across the entire CAOB. The tectonic origin of the western Junggar is believed to be related to either intracontinental or intra-oceanic arc-related subduction systems which developed in the early Paleozoic and ended in the late Paleozoic. However, the mode of subduction is still contentious. Based on geological and geochemical studies, several competing models of the subduction have been proposed, including northwestward subduction, a double-sided subduction and subduction of an oceanic ridge. These different models would predict different crustal structure. Thus, imaging the crustal structure at high resolution may help to discriminate among the competing models.

We have generated a shear wave velocity model of the crust in western Junggar based on data from an array of 31 portable broadband seismic stations. According to our model, large Vs contrasts are observed in the shallow crust between the Junggar basin and the Zaire mountain, with the boundary following the hidden Karamay-Urho Fault (K-U fault). Low-Vs anomalies dominate the upper crust beneath the Junggar basin with the velocity varying from ~1.5 km/s in the surface to ~3.0 km/s around 10 km depth. To the northwest of the K-U Fault, relatively high S-wave velocities (>3.5 km/s) are seen in the upper crust beneath the Hongshan and Karamay intrusions. At depths of ~20 km, the patterns of shear velocities anomalies are very different from those in the upper crust. Very high S-wave velocities (3.7-4.1 km/s) occupy most of the area beneath the Junggar basin (Fig. 1c).

In our velocity model the body with high shear-wave velocity is nearly flat beneath the western Junggar basin and dips gently northwestward. This geometry probably reveals a SE-to-NW fossil subduction beneath the western Junggar, consistent with high velocity body as a remnant oceanic plate is also supported by our CCP imaging as shown in Fig. 2, where a clear Moho offset is visible slightly to the right beneath the Karamay-Urho fault. This Moho offset is likely to associated with the paleo-subduction interface, and the K-U fault can be interpreted as one of the major thrust faults separating the arc from the accretionary prism in the southeast. The zone without high velocities, between the western Junggar basin and the Zaire mountains, can be interpreted as the forearc accretion wedge,

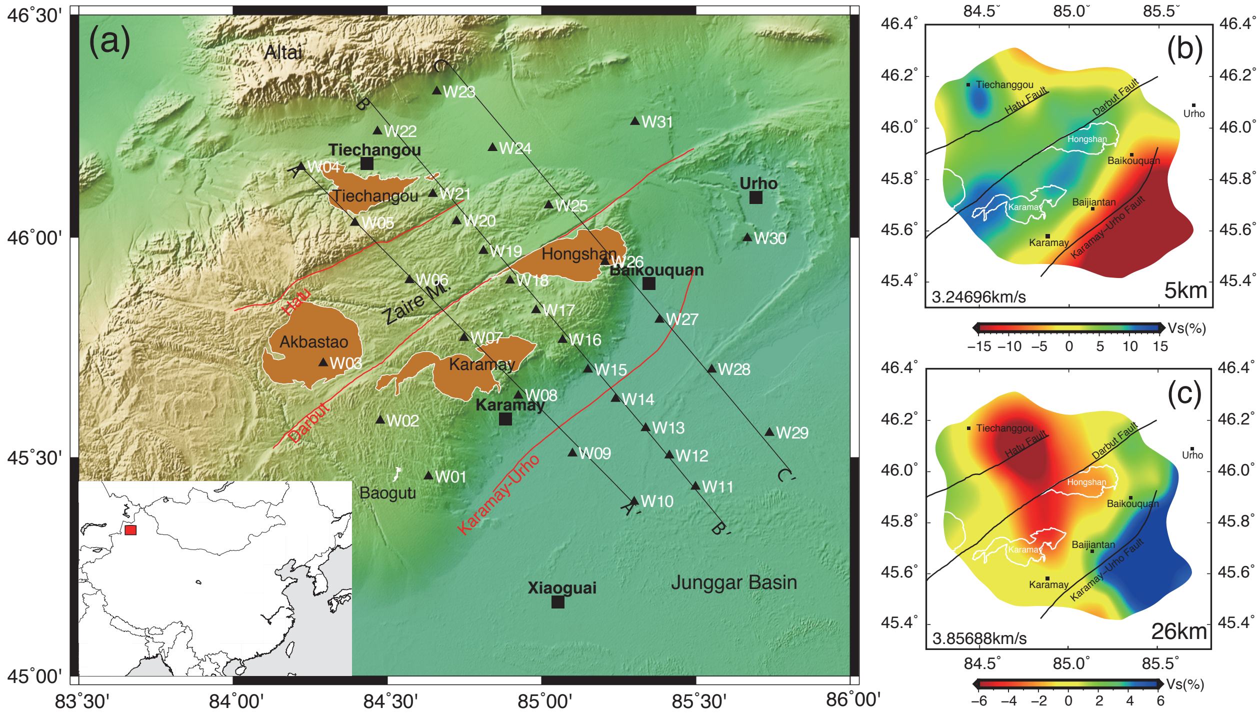
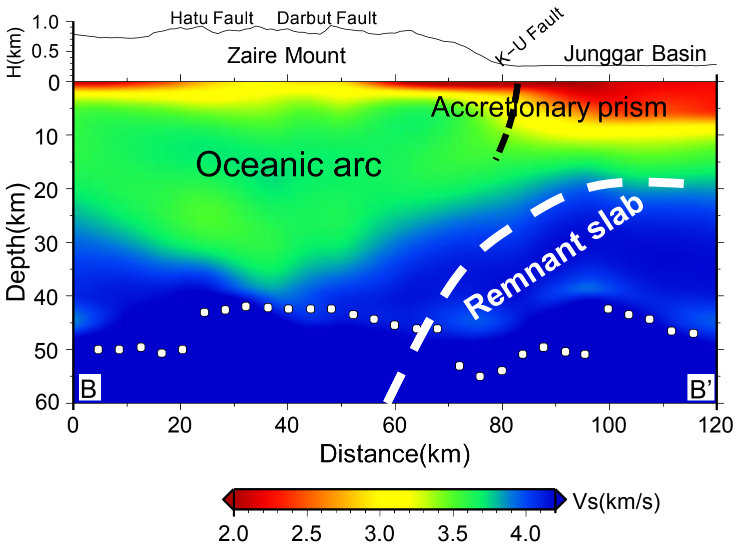


Figure 1. (a) Tectonic setting of the western Junggar region. The red lines indicate three major faults, black triangles indicate the locations of seismic stations, and the orange areas represent major intrusions. (b) and (c) S-wave velocity anomaly maps at 5 and 26 km depth from surface wave tomography with reference velocity of 3.247 km/s and 3.857km/s, respectively.

the interpretation of MT results (Xu et al., 2016). It appears that a fossil subducting oceanic slab and an intra-oceanic arc system are well preserved in the Darbut belt. The interpretation of the corresponding to the depression of the Moho interface. The distribution pattern of S-wave velocities strongly supports the model of a subduction zone which failed to be underthrust during the late Paleozoic and has been preserved ever since.



This project is part of CCFS theme 3, Earth Today, and contributes to understanding Earth's Architecture.

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Funded by: NSFC 41530319 and 41374079, CCFS Flagship Program 3

Figure 2. Vertical cross-section of S-wave velocities and our interpretation of a well-preserved fossil oceanic slab along BB' shown in Figure 1a.

Distinctive aberrant geochemical fingerprints for Ancient SCLM in collision zones

Pyroxenites are more abundant in the lower crust of volcanic arcs and in sub-arc mantle than in most other mantle tectonic environments. The petrological processes responsible for their formation and evolution may play a key role in the development of chemical and isotopic heterogeneities in the mantle.

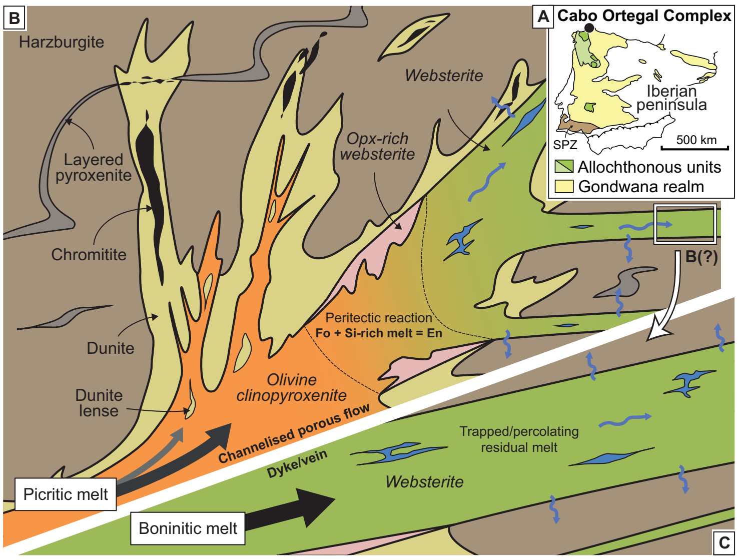

Figure 1. Location of the Cabo Ortegal Complex in the Variscan belt of the Iberian Peninsula (A) and conceptual petrogenetic model for Cabo Ortegal pyroxenites, dunites and chromitites, assuming an initially picritic (B) and boninitic melt (C).

However, their contribution has remained poorly constrained due to their complex petrogenesis and the uncertainty about the extent of their recycling. In the Cabo Ortegal Complex, Spain (Fig. 1A), abundant pyroxenites, associated with dunites and harzburgites, have formed by fractional crystallisation and melt/peridotite interaction after picritic and/or boninitic melts (Fig. 1B, C), probably in a sub-arc mantle.

Based on the availability of a robust tectonothermal, petrologic and geochemical background, we have applied Lu-Hf and Re-Os isotopic systematics to clinopyroxene, amphibole, and whole-rock samples from Cabo Ortegal pyroxenites and associated peridotites and chromitites. Our data show that the pyroxenites are characterised by uncorrelated $^{176}Lu/^{177}Hf$ and $^{176}Hf/^{177}Hf$ (0.2822-0.2855) and a wide range of $^{187}Re/^{188}Os$ and $^{187}Os/^{188}Os$ (0.16-1.44).

While Sm-Nd geochronology indicates that the pyroxenites probably formed during Cadomian arc magmatism (421-762 Ma), strikingly decoupled Nd- and Hf-isotope compositions (Fig. 2) along with EM I-like Sr and Nd signatures ($^{87}Sr/^{86}Sr_{(t)}$ = 0.7037-0.7045 and $\varepsilon_{Nd(t)}$ = 0.3-7.5) suggest a contribution from the sub-continental lithospheric mantle (SCLM), probably during the development of the arc on a continental margin. This is in good agreement with old Hf and Os (T_{MA}) model ages, and Re-Os (0.6-1.0 Ga) and Lu-Hf (1.1 Ga) isochron ages. In addition, cpx and amphibole exhibit a slight disequilibrium in terms of Hf isotopes, indicating a partial resetting of the system during amphibolitisation and the multi-stage nature of this process. Some amphibole growth is ascribed to the exposure of sub-arc mantle to a Devonian subduction zone, probably leading to sub-solidus reactions under granulite- to amphibolite-facies conditions, and to the remobilisation of Re, as evidenced by correlations between amphibole content, LREE enrichment and $^{187}Re/^{188}Os$.

Despite these isotopic perturbations, we show that different sections of a progressively LREE-enriched sample *preserve apparent Sm-Nd, Lu-Hf and Re-Os isochrons* that predate metamorphic amphibolitisation. This may reflect a relatively short distance of isotopic equilibrium arising from differential elemental and isotopic diffusivities during melt transport. We suggest that this transient phenomenon may be characteristic of (pyroxenite-forming) melt-peridotite interactions during the reworking of old continental lithosphere by arc magmatism. The recycling of arc pyroxenites may thus potentially account for the ubiquitous observation of decoupled Hf and Nd isotopes in the lithospheric mantle, consistent with the extensive preservation of Archean SCLM.

This project is part of CCFS themes 2 and 3, Earth's Evolution and Earth Today, and contributes to understanding Earth's Architecture and Fluid Fluxes.

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Funded by: CCFS Flagship Program 1

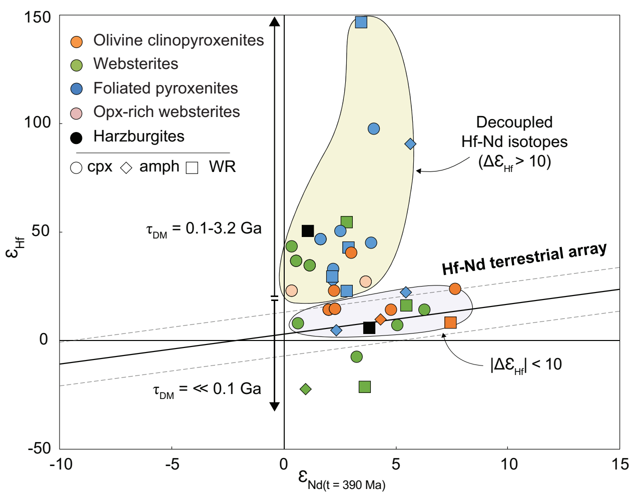

Figure 2. Decoupled Hf-Nd isotopes measured in Cabo Ortegal pyroxenites. $\Delta\varepsilon_{Hf}$ corresponds to the vertical distance to the terrestrial array in ε notation; corresponding Hf model ages (T_{DM}) are also shown.

Crustal evolution of the Albany-Fraser Orogen

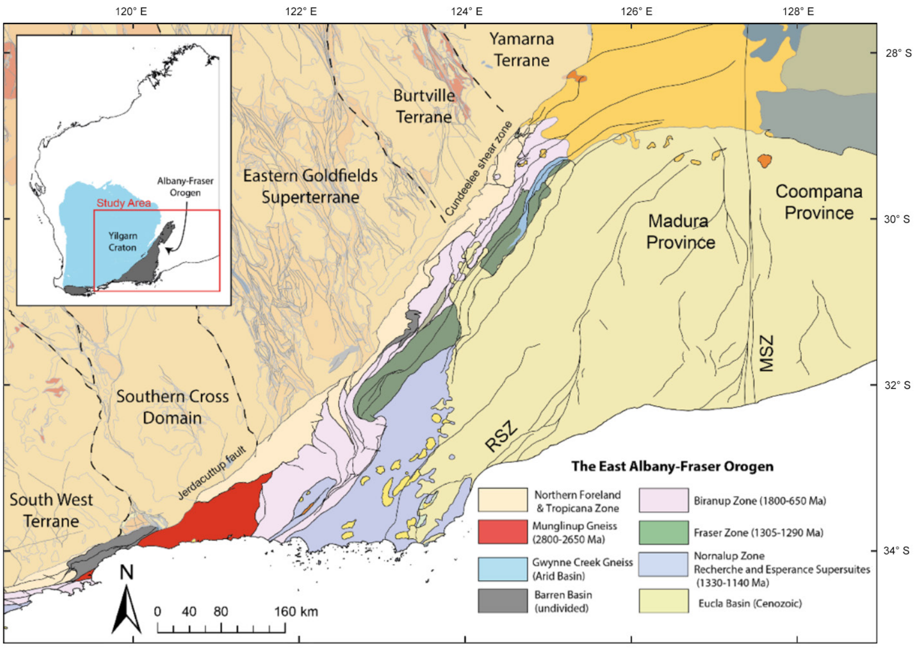

Figure 1. Geological Map of the Albany-Fraser Orogen showing the location of the study area.

The Albany-Fraser Orogen is a NE-SW trending Paleoproterozoic to Mesoproterozoic orogenic belt that lies wraps around the southern margin of the Yilgarn Craton (Fig. 1). Previous interpretations of the tectonic setting of the Albany-Fraser Orogen invoked the accretion of exotic or suspect terranes, but recent U-Pb geochronology, whole-rock geochemistry, Hf -and Nd-isotopic datasets have radically refined our understanding of the orogen. Recent work suggests that the Albany-Fraser Orogen contains no exotic components but formed through the episodic addition of juvenile magmas into the existing Archean crust of the Yilgarn Craton, in a series of events that overprinted but did not obliterate the original Archean signature.

Heterogeneity in the composition of granitic magmas is influenced by both large-scale lithospheric architecture and magma-generation processes (both related to geodynamic setting) as well as the composition of the crustal substrate. To test the influence of these processes on magma compositions we use zircon hafnium-isotopic compositions and whole-rock geochemistry from granitic rocks associated with a period of Paleoproterozoic magmatism called the Biranup Orogeny (1730-1650 Ma). A map of the median εHf of zircons from the Paleoproterozoic magmas of the Albany-Fraser Orogen shows a similar pattern to the variation in the large-scale structure of the Yilgarn Craton (Fig. 2). Sr/Y ratios of these granitic magmas are uniformly low along the length of the orogen, implying that crustal thickness was uniformly thin (ca 15 km) along the margin of the Yilgarn craton during this period in geological time (Fig. 3).

Thus, we conclude that the heterogeneity in the composition of zircons from the granitic rocks of the Biranup Orogeny largely reflects the regional-scale heterogeneity of the Archean basement terranes that were reworked to produce the Paleoproterozoic magmas, and not by large-scale variations in

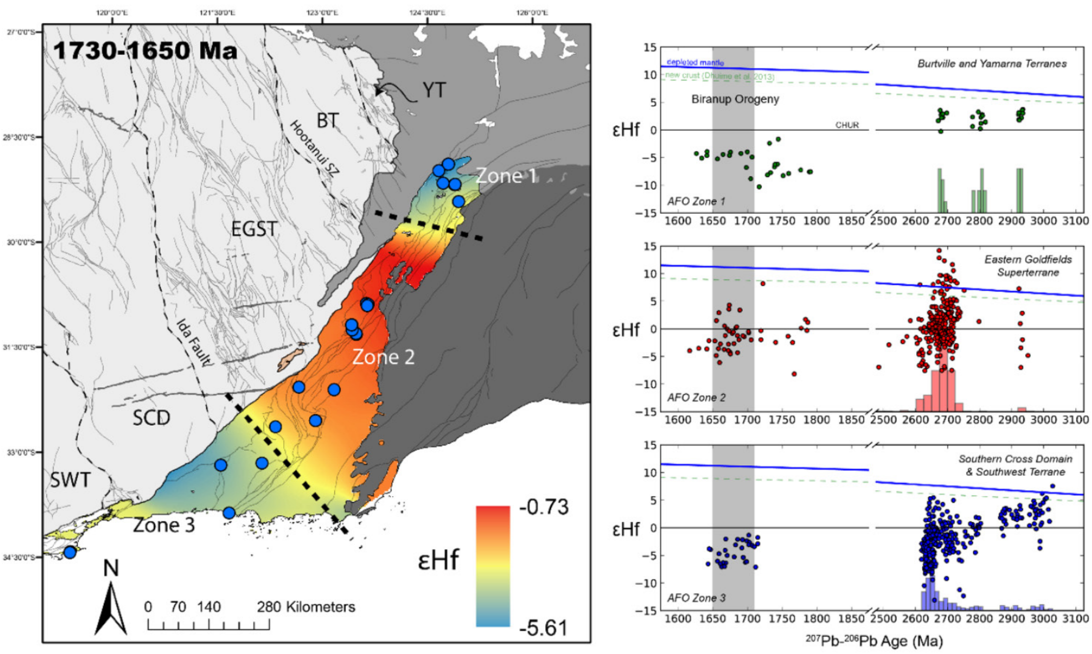

Figure 2. Map of zircon εHf of Paleoproterozoic (1700-1650 Ma) granitic magmatism along the Albany-Fraser Orogen. Heterogeneity in zircon hafnium-isotope compositions reflects the large-scale heterogeneity and architecture of the adjacent Yilgarn Craton.

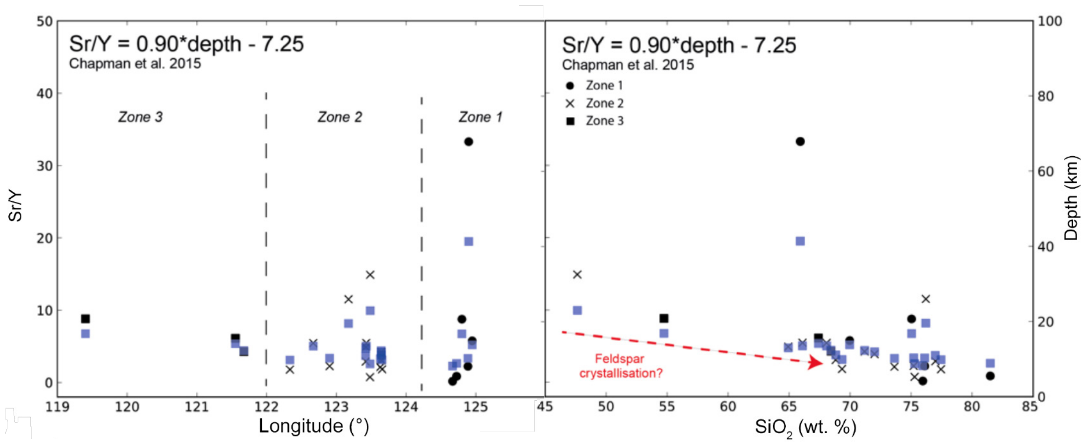

Figure 3. Plots of Sr/Y for the Paleoproterozoic magmas show uniformly low values along the length of the Albany-Fraser Orogen. This implies that crustal thickness was uniformly thin along the margin of the Yilgarn Craton during this period in time.

lithospheric architecture or crustal thickness. These data provide a means of visualising and tracking the influence of different basement terranes through space and time.

This project is part of CCFS theme 1, Earth's Evolution, and contributes to understanding Earth's Architecture.

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Funded by: CCFS Flagship Program 7

El Dorado in El Indio Belt, Chile-Argentina

This project aimed to understand the structure of one of the most highly Au-endowed provinces of the Andes Cordillera: the Miocene El Indio Belt (EIB).

This 150 km x 100 km metallogenic camp located in the Chilean-Argentinean Andes Cordillera hosts >45 Moz Au, mostly in world-class Au-Ag epithermal deposits (Pascua-Lama, Veladero, El Indio-Tambo District and the most recent discovery, Alturas). It provides a natural laboratory to study the trans-lithospheric architecture that provided the magma/fluids/gold pathway and the architecture's geodynamic evolution related to metallogenic events.

The project is divided into several components, including surface structural mapping, geophysical (mainly magnetometry and gravity) reinterpretation, and geochemical analysis. Targeted geochronology and partial isotopic mapping (O-isotopes) using zircons help define the crustal architecture into which the Au deposits have been emplaced.

Both the Permian-Triassic granitic basement and Cenozoic intrusives or *in situ* domes (related to Au-Ag mineralisation) in Chile and Argentina were sampled for zircon analyses. U-Pb SHRIMP-II geochronology, O-isotopes and Lu-Hf LA-ICP-MS analyses are being performed.

Preliminary results on the O-isotopes show a marked difference between zircons from Permian-Triassic basement rocks and zircons in Cenozoic magmas of the El Indio Belt. Basement zircons have high $\delta^{18}O$ (a crustal signature), and the oldest

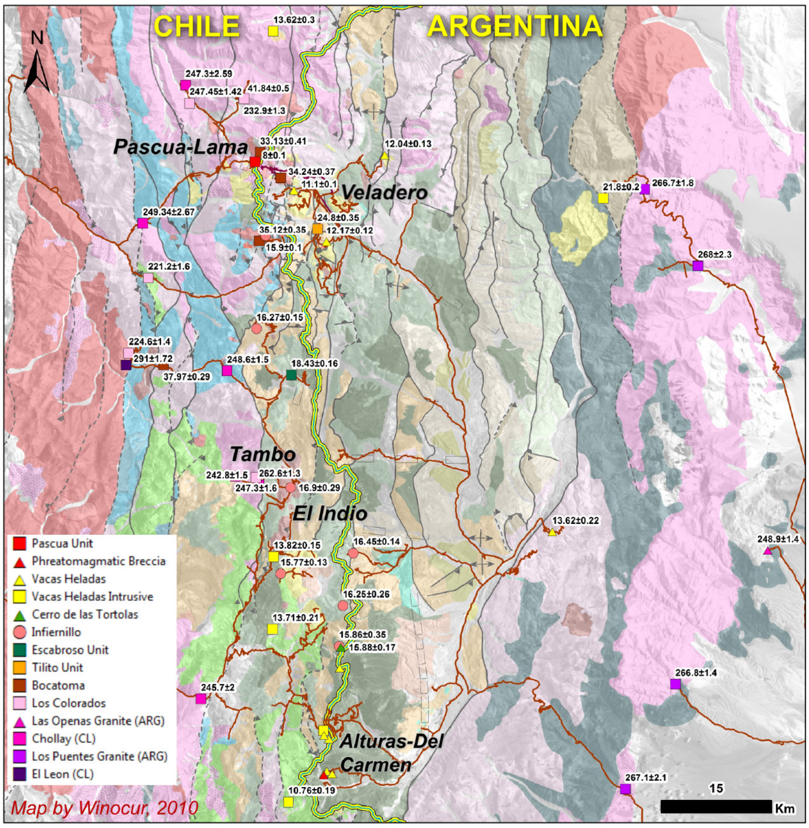

Figure 1. U-Pb zircon age of samples considered for zircon O-isotopes and Lu-Hf analyses on this project.

Fieldwork in the Argentinean Andes, El Indio Belt project (Constanza Jara).

inherited cores of all samples show the highest crustal component. Zircons from early Cenozoic magmas all show a strong crustal component, but the zircon O-isotope signature becomes more mantle-like during the Oligocene to Miocene, with almost no crustal component in the later magmas.

Significant variations in age and O-isotopic signatures are observed between the E and W domains of EIB. Late magmas in the Argentinian area of the EIB show higher $\delta^{18}O$, probably indicating a greater degree of crustal involvement in the east, where the crust may be thicker and older. The preliminary data suggest a large N-S structure separates the two domains, and appears to survive the subsequent Cenozoic events.

The goals of this project are to stimulate new approaches to identifying new Au-rich provinces at early stages, by recognising key trans-lithosphere structures.

This project is part of CCFS theme 2, Earth's Evolution, and contributes to understanding Earth's Architecture.

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Funded by: Barrick Exploration

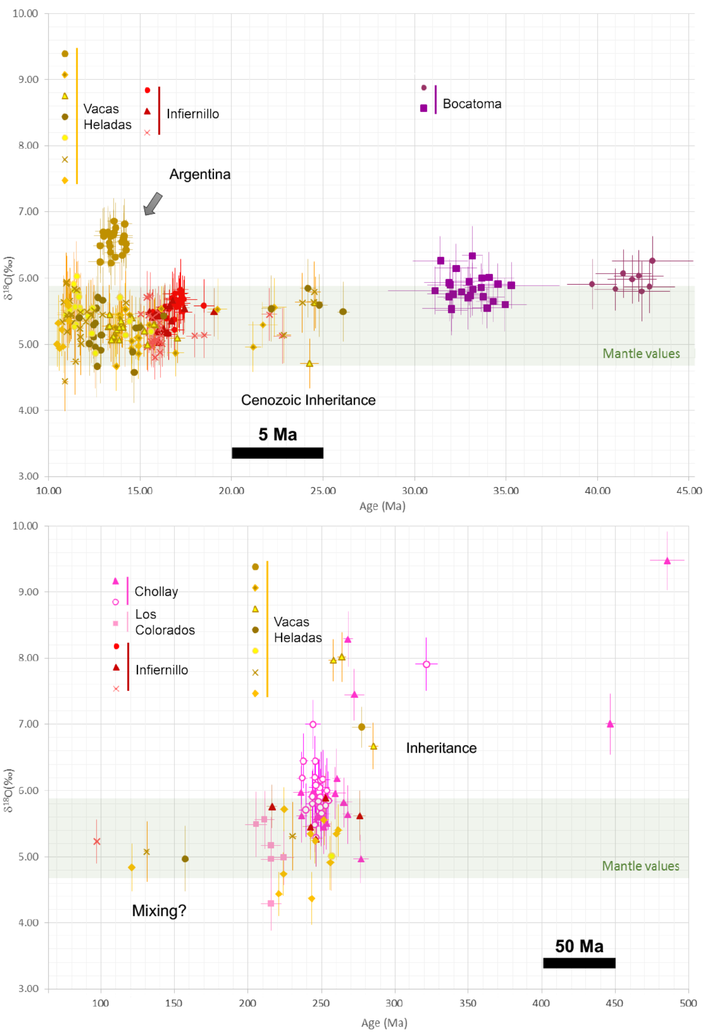

Figure 2. $\delta^{18}O$ vs U-Pb zircon age plot for each sample analysed spots. 10 to 500 Ma timespan, note change of timescale at 50 Ma. Error bar in 2σ.

Pyroxenite layering in the upper mantle and how to find it

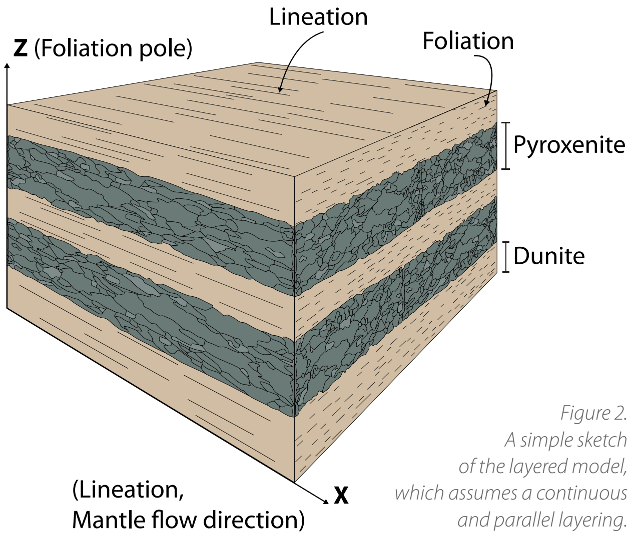

Figure 2. A simple sketch of the layered model, which assumes a continuous and parallel layering.

Seismic waves reveal information on the interior of the Earth because their travel times reflect a complex combination of temperature, mineralogy, composition and the presence of melt or fluid along their trajectory. Because of the way minerals deform when subjected to stress, an alignment of the minerals develops during deformation and new bulk elastic properties arise. This process will give rise to a fast and a slow velocity direction for elastic waves travelling through the deformed rock (i.e., an anisotropy). Based on seismic data, seismologists can compute the anisotropy of the different seismic waves in the upper mantle domains. Their interpretation has been traditionally focused on the most volumetrically significant mineral (i.e., olivine) despite the fact that pyroxenites make up significant proportions in specific mantle domains. However, correctly understanding seismic data requires the determination of the seismic properties of a pyroxenite-rich domain to account for their effect on the resulting seismic signal. Following up on our previous research, we used the Herbeira massif, Cabo Ortegal, Spain as an example of a pyroxenite-rich domain from Earth's upper mantle. As the structure of Herbeira is not homogeneous, a new modelling protocol that incorporates the effects of this specific layered geometry was developed.

Figure 1. Typical outcrop of layered pyroxenite in the Herbeira massif. The dark green layers (pyroxenites) alternate with brownish layers (dunites).

This new calculation approach, combined with the data from Herbeira, allowed us to model a realistic supra-subduction upper mantle domain infiltrated by subduction-related melts.

The modelled seismic properties of a pyroxenite-rich domain similar to the Herbeira massif are comparable to that of common supra-subduction material (e.g., harzburgite xenoliths from the Kamchatka volcanoes) but will induce specific signal deviations in the anisotropic spectrum.

Along the volcanic front of subduction zones, down in the mantle wedge, a switch of the P-wave Fast-Velocity Direction (FVD) from trench-normal to trench-parallel is documented in seismic databases. Our model shows that the presence of layered pyroxenite complexes in this specific region is consistent with this large-scale observation. Although the model may not account for the whole switch, its observed sharpness could reflect the presence of pyroxenite. Large volcanic fronts can extend laterally for 200 km or more along the arc collision zone. Mantle pyroxenitic layering similar to that of Herbeira along this front, would delay P-waves travelling perpendicular to the arc strike by more than 0.4 sec, which is measurable.

We also have characterised the specific deviations that a layered pyroxenite-rich domain would have on the different shear waves and have recognised a seismic fingerprint for these kinds of domain, which potentially can be used to identify the presence of pyroxenites in subduction zones. This could be a starting point to bridge the gap between geophysical observations and isotope geochemistry in understanding the contribution of pyroxene-rich lithologies to the genesis of mantle-derived magmas in many tectonic environments, as well as potentially using seismic-velocity signatures to track paleo-subduction domains that have been infiltrated by fluids, thus forming pyroxenites.

This project is part of CCFS themes 2 and 3 and Earth's Evolution and Earth Today, and contributes to understanding Earth's Architecture and Fluid Fluxes.

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Funded by: CCFS Flagship Program 1, iMQRES, EPS postgraduate funds, cotutelle program - Paul Sabatier University, CNRS

The oldest rocks formed by microbes: Unexpected diversity

Microbialites are rocks produced by microbial life, and they commonly preserve fossils of some of Earth's earliest lifeforms – stromatolites. The microbialites of the 2.4 Ga Turee Creek Group, first reported in 2016, include the earliest known expression of clotted microbial growth in the rock record; clotted microbialites (or thrombolites) are preserved amongst stromatolites in a 300 m thick dolomite-carbonate reef. CCFS-funded research in 2017 has allowed for a more detailed examination, which has revealed that these clotted microbialites are far more diverse in both morphology and microtextures than previously realised.

Figure 1. Interconnected thrombolitic texture with the microbial framework (blue-grey colour, black arrows) surrounded by dolomite sand (tan colour, white arrows).

A total of three main types of clotted microbialite have been identified and described, two of which are new to the locality:

1. Clotted microbial aggregate: this texture is an aggregate of isolated fine-grained clumps of microbial carbonate, each enveloped by coarse carbonate cement, that appears to have buried stromatolites. These clumps contain preserved traces of kerogen, identified using Raman spectroscopy, which confirms their biological origin. The microbialite is not benthic but an aggregate that probably formed when clumps of microbial material settled out from the overlying water column and were rapidly cemented. This is the only clotted microbial texture that had previously been described from this locality.

2. Lobate thrombolites: these structures have the gross morphology of a stromatolite but lack internal layering. Preserved bedded sediment and marine precipitates fill the intercolumn space between individual thrombolites and indicate that primary textures have not been destroyed by diagenetic fluids; this indicates that the thrombolitic textures are also primary. These represent the earliest thrombolites with bioherm morphology, more than 400 Ma older than other examples.

3. Interconnected thrombolitic textures: these are comprised of an interconnected microbial framework of fine to medium carbonate with interstitial spaces filled by either carbonate sediment or marine cement. They are found in beds and mounds, and often have a gradational contact with stromatolitic units above and below. These thrombolites have morphologies that otherwise are only known from much younger (Neoproterozoic and Phanerozoic) rocks.

These discoveries add to the already diverse range of microbialites in the Turee Creek Group and supplement newfound diversity in deep-water microfossil communities and in problematic siliceous structures from shallow-water facies at the same locality. When considered alongside these other discoveries, the clotted microbialites of the Turee Creek Group represent just one facet of an apparent explosion in biotic complexity at 2.4 Ga, the driver of which is still under investigation.

This project is part of CCFS theme 1 Early Earth, and contributes to understanding Earth's Architecture and Fluid Fluxes.

Contacts: Brendan Nomchong, Martin Van Kranendonk
Funded by: CCFS Flagship Program 4

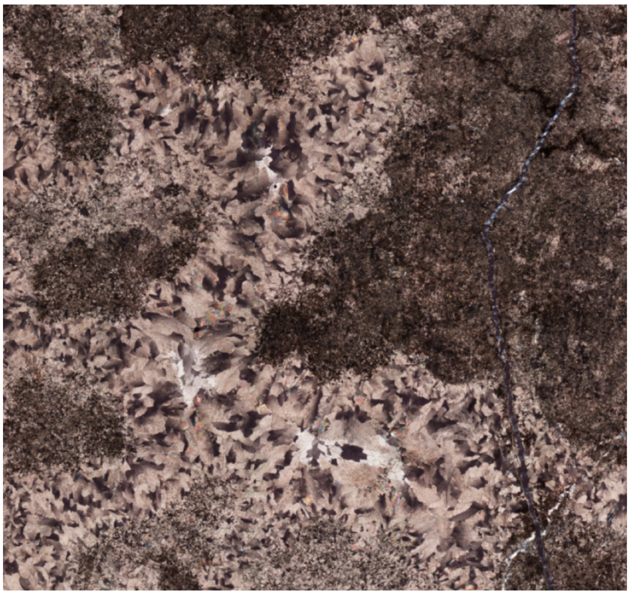


Figure 2. XPL image of interconnected thrombolitic texture. Microbial carbonate (dark, fine grained) is encased by a coarsely bladed marine cement. The microbial portion contains preserved kerogen. Image width: 1 cm.

Supercontinent Nuna formed in two stages

Figure 1. Sampling of the Hart Dolerite (low outcrop in the foreground) that intrudes the Paleoproterozoic Kimberley Group (cliff in the background) (Photo: Zheng-Xiang Li).

While there exists a general consensus regarding the configuration of the Earth's youngest supercontinent, Pangea, much uncertainty still surrounds that of arguably the oldest supercontinent, Nuna. Recent work suggests Nuna's final assembly was not completed until ca 1600 Ma, and that the preceding interval of ca. 2000-1700 Ma might represent a time when the building blocks of Nuna, including proto-Laurentia, proto-Australia and proto-Baltica, were assembled.

Current paleomagnetic constraints are still insufficient for establishing a detailed paleogeography for this assembly process. This is especially true for one of the key continent-continent connections in building Nuna, the speculated connection between western Laurentia and eastern proto-Australia. A 1976 preliminary study of the ca 1.8 Ga Hart Dolerite in the eastern Kimberley craton, north-western Australia, showed some promising results, although a subsequent study in 2008 in western Kimberly proved to be less successful. We undertook a meticulous sampling of the Hart Dolerite from the eastern Kimberley craton (Fig. 1), which yielded well defined paleomagnetic directions with dual polarities. A comparison of our resulting paleopole with other Australian poles for the period of 1800-1600 Ma indicates that proto-Australia, as a whole, underwent only very minor amounts of plate motion during that time. Our new results, along with existing data, also support the previously interpreted 40° intracontinental rotation between the North Australia and South Australia cratons during the Neoproterozoic (see *2011 CCFS Research highlights*).

A comparison of the Australian poles with that of Laurentia for the time between 1800 Ma and ~1400 Ma yielded more important findings: there are two distinct segments in the apparent polar wander paths (APWPs) of both continents for that time interval, suggesting similar movements of the two continents during these two time intervals. Comparable APWPs between 1800 Ma and 1730 Ma imply that the two continents were already close to each other then and shared similar plate motions (Fig. 2a). This was followed by a ca. 1000 km relative plate motion between them before ca. 1650 Ma, leading to the final assembly of Nuna by ca. 1600 Ma. The two continents as a core part of Nuna again shared common APWP after 1650 Ma that lasted at least until ~1400 Ma (Fig. 2b). We therefore suggest that there was a two stage assembly between Australia and Laurentia as part of the assembly of the supercontinent Nuna.

This project is part of CCFS theme 2, Earth's Evolution, and contributes to understanding Earth's Architecture.

Contacts: Uwe Kirscher, Zheng-Xiang Li
Funded by: CCFS Flagship Program 5, ARC Laureate Fellowship to ZXL, ARC LIEF grant to establish the new palaeomagnetism laboratory at Curtin University

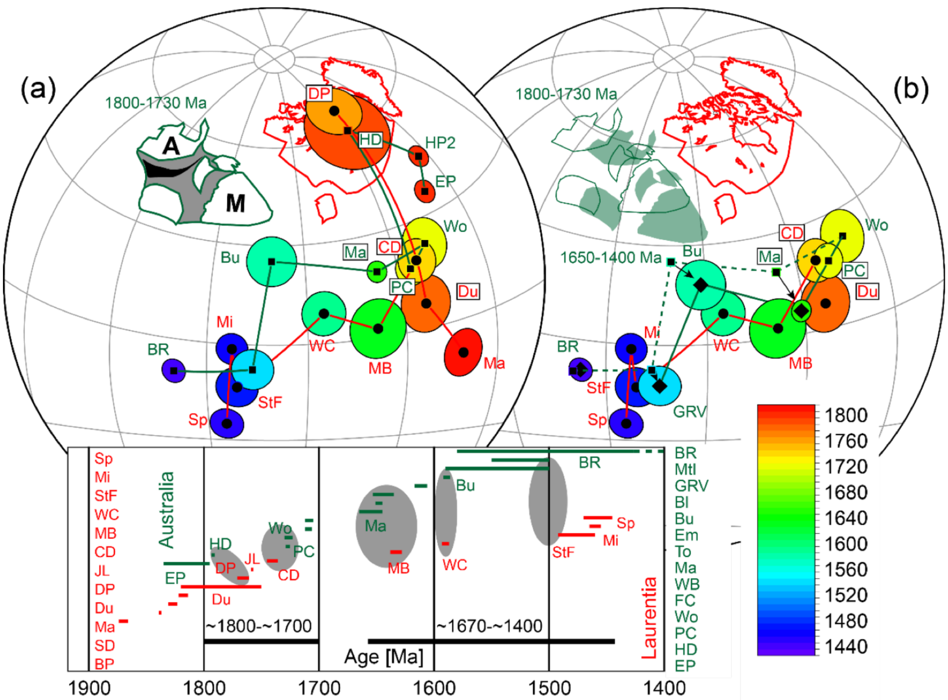


Figure 2. (a) Apparent polar wander paths of Australia (poles shown as squares and diamonds) and Laurentia (poles shown as black dots), colour coded with ages between 1900 and 1400 Ma after rotating proto-Australia to Laurentia to match their 1800-1730 apparent polar wander paths, or APWPs). (b) Proto-Australia rotated further to Laurentia, moving from the pre-1730 Ma position (green cratonic outlines) to its Nuna position after 1650 Ma (green shaded cratons), to match their APWPs for the1650-1400 Ma time interval, signalling the final assembly of the supercontinent Nuna soon after 1650 Ma.

Riding high on new wave model for southern California

Southern California, on the Pacific-North America plate boundary, is a tectonically active region where geological terranes are merged by major tectonic events during the evolution of the plate boundary. A 200-300 km wide zone of transpressive deformation (*Hauksson, 2000*) results from this interaction. These tectonic events have produced the complex 3D crustal structure of southern California, including terranes such as the Peninsular Ranges, Salton Trough, Transverse Ranges and southern Sierra Nevada Range (Fig. 1). Tape et al. (*2009, 2010*) generated a new 3-D crustal model M16 by applying adjoint tomography to a dataset of waveforms recorded at 203 stations from 143 local earthquakes. Their inversion used frequency-dependent travel-time measurements of three-component body waves and surface waves filtered at periods in the band 2-30 s. In this study, we apply *adjoint tomography* to 5-50 s Rayleigh waves extracted from ambient noise to further improve the M16 model, especially in the lower crust. A spectral-element method was used to simulate wave propagation in M16 and successively updated the models.

The final model shows features generally in agreement with the initial model, especially at the shallowest depths (≤ 5 km). However, the new Vs model also reveals several new features in the mid-to-lower crust, including: (1) the mean speed of the lower crust is slowed down by about 6%; (2) high Vs anomalies (up to +4%) are observed throughout the crust in the Los Angeles Basin (LAB) and Central Transverse Ranges (CTR); (3) high Vs anomalies are observed in the lower crust beneath the westernmost Peninsular Range Batholith and Sierra Nevada Batholith; (4) an enhanced shallow high-velocity zone in the mid-crust is observed beneath Salton Trough Basin (STB). Our model also shows a refined lateral velocity gradient across PRB-SNB-SAF which provides constraints on the west-east compositional boundary of PRB-SNB, as well as the dip angle and the depth extent of SAF. As ambient noise cross-correlations are available between all station pairs, the new tomographic model we have obtained shows a better resolution than the initial one in areas not well-covered by event-station paths. Owing to the long-period features of ambient noise, the lower crust is much better illuminated through gradual fitting of long-period signals. The total misfit reduction, model validation from earthquake data, and a series of point-source resolution tests all confirm the robustness of our new tomographic model.

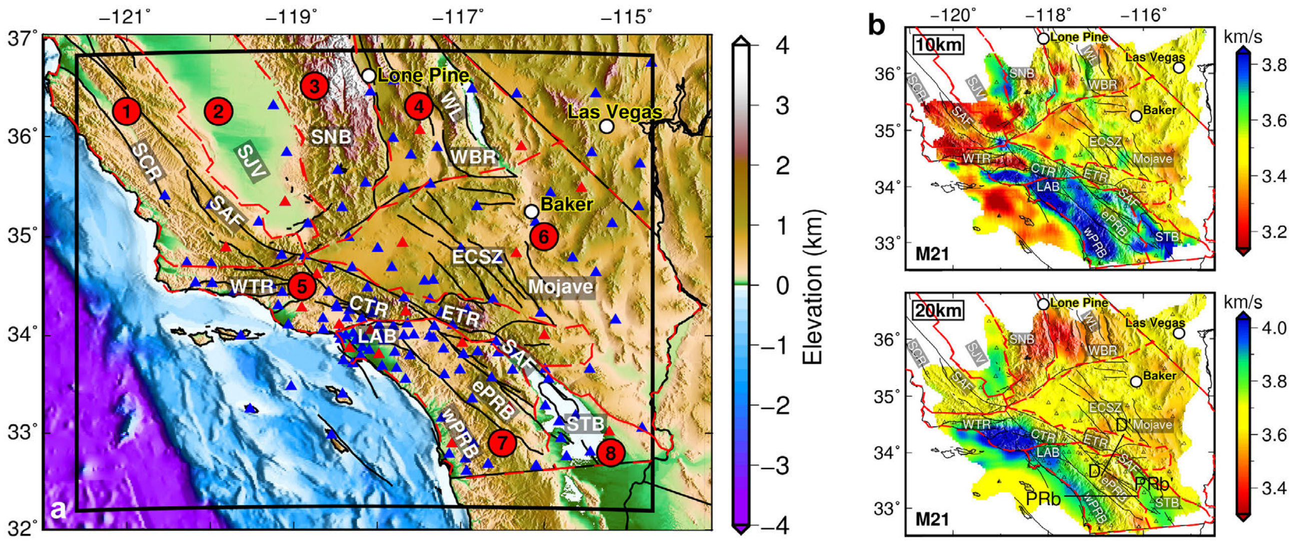


Figure 1. (a) Map of southern California with topography, bathymetry and active faults. The solid black outline defines the simulation region. The 148 stations used in this tomographic study are shown as triangles, out of which 19 are selected for the line search shown in red. Faults are indicated by bold black lines. Labels 1-8 denote eight geological provinces bounded by red dashed lines: 1. Coastal Ranges; 2. Great Central Valley; 3. Sierra Nevada; 4. Basin and Range; 5. Transverse Ranges; 6. Mojave Desert; 7. Peninsular Ranges; 8. Salton Trough. Geological features labeled in bold white letters as references for subsequent figures: SCR, southern Coast Range; SJV, San Joaquin Valley; SAF, San Andreas Fault; LAB: Los Angeles Basin; ePRB and wPRB: east and west Peninsular Ranges Batholith; SNB, Sierra Nevada Batholith; STB: Salton Trough Basin. (b) Horizontal slices of shear velocity for model M21 at 10 and 20 km.

We compared the initial model M16 and our final model M21 to two other models: one is Barak2015 from traditional ambient-noise tomography, and the other is CVM-S4.26 from a full waveform inversion of earthquake and ambient noise data. In general, the CVM-S.4.26 model contains more small-scale features than the other three models and has much higher velocities, perhaps due to the larger number of data used and iterations performed. Based on similar initial models and data sets, our final model shows velocity variations that are generally in agreement with those of Barak2015. However, our final model also differs from Barak2015 in several aspects, as shown in Figure 2. At the central section of SAF (profiles DD'), we observe a high-velocity zone in the middle crust that shows a slight NE dip, while Barak2015 shows it dipping into the lower crust. The high-velocity region in the lower crust beneath wPRB of our model is

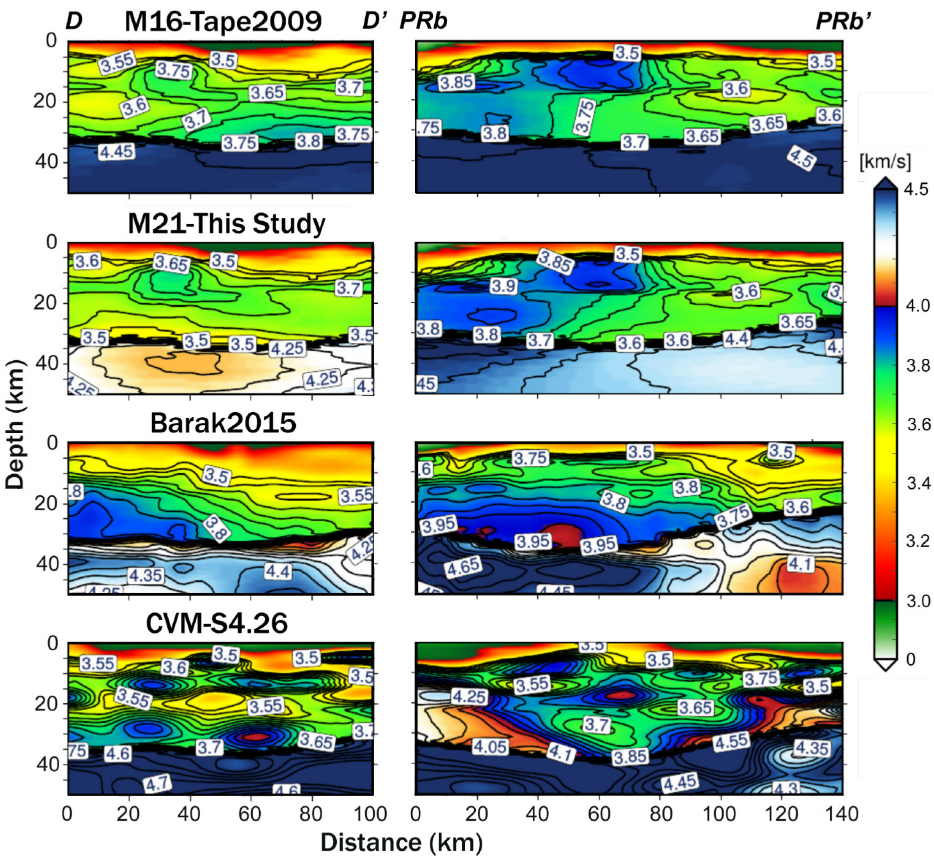


Figure 2. Comparison of model M16, M21, Barak2015 and CVM-S4.26 along DD' profile across SAF and PRbb' profile across PRB.

not as evident as that shown in Barak2015 and is only observed in the westernmost part (profile PRaa'). Our model shows that the southern boundaries of wPRB and ePRB have vertical-to-steep NE dips into lower crust, while Barak2015 shows only a slight NE dip in the middle crust (PRbb'). Moreover, our model shows increased shear velocities beneath LAB and CTR which are not identified in Barak2015.

Our study demonstrates the feasibility of applying adjoint tomography to ambient-noise data in southern California, which is complementary in coverage to the earthquake data used in previous studies. The numerical spectral-element solver used in adjoint tomography provides accurate structure sensitivity kernels through 3D model iterations, and hence generates more robust images than those produced by traditional ambient -noise tomography based on analytical methods.

This project is part of CCFS theme 3, Earth Today, and contributes to understanding Earth's Architecture.

Contacts: Kai Wang, Yingjie Yang

Funded by: IMQRE 43887678, DP120102372, DP120103673

Mapping the basaltic underplate: Plume-related zircons from Mt Carmel

Xenocrystic zircons from Cretaceous pyroclastic vents on Mt Carmel, N. Israel, document three major periods of earlier mafic magmatism: Permo-Triassic (285-250 Ma), Triassic (250-220 Ma) and Jurassic (210-160 Ma), which are only poorly represented in the local crustal record. Related alluvial deposits also contain these zircon populations, but most alluvial zircons are Cretaceous (118-80 Ma), or derived from much younger volcanic episodes (age peaks at 30, 13, 11, 9-10 and 4 Ma) (Fig. 1a, b). The Permo-Triassic-Jurassic zircons are typically large and glassy; they have irregular shapes and a wide variety of internal zoning patterns (Fig. 2). They appear to have grown from melts in the interstitial spaces of coarse-grained rocks (cumulates, peridotites); many show evidence of recrystallisation, including brecciation and rehealing by chemically similar zircon. Igneous-looking grains have mantle-like $\delta^{18}O$ (5.5±1 ‰), but recrystallisation leads to lower values (down to 3.1‰). Hf-isotope

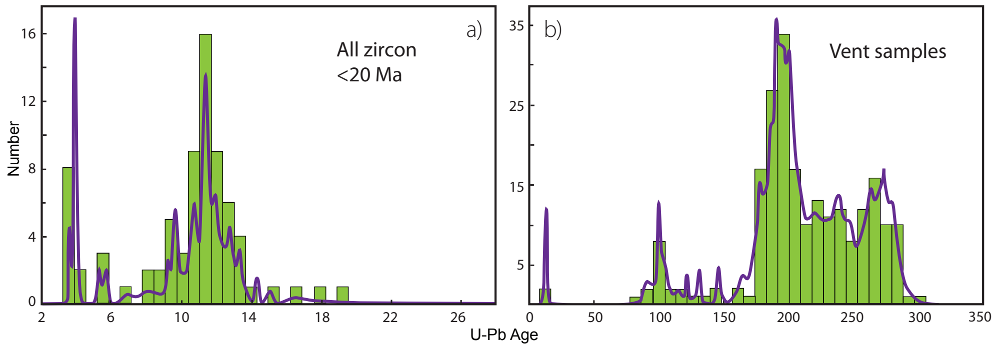


Figure 1. Age histogram/ cumulative probability curve for U-Pb data of a) Alluvial samples (0-20 Ma) and b) Vent samples (0-350 Ma).

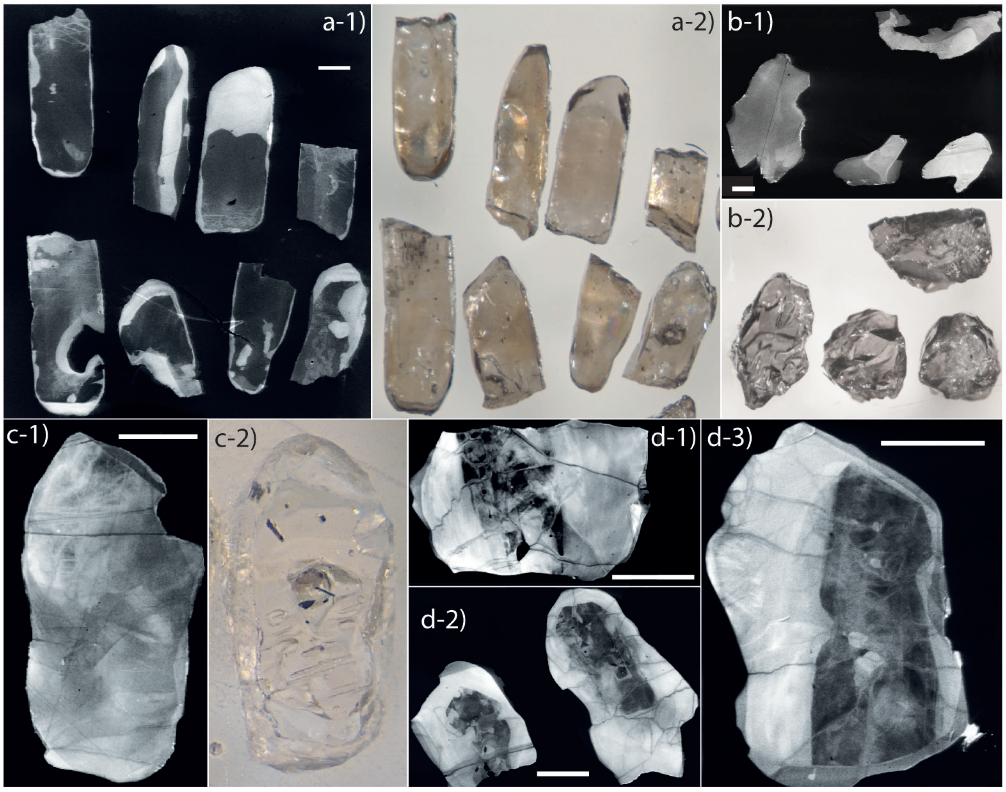


Figure 2. Images of Mount Carmel zircons. Scale bars are 200 microns. a. optical-microscope and cathodoluminescence 838 (CL) images of zircons showing corroded-prismatic shapes and core-rim zoning. b. Typical Mt Carmel-type zircons illustrating irregular shapes and internal structures. c. optical and CL images of large Mt Carmel-type zircon showing irregular form and internal brecciation. d. CL images of zoned Mt Carmel-type zircons, with brecciation.

compositions lie midway between the CHUR and Depleted Mantle (DM) reservoirs; Hf model ages suggest that the source region separated from DM in Neoproterozoic time (1000-1500 Ma). Most Cretaceous zircons have $^{176}Hf/^{177}Hf$ similar to those of the older zircons, suggesting they recrystallised in the Cretaceous thermal event. Calculated melts in equilibrium with the Permian to Cretaceous zircons are depleted in LREE and P, and have large positive Ce anomalies and negative Eu anomalies, variable Ti anomalies, and high and variable Nb, Ta, Th and U, consistent with the fractionation of monazite, zircon, apatite

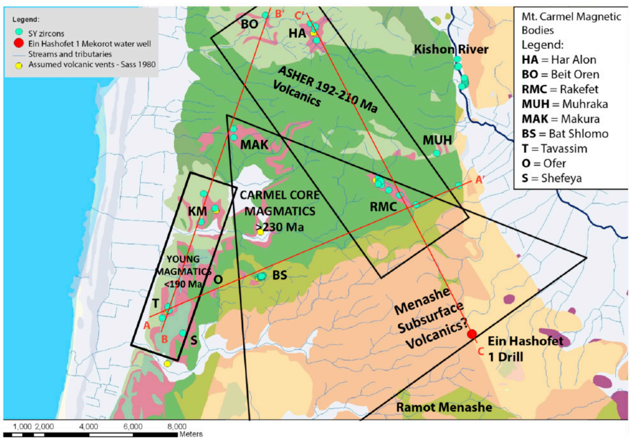
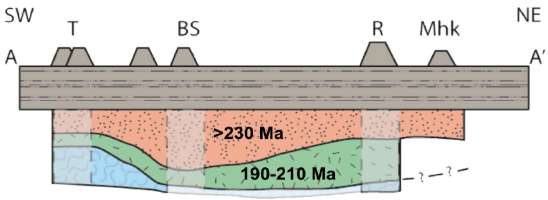


Figure 3. Map showing the distribution of zircon age populations in vents. Lines A-A', B-B', C-C' mark corresponding sections 1-3 in Figure 4.

and Ti-bearing phases from the host magma. We suggest that these coarse-grained zircons crystallised from late differentiates of basaltic magmas, ponded near the crust-mantle boundary (ca 30 km depth), and were reworked repeatedly by successively younger igneous/ metasomatic fluids.

The distribution of zircon populations in the Cretaceous volcanoes can be used to map the buildup of this basaltic underplate (Fig. 3). The Permian-Triassic (280-220 Ma) zircons are most abundant in the main central vents (Rakefet, Bat Shelomo, Makura) and the Ein Hashofet centre in the Ramot Menashe syncline. The Triassic-Jurassic zircons are found mixed with Permian-Triassic ones in Ein Hashofet and Rakefet, but make up the bulk of the sample in the northern bodies (BO, KM, and HA); the younger zircons are found mainly in KM, TAV and MH on the western side of Mt Carmel. This pattern suggests that the Permo-Triassic magmatism built up a *'pillow'* beneath the core of the Mt Carmel-Menashe area, so that the magmas of the younger episodes tended to intrude toward the margins of this central area (Fig. 4).

The trace element patterns of the Permo-Jurassic resemble those of zircons that crystallised from plume-related magmas (Iceland, Hawaii), and this is consistent with the compositions of Permian to Miocene basalts in the region. The zircon data support a published model that locates a fossil Neoproterozoic plume head beneath much of the Arabia-Levant region, which has been intermittently remelted to generate the volcanic rocks. The Cretaceous magmas carry mantle xenoliths derived from up to 90 km deep, providing a minimum depth for the possible plume head. Post-Cretaceous magmatism, as recorded in detrital zircons from the area, shows distinct peaks at 30 Ma, 13 Ma, 11.4±0.1 Ma (a major peak; n=15), 9-10 Ma and 4 Ma, representing the Lower and Cover Basalts in the area. Some of these younger magmas tapped the same mantle source as the Permian-Jurassic magmatism, but many young zircons have Hf-isotope compositions extending up to DM values, suggesting derivation of magmas from deeper, more juvenile sources.



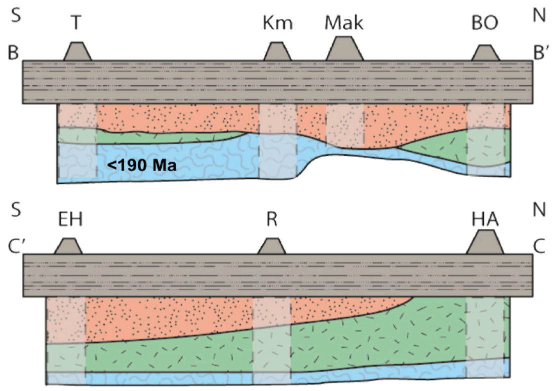


Figure 4. Cartoon showing the relative abundance of three zircon age populations in different vents, to illustrate the general structure of the gabbroic underplate at the crust-mantle boundary beneath the Mt Carmel area. Not to scale.

This project is part of CCFS theme 2, Earth's Evolution, and contributes to understanding Earth's Architecture and Fluid Fluxes

Contact: Bill Griffin
Funded by: CCFS Flagship Program 1

Seismic image of the Capricorn Orogen – Revealing the crustal component

The Capricorn Orogen records the Paleoproterozoic amalgamation of the Archean Pilbara and Yilgarn cratons to form the Western Australian Craton. Regional surveys involving geological mapping, geochemistry, and geophysics reveal a prolonged tectonic history of craton assembly and subsequent intracratonic reworking, which has significantly re-shaped the orogenic crust.

To better understand the tectonic history, we targeted the seismic structure of the orogenic crust and sub-crustal lithosphere. We deployed a 76-station broadband array (COPA, Capricorn Orogen Passive-source Array) that covers the orogen in a 2D grid over nearly 500 km by 500 km surface area with roughly 40 km station spacing. The planned 36-month deployment could guarantee enough data recordings for 3D structure imaging using body wave tomography, ambient noise surface wave tomography and P- and S-wave receiver function Common Conversion Point (CCP) stacking techniques. Upon a successive instrument loan of 36 sets of seismometers from the ANSIR national instrument pool, 34 broadband seismometers (2 as backup) were first deployed in the western half of the orogen. In late 2015/early 2016, most stations were rolled over to the eastern half.

Here we report preliminary results from ambient noise tomography that focuses on the shear-wave velocity structure of the orogenic crust (Fig. 2). Some interesting results are noted.

1. Significant velocity differences are found between the western and eastern parts of the orogen;

2. The Glenburgh Terrane has slow velocities in the mid- to lower crust, similar to the bounding Pilbara and Yilgarn cratons.

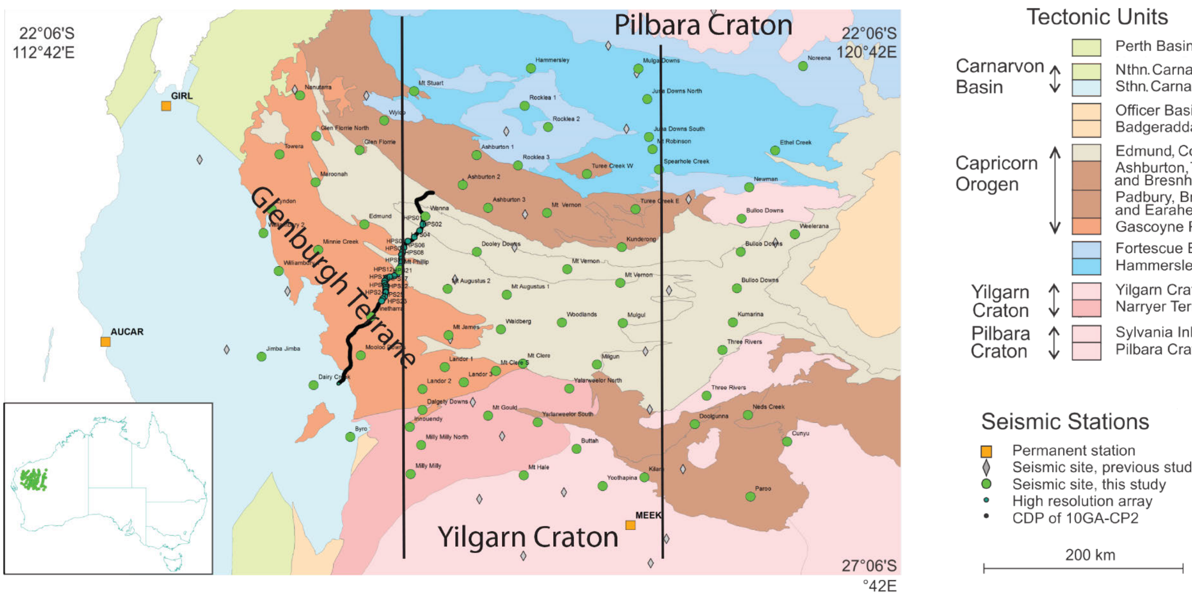


Figure 1. Capricorn seismic deployments and tectonic units. Green dots in the left panel are the 76 COPA stations from March 2014 to Nov 2017. Black line indicates the location of the 2010 active-source reflection line.

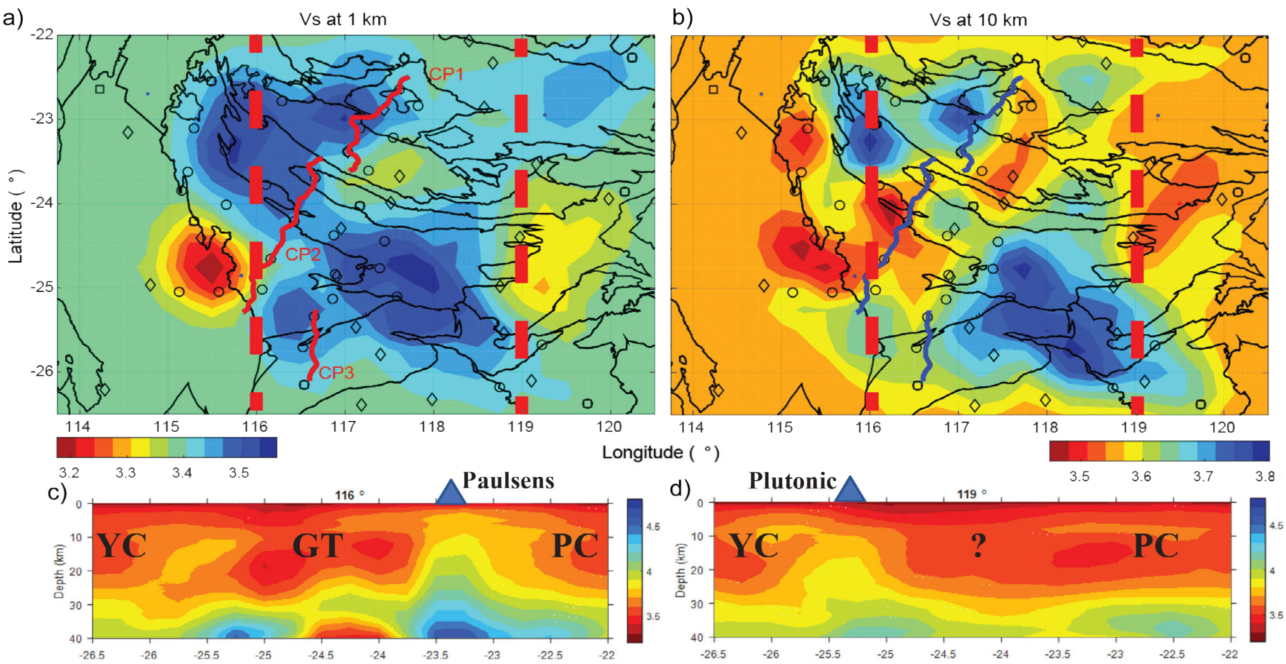


Figure 2. Initial ambient-noise tomography results for the orogen-scale COPA array. a) Vs at 1 km depth. b) Vs at 10 km depth. Stations used in the study are shown as open circles (deployed in this study) and open diamonds (early temporary deployments and permanent sites in the region). c) a cross-section for the western part of the orogen along 116° Longitude. d) a cross-section of the eastern part of the orogen along 119° Latitude. YC, Yilgarn Craton; GT, Glenburgh Terrane; PC, Pilbara Craton. The question mark indicates the region currently lacking station coverage. Blue triangles show the approximate locations of the Paulsens and Plutonic gold mines.

3. Clear Terrane boundaries may be marked by fast velocity lower crust that may represent mafic underplating associated with the 2.2 Ophthalmian and 2.0 Glenburgh Orogenies. These might represent the deep crustal sources of the mineral deposits (gold mines indicated in Fig. 2).

Combining our earlier crustal results (see, *2016 Research highlight "An Archean microcontinent lurking in the Capricorn Orogen"*), we can draw broader conclusions.

- Seismic signatures are found in the crust for the paleo-subduction associated with the 2.2 Ga Ophthalmian Orogeny, although there is no associated magmatic evidence at the surface.
- The Glenburgh microcontinent shares some crustal signatures (slow velocity, felsic composition, resistive crust) found in other Archean cratons, suggesting its formation may be associated with Archean vertical plume accretion.
- Significant reworking of the terrane crust left marks along the margins (lower crustal underplate, tectonic wedges), and inside the terrane (the fast-velocity upper crustal layer).

This project is part of CCFS themes 1, 2 and 3, Early Earth, Earth's Evolution and Earth Today, and contributes to understanding Earth's Architecture.

Contacts: Huaiyu Yuan, Klaus Gessner
Funded by: CCFS Flagship Program 7

Sulfidised stromatolites from the Pilbara: A new benchmark for oldest life on Earth

Definitive benchmarks for evidence of the oldest life on Earth remain controversial. Over the past decades, one has been the ~3.46 Ga Apex chert microfossil locality in the East Pilbara Terrane of Western Australia, but recent studies have convincingly shown that the filamentous structures in those cherts are abiotic artifacts rather than true microfossils. Claims for even older microfossil remains from Quebec, Canada, around 3.8 Ga, are even more contentious because they are less well-preserved in strongly metamorphosed rocks, and are not evidently composed of biological matter. Putative remains of microbial communities, generally known as stromatolites, have been reported from ~3.7 Ga old rocks of Greenland. However, stromatolite morphology – though compelling for most – remains contentious in the absence of microfossils, convincing biomineralisation, or chemical-based evidence. Here we report unequivocal microbial remains preserved in biologically precipitated stromatolitic sulfide (pyrite ± sphalerite, millerite and galena) laminae from the ~3.48 Ga old Dresser Formation, Pilbara Terrane, Western Australia. Although prone to recrystallisation and multiple stages of sulfide overgrowth, they preserve early-stage framboidal pyrite in nanoporous pyrite rich in organic matter, replicating textures known from *in situ* sulfidisation of

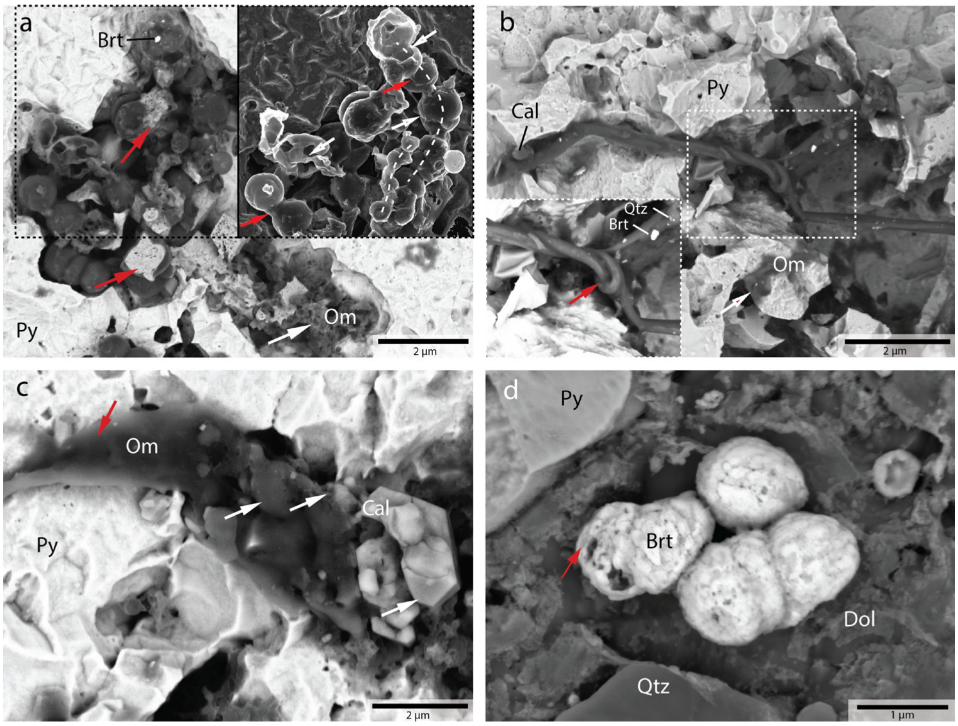


Figure 1. Backscattered electron- (BSE-) and secondary electron- (SE-) images of biomorphs rich in organic matter and barite mineralisation in stromatolitic sulfide laminae, observed following nitric acid etching. a. Irregularly-structured organic matter (white arrow), along with coccus-like hollow spheres and bulbous sheaths containing relict nanoporous pyrite cores (red arrow). The subfigure outlines the chain-like arrangement of coccus-like spheres and smaller irregular particles of organic matter (dashed lines), menisci of structureless organic matter (red arrows) interpreted as mineralised extracellular polymeric substance (EPS), as well as divided and bulbous arrangements of connected sphere (white arrows) suggestive of cell division (i.e., binary fission). b. Putative mineralised biofilm represented by a rope-like twisted and branched (red arrow) filament bundle speckled with quartz, calcite, and barite. c. Strand (white arrow) rich in organic matter yielding partly carbonatised (calcite) submicron-sized spheroids of organic matter (white arrows) occurring side by side with euhedral platy hexagonal calcite, replicating biofilm carbonatisation involving fossilisation of cocci bacteria. d. Agglomeration of submicron-scale barite spherulites in heavily etched dolomite. These barite textures are known from modern-day marine bioaccumulations, and have been replicated many times in laboratory experiments employing living strains of modern sulfur- oxidising marine bacteria. Brt = barite; Cal = calcite; Dol = dolomite; Om = organic matter; Py =Pyrite; Qtz = quartz.

modern biofilms. Furthermore, we report candidate microfossils represented by spheres of organic matter that resemble coccus bacteria (Fig. 1a), as well as strands and filaments (Figs. 1b, c) interpreted as mineralised biofilms. Supporting evidence for a biological origin is derived from micromineralogy including spherulitic barite biomineralisation (Fig. 1d), as well as Micro-Raman Spectroscopy (MRS) analysis of organic matter (Fig. 2a) combined with Nanoscale Secondary Ion Mass Spectrometry (NanoSIMS) isotope mapping of elements necessary for life (carbon, nitrogen and oxygen; Fig. 2b, c). Collectively, the remarkable range of textural, mineralogical, and chemical biomarkers provides new

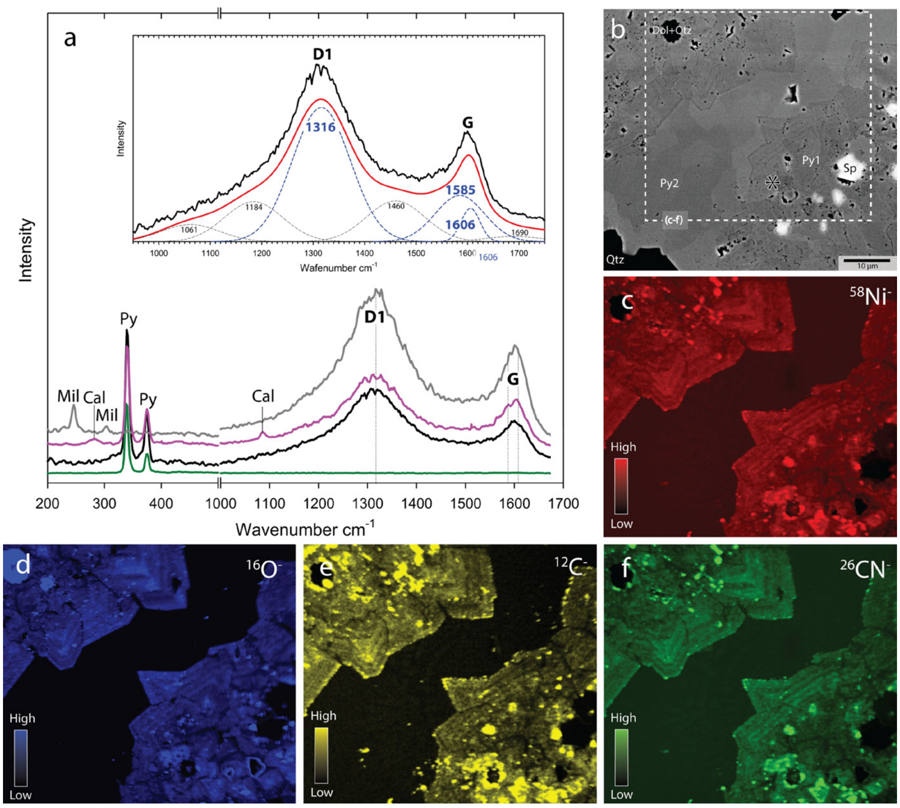


Figure 2. Molecular and isotopic analysis of organic-matter-rich sulfide (pyrite ± millerite) assemblages in stromatolitic sulfide laminae. a. Micro-Raman Spectroscopy (MRS) analyses of organic-matter-rich nanoporous pyrite and millerite compared with barren nonporous pyrite. Spectral deconvolution in the 900-1700 Δcm^{-1} range (subfigure) illustrates the immature kerogen-like nature of organic matter; i.e. predominance of molecular disorder (D1 band) relative to graphite-like order (G band). b-f. Backscattered electron (BSE-) image, and Nanoscale Secondary Ion Mass Spectrometry (NanoSIMS) maps of ^{51}Ni-, ^{16}O-, ^{12}C-, and ^{26}CN-, indicating coupled enrichments in nanoporous pyrite (Py1) relative to ubiquitous overgrowths of annealed nonporous pyrite (Py2). Cal = calcite; Dol = dolomite Mil = millerite; Py1 = nanoporous pyrite; Py2 = nonporous pyrite; Py = pyrite; Qtz = quartz; Sp = sphalerite.

definitive evidence of the oldest life on Earth at ~3.48 Ga, and points to a new taphonomy involving microbial sulfidisation that is important not only in the search for ancient life on Earth, but elsewhere in the solar system.

This project is part of CCFS themes 1 and 2, Early Earth and Earth's Evolution, and contributes to understanding Fluid Fluxes.

Contacts: Raphael Baumgartner, Martin Van Kranendonk, David Wacey, Marco Fiorentini, Stefano Caruso

Funded by: CCFS Flagship Program 4

Zircon morphology, isotopes and the magmatic fertility of porphyry Cu-Au deposits

Porphyry Cu-Au systems are associated with intrusive complexes made up of hydrous magmas related to continental and island arcs. These systems have a relatively well defined geodynamic framework. Increasing the understanding of the geologic processes and factors that lead to their formation will allow a better exploration success rate. Zircon compositions are powerful tools for unravelling the petrogenesis and magmatic evolution of Cu-ore-forming magmas. The Tampakan and Batu Hijau deposits (Fig. 1) are set in island-arc systems associated with subduction zones, and can be used to evaluate the importance of crustal contamination of the magmas.

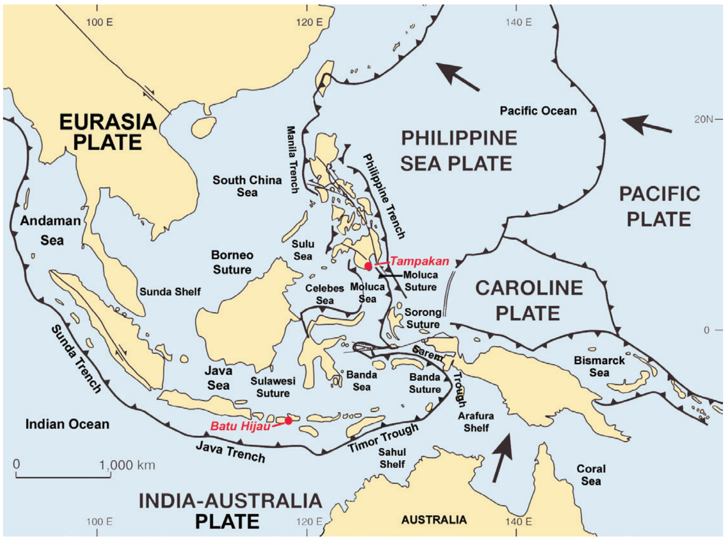


Figure 1. General plate boundaries across Indonesia, showing the most prominent trench and suture zones. Light grey shaded area represents the extension of the Sunda-Banda arc. Location of the Batu Hijau and Tampakan deposits represented by red dots. Modified after Metcalf (2009).

The Batu Hijau deposit sits along an arc system that has subducted older remnants of the Australian continental shelf (Figs. 1 and 3).

The Batu Hijau district (Fig. 1) contains 914 Mt of ore (0.53% Cu and 0.40 g/t Au). It is located on the island of Sumbawa along the Sunda-Banda volcanic arc segment between Wetar and Eastern Java. The arc consists of a succession of Miocene to Holocene units built over oceanic crust sitting close to the margin of the Sunda continental shelf. Parts of the Australian continental margin, with ages between ca 3200 and 500 Ma have been subducted along the arc, while parts of the fore-arc were dynamically uplifted.

The Tampakan district (Fig. 1) hosts giant high-sulfidation and porphyry Cu-Au deposits of Pliocene age, with estimated ore reserves of 12.5 million tonnes Cu and 500 tonnes Au. It lies at the northern end of the Miocene to Pliocene Sangihe volcanic arc on Mindanao Island, between crustal remnants derived from the Australian and Euroasian continental plates. This is a syn- to post-collisional setting as the result of terrane accretion and

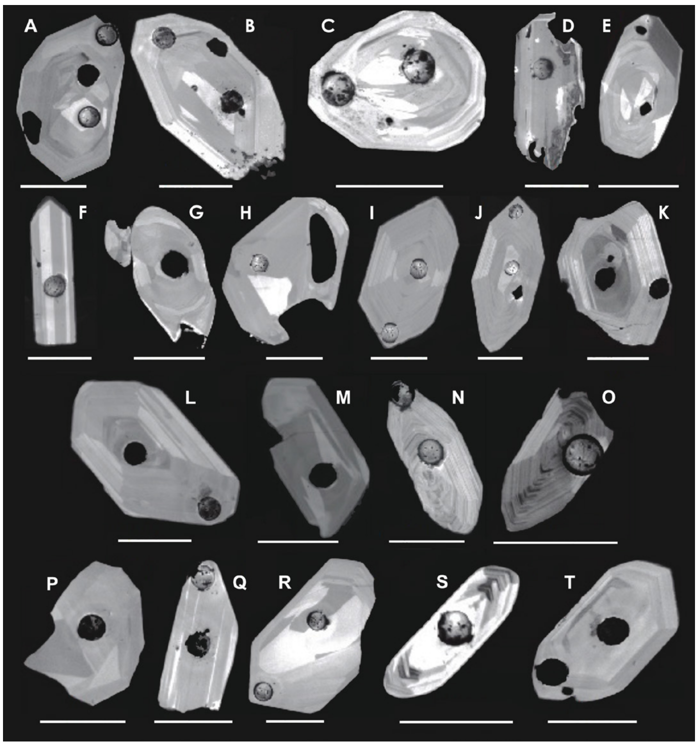


Figure 2. Morphologically, syn-ore zircons from the two studied deposits are characterised by unzoned cores surrounded by thin oscillatory zoned rims. Scale bars 100 µm.

arc collision. The geology of the region is dominated by a series of basalts and basaltic andesites of early to mid-Miocene age and related volcanoclastic sediments. The basaltic andesite unit is intercalated with a limestone unit. The package is unconformably overlain by the Tampakan Andesite Sequence. The Tampakan Andesite sequence represents an eroded stratovolcanic complex comprising 4 andesitic volcanic cycles lasting around 4.5 Myrs.

Zircon textural characteristics (Fig. 2) reflect two stages of magma emplacement. Unzoned cores suggest crystallisation within a long-lived, deep, hot magma chamber while the thin zoned rims suggest a relatively short residence time in the shallow crust, which may have prevented the loss of Cu metals. Preliminary O-isotope analyses show no sign of crustal contamination. I have had to infer that preliminary results show that zircons from pre- and post-ore samples, although not mineralised, display the same characteristics as syn-ore samples. The fact that all samples display such characteristics suggests that factors other than magma fertility played an important role in leading to mineralisation.

This project is part of CCFS themes 2 and 3 and Earth's Evolution and Earth Today, and contributes to understanding Earth's Architecture and Fluid Fluxes.

Contacts: Luis Parra-Avila, Bob Loucks, Marco Fiorentini, Yongjun Lu
Funded by: GSWA

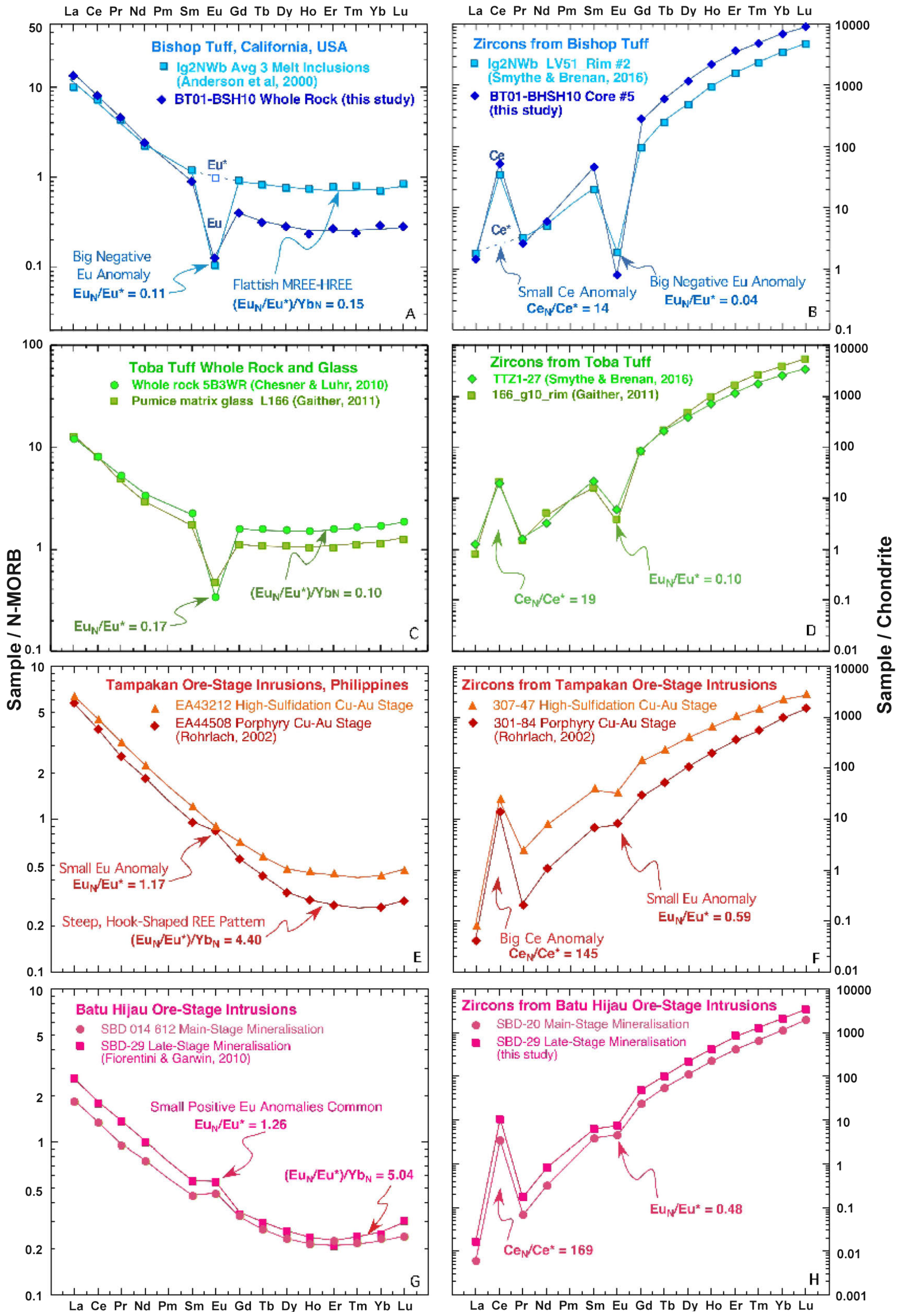


Figure 3. Whole rock (left) and zircon elemental data (right) display typical features of felsic arc magmas associated with magmatic-hydrothermal Cu ore deposits. These features include: steep, hook-shaped REE patterns, minimum around Er, and absence of a significant negative Eu anomaly.

Porphyry Cu fertility in the Tibetan Plateau

Cenozoic porphyry Cu deposits in the Tibetan Plateau are typical of porphyry systems developed in continental collision zones. Understanding the temporal and spatial distribution of these deposits will help unravel the genesis of porphyry deposits in collision zones in general, and exploration targeting of porphyry deposits in similar orogenic belts.

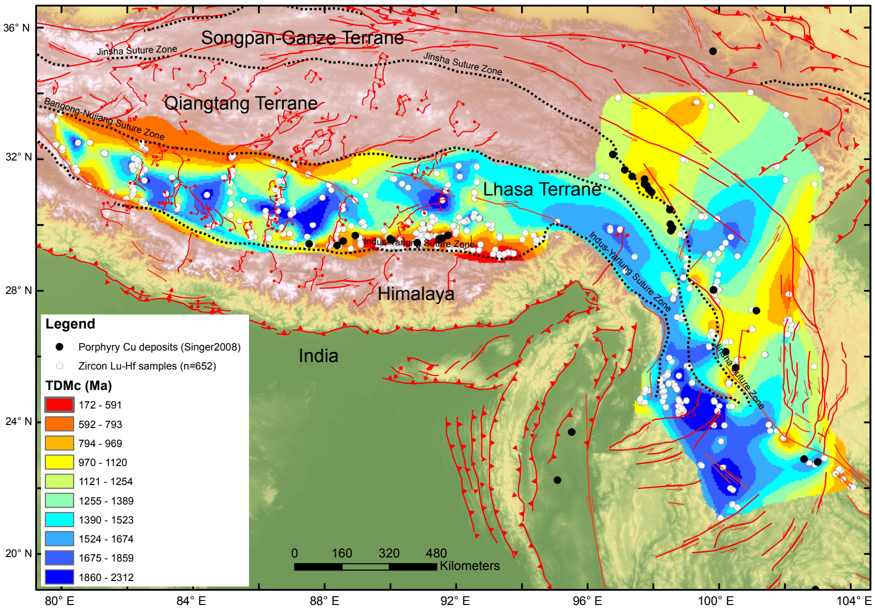


Figure 1. Contour map of zircon two-stage depleted mantle model ages (TDMc) for granitoid and felsic volcanic rocks in the Tibetan Plateau.

Results of zircon Lu-Hf isotopic mapping using 652 zircon samples from the Tibetan Plateau are shown in Figure 1. They demonstrate that most porphyry Cu deposits are associated with isotopically juvenile domains along the terrane-bounding Indus-Yarlung and Jinsha suture zones (Fig. 1). Such isotopic mapping can narrow the search space from over 2500 km scale to ~500 km scale.

Whole-rock geochemical mapping using ca 1200 samples across the Lhasa Terrane shows that all porphyry Cu deposits occur in domains of high 10000*(Eu/Eu*)/Y (>800; Fig. 2). Thus, the (Eu/Eu*)/Y ratio is the best whole-rock fertility indicator, and is interpreted to indicate extremely high magmatic water contents which induce early and prolific fractionation of hornblende and suppress early plagioclase crystallisation.

Zircon U-Pb and trace-element data were obtained from 66 igneous samples of Jurassic to Miocene age (181-11 Ma) in the eastern Gangdese belt. Both xenocrystic and magmatic zircons show systematic compositional evolution from Jurassic to Miocene. From ca 200 Ma to ca 55 Ma, zircon Eu/Eu* (0.1-0.4), 10000*(Eu/Eu*)/Y (0.1-10), and (Ce/Nd)/Y (0.001-0.05) ratios remain broadly similar. However, these zircon trace-element ratios increase rapidly after ca 55 Ma and peak at ca 13 Ma with Eu/Eu*, 10000*(Eu/Eu*)/Y, and (Ce/Nd)/Y up to 1, 70, and 2, respectively (Fig. 3). Similar temporal trends are also observed for whole-rock Sr/Y, La/Yb, and (Eu/Eu*)/Y, although whole-rock Eu/Eu* ratios appear to be similar throughout the Jurassic-Miocene period. In addition, Cretaceous samples show juvenile Hf-O isotopic signatures, whereas Eocene-Miocene intrusions show increasing zircon $\delta^{18}O$ values and decreasing epsilon Hf values, suggesting that increasing amounts of supracrustal materials were involved in magma genesis after c. 55 Ma.

Exploration is a scale-reduction process. Zircon Lu–Hf isotopic mapping is powerful in identifying juvenile crustal domains which are more prospective for porphyry Cu deposits. The combined mapping of zircon Hf isotopes and whole-rock 10 000*(Eu/Eu*)/Y

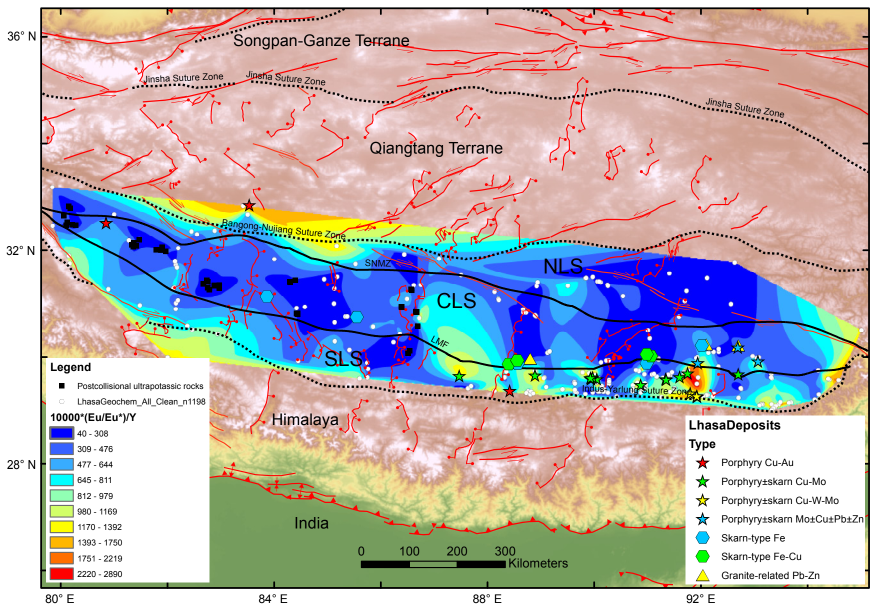
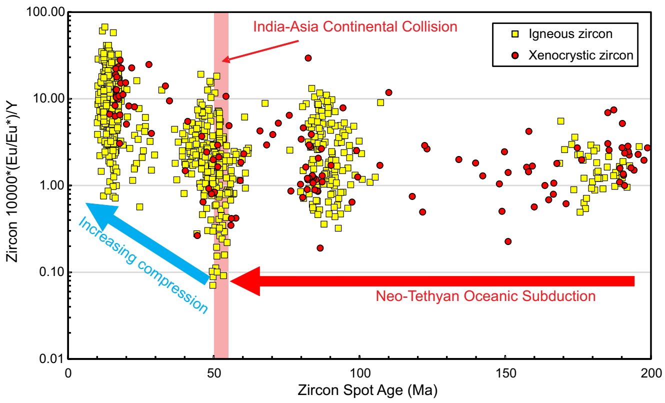


Figure 2. Contour map of whole-rock geochemical ratio of 10000(Eu/Eu*)/Y for mafic to felsic intrusive and volcanic rocks in the Lhasa Terrane, southern Tibet.*



ratio can help focus exploration on prospective areas.

This project is part of CCFS themes 2 and 3 and Earth's Evolution and Earth Today, and contributes to understanding Earth's Architecture.

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Funded by: CCFS Flagship Program 2

Figure 3. Zircon 10000 (Eu/Eu*)/Y ratio vs Age (Ma) for 66 magmatic rocks in the eastern Gangdese belt, Lhasa Terrane, southern Tibet.*

Following the tracks of carbon in the upper mantle

The mantle carbon cycle is an important, but largely unconstrained and debated problem in the deep Earth volatile cycle. The uncertainty derives from two main causes:

1) The location and conditions of carbonate melting in subduction slabs, along with the physical mechanisms by which carbon is removed from the slab into the overlying mantle wedge;

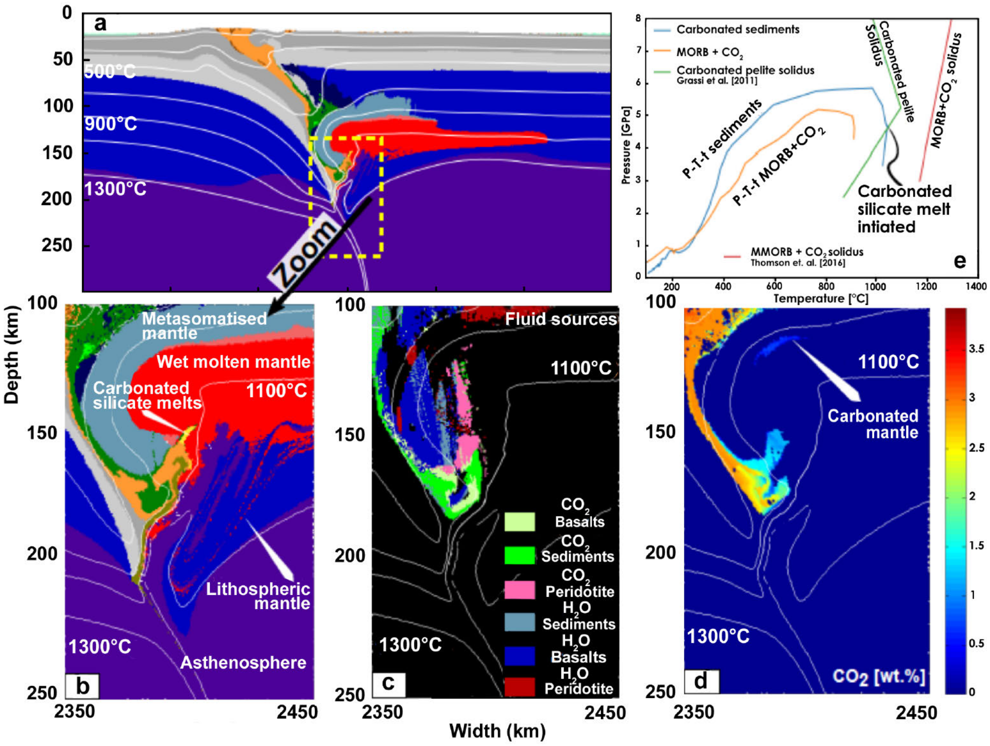
2) release of CO_2 from the downgoing slab causes changes in the chemical and physical properties of the lithospheric mantle by metasomatic interaction.

To better constrain these processes we have undertaken theoretical modelling to couple decarbonation reactions and experimentally-produced melting curves for carbonated basalts (MORB + CO_2) and sediments at pressures and temperatures relevant to upper mantle conditions.

The results confirm the hypothesis that carbon probably is likely filtered out at uppermost mantle conditions, suggesting a carbon increase in the lithospheric mantle over time. Carbonate melting in the mantle transition zone may provide an important component for organic-carbon signatures in diamonds. Lithospheric mantle enriched in CO_2 can be reactivated in subsequent tectonic events and lead to massive CO_2 release far from its original source – the subduction zone.

Overall, this study, though just beginning, is contributing to better understanding the deep carbon cycle and our ability to quantify the amount of CO_2 stored in the mantle.

This project is part of CCFS themes 2 and 3 and Earth's Evolution and Earth Today, and contributes to understanding Earth's Architecture and Fluid Fluxes.



Contacts: Weronika Gorczyk, Christopher Gonzalez
Funded by: CCFS Flagship Program 2

Figure 1. Model evolution for the initiation of carbonated silicate melts within a subarc region within the phase topology of a carbonated silicate melt:
a) Model domain and evolution at 19.09 Ma. b) Enlarged area of carbonated silicate melting. c) CO_2 [wt. %] in rocks determined as stable by thermodynamic modelling. d) Devolatilised fluids at depth determined as unstable from thermodynamic modelling. e) Selected P-T paths of basalts and sediments crossing solidi determined by petrological experiments.

CO_2 released in continental rifts is "*fried lithospheric diamonds*"

Continental rifts around the world are characterised by a strong accumulation of carbonate-rich volcanoes, including carbonatites and ultramafic alkaline rocks. These rocks store enormous quantities of carbon that appears to have its source in the lower parts of the continental lithosphere. These rocks are well known for extremely runny and fast-flowing lavas at Oldoinyo Lengai in northern Tanzania, but are also important as the best examples of primary melts of the mantle from the lower cratonic lithosphere at depths of 120-180 km (known as ultramafic lamprophyres).

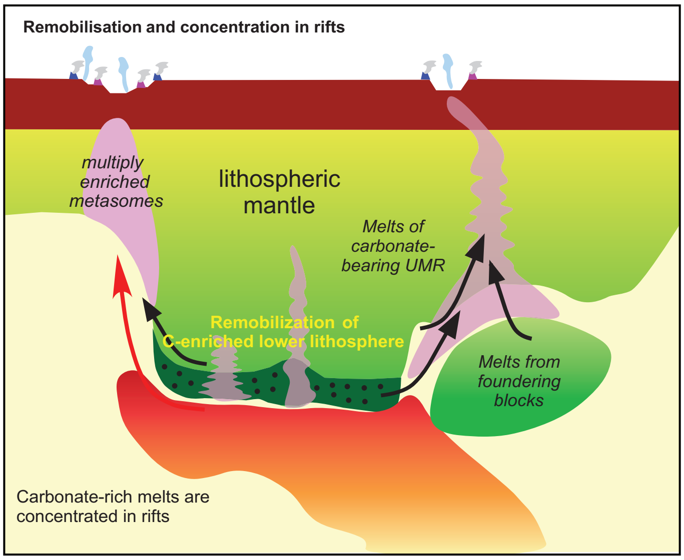


Figure 1. Stored carbon is reactivated by partial melting, concentrating the carbon in zones (purple; 150–240 Mt C km^{-3}) above which rifts may develop. Carbon escapes any foundering blocks, adding to the concentration in the sub-rift zones. Rift degassing thus involves carbon reactivated from an initially large volume. UMR, ultramafic rocks.

Studies of the release of CO_2 gas from continental rifts are being undertaken to assess the natural release of CO_2 into the atmosphere over time in order to compare and contrast it to levels of anthropogenic (man-made) carbon dioxide, which is accepted as being principally responsible for climate change. Measurements of CO_2 release have shown that even more carbon dioxide is released along rift faults and from volcanoes during their quiescent periods than volcanoes during eruptions.

Our interdisciplinary study brings together experts on degassing in continental rifts (Tobi Fischer of the University of New Mexico) and melting of the mantle (Stephen Foley, CCFS) in an attempt to understand where the carbon comes from, and whether we can explain how the concentration in continental rifts occurs. The result, published in *Nature Geoscience* in December 2017 (*CCFS Publication #995 Foley & Fischer, 2017, Nature Geoscience, 10, 897-902*), match the measured output of CO_2 gas in continental rifts to its capture, storage and remobilisation at the lithosphere base (150-200 km) within a factor of two – an excellent agreement in view of the great uncertainties involved.

The trapping and storage of carbon in the lower lithosphere was modelled as a three-stage process: (1) the original formation and stabilisation of the cratonic lithosphere, (2) gradual degassing from the mantle over time, and (3) carbon acquired from the passage of mantle plumes that contain carbon recycled into the mantle at subduction zones. When continental rifts form, this carbon, which has been stored for up to 3 billion years in the lithosphere, is remobilised by melting and focused into restricted zones beneath rifts, where deep fracture zones facilitate its concentration (Fig. 1).

Our calculations showed that the first step – the formation of the lithosphere itself – is insignificant in the deep carbon budget. The gradual degassing and release from mantle plumes were found to be similar in importance, with the latter slightly outweighing the former. To assess gradual degassing, we used similar models to those used for degassing at mid-ocean ridges, but modifying them for the depth zone relevant to sub-cratonic areas. Degassing from mantle plumes has been calculated before, because of the suspicion that mantle plumes may have caused the mass extinction of 96% of species at the end of the Permian. Here again, we used similar models, but modified the details for the pressure-temperature conditions and age ranges relevant to cratons.

The entrapment and release of carbon in the lower lithosphere is controlled largely by redox processes:

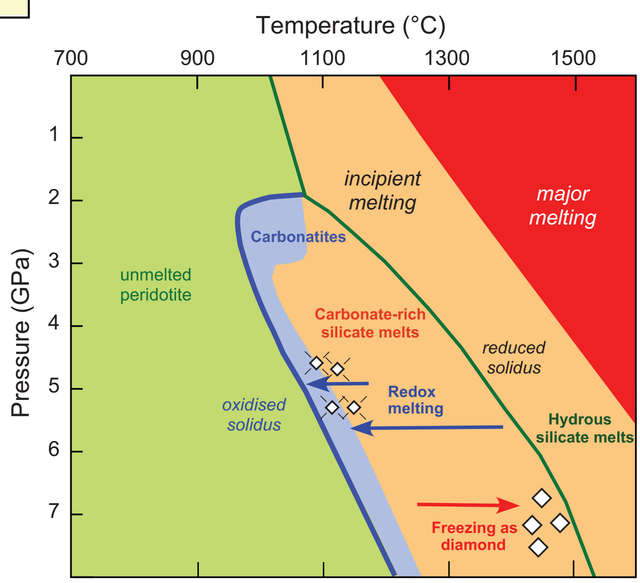


Figure 2. Melting curves of peridotite in reduced (green line) and oxidised (blue line) conditions in the incipient melting regime (blue to brown background). Carbon is immobilised in the reduced lower lithosphere by freezing to form diamond (red arrow) due to the change from blue to green melting curve. Later rifting and mantle upwelling causes access of oxidised melts to stored reduced carbon, depressing the solidus (redox melting; green line to blue line; blue arrows). Blue area indicates carbonatitic melts.

carbonate-bearing melts freeze in the lithosphere because the environment there is more reduced, so that the carbon is stored as diamonds. Conversely, when melting occurs, the diamonds are oxidised and dissolve in the melts as carbonate (Fig. 2), enabling its transport and focusing into the zones beneath the rifts.

The values estimated for CO_2 release in rifts are 19 megatons of carbon per year (Mt/yr), and for time-integrated input into the lithosphere and focusing beneath rifts around 30 Mt/yr, just 50% higher. These values are closer than appears when one considers that much carbonate is not released into the atmosphere, but remains in igneous rocks near the surface.

However, this is a generalised model based on today's degassing pattern. At times in the past when supercontinents were breaking up, the total length of rifts was probably 3-5 times that on the Earth today. In these times, the amount of CO_2 released must have been correspondingly higher, so that natural CO_2 release may have directly affected the atmosphere to warm the climate.

This project is part of CCFS themes 2 and 3, Earth's Evolution and Earth Today, and contributes to understanding Earth's Architecture and Fluid Fluxes.

Contact: Stephen Foley

Funded by: CCFS Flagship Program 3, USA National Science Foundation Grant EAR-11130660

Tiny droplets betray mantle melt origins

Melts in the upper mantle are commonly responsible for metasomatic reactions, which change the mineral and geochemical composition of the peridotite wall-rock. In most cases, the presence of an infiltrating melt is only evidenced by these characteristic compositional features in mantle rocks. However, on rare occasions, the melt can be '*caught in the act*' when trapped as primary silicate melt inclusions in newly-forming crystals.

Such an example was investigated in a metasomatically altered upper-mantle xenolith from the Nógrád-Gömör Volcanic Field, northern Pannonian Basin (Central Europe). Xenoliths from this locality have recently been shown to be affected by multiple metasomatic events (see *CCFS publication #1004*) the latest of which was caused by an intraplate mafic melt, resulting in clinopyroxene enrichment and elevated Fe contents. These metasomatic clinopyroxenes frequently host primary silicate melt inclusions (Fig. 1), which are about 10-20 μm in diameter and are partially crystallised, with several daughter minerals, residual glass and a gas bubble. The mineralogical, major- and trace-element compositions of several silicate melt inclusions were analysed to constrain the composition of the trapped melt.

We have used Raman spectroscopy to identify the daughter minerals, compromising clinopyroxene, apatite, anhydrite, barite, amphibole and mica. The gas bubbles are dominantly composed of CO_2. Subsequently, silicate melt inclusions were analysed by focused ion beam coupled scanning electron microscopy (FIB-SEM), a novel technique in nanoscale geological studies. The technique involves using the ion beam to slice through a small sample volume containing an inclusion, saving an image of each slice and carrying out *in situ* geochemical analyses on the exposed phases of the silicate melt inclusion (Fig. 2). Additional daughter phases were identified (spinel,

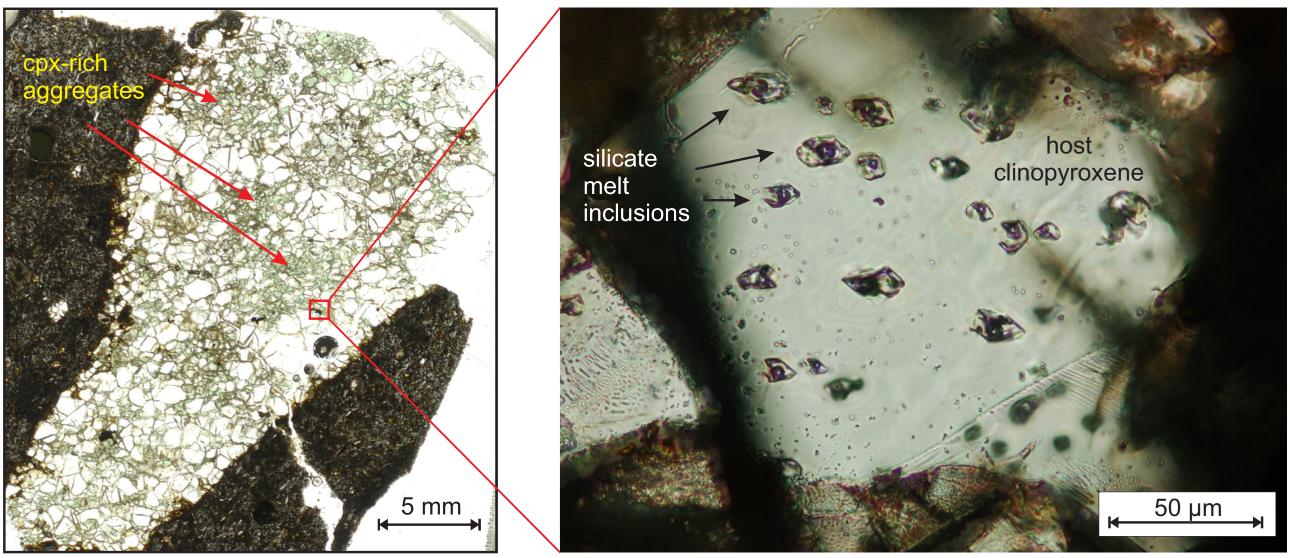


Figure 1. Left: clinopyroxene-rich, metasomatically altered xenolith. Right: merged image of plane- polarised photos, taken at different foci, of a clinopyroxene grain with primary silicate melt inclusions.

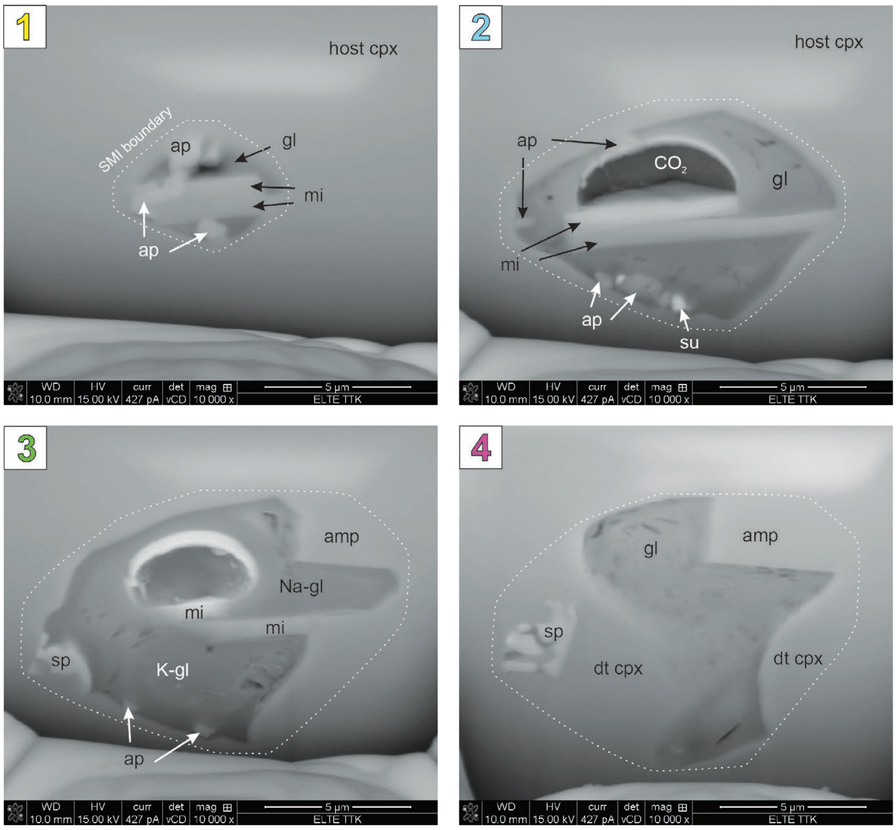
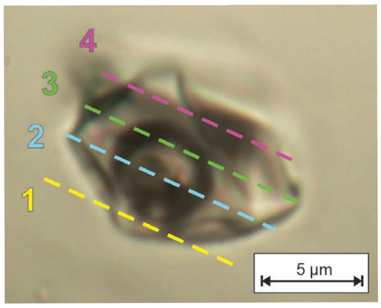


Figure 2. Plane-polarised light photomicrograph of a silicate melt inclusion and backscattered-electron images at different stages of the slicing process. Abbreviations of daughter phases: cpx – clinopyroxene, amp – amphibole, mi – mica, ap – apatite, sp – spinel, su – sulfide, gl – glass.



sulfide) by this technique, and a 3D phase map was constructed for the silicate melt inclusions, allowing calculations of the bulk modal and major-element compositions. Trace-element compositions then were determined using laser-ablation inductively coupled plasma mass spectrometry.

Bulk compositions lie within a narrow range for all the analysed silicate melt inclusions, indicating that they have trapped the same melt in similar conditions. This melt appears to be mafic in composition, with an enrichment in the most incompatible trace elements, like the host alkali basalt (Fig. 3). However, their high Fe contents verify that the trapped melt is the one linked to the latest metasomatic event in the studied locality. A simple geochemical model of Zajacz et al. (*2007, J. Petrology*) was applied, using the relationship of Nb and Y, to constrain the genesis of this melt (Fig. 3). The concentration of Y is commonly regarded as an indicator for the presence of garnet in the source, whereas Nb can be used to calculate the degree of partial melting. Based on the results, the metasomatising melt was generated by low-degree (~ 2%) partial melting of a garnet lherzolite, with slightly different composition than the source of the host magma.

Several post-entrapment processes can be reconstructed from the appearance and composition of the silicate melt inclusion daughter phases. The low density of the CO_2 bubble indicates that it was exsolved from the residual glass at shallow depths, most likely during ascent to the surface. Subsequently, secondary daughter minerals (sulfates, mica) crystallised on the boundary between the bubble and the glass, indicating the previous presence of S and H_2O in the volatile phase. Chemical heterogeneity in the glass may indicate a lack of equilibration before the '*freezing*' of the system under surface conditions.

This project is part of CCFS theme 2, Earth's Evolution and contributes to understanding Earth's Architecture and Fluid Fluxes.

Contacts: Nora Liptai, Sue O'Reilly, Bill Griffin, Csaba Szabó, Márta Berkesi (Eötvös University, Budapest, Hungary)
Funded by: CCFS Flagship Program 1, iMQRES, EPS postgraduate funds. This project is part of a cotutelle PhD program between Macquarie University and Eötvös University in Budapest, Hungary.

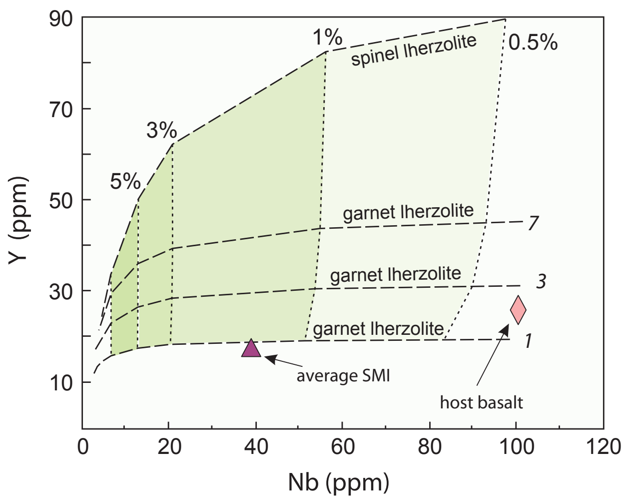


Figure 3. Nb vs Y diagram modelling the source composition and degree of partial melting for the genesis of the metasomatising melt. Dashed lines represent primitive mantle spinel- and garnet-lherzolite compositions; italic numbers refer to the clinopyroxene/garnet ratio in the source region. Dotted lines represent the degree of partial melting expressed in percentage.

Super-reducing conditions in a modern volcanic system: Key to the redox evolution of cratonic lithosphere

Estimates of the oxygen fugacity (fO_2) of the cratonic subcontinental lithospheric mantle (SCLM) range from above the quartz-fayalite-magnetite (QFM) buffer to just above the iron-wustite (IW) buffer, and generally decrease with depth. Several lines of evidence suggest that the fO_2 of the sublithospheric mantle may be constrained by the IW buffer (the presence of metallic Fe), but there also is evidence that volumes of significantly lower fO_2 must exist within the SCLM, and perhaps within the deeper mantle. The remarkable super-reduced conditions in an off-craton volcanic setting (Mt Carmel, Israel; *Griffin et al., Geology 2016; CCFS # 830*) may provide a key to the evolution of the redox state of the cratonic SCLM through time.

Aggregates of hopper-formed crystals of Ti-rich corundum are abundant in Upper Cretaceous basaltic pyroclastic rocks (vent breccias, tuffs) exposed on Mt Carmel near Haifa, Israel. Melt pockets trapped within and between corundum crystals contain mineral assemblages (SiC (moissanite), TiC, Fe-Ti-Zr silicides/phosphides and native V) that require P ≥ 1 GPa, T = 1500-1100 °C and extremely low fO_2 (10 to 12 log units below IW). Mineral parageneses suggest that the corundum and the low-fO_2 assemblages developed through interaction of basaltic magmas with mantle-derived (CH_4+H_2) at high fluid/melt ratios, leading to progressive lowering of fO_2.

A schematic illustration of the process is shown in Figure 1; this model envisions a magma chamber being flushed by a steady supply of $CH_4 \pm H_2$, but other configurations are possible. The material described here comes from at least 8 different volcanoes, with eruptions spread over ca 10 Ma, sampling similar magmatic systems erupted at different stages of their evolution, and has been used to reconstruct the evolution of a single synthetic system. The early oxidation of CH_4 may have led to the precipitation of vesicular wustite (FeO) and abundant high-Mg calcite, found in the ejecta. The progressive lowering of fO_2 to the IW buffer is marked by the appearance of a suite of mutually immiscible melts: native Fe, Fe-oxide/silicate melt and Ti-oxide/silicate melt, coexisting with the host CaO-Al_2O_3-SiO_2 melt. This reaction appears to have removed most of the FeO from the system; none of the silicate phases in the trapped melts (see below) have significant contents of Fe. The removal of the Fe-FeO buffer would allow fO_2 to decline (rapidly?) to the levels (6 to 8 log units below IW) where silicide melts would separate and SiC could precipitate. This would remove SiO_2 from the melt (now dominated by CaO-Al_2O_3-MgO), driving it into Al_2O_3 –supersaturation which causes the rapid growth of corundum and the trapping of melt pockets. This desilication process

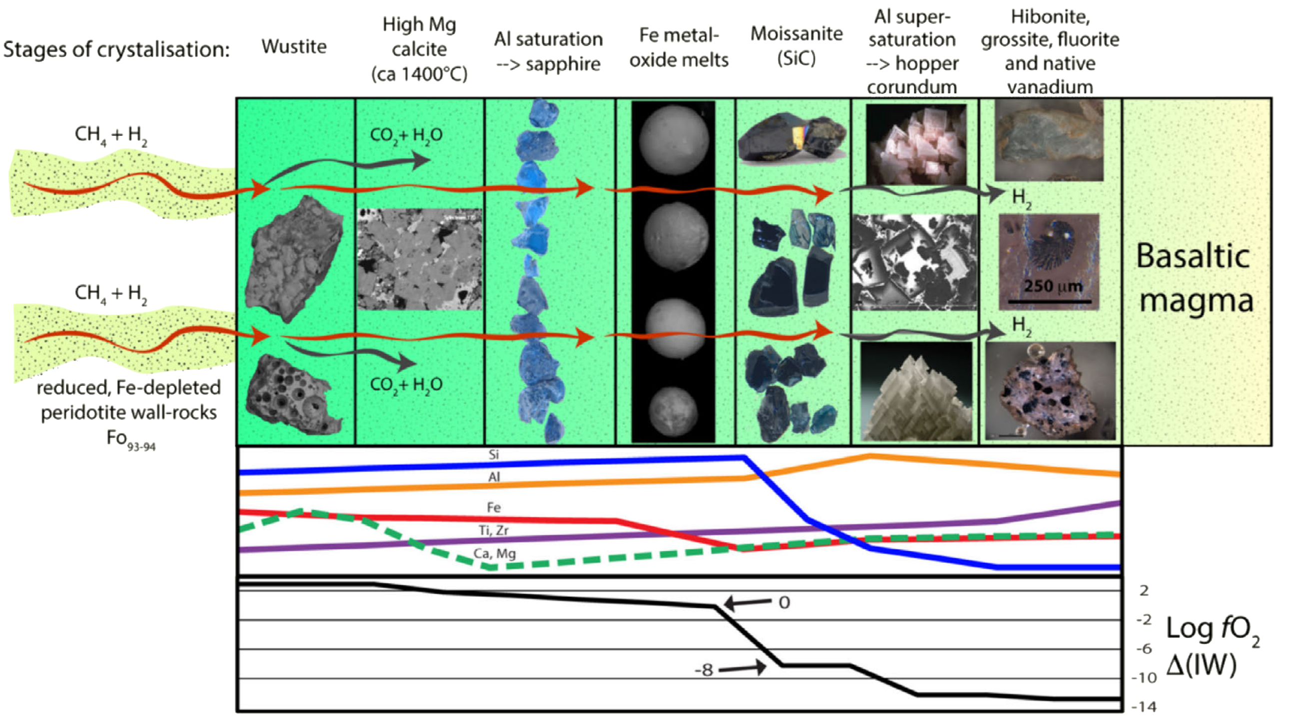


Figure 1. Model for the evolution of the Mt Carmel corundum-SiC system(s), as a progressive interaction between mantle-derived volatiles ($CH_4 \pm H_2$) and a basaltic magma. The evolution of the melt composition and the fO_2 of the system is illustrated schematically in the lower panels; the curves for elemental abundance are not to scale. The most important aspects are the drop in Fe (especially FeO) at the IW buffer, the rapid desilication of the melt following the onset of SiC crystallisation, and the extremely low fO_2 required by the presence of abundant native V in the hibonite-grossite assemblage. The incongruent melting of anorthite suggests P ≥9 kb, while phase relationships in immiscible silicide melts indicate T = 1500-1200 °C. After Xiong et al., EJM 2017; CCFS#968).

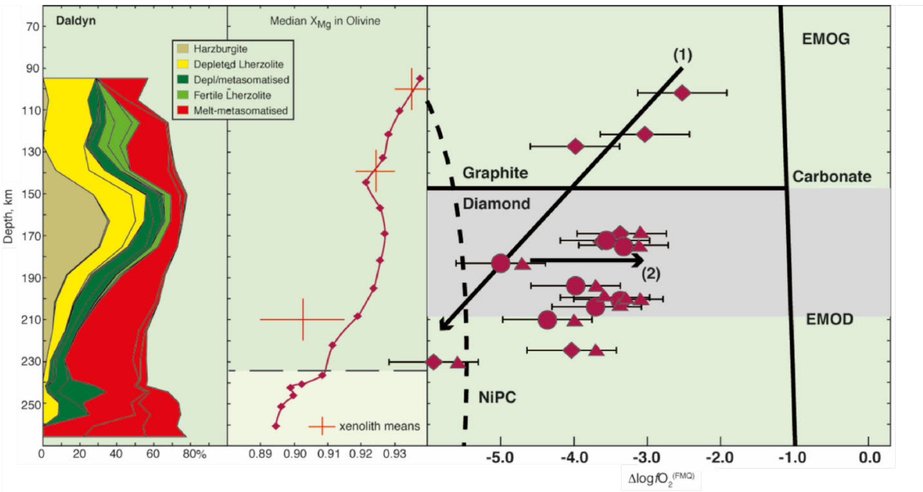


Figure 2. Left panel shows a lithospheric section of the SCLM beneath the Daldyn kimberlite field, constructed from garnet/chromite concentrates (Griffin et al.,1996) showing vertical distribution of rock types and metasomatic styles. The middle panel shows the median values of XMg in olivine, reconstructed from garnet compositions and temperature); note the inverse correlation between XMg and the degree of melt-related metasomatism. The right-hand panel (after Yaxley et al., 2012) shows estimated fO_2 based on Fe_3+/εFe; depleted samples define a trend of decreasing fO_2 with depth (Trend (1)), while metasomatised ones have experienced oxidation (Trend (2)). NiPC = Nickel Precipitation Curve.

apparently continued to near-completion, leading to a coarse-grained assemblage of hibonite ($CaAl_{12}O_{19}$) + grossite ($CaAl_4O_7$) + MgAl spinel + fluorite + native V, at $fO_2 \leq 11$ log units below IW. Many of the larger corundum aggregates are cut by breccia veins of amorphous (commonly vesicular) carbon, which also occurs in parallel-sided veinlets down to the sub-micron (TEM) scale, emphasising the important role of carbon in the evolution of these systems.

If this process reflects the rise of CH_4+H_2 from the sublithospheric mantle, much of that mantle probably is metal-saturated, consistent with observations of metallic inclusions in sublithospheric diamonds (e.g., *Smith et al., 2016*). Such fluids could penetrate up into a primitive depleted cratonic root, establishing the observed trend of decreasing fO_2 with depth (Fig. 2; *Yaxley et al., Lithos 2012*).

However, repeated metasomatism by silicic melts will raise the FeO content near the base of the craton, developing a carapace of oxidising material (Fig. 3). Oxidation of later CH_4-rich fluids in this carapace would release CO_2 and H_2O to drive metasomatism and low-degree melting in the SCLM. This model can explain the genesis of cratonic diamonds from both reduced and oxidised fluids, the existence of SiC as inclusions in diamonds, and the abundance of SiC in some kimberlites.

The recognition that $CH_4 \pm H_2$ may accompany melts rising from a deeper, metal-saturated mantle also suggests an explanation for the zones of high conductivity that mark the tracks of mantle-

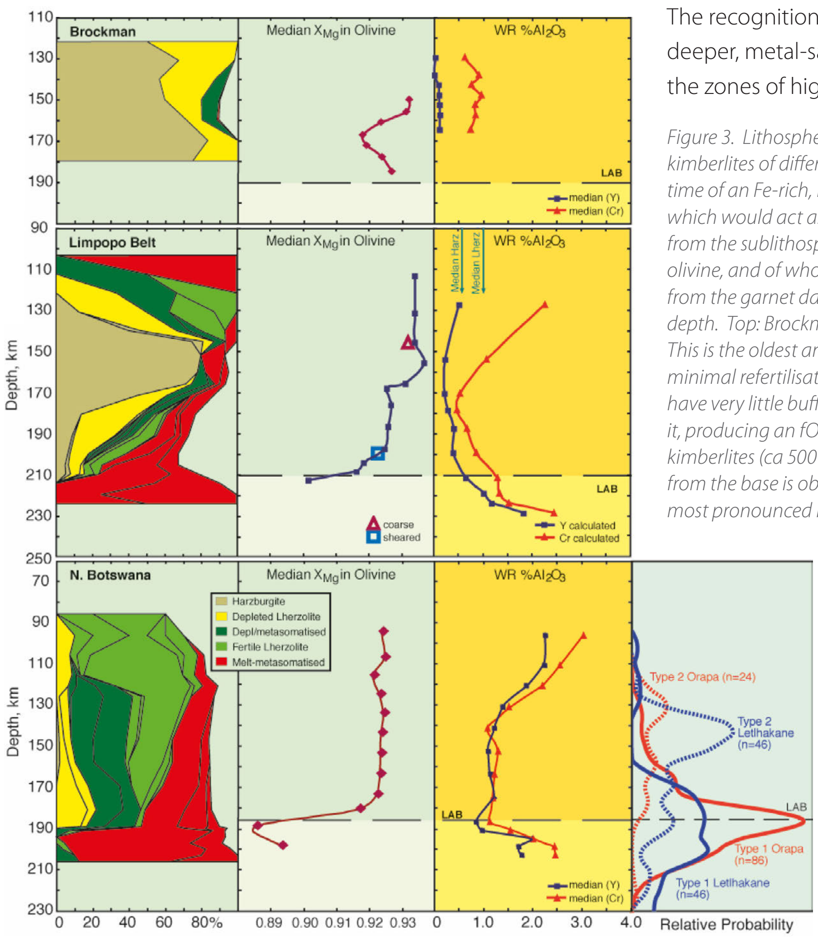


Figure 3. Lithospheric sections (as in Fig. 2) beneath three cratonic areas with kimberlites of different ages. The sections illustrate the development over time of an Fe-rich, melt-metasomatised carapace at the base of the SCLM, which would act as a filter to capture and oxidise (CH_4+H_2) rich fluids rising from the sublithospheric mantle. Estimates of the median Mg# of coexisting olivine, and of whole-rock Al_2O_3 content (based on two methods) are derived from the garnet data and illustrate the extent of metasomatism at each depth. Top: Brockman kimberlite (ca 1800 Ma), Pilbara Craton, W. Australia. This is the oldest and most primitive SCLM section known; it has experienced minimal refertilisation of the primary, highly depleted harzburgite. It would have very little buffering capacity and reduced fluids could penetrate well into it, producing an fO_2 gradient like that seen in Figure 2. Middle: Limpopo Belt kimberlites (ca 500 Ma), South Africa-Zimbabwe. The refertilisation of the keel from the base is obvious, but the changes in Fe content are moderate and most pronounced in a 10-15 km thick zone at the base. Mean compositions and P-T estimates are shown for two types of peridotite xenoliths.

Bottom: N. Botswana kimberlites (90-100 Ma). The metasomatic refertilisation has reduced the overall Mg# (and raised the Al content) of the whole section, but the most intense Fe-enrichment is concentrated in a 20-km thick zone at the base. Mean compositions and P-T estimates are shown for three types of peridotite xenoliths. There is a strong correlation of Fe enrichment with the distribution of eclogites, especially in the basal zone; Type I eclogites are typically heavily metasomatised. This Fe-rich basal barrier would represent a barrier to the passage of reduced fluids, and hence a source of CO_2 and H_2O for metasomatism and melt generation in this layer and above.

derived magmatic systems (from kimberlites to Bushvelds). The oxidation of CH_4 in rising fluids could propagate networks of microveinlets of amorphous carbon (even if later recrystallised to other forms), which might provide the fine-scale connectivity of conductive material in some mantle domains implied by the striking magnetotelluric images now becoming more widely available. See CCFS publications #830 and #968.

This project is part of CCFS theme 2, Earth's Evolution, and contributes to understanding Earth's Architecture and Fluid Fluxes.

Contact: Bill Griffin
Funded by: CCFS Flagship Program 1

Phosphorites - Older than you think!

Figure 1. Float illustrating centimetre-scale stromatolites and attached millimetre-scale (red) branching structures (Photo: Martin Van Kranendonk).

Phosphorites (sedimentary rocks with high contents of Ca-phosphate) are direct evidence in the rock record of oxygenation within the oceans and atmosphere. Phosphorites thus are restricted in age, first appearing about 2.2 Gyrs ago. They generally form as the result of microbial processes and in the Paleoproterozoic record, only occur as thin, peritidal deposits parallel to shorelines. In 2017 evidence of an older phosphorite, phosphate-rich microbial mats and peloids, was documented within the 2.4-2.3 Ga Turee Creek Group. The same carbonate reef that contains this phosphorite, also has very diverse stromatolites, thrombolites and deep-water microbial communities. Field work in 2017 enabled greater mapping of the 150 cm unit containing the phosphorous-rich microbial mats and established that they are adjacent to stromatolites with attached complex branching structures (Fig. 1). The branching structures are unique to this site and could potentially represent a new form of complex life. Further work will investigate the potential relationship between oxygen in the water during the deposition of these rocks, and the increased complexity of structures within the reef, possibly as the result of life adapting to an oxygenated environment. Part of this work involves studying the range in morphology and the environment in which the branching structures developed, to determine whether these are a new form of complex life and whether there is a connection between their evolution and oxygen.

This project is part of CCFS theme 1 Early Earth, and contributes to understanding Fluid Fluxes.

Contacts: Martin Van Kranendonk, Georgia Soares
Funded by: CCFS Flagship Program 4

Figure 2. PhD Students Brendan Nomchong and Georgia Soares working hard in the field documenting the ridge (Photo: Martin Van Kranendonk).

Zircon signals mineralisation potential of Archean granites

Porphyry Cu deposits are major sources of Cu and Mo. They range in age from Archean to modern, although most are Jurassic and younger; porphyry deposits in Precambrian terranes are rare. Nevertheless, several porphyry-type Cu or Au deposits occur in the Superior Craton of Canada, and in the South West Terrane of the Yilgarn Craton, suggesting that their potential in Archean cratons may not be fully recognised.

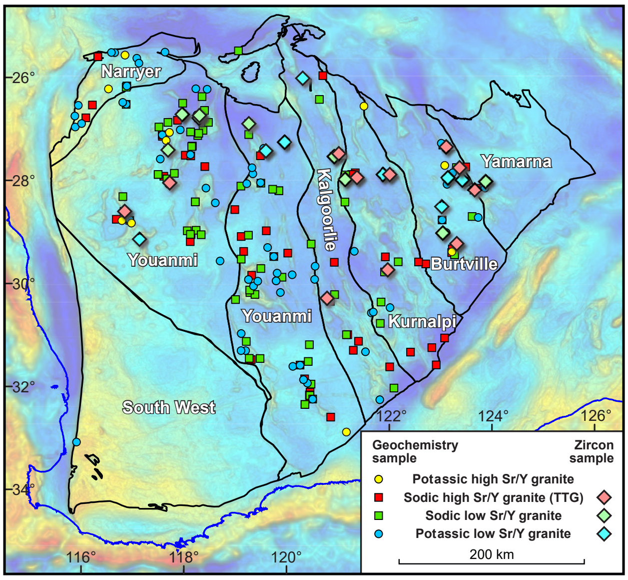


Figure 1. Granite whole-rock and zircon sample locations superimposed on a gravity image of the Yilgarn Craton, labelled by terrane.

In Phanerozoic porphyry Cu systems, mineralised magmatic rocks have distinctive chemical fingerprints, including high Sr/Y, V/Sc, Eu/Eu*, and (Eu/Eu*)/Y ratios. Zircons in these rocks also have distinctive compositions, such as higher Eu/Eu* ratios. These signatures can be attributed to high magmatic water and sulfur contents and high oxidation states and can be used as indicators of ore fertility.

To test whether these fertility indicators can be applied to Archean granitic rocks across the Yilgarn Craton, we have compiled GSWA geochronology and geochemistry data for 230 unaltered and non-mineralised granites. The granitic rocks are divided into four groups (Fig. 1).

We also examined >2000 trace element analyses of zircons from 42 Yilgarn granite samples (Fig. 1).

We compared Yilgarn granites with well-characterised hydrous and oxidised Miocene Cu-mineralised granites in southern Tibet. The Tibetan granites crystallised from very hydrous magmas with >10 wt% water contents at depth, resulting mainly from high-pressure differentiation of hydrous mafic melts of Tibetan mantle.

Figure 2a shows that neither hydrous melting nor dehydration melting of mafic lower crust can produce melts with Mg# >50. Tibetan granites typically have Mg# >50 (Fig. 2a), consistent with input of primary mafic magmas through magma mixing. In contrast, most Yilgarn granites have Mg# <50, suggesting derivation mainly through crustal melting with limited mantle input.

Yilgarn high-Sr/Y granites are moderately- to strongly oxidised, whereas low-Sr/Y granites are moderately reduced to strongly oxidised (Fig. 2b). Tibetan Cu-mineralised granites are mainly strongly oxidised and tend to have higher Fe_2O_3/FeO at a given FeO_{total}, suggesting that Tibetan granites are generally more oxidised (Fig. 2b).

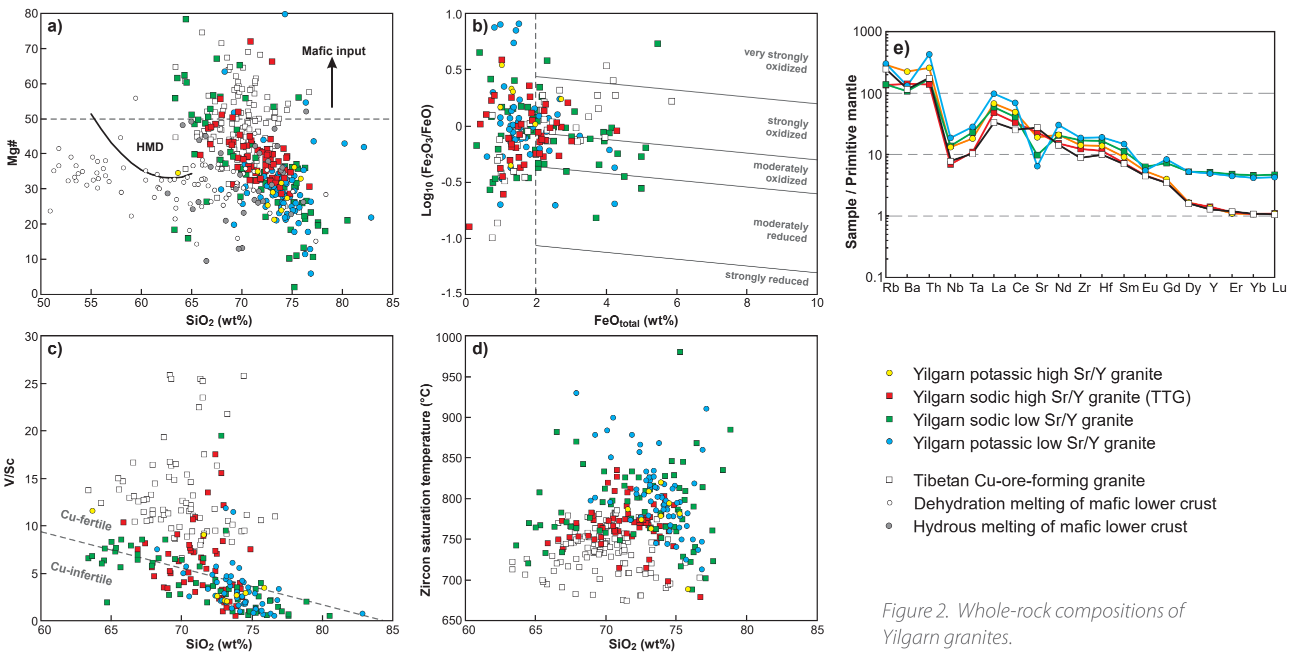


Figure 2. Whole-rock compositions of Yilgarn granites.

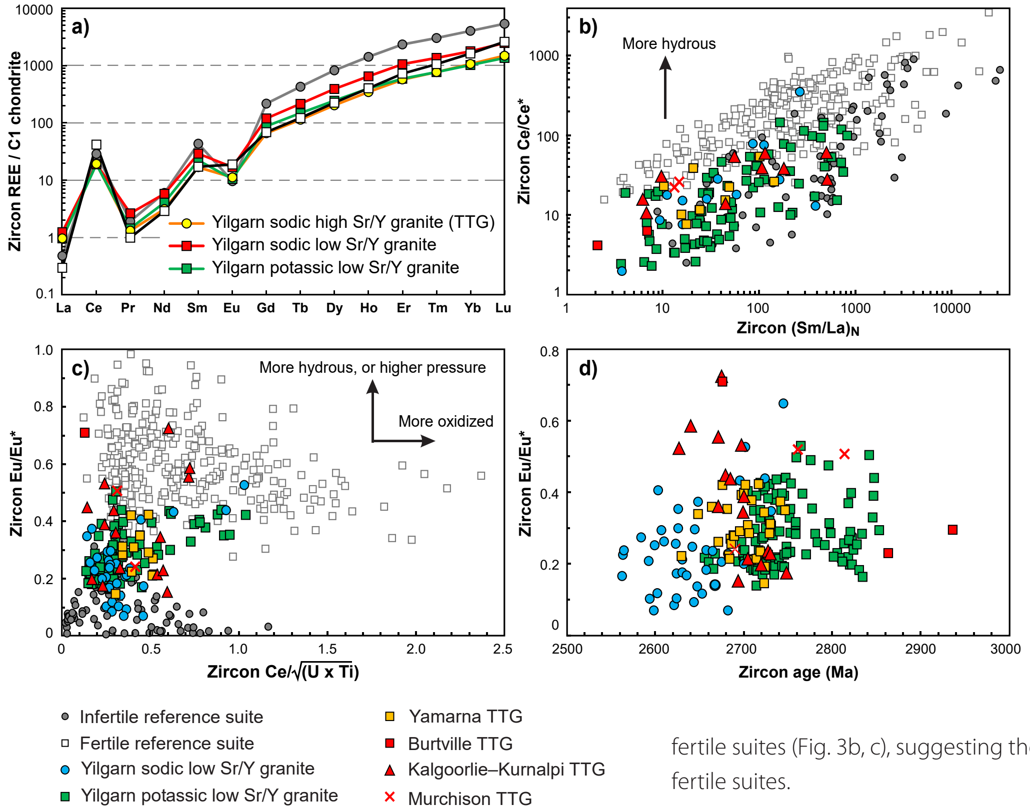


Figure 3. Compositions of zircons from Yilgarn granite.

Most Yilgarn granites plot in the Cu-infertile field in a diagram of V/Sc vs SiO_2 (Fig. 2c), whereas all Tibetan Cu-mineralised granites plot in the Cu-fertile field. High V/Sc is caused by amphibole fractionation, which removes Sc, and by suppression of magnetite fractionation, which increases V in an oxidised and hydrous melt. The average V/Sc ratio for each group of Yilgarn granites is significantly lower, suggesting that Yilgarn granites are less fertile than Tibetan granites because the former are generally less oxidised and less hydrous. Zircon saturation temperatures indicate that Yilgarn granites crystallised at higher temperatures than Tibetan granites (Fig. 2d), which also suggests the magmas were less hydrous.

The trace-element patterns of Yilgarn high-Sr/Y and low-Sr/Y granites are distinctly different (Fig. 2e). High-Sr/Y granites are characterised by an absence of Sr and Eu anomalies, and depletion in heavy rare earth elements (HREE). Yilgarn low-Sr/Y granites have significant negative Sr and Eu anomalies and elevated HREE concentrations (Fig. 2e). These features suggest that Yilgarn high-Sr/Y granites were derived from high-pressure melting of mafic crust within the garnet stability field, whereas low-Sr/Y granites originated mainly from low-pressure melting of crust within the plagioclase stability field. Tibetan Cu-mineralised granites have similar HREE patterns to the Yilgarn high Sr/Y granites, but are more enriched in Sr and depleted in Zr (Fig. 2e), consistent with their derivation from high-pressure differentiation of more hydrous melts.

We also compared trace-element compositions of zircon in Yilgarn granites with those of reference suites from infertile and fertile granites. The zircon REE patterns of Yilgarn granites are similar to both Phanerozoic fertile and infertile suites (Fig. 3a). However, Yilgarn granites have consistently lower zircon Ce/Ce* and Eu/Eu* than Phanerozoic fertile suites (Fig. 3b, c), suggesting they were less hydrous than fertile suites.

Zircon Ce/√(U x Ti) was recently proposed as a proxy for magma oxidation state. Values for Yilgarn granites are lower than those for Phanerozoic fertile suites and similar to those of infertile suites. This also suggests that Yilgarn granites are less oxidised than Cu-fertile granites (Fig. 3c), and this is consistent with interpretations from whole-rock Fe_2O_3/FeO data (Fig. 2b).

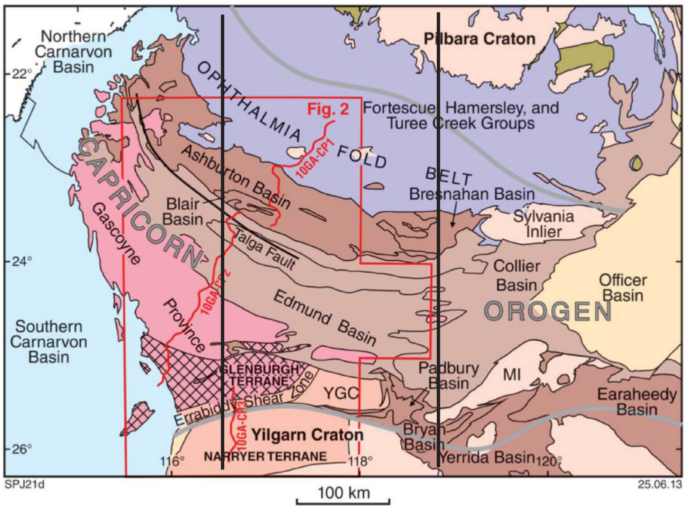
Both whole-rock and zircon compositions indicate that many Yilgarn granites are less hydrous and less oxidised than Phanerozoic Cu-mineralised granites. The systematic difference in zircon chemistry between Archean granites and Phanerozoic fertile and infertile suites suggests that different processes were involved in forming Archean granites. We argue that Archean high-Sr/Y granites were formed mainly through intracrustal partial melting of mafic lower crust in the garnet stability field, whereas Phanerozoic fertile suites were formed by intracrustal amphibole-dominated fractionation of mafic magmas. Granites formed by the former process have lower potential for porphyry Cu mineralisation due to insufficient water and the absence of copper and sulfur accumulation in the melt.

This project is part of CCFS theme 2, Earth's Evolution, and contributes to understanding Earth's Architecture.

Contacts: Yongjun Lu, Hugh Smithies, Michael Wingate, Noreen Evans, Paul Morris, David Champion, Cam McCuaig
Funded by: CCFS Flagship Program 7

Seismic image of the Capricorn Orogen – Revealing the mantle component

The Proterozoic Capricorn Orogen in central Western Australia (Fig. 1) records the collisions of the Archean Pilbara and Yilgarn Cratons to form the West Australia Craton during two stages of Paleoproterozoic orogeny: 1) the 2.21-2.14 Ga Ophthalmian



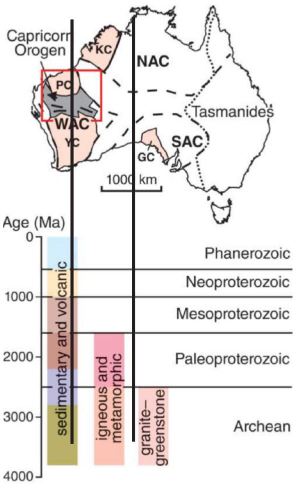


Figure 1. Tectonic map of the Capricorn Orogen modified from Johnson et al. (2013). Black N-S lines are the seismic transects shown in Figure 3.

Orogeny, when the Glenburgh Terrane, a microcontinent between the Pilbara and Yilgarn, first collided with the Pilbara Craton; 2) the 2.00-1.95 Ga Glenburgh Orogeny, when the combined Pilbara Craton/ Glenburgh Terrane further collided with the Yilgarn Craton to form the West Australia Craton. After the final assembly, the Capricorn Orogen was affected by more than 1 billion years of episodic intracontinental reworking and reactivation processes.

To evaluate how these tectonic processes have imprinted the orogenic lithosphere, and thus shed light on the dynamics of early continental collision and stabilisation, we conducted a finite-frequency body-wave tomographic study, taking advantage of the new data recorded by a portable seismic array COPA (Capricorn Orogenic Passive-source Array, part of the SIEF program, Distal Footprint of Gigantic Ore systems - a Capricorn Case Study), which has been in the field since April 2013. We were able to extract travel-time information from 486 teleseismic events. We also incorporated data recorded during earlier field campaigns conducted by ANU.

Our provisional tomographic model reveals the following intriguing observations: 1) the Capricorn orogen is imaged clearly as a significant low-velocity anomaly, extending downwards to nearly 250 km depth, rather than a more typical high-velocity cratonic root. The low velocity may reflect the effects of punctuated lithospheric reworking and reactivation during the cratonisation processes; 2) the Glenburgh Terrane is underlain by a high-velocity anomaly ~150 km thick; 3) the northern edge of the Yilgarn Craton is characterised by a high-velocity anomaly that extends northwards to ~300 km depth beneath the Capricorn Orogen; and 4) the tomographic model captures likely remnant subducted slab pieces which are now part of the cratonic lithosphere.

This project is part of CCFS themes 1, 2 and 3, Early Earth, Earth's Evolution and Earth Today, and contributes to understanding Earth's Architecture.

Contacts: Xiaobing Xu, Liang Zhao, Huaiyuan Yuan

Funded by: CCFS Flagship Program 7

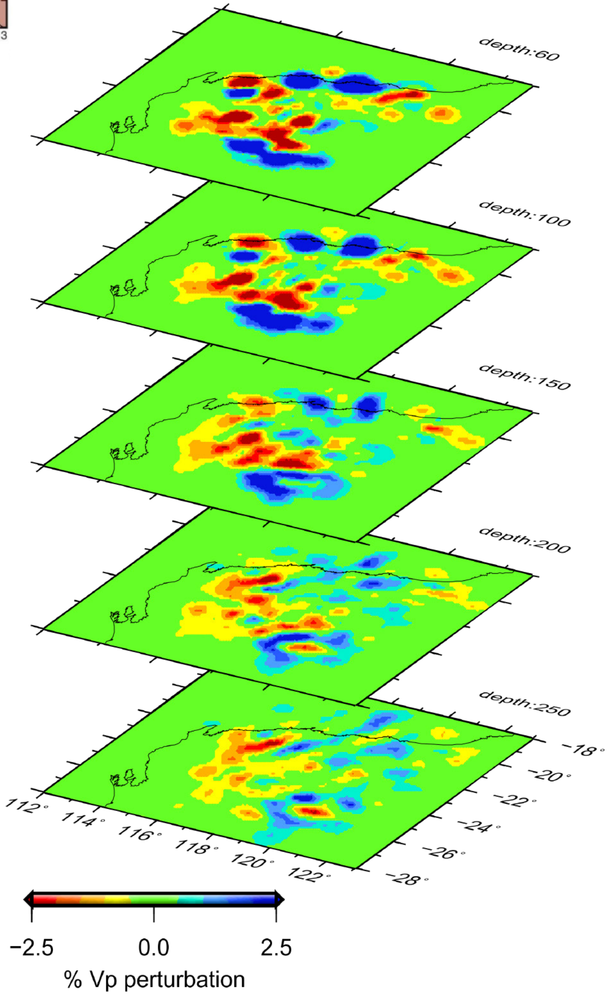
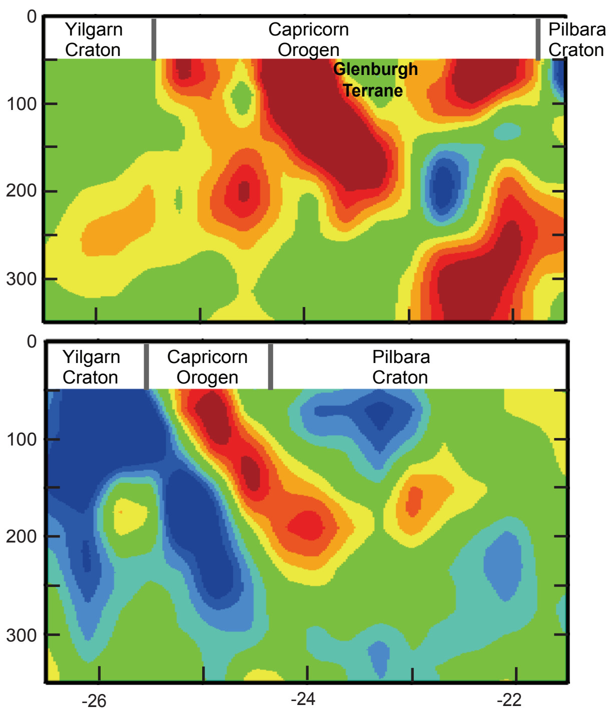


Figure 2. Map views of the preliminary P-wave velocity model.



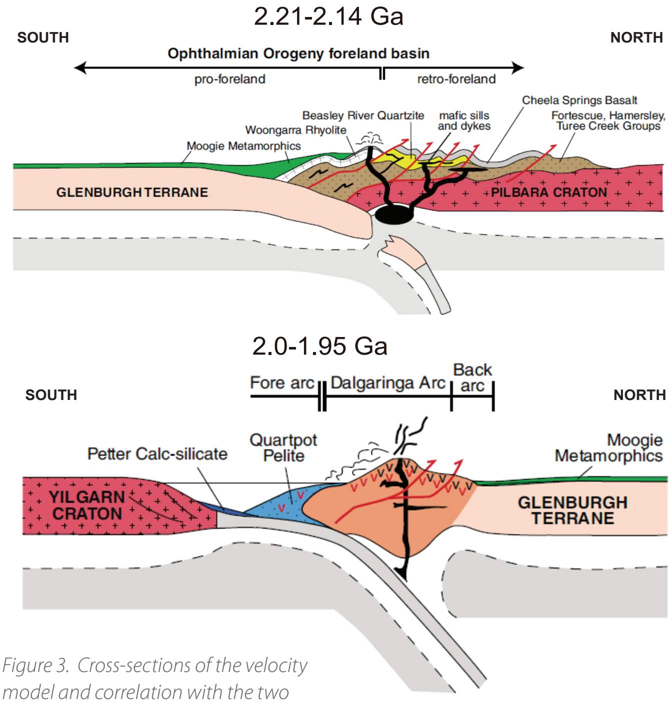


Figure 3. Cross-sections of the velocity model and correlation with the two Paleo-Proterozoic orogenies.

New petrogenetic model for the adakitic magmatism of Patagonia and the Austral Volcanic Zone

The *'Adakites'* from the Patagonian Cordillera and the Austral Volcanic Zone (AVZ) on the southwest margin of South America are widely regarded as true slab-melts, rare on Earth. These differ from ordinary calc-alkaline arc andesites and dacites by steeper REE patterns with low concentrations of HREE and Y, and high values of Mg#, Cr, Ni, and Sr for SiO_2 contents mainly in the range 56-63 wt%. The steep REE patterns have been interpreted as evidence for partial melting of eclogite in the subducting plate, by analogy with the *'adakites'* on Adak Island in the central Aleutian arc. However, an alternative interpretation of the type *'adakite'* by petrogenesis differentiation of hydrous magmas at high pressure and temperature is suggested by: 1) recognition of xenolith suites as cognate cumulates; 2) seismic evidence of a slab-mantle interface to at least 270 km depth under the central Aleutians, which means that slab temperature is less than 650°C under the volcanic front, too cool to be melted; and 3) along-arc variations of tectonic stress. This project will explore this alternative interpretation in the Plio-Holocene volcanic centres of the AVZ, as well as the mid-Miocene Patagonian *'adakites'*.

Why Patagonia? The western margin of Patagonia has experienced the subduction of the Chile Rise since ~22 Ma. A series of adakitic igneous complexes is correlated with the

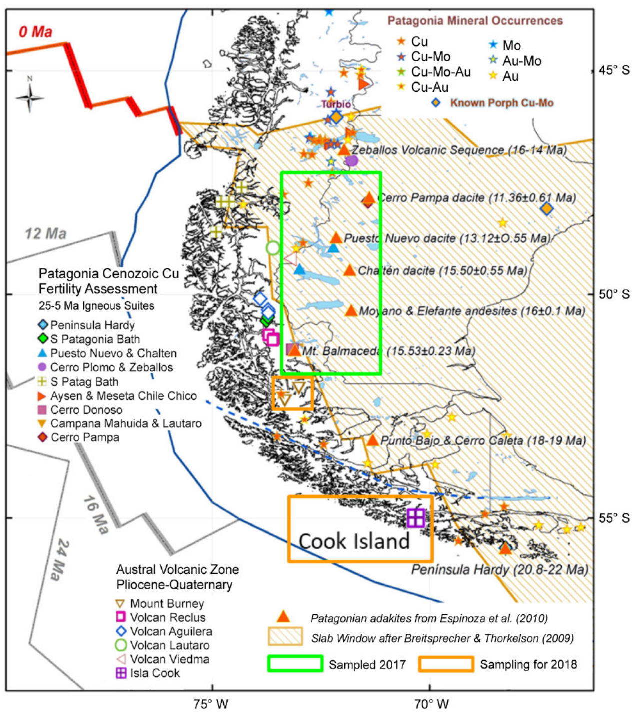


Figure 1. Distribution of the Miocene Patagonian Adakites and the Austral Volcanic Zone with Sampling Locations in this project.

northward-propagating compressive deformation wave, which seems to be associated with the young, warm and buoyant southern part of the subducted Nazca Plate. On the other hand, all six Holocene volcanic centres of the Andean AVZ (49-54°S), associated with subduction of the Antarctic Plate under the South American and Scotia Plates, have erupted exclusively adakitic andesites and dacites. The presence of these two

Gonzolo Henriquez enjoying the magnificent views during fieldwork in the Cerro Moyano, Patagonia - Argentina (Photo: Mario Coloma).

scenarios in one tectonic setting makes Patagonia a perfect location to understand the genesis of adakitic magmas.

The project integrates whole-rock geochemistry with U-Pb dating and trace-element analysis of zircons (*in situ* and detrital). Cathodoluminescence (CL) images will be used to search unzoned cores in zircon grains, which could imply deep, slow crystallisation of the plutonic rocks. We also will perform Al-in-hornblende (EPMA) barometry on hornblende phenocrysts in host rocks and plutonic enclaves at the CMCA (UWA).

Rock and stream sediments were taken from 5 mid-Miocene igneous centres, during 2017 in Patagonia (Chile and Argentina). Zircon separation and CL Imaging and geochemical sample preparation have already been done at the School of Earth Sciences and the CMCA (UWA). Over 2000 zircon LA-ICP-MS analyses were performed at QUT to November 2017, in addition to 15 whole-rock analyses (LabWest, Perth). Field work in 2018 will sample 2 adakitic volcanoes from the AVZ.

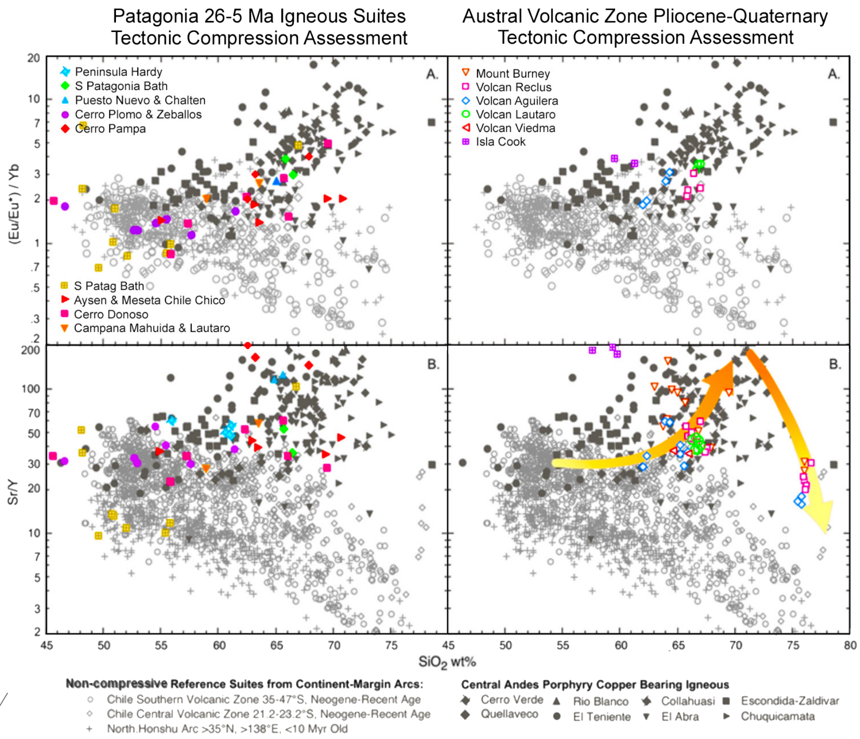


Figure 2. High-pressure magmatic evolution of Patagonian Igneous Centres exposed by use of Sr/Y and (Eu/Eu)/Yb ratios. Over ~400 geochemical analyses from the Patagonian region were compiled from literature and added to Robert Loucks' Global Data Base, according to 3 main criteria: Sr/Y > 35 and/ or (Eu/Eu*)N/YbN > 1.9 and SiO_2 > 57 wt%.*

This project is part of CCFS theme 2, Earth's Evolution, and contributes to understanding Earth's Architecture and Fluid Fluxes.

Contacts: Gonzalo Henriquez, Marco Fiorentini, Bob Loucks

Funded by: CCFS Flagship Programs 2 and 3

CCFS postgraduates

MASTERS OF RESEARCH, MQ

From 2013, the honours program at Macquarie University was replaced by a two-year Masters of Research (MRes) combining advanced coursework with research training to better prepare research students for further postgraduate study. The MRes aligns Macquarie's HDR program with those of many international universities and allows for a smoother transition into international postgraduate programs. From 2014, the MRes or equivalent is the prerequisite for enrolling in Macquarie's postgraduate research (PhD) program. This change fulfils one of the CCFS goals - introducing high-level postgraduate coursework units.

COMPLETED 2017

Christopher Corcoran: The relationship between crystal-plastic deformation and chemical variation in peridotites

Michael Farmer: Migmatite delineates zones of melt flux through the upper crust, Wongwibinda, NSW

Lucas Gamertsfelder: A Compressible formulation for multiphase flows of geophysical and geodynamic interest

Byron Gear: A Preliminary Thermochemical Model of the Australian Lithosphere

Mitchell Gerdes: Amphibole and magma evolution: Insights from composite xenoliths from Batan Island, Philippines

Hindol Ghatak: Distinguishing hydration in shear zones by aqueous fluid versus silicate melt

Morgan Stewart: Determining the self-diffusion coefficient of iron under mantle conditions

CONTINUING 2018

Angela Mabee: Unravelling the circumpolar current in the earth

Cameron Brown: The geomechanics of granular asteroids

SUBMITTED 2017

Omar Elkhaligi: Olivine trace element geochemistry of volcanics from central and southern Africa

Anthony Finn: Tracing shallow lateral preferential pathways of fluid movement using electrical geophysics

Tasman Gillfeather-Clark: The electrical properties of the Woodroffe Thrust: A resistive shear zone

Harrison Jones: Geophysical signatures of small-scale base metal occurrences in southeastern NSW

Carla Raymond: Mummification unwrapped: investigating an Egyptian votive mummy using novel, non-invasive archaeometric techniques

Luke Smith: Precision positioning in unmanned aerial geophysics

Alexander Tunnadine: Fingerprinting the source of mineralising fluids in IOCG systems, Mount Woods Inlier

Harry West: Metal-silicate-sulfide segregation within the Yaringie Hill Meteorite

Haoming Wu: Constraining crustal and sedimentary structure of Southeast Australia with Rayleigh wave ellipticity

Victoria Elliott: Zircon growth and modification during deep melt flux through a magmatic arc

Jean-Antoine Gazi: Evolution of small planetary bodies: A view from carbonaceous chondrites

COMMENCING 2018

Michael Alderson: Chemical and isotopic vectors to Ag Pb mineralisation at the Bowden ore deposit

Benjamin Alsop: Melt rock interactions in the Pembroke Valley New Zealand

Thomas Connell: Geophysical application of approximate bayesian computation

Joyjit Dey: The microchemical and microstructural evolution of fluid and melt transfer in deep crustal shear zones

Stephanie Hawkins: Rifting and the Sydney Basin: Did it produce igneous rocks?

Joshua Shea: Trace elements in olivine in volcanic rocks in Eastern Australia

Alice Van Tilburg: Magnetotellurics in the crust

Master of Research student Ben Alsop with Nathan Daczko and Stephen Foley examining geological processes occurring in the deep (40 km) roots of a magmatic arc (Photo: Tom Raimondo, University of South Australia).

CCFS POSTGRADUATES

CCFS postgraduate students include those already in progress in 2011 with projects relevant to CCFS Research Themes, as well as those who commenced in 2012-2017. 42 papers with CCFS postgraduates as authors were published in high-profile international journals in 2017, including *Scientific American, Nature Communications, Gondwana Research, Tectonophysics, Special Papers GSA, Precambrian Research, Earth and Planetary Science Letters, Geology, Lithos, Ore Geology Reviews* and *Chemical Geology*. 73 presentations were also given at international conferences (see *Appendix 6*).

2017 HIGHLIGHTS

Stefano Caruso received a Society of Economic Geology, Student Research Grant from the McKinstry Fund for mining and economic geology.

Nora Liptai was awarded a PGRF grant to attend the 2017 Goldschmidt Conference in Paris.

The Vice Chancellor's Commendation was awarded to **Beñat Oliveira** for his PhD Thesis *"Multicomponent and multiphase reactive flows in the Earth's mantle"*.

Liene Spruzeniece was selected as one of only two Australian representatives to attend the European Workshop on Modern Development and Applications in Microbeam Analysis in Konstanz, Germany. Her participation was sponsored by an Early Carrier Scholarship from the European Microbeam Analysis Society.

The winners of this year's HDR poster competition at the CCFS Whole of Centre Meeting were **Constanza Manassero** and **Enjoo Choi**. Honourable mentions went to **Rosanna Murphy**, **Nora Liptai** and **Cait Stuart**.

COMPLETED

Bataa Baatar (MSc): Fertility of the Lock Lilly Belt for porphyry Cu-Au mineralisation - constraints from whole-rock chemistry and zircon studies (UWA 2017)

Raphael Baumgartner (PhD): Ore deposits of the future; magmatic Ni-Cu-PGE sulfide mineral systems on Mars (UWA 2017) See *Research highlight pp. 58-60.*

Rachel Bezard (PhD): Impact of crustal assimilation on the Lesser Antilles arc lava geochemistry (MQ 2014)

Katarina Bjorkman (PhD): 4D lithospheric evolution and controls on mineral system distribution: Insights from Marmion Terrane, Western Superior Province, Canada (UWA, 2017)

Eleanore Blereau (PhD): Petrochronology of the Ultrahigh-Temperature (UHT) Metamorphic Rogland–Vest Agder Sector, Southwestern Norway (CU 2017)

Lauren Burley (MSc): The geology of the Fisher East komatiite-hosted nickel sulfide deposit (UWA 2015)

Montgarri Castillo-Oliver (PhD): Compositional evolution of indicator minerals: Application to diamond exploration (MQ 2016)

David Child (PhD): Characterisation of actinide particles in the environment for nuclear safeguards using mass spectrometric techniques (MQ 2016)

David Clark (PhD): Integrated magnetics: Contributions to improved processing and interpretation of magnetic gradient tensor data, new methods for source location and estimation of magnetisation, and predictive magnetic exploration models (MQ 2014)

Bruno Colas (PhD): Structural constraints on the crystallisation of Amorphous Calcium Carbonate (MQ 2017)

Jane Collins (PhD): The structural evolution and mineralisation history of the Flying Fox komatiite-hosted Ni-Cu-PGE sulfide deposit, Forrestania Greenstone Belt, Western Australia (UWA 2013)

Stephen Craven (PhD): The evolution of the Wongwibinda Metamorphic Complex, New England Orogen, NSW, Australia (MQ 2016)

Daria Cyprych (PhD): Deformation behaviour of polymineralic rocks: implications for rheology and seismic properties of the middle to lower crust (MQ 2017)

Cara Danis (PhD): Geothermal state of the Sydney-Gunnedah-Bowen Basin system (MQ 2012)

Tara Djokic (MPhil): Assessing the link between Earth's earliest convincing evidence of life and hydrothermal fluids: The c. 3.5 Ga Dresser Formation of the North Pole Dome, Pilbara Craton, Western Australia (UNSW 2015)

Timmons Erickson (PhD): Deformation microstructures in zircon and monazite: implications for shock, tectonic and geochronological studies (CU 2017)

Christopher Firth (PhD): Elucidating magmatic drivers and eruptive behaviours of persistently active volcanoes (MQ 2016)

Fiona Foley (PhD): Magmatic consequences of subduction initiation and its role in continental crust formation (MQ 2013)

Denis Fougerouse (PhD): 4D geometry and genesis of the Obuasi gold deposit, Mali (UWA 2016)

Yuya Gao (PhD): Origin of A-type granites in East China: Evidence from Hf-O-Li isotopes (MQ 2015)

Robyn Gardner (PhD): Flow behaviour of the middle and lower crust: Insights from field observations and numerical modelling (MQ 2017)

Sue O'Reilly and Bill Griffin celebrating with CCFS PhD graduates Robyn Gardner and Romain TIlhac.

Rongfeng Ge (PhD): Precambrian to Paleozoic tectono-thermal evolution in the Korla area, northern Tarim Craton, NW China (CU 2015)

Markus Gogouvitis (MSc): Distinguishing hydration in Shear Zones by Aqueous Fluid versus Silicate Melt (UNSW 2017)

Felix Genske (PhD): Assessing the heterogeneous source of the Azores mantle plume (MQ 2013)

Christopher Gonzalez (PhD): CO_2 devolatilisation and its influence on partial melting, subduction, and metasomatism in the mantle lithosphere (UWA 2016) See *Research highlight p. 63.*

Erin Gray (PhD): Deformation of Earth's upper mantle: insights from naturally occurring fabric types (UWA 2014)

Christopher Grose (PhD): Thermochemical models of oceanic upper mantle (MQ 2015)

Celia Guergouz (MSc): Study of the dynamic emplacement of Nickel mineralisation, as well as the geodynamics of the lithosphere (UWA/Nancy 2014)

Matthew Hill (PhD): 4D structural, magmatic and hydrothermal evolution of the Au-Cu-Bi system in the Tennant Creek Mineral Field, NT, Australia (UWA 2015)

Yosuke Hoshino (PhD): Investigation of hydrocarbon biomarkers preserved in the Fortescue Group in the Pilbara Craton, Western Australia (MQ 2015)

Jin-Xiang Huang (PhD): Origin of eclogite and pyroxenite xenoliths in kimberlites and basalts (MQ 2012)

Huiqing Huang (PhD): The petrogenesis of Jurassic granitic rocks in Western Nanling Ranges of South China and tectonic implications (CU 2013)

Linda Iaccheri (PhD): Petrogenesis of granitic rocks in the Granites-Tanami Orogen (UWA 2017)

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 (UWA 2015)

Ms Inalee Jahn (PhD): Crustal evolution of the Capricorn Orogen, Western Australia (CU 2017)

Chengxin Jiang (PhD): Combining seismic tomography and sedimentology to understand the deep structure and evolution of the northern edge of Tibetan Plateau (MQ 2016)

Erwann Lebrun (PhD): 4D structural modelling and hydrothermal evolution of the sediment hosted Siguiri gold deposit (Guinea) and implication on Paleoproterozoic gold targeting in West Africa (UWA 2015)

Margaux Le Vaillant (PhD): Characterisation of the nature, geometry and size of hydrothermal remobilisation of base metals and platinum group elements in magmatic nickel sulfide deposit systems. Implications for exploration targeting (UWA 2015)

Ben Li (PhD): Evolution of fluid associated with gold mineralisation in the Paleoproterozoic Granites-Tanami Orogen (UWA 2015)

Shan Li (PhD): Early Mesozoic magmatism and tectonics in the Beishan area of Inner Mongolia, China (CU 2013)

Li-Ping Liu (PhD): Timing and kinematics of Mesozoic-Cenozoic mountain building and cratonic thinning in eastern North China: a combined structural and thermochronological study (CU 2015)

Yingchao (Leo) Liu (PhD): Recognising gold mineralisation zones using GIS-Based modelling of multiple ground and airborne datasets (CU 2015)

Yongjun Lu (PhD): Controls on porphyry emplacement and Porphyry Au-Cu mineralisation along the Red River Fault, Hunan Province, China (UWA 2012) See *Research highlights pp. 60-61, 62-63, 70-71.*

Volodymyr Lysytsyn (PhD): Mineral prospectivity analysis and quantitative resource assessments for exploration targeting-development of effective data integration models and practical applications (UWA 2015)

Jelena Markov (PhD): 3D geophysical interpretation of the Archean-Paleoproterozoic boundary, Leo-Man Shield, West Africa (UWA 2015)

Quentin Masurel (PhD): Controls on the genesis, geometry and location of the Sadiola-Yatela Gold Deposit, Republic of Mali (UWA 2016)

Nicole McGowan (PhD): Messages from the mantle: Geochemical investigations of ophiolitic chromites (MQ 2017)

Vicky Meier (PhD): Metamorphic evolution of the Kerala Khondalite belt, India (CU, 2016)

Kombada Mhopjeni (MSc): Investigating the uranium potential in Namibia using GIS-based techniques (UWA 2013)

David Mole (PhD): Quantifying melt-lithosphere interaction in space and time: understanding nickel mineral systems in the Archaean Yilgarn Craton (UWA 2013)

Melissa Murphy (PhD): A novel approach for economic uranium deposit exploration and environmental studies (MQ 2013)

Rosanna Murphy (PhD): Stabilising a craton: The origin and emplacement of the 3.1 Ga Mpuluzi Batholith (MQ 2015)

Antoine Neaud (MSc): The geology of the Savannah nickel sulfide deposit, Western Australia (UWA 2016)

Jiawen Niu (MPhil): Neoproterozoic paleomagnetism of South China and implications for global geodynamics (CU 2016)

Beñat Oliveira Bravo (PhD): Multicomponent and multiphase reactive flows in the Earth's mantle (MQ 2017) See *Research highlight p. 51.*

Chongjin Pang (PhD): Basin record of Mesozoic tectonic events in South China (CU 2014)

Matthew Pankhurst (PhD): Geodynamic significance of shoshonitic magmatism within the Andean Altiplano (MQ 2013)

Luis Parra-Avila (PhD): 4D evolution of felsic magmatic suites and lithospheric architecture of the Paleoproterozoic Birimian terranes, West Africa (UWA 2016) *Research highlights pp. 60-61, 62-63.*

Carl Peters (PhD): Deep time biomarkers - A study of organic matter and fluid inclusions in Precambrian rocks (MQ 2017)

Jonathon Poh (MSc): Numerical investigation of the driving forces of Archean fluid and heat transfer flows (UWA 2015)

Ekaterina Rubanova (PhD): Fluid processes in the deep mantle: Geochemical studies of diamonds and related minerals (MQ 2013)

James (Ed) Saunders (PhD): The nature, abundance and mobility of gold in the mantle (MQ 2014)

Elyse Schinella (PhD): Constraining the contribution of isostasy and dynamic uplift at Venusian volcanic rises and tessera terrain: implications for rifting and volcanism (MQ 2014)

Vikram Selvaraja (PhD): Multiple sulfur isotopes as a tracer of geological processes (UWA 2017) See *Research highlight p. 43.*

Liene Spruzeniece (PhD): Fundamental link between deformation, fluids and the rates of reactions in minerals (MQ 2017)

Jack Stirling (MSc): Geochronology of lower crustal cumulate complexes in the Kohistan Terrane, North-East Pakistan (UWA 2017)

Mingdao Sun (PhD): Late Mesozoic magmatism and its tectonic implication for the Jiamusi Block and adjacent areas of NE China (CU 2013)

Rajat Taneja (PhD): The origin of seamount volcanism in the Northeast Indian Ocean (MQ 2015)

Ni Tao (PhD): Thermochronological record of tectonic events in central and southeastern South China since the Mesozoic (CU 2015)

Romain Tilhac (PhD): Petrology and geochemistry of pyroxenites from the Cabo Ortegal Complex, Spain (MQ 2017) See *Research highlights pp. 47, 51.*

Mehdi Tork Qashqai (PhD): Multi-observable probabilistic inversion for the thermochemical structure of the lithosphere (MQ 2017) *Pictured left with Sue O'Reilly*

Irina Tretiakova (PhD): The nature, extent and age of the lower crust and underlying subcontinental lithospheric mantle (SCLM) beneath the Siberian Craton (Russia) (MQ 2017)

Zoja Vukmanovic (PhD): A micromechanical and geochemical analysis of remobilisation of komatiite-hosted Ni sulfide ores (UWA 2013)

Qian Wang (PhD): A geological traverse across the Jack Hills Metasedimentary Belt, Western Australia: isotopic constraints on the distribution of Proterozoic rocks and the evolution of Hadean crust (CU 2015)

Yu Wang (PhD): Melting process in recycled continental crust (MQ 2015)

James Warren (PhD): 4D evolution of the Ora Banda and Coolgardie Domains (UWA 2016)

Jun Xie (PhD): Verification and applications of surface waves extracted from ambient noise (MQ 2017)

Qing Xiong (PhD): Shenglikou and Zedang peridotite massifs, Tibet (China): Upper mantle processes and geodynamic significance (MQ 2015)

Weihua Yao (PhD): Lower Paleozoic basin record in southern South China: Nature of the Cathaysia basement and evolution of the Wuyi-Yunkai Orogeny (CU 2014)

Yao Yu (PhD): The evolution and water inventory of the subcontinental lithospheric mantle: A new perspective from peridotite xenoliths (SE China) and zircon megacrysts from basalts (MQ 2014)

Qingtao Zeng (PhD): Regional controls on gold mineral systems in the western Qinling Belt, Gansu Province, China (UWA 2013)

Ganyang Zhang (PhD): Sb-Au mineralisation mechanism and exploration targeting prediction research in the Northern Himalaya Metallogenetic Belt, Tibet, China (UWA 2013)

Jianwei Zi (PhD): Igneous petrogenesis and tectonic evolution of Cretaceous plutons, eastern Tibetan Plateau (UWA 2013)

Kongyang Zhu (PhD): Petrogenesis and tectonic setting of Phanerozoic granitic rocks in eastern South China (CU 2014)

CONTINUING

Arash Amirian (PhD): Quantitative determination of the amount and location of water in the Earth; *iRTP* (MQ, commenced 2017)

Sonia Armandola (PhD): Palaeo- to Mesoproterozoic structural and metamorphic evolution of NE Australia and implications for the assembly of the supercontinent Nuna: Multi-scale analytical approach to decrypt ancient signatures; *CIPRS* (CU, commenced 2016)

David Barbosa da Silva (PhD): The microchemical and microstructural evolution of fluid and melt transfer in deep crustal shear zones; *iMQRES* (MQ, commenced 2016)

Erica Barlow (PhD): Microfossils of the Paleoproterozoic Turee Creek Group: Biological evolution resulting from atmospheric change?; *RTP* (UNSW, commenced 2015) *Pictured left: CCFS Whole-of-Centre Meeting*

Hugh Bannister (MPhil): Adaptive response of the biosphere to Paleoproterozoic glaciations at the Great Oxygenation Event; *FP4* (UNSW, commenced 2016)

Jason Bennett (PhD): The *in situ* microanalysis of cassiterite to constrain the genesis, evolution and geochronology of tin bearing mineralised systems; *RTP* (UWA, commenced 2015)

Richard Blake (MPhil): Determining recent organic contamination in ancient rocks; *FP4* (UNSW, commenced 2015)

Raul Brens Jr (PhD): Constraints on petrogenesis and elemental recycling of the Tonga-Kermadec Island Arc system; *iMQRES* (MQ, commenced 2011)

Stefano Caruso (PhD): Geological controls on the fractionation of multiple sulfur isotopes in Archean mineral systems; *SIRF & MRIWA Postgraduate Scholarship* (UWA, commenced 2015) See *Research highlight p. 43.*

Julian Chard (PhD): Petrochronology of accessory minerals related to metamorphism and fluid-flow events in the Albany-Fraser Orogen and Eucla basement, Western Australia; *CIPRS* (CU, commenced 2016)

Mathieu Chassé (PhD): Geochemical and crystal-chemical processes of scandium enrichment from the mantle to lateritic contexts; *CTIMRTPS* (MQ, submitted 2017)

Eunjoo Choi (PhD): Alkaline magmatism as a probe into the lithospheric mantle; *IRPT, MRIWA* (UWA, commenced 2016)

Gregory Dering (PhD): Dynamics and emplacement mechanisms of mafic magma networks with implications for intrusion-hosted magmatic Ni-Cu-PGE sulfide deposits; *APA, IPRS* (UWA, commenced 2014) *See Research highlight pp. 42-43.*

Tara Djokic (PhD): Did diverse microbial ecosystems inhabit Paleoarchean terrestrial hot springs?; *APA* (UNSW, commenced 2016) See *Research highlight p. 37.*

Raphael Doutre (PhD): Spatial periodicity, self-organisation and controls on large ore deposits; *International Sponsorship, Teck Resources Ltd* (UWA, submitted 2017)

Katherine Farrow (PhD): *In situ* melt generation and thermal origin of the Nagadarunga Granite: Implications for the geochronology and tectonic evolution of the eastern Arunta Region, Central Australia; *RTPT* (MQ, part time, commenced 2014)

Michael Förster (PhD): Earth's Deep Nitrogen Cycle; *IPRS* (MQ, commenced 2016) *Pictured right: EPS Postgraduate seminar*

Hamed Gamal El Die (PhD): Neoproterozoic Oceanic Large Igneous Province (O-LIP) Record and crustal growth of the Arabian-Nubian Shield; *CIPRS* (CU, commenced 2017)

Hindol Ghatak (PhD): Characterising silicate melt flow within lower crustal rocks; *iMQRTP* (MQ, commenced 2017)

Louise Goode (PhD): Volcanological and geochemical evolution of East Javanese volcanoes, Indonesia; *iMRTPS* (MQ, commenced 2014)

Kui Han (PhD): Modelling the physical properties of multiphase rock assemblages; *IRPT* (MQ, commenced 2017)

Michael Hartnady (PhD): Crustal evolution of the Albany-Fraser Orogen; *CIPRS* (CU, commenced 2016) See *Research highlight pp. 48-49.*

Gonzalo Henriquez (PhD): Evaluating zircon morphology and chemistry to rank PCD prospectivity; *Industry - BHP Billiton* (UWA, commenced 2017) See *Research highlight pp. 73-74. Pictured left*

Hadrien Henry (PhD): Mantle pyroxenites: Deformation and seismic properties; *CTIMRTPS* (MQ, commenced 2015) See *Research highlight p. 51.*

Constanza Jara Barra (PhD): Gold pathways: in the El Indio Belt, Chile-Argentina; *Barrick Exploration* (UWA, commenced 2015) See *Research highlight pp. 49-50.*

Kim Jessop (PhD): The role of fluids in HTLP metamorphism; *RTPS* (MQ, submitted 2017)

Jelte Keeman (PhD): Zircon as a tool in provenance and crustal evolution studies; *RTP* (MQ, commenced 2015)

Heta Lampinen (PhD): Defining mineral systems footprints in the Edmund Basin of the Capricorn Orogen; *SIRF, SIEF* (UWA, commenced 2014)

Pablo Lara (PhD): Late Neoproterozoic granitoid magmatism of the southernmost section of the Dom Feliciano Belt in Uruguay: Regional geology, geochemistry, geochronology and its significance for the geotectonic evolution of the region; *iMRTPS* (MQ, part time, commenced 2010) *Pictured above: EPS Postgraduate seminar*

Jiangyu Li (PhD): NE Australia in the supercontinent Nuna; *CIPRS* (CU, commenced 2016)

Guoliang Li (PhD): Joint inversion of multiple seismic data for Basin structures; *iMRTP* (MQ, commenced 2017)

Shaijie Li (PhD): Isotopic dating oil generation and charge events in Canning (Australia) and Sichuan (China); *CIPRS* (CU, commenced 2015)

Nora Liptai (PhD): Geochemical and physical properties and evolution of the lithospheric mantle beneath the Nógrád-Gömör Volcanic Field (Northern Pannonian Basin, Central Europe); *iMQRES, COT* (MQ, commenced 2015) See *Research highlight pp. 65-66.*

Kai Liu (PhD): The tectonic evolution of the paleo-Pacific Ocean in the Eastern Central Asian Orogenic Belt during the Mesozoic: Constraints during magmatism and detrital zircons; *CSC CIPRS* (CU, commenced 2016)

Yebo Liu (PhD): Paleomagnetism of Proterozoic igneous rocks in Australia and East Antarctica: implications for pre-Pangea supercontinents and supercontinent cycle; *CIPRS* (CU, commenced 2015)

Zairong Liu (PhD): Identifying source rocks and oxidation states in southern Australian volcanic rocks; *CTiMRTP* (MQ, commenced 2017) *Pictured right: CCFS Whole-of-Centre Meeting*

Jianggu Lu (PhD): Mantle xenoliths from SE China and SE Australia: Nature and evolution of the lithospheric mantle; *CFIMRTPS* (MQ, submitted 2017)

Maria Constanza Manassero (PhD): Multi-observable probabilistic inversions for the physical state and water content of the continental lithosphere; *iMQRES* (MQ, commenced 2016)

Erin Martin (PhD): Evaluating Neoproterozoic geodynamics using Hf isotopes in zircon; *APA* (CU, commenced 2016)

Samuel Matthews (PhD): Gravity gradient monitoring of CO_2 sequestration in the Otway Basin; *CO_2CRC Scholarship* (MQ, submitted 2017)

Keith McKenzie (PhD): Magnetic and gravity gradient tensors and the application to the analysis of remanence; *RTPT* (MQ, commenced 2015)

Holly Meadows (PhD): Mineral geochemistry, deformation and ore-fluid evolution in the Capricorn Orogen, WA; *CIPRS* (CU, submitted 2017)

Uvana Meek (PhD): Melt metasomatism within the lower crust; *RTPT APA* (MQ, commenced 2016)

Stephanie Montalvo Delgado (PhD): Compositional modification of zircon at the nanoscale; *CIPRS* (CU, commenced 2016)

Jonathan Munnikhuis (PhD): Geochemical and microchemical signatures of mass transfer by disuse porous flow, Finero, Italy; *iRTP* (MQ, commenced 2017)

Stephanie Nichols (PhD): Metasomatic evolution of eclogites and pyroxenites from the Jericho kimberlite, northern Slave craton, Canada; *iMQRTP* (MQ, commenced 2017)

Thusitha Nimalsiri (PhD): Gravity and magnetic response of the Marulan Supersuite, focusing around the Yerranderie Area; *iMRTPS* (MQ, commenced 2016)

Brendan Nomchong (PhD): Paleoenvironmental context of the 2.4 Ga Turee Creek Group, Kazput Syncline, Western Australia; RTP (UNSW, commenced 2017) See *Research highlight p. 52.*

Adam Nordsvan (PhD): Sedimentology and provenance of the NE Australian Proterozoic basins to understand the supercontinent Nuna; *APA* (CU, commenced 2016)

Zsanett Pintér (PhD): The composition of melts in the incipient melting regime; *IMRTPS* (MQ, commenced 2016)

Greg Poole (PhD): Permian magmatism in an early Andean metallogenic belt, Cordillera Frontal, Argentina; *APA* (UWA, commenced 2015)

Valerie Roy (MSc): Hydrogeological and hydrogeochemical study of the Peak Hill-Horseshoe Deposit, Capricorn Orogen to identify mineral system footprints; *RTP* (UWA, commenced 2015)

Farshad Salajegheh (PhD): Probabilistic joint inversion in the spherical coordinate; *RTPT* (MQ, part time, commenced 2014) *Pictured below: CCFS Whole-of-Centre Meeting*

Sarath Patabendigedara (PhD): Developing a geophysical relevant proton conduction model for the upper mantle*; IMRTPS iMQRES/ ANSTO* (MQ, commenced 2016) *Pictured p. 23*

Camilla Stark (PhD): Decoding mafic dykes in the southern Yilgarn Craton: Significance to Australia's position in supercontinent -superplume cycles; *Curtin CIPRS* (CU, commenced 2014)

Georgia Soares (PhD): A moment in time; the exploration of life that flourished after the Great Oxidation event 2.4Ga; *RTP* (UNSW, commenced 2017) See *Research highlight p. 69.*

Catherine Stuart (PhD): Melt migration in the lower crust by porous melt flow; *MQRES* (MQ, submitted 2017)

Dennis Sugiono (PhD): Multiple sulfur Isotope analysis in Kanowna Belle Deposit; *SIRF, Northern Star (Kanowna) Pty Ltd* (UWA, commenced 2017) See *Research highlight p. 43.*

Sahand Tadbiri (MSc): The geometry and kinematics of hydrothermal veins in the c. 3.5 Ga Dresser Formation, North Pole Dome, Western Australia; *FP4* (UNSW, commenced 2015)

Rick Verberne (PhD): Trace element distribution and mass transfer processes in Rutile; *CIPRS* (CU, commenced 2016)

Marina Veter (PhD): Investigating trace elements as indicators of the mode of origin of orthopyroxene in mantle rocks; *IRTPS* (commenced 2017)

Silvia Volante (PhD): Palaeo- to Mesoproterozoic structural and metamorphic evolution of NE Australia and implications for the assembly of the supercontinent Nuna: Multi-scale analytical approach to decrypt ancient signatures; *CIPRS* (CU, commenced 2016) *Pictured right: CCFS Whole-of-Centre Meeting*

Alexander Walker (PhD): Trace elements and sulphur isotope signatures from sulfides in mineralised and unmineralised environments within the Albany-Fraser Orogen, Western Australia; *CIPRS* (CU, commenced 2016)

Chong Wang (PhD): Paleomagnetism of mafic dykes from eastern North China Craton, and implications for Proterozoic paleogeography; *CIPRS* (CU, commenced 2017)

Kai Wang (PhD): Joint inversion of surface waves and body waves from ambient noise seismic interferometry; *iMQRES* (MQ, commenced 2015) See *Research highlight pp. 54-55.*

Jonathon Wasiliev (PhD): Activating the lower mantle: Constraints on deep mantle rheology; *MRTPS* (MQ, commenced 2013)

Shucheng Wu (PhD): The geodynamic setting of the Western Junggar region during the Late Paleozoic: evidence from seismic tomography; *IMRTPS* (MQ, commenced 2015) See *Research highlight pp. 45-46.*

Bo Xu (PhD): Tibetan Plateau Tectonics from Gangdese Granitoids; *CFIMRTPS* (MQ, commenced 2014)

COMMENCING 2018

Marti Burcet (PhD, MQ)

Ananuer Halimulati (PhD, MQ)

Anthony Lanati (PhD, MQ)

Bronwyn Teece (PhD, UNSW)

Infrastructure and technology development

CCFS links three internationally recognised concentrations of analytical geochemistry infrastructure: GEMOC's Geochemical Analysis Unit (Macquarie University, reorganised in 2016 as MQGA) 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, and facilities for experimental mineralogy and petrology are being built up at Macquarie and Curtin.

CCFS/GEMOC INFRASTRUCTURE, LABORATORIES AND INSTRUMENTATION

The analytical instrumentation and support facilities of the Macquarie University GeoAnalytical facilities contain:

- a Cameca SX-100 electron microprobe
- a Zeiss EVO MA15 Scanning electron microscope (with Oxford Instruments Aztec Synergy EDS/EBSD and Horiba HCLUE spectral cathodoluminescence detector)
- Scanning X-ray spectrometer M4 Tornado from Bruecker
- four Agilent quadrupole ICPMS (industry collaboration; two 7500cs; two 7700cx)
- two Nu Plasma multi-collector ICPMS (one decommissioned in June 2015)
- a triple quad (Q3) ICP-MS 8900 (installed December 2017)
- a Nu Plasma II multi-collector ICPMS (installed in June 2015)
- a Nu Attom high resolution single-collector sector field ICPMS
- a Thermo Finnigan Triton TIMS
- a Photon Analyte LSX213nm laser ablation system (installed December 2017)
- two Photon Machines Excite Excimer laser ablation systems
- a Photon Analyte G2 Excimer laser ablation system
- a Photon Machines Analyte198 Femtosecond laser ablation system
- a PANalytical Axios 1kW XRF with rocker-furnace sample preparation equipment
- a Vario El Cube CHNS elemental analyser
- an Ortec Alpha Particle counter
- a New Wave MicroMill micro-sampling apparatus
- a ThermoFisher iN10 FTIR microscope
- a Horiba LABRAM HR Evolution confocal laser Raman microscope
- a 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.

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

This facility was built up to fulfil the vision of providing spatially controlled high-resolution analysis and imaging of trace elements and isotopic abundances *in situ*, analogous to the then routine capabilities of the mature technology of the electron microprobe for major elements in geological materials. This unique vision and approach enabled benchmark technology and *in situ* analytical methodology milestones in GEMOC starting with trace elements in mantle minerals from the mid-1990s, Hf isotopes in zircon from 2000, and Re-Os in mantle sulfides and alloys also from 2000. This distinctive *in situ* approach sparked research into new ways of understanding earth processes and identified GEMOC, then CCFS, as the leading geochemical facility for such applications, and distinguished it from outstanding analytical laboratories that continued to undertake bulk analytical approaches. The new Decadal Plan for Earth Sciences prepared by the Australian Academy of Science National Committee of Earth Sciences has identified the continuation of *in situ* analysis as the preferred direction for geochemical analytical applications for industry and academia over the next 10 years.

This facility is based on *in situ* imaging and microanalysis of trace elements and isotopic ratios in minerals, rocks and fluids. The Facility for Integrated Microanalysis 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*').

The FIM has been in operation since mid-1999. Major instruments were replaced or upgraded in 2002-2004 through the $5.125 million DEST Infrastructure grant awarded to GEMOC, Macquarie University with the Universities of Newcastle, Sydney, Western Sydney and Wollongong as partners. Further enhancement of the facility took place following the award of an ARC LIEF grant in 2010 to integrate the two existing multi-collector inductively-coupled-plasma mass spectrometers (MC-ICPMS) with three new instruments: a femtosecond laser-ablation microprobe (LAM; installed in June 2012); a high-sensitivity magnetic-sector Nu Attom ICPMS (installed in January 2013); an Agilent 7700 quadrupole ICPMS (installed in 2010). In 2012 GEMOC was awarded ARC LIEF funding for a second-generation MC-ICPMS, and a Nu Plasma II was installed in June 2015.

The geochemical facilities operations at Macquarie University were reorganised by the Department of Earth and Planetary Sciences in 2016 without consulting CCFS, and input from CCFS during the subsequent GAU review process, to ensure operational security, was not taken into account. Despite a staff shortfall of three key positions that compromised the functioning of some instruments in 2016, CCFS research staff were able to ensure the continuation of CCFS-GEMOC's unique suite of *in situ* results, the key to many CCFS projects. CCFS continues to work towards ensuring that the full suite of *in situ* analytical capabilities regains its leading edge, that frontline methodology development resumes, and delivery of geochemical datasets for fundamental research and external collaborative programs (including *TerraneChron*®) regains high-level efficiency.

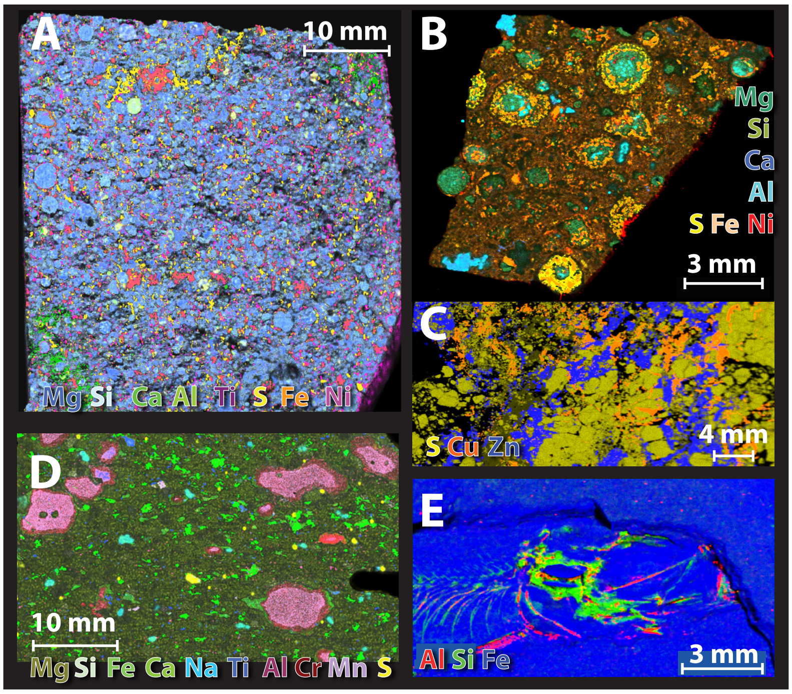


Figure 1. Chemical X-ray maps obtained with the µXRF M4 Tornado (Bruecker). A: Saratov ordinary chondrite (sample O. Alard), unpolished slab. B: Allende (Carbonaceous Chondrite, CV3) thin section (sample O. Alard). C: sulfide bearing rock from Bowden's silver mine deposit, NSW, Australia (MRes project, M. Alderson and T. Murphy). D: Thin section of garnet-bearing peridotite from the Alpe Arami massif, Switzerland. E: Jurassic fossil fish (Cavenderichthys) from Talbragar (submitted manuscript, W.W. Schwarzhans, T. D. Murphy, and M. Frese, J. Vertebrate Paleontology).

EQUIPMENT FOR HIGH-PRESSURE EXPERIMENTATION

The experimental laboratory will be closed between February and December 2018, for renovations and extensions. Upon re-opening, the extended laboratory will include four multi-anvil apparatuses, three piston-cylinder apparatuses (one of them rapid-quench), a Laser-heated diamond anvil cell facility, two Griggs apparatuses, and one-atmosphere quench furnaces.

Experimental projects currently underway include partial melting of peridotites in controlled volatile-present conditions at mantle pressures, electrical conductivity measurements on mantle minerals and rocks, reaction experiments that juxtapose subducted sedimentary materials with mantle peridotite to study melting behaviour, and the stability of nitrogen-bearing phases at high pressures, including the partitioning behaviour of nitrogen between minerals and melts.

PROGRESS IN 2017:

1. Facility for Integrated Microanalysis

a. Electron Microprobe: Dr Timothy Murphy (*pictured below*) has been appointed to oversee the electron microprobe functions, and arrived in early 2017. The SX100 has been fully refurbished by Cameca engineers (thanks to Nicolas Boutron and Pierre-Yves Corre) in November 2017 and is now performing extremely well on a day to day basis. High-quality mapping of amazing microstructures in corundum from Israel (*Griffin et al., CCFS publication #830*) were published in the CAMECA user guide and marketing booklet. The EPMA is being updated with the "*Probe*" software developed by John Donovan.

CCFS has provided significant funding support and scientific expertise to purchase a Scanning X-ray spectrometer to enable fast scanning and mapping of thin sections and blocks, thus providing a wider and more complete spatial framework for *in situ* analysis. The acquisition and running of this instrument is a joint venture with Professor Damien Gore (Dept. Environmental Sciences). The versatility of this instrument has attracted significant interest from most faculties across Macquarie University, including Arts, and is heavily used by MRes and PhD students. Outstanding high-resolution images revealing the distribution of elements in fossil fishes, archaeological remains, ores and meteorites are readily obtained (Fig. 1).

b. Laser-ablation ICPMS microprobe (LAM): Dr Yi-Jen Lai (*pictured p. 84*) was hired (commenced May 2017) to manage the extensive LA-ICP-MS and MC-ICP-MS instrument park available at Macquarie. CCFS Research Associates Rosanna Murphy and Yoann Gréau provided invaluable technical help and expertise, with CCFS technical and research staff Sarah Gain, Romain Tilhac, Jinxiang Huang, Qing Xiong and Hadrien Henry providing generous assistance for users.

The Photon Machines Excite/G2 laser system and Agilent 7700 ICPMS are used for *in situ* trace element analyses and U-Pb geochronology. The facility was used by 7 Macquarie PhD thesis projects, 5 international visitors, 6 Masters Research students, 6 users from other Australian institutions and several in-house funded research projects and industry collaborations. Projects included the analysis of minerals from mantle-derived peridotites, pyroxenites and chromitites, meteorites, unusual types of ultra-reduced phases from volcanic sources and ultra-high pressure terranes, high-grade metamorphic rocks and biominerals.

More unusual materials were also analysed, including archaeological metal through our ongoing collaboration with University of New England and with the Department of Ancient History at Macquarie University, and imaging of Zn distribution in human skin has been developed through collaboration with the Physics department (Zara Heyworth and Yi-Jen Lai).

Yi-Jen Lai using the new Q3-ICP-MS (Agilent 8900).

The new Q3-ICP-MS (Agilent 8900) was installed in December 2017 and is co-located with the upgraded Nu-Plasma HR. The development of *in situ* Rb-Sr analysis is already underway. Preliminary results are extremely promising and are opening new research perspectives. In-house reference materials are being characterised to extend the range of material (matrix) analysed. The team lead by Olivier Alard is also working on other developments for the precise (interference-free) measurement of chalcophile and siderophile elements. Julie Salme, an internship student from ENS (Ecole Normale Supérieure) Chemistry, Paris is helping with the development of S-Se and Te analyses.

c. MC-ICPMS: A Nu Plasma II MC-ICPMS was installed in June 2015 and followed the decommissioning of the Nu Plasma 005 after 16 years of service. Although the Nu Plasma II represents a significant advance in its electronics and engineering, much of the fundamental design is adapted from the Nu Plasma I. This enabled a relatively seamless transition of existing methods developed over the past 15 years on the Nu Plasma I. The combination of the expanded collector array (16 Faraday cups and 5 ion counters) and enhanced sensitivity compared to the first-generation Nu Plasma instruments has enabled the refinement of several *in situ* techniques pioneered at GEMOC, Macquarie. Montgarri Castillo-Olivier and Yoann Gréau have refined the measurement of *in situ* Sr isotopes in carbonate and clinopyroxene by LA-MC-ICP-MS. New results are under review.

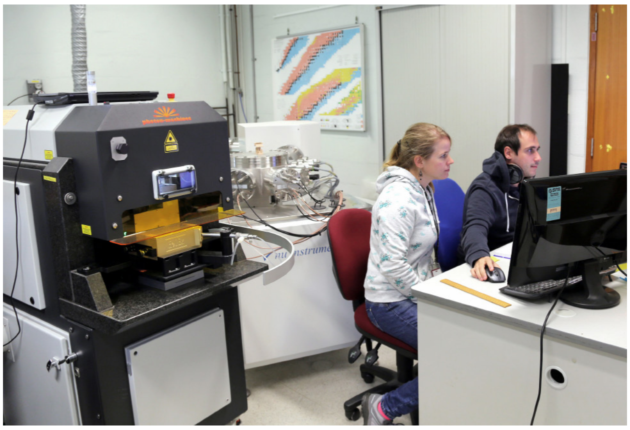
The *in situ* measurement of U-Pb isotopes in zircon using the combination of the femtosecond laser system and the Nu Plasma II was a world first, with preliminary results reported at the Goldschmidt Conference in Prague, August 2015 (*N.J. Pearson, W.J. Powell, Y. Gréau, R.C. Murphy, J.L. Payne, E. Belousova, W.L. Griffin and S. Y. O'Reilly 2015. U-Pb geochronology of zircon by femtosecond laser ablation, Goldschmidt Abstracts, 2015, 2437*). The development of standard operating procedures for *in situ* U-Pb, Re-Os and Rb-Sr isotope measurements is on-going. At the time of the installation of the new Nu Plasma II, the Nu Plasma HR 034 underwent an upgrade with an enhanced interface. The upgrade increased sensitivity between 1.5 and 2 times, and this contributed to an overall improvement in signal stability, as well as in the precision of single measurements and long-term reproducibility. In 2015 a third Photon Machines excimer laser microprobe was installed and co-located with the Nu Plasma HR 034. After successful installation and commissioning had been achieved and the first experiments with the Femtosecond laser microprobe were completed (and presented at the 2015 Goldschmidt conference), key staff to develop the integrated system and applications were no longer available in 2016.

In addition, CCFS has funded a technology development program employing a Research Associate with a high level of instrument expertise (Dr Yoann Gréau) who, with Dr Olivier Alard (Future Fellow who brought the relevant expertise), has been recently making good progress with the envisaged developments. A novel split-stream approach is now being investigated, involving additional gas lines and mass-flow controllers to control the amount of aerosol transported into each instrument. Ultimately, this approach will assist in achieving adequate sensitivity on both sides of the system, and therefore will optimise both signal outputs for a given ablated volume. The planned first application of this new methodology will be combined U-Pb and Lu-Hf characterisation of zircons and simultaneous measurements of Pb-Pb and Re-Os in sulfides. New technique strategies involving splitting with the Q3-ICP-MS are also being investigated.

Olivier Alard and Yoann Gréau examine the entrails of the ICPMS.

CCFS/GEMOC remains one of the few facilities with the capability to perform *in situ* Re-Os dating of single grains of Fe-Ni sulfides and alloys in mantle-derived rocks. CCFS is translating the full methodology to the Taiwan Academia Sinica laboratories under the auspices of Dr Kuo-Lung Wang, a former GEMOC Research Fellow and CCFS Associate Researcher, to ensure preservation of the associated intellectual property and approach. CCFS Future Fellow Olivier Alard is undertaking studies of mantle sulfides worldwide, integrating *in situ* Re-Os and S isotopes obtained using the LA-MC-ICP-MS (Macquarie University) and ion probe (CAMECA 1280, CMCA Perth), respectively, in collaboration with CCFS Research Associate Laure Martin. This activity was also made possible by the expertise of CCFS Research Associates Rosanna Murphy and Yoann Gréau.

The LAM MC-ICPMS is the vehicle to deliver *in situ* high-precision ratio measurements including the analysis of Lu-Hf isotopes in zircon as a major part of *TerraneChron*® (see http://www.gemoc.mq.edu.au/TerraneChron.html). *TerraneChron*® applications continued and have been recently up-scaled with the involvement of Dr Romain Tilhac, Nora Liptai (*pictured below*) and Hadrien Henry (*pictured below*) to meet the increasing demand for this powerful tool for understanding the evolution of Earth's crust, for isotopic mapping and paleogeophysics, and geochemical remote sensing for the exploration industry.



d. Laboratory development: The clean-room facility established in 2005 continued to be used primarily for isotope separations for analysis on the Triton TIMS and the Nu Plasma MC-ICPMS. Routine procedures continued 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 online interactive program for quantitative trace element and isotopic analysis and features dynamically linked graphics and analysis tables. This package provides real-time interactive data reduction for LAM-ICPMS analysis, allowing inspection and evaluation of each result before the next analysis spot is chosen. GLITTER's capabilities include the on-line reduction of U-Pb data. Sales of GLITTER are handled by AccessMQ and GEMOC provides customer service and technical backup. During 2017 a further 16 full licences of GLITTER were sold, bringing the total number in use to more than 300 worldwide, predominantly in Earth sciences applications but with growing usage in forensics and materials science.

Dr Will Powell continued in his role in GLITTER technical support and software development through 2017 on a consultancy basis, following his resignation and relocation to Rio Tinto (Melbourne) in early 2016. The current GLITTER release is version 4.4.5 and is currently available without charge to existing customers.

2. X-Ray Fluorescence Analysis

2.1. In November 2012, a PANalytical Axios 1 kW X-ray Fluorescence (XRF) Spectrometer was installed and is used routinely to measure whole-rock major element compositions on fused glass discs and trace-element concentrations on pressed-powder pellets. In 2013 the sample preparation equipment was upgraded and included a new furnace to make high-quality cast glass beads. The major element calibration was modified in 2015 to extend the spectrum of rock types that could be analysed to include Fe-rich samples such as iron ores and laterites.

2.2. The high performance CHNS elemental analyser from Elementar (Vario El Cube) fitted with an extra IR-detector for low-level sulfur analysis is now in operation and is providing high quality S analyses for projects involving Re-Os isotopic analysis but also the distribution and abundance of volatile elements in the Earth's mantle (PhD students Alimulati Ananuer, Michael Förster). A large suite of reference materials (n≈30), with variable matrix and composition, has been measured and the results will be presented at the Geoanalysis Conference to be held at Macquarie University in July 2018. This facility enables us to better estimate whole-rock sulfur contents and thus sulfide abundance crucial to interpreting whole-rock and *in situ* Re-Os isotopic analysis. The reproducibility and low detection limit of the El Cube Elementar analyser yields remarkably accurate measurement of C, H and N at low levels for relatively small samples (i.e. ≈20 mg).

3. Whole-rock solution analysis

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

The ICPMS dedicated to solution analysis is also used to support the development of 'non-traditional' stable isotopes with the refinement of separation techniques and analytical protocols (see 1. d).

4. selFrag - a new approach to sample preparation

GEMOC's selFrag instrument was installed in May 2010 and was the first unit in Australia. This instrument uses high-powered electrical pulses to disaggregate rocks and other materials along the grain boundaries. It removes the need to crush rocks for mineral separation and provides a higher proportion of unbroken grains of trace minerals such as zircon. Since its installation selFrag has been used for a range of applications including zircon separation, the analysis of grain size and shape in complex rocks, and the liberation of trace minerals from a range of mantle-derived and crustal rocks.

5. Spectroscopy

The spectroscopy infrastructure includes an FTIR microscope (ThermoFisher iN10 FTIR microscope; 2008). The FTIR is used to measure H abundance in a range of nominally anhydrous minerals (e.g. olivine, pyroxene, garnet) and H and N contents in diamond. In developing the spectroscopy capability, an emphasis has been placed on hyperspectral mapping to produce integrated datasets and multi-layered information in a spatial context. A Horiba H-CLUE CL monochromator was installed on the Zeiss EVO SEM in January 2016. The monochromator system provides spatially resolved quantitative cathodoluminescence spectra, which allow identification of emitters (e.g. REE in zircons), crystal lattice vacancies (e.g. in diamond) and crystallographic information on how specific elements are incorporated in the mineral crystal lattices (e.g. Mn in aragonite). The new instrumentation is acquiring a growing group of users and is currently part of projects in biomineralisation (HDR student Laura Otter/Prof Dorrit Jacob), diamond growth (Professor Dorrit Jacob) and zircon characterisation (Honorary Associate Dr Christoph Lenz/Dr Elena Belousova).

6. Raman spectrometry

A confocal laser Raman microscope (co-funded by the Macquarie University Strategic Infrastructure Scheme (MQSIS), 2014 and Future Fellowship funding to Professor Dorrit Jacob) delivers information for non-destructive phase-identification and -characterisation at one micrometre spatial resolution. The Raman spectrometer continues to serve the CCFS, the Department and the Faculty. This year the system's capabilities were extended with the purchase of two new laser wavelengths (MQSIS 2017; 785 and 432 nm), upgrading the Raman spectrometer to one of the most versatile and capable in the Sydney area. The instrument enjoys attention from a growing user group across the Faculty of Science and Engineering at Macquarie University with users from Chemistry, Physics, Biology and Environmental Sciences as well as continued popularity with Dr Christoph Lenz from ANSTO. Professor Lutz Nasdala (University of Vienna), one of the world-leading experts in Raman Spectrometry, provided a short course on Raman spectrometry for CCFS in December 2016.

In 2018 we plan to extend the applications of Raman Spectrometry towards other areas of scientific research. These include:

- Forensics applications, namely ink characterisation on Egyptian papyrus (with Prof Damian Gore and Assoc Prof Malcolm Choat)
- Environmental, analysis of graphene oxide membranes (Prof Damian Gore and Yibin Wei)
- Archeology, mummified cats from Ancient Egypt (Prof Simon Clark and Carla Raymond)
- Paleo-biology, analysis of carbonaceous materials to determine thermal palaeoenvironments (Prof Simon Clark and Bonnie Teece)
- Chemistry, surface enhanced Raman spectroscopy (SERS) of nano particle interactions in serum (Dr Alfonso Garcia-Bennett and Inga Kuschnerus)
- Physics, analysis and mapping of element distribution in wave guides (Prof Simon Gross, Dr Toney Fernandez and Thomas Gretzinger)

7. Computer cluster

The cluster Enki has continued to be a powerhouse for the geodynamics group, having supported multiple research projects, > 5 PhD projects, postdocs, and numerous Masters-level projects. Recent developments have included the incorporation of melt transport and crustal creation into the mantle convection code Aspect (based on the deal.II finite element libraries), led by Siqi Zhang. Other codes utilising Enki for simulation include O'Neill and Zhang's smoothed-particle hydrodynamic codes to simulate early solar-system processes (currently in review). In addition, the lithosphere/seismic cluster "*Toto*" (managed by J.C. Afonso) continues operation, while a GPU Tower (supplied by Xenon systems) acts as a development machine for GPU-capable code, including the SPH code. A Xeon-Phi server (supplied by Dell) has recently been installed, enabling the modelling group to start development and migration of their codes onto this next generation hardware.

For further information please consult http://ccfs.mq.edu.au/Tech/Tech.html/

CMCA TECHNOLOGY DEVELOPMENT AND INSTRUMENTATION

The University of Western Australia's Centre for Microscopy, Characterisation and Analysis (CMCA) is a $50M 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:

- Secondary Ion Mass Spectrometry (CAMECA IMS 1280 and CAMECA NanoSIMS 50 and NanoSIMS 50L)
- Electron probe microanalysis (JEOL JXA 8530F)
- Focused ion beam (FEI Helios)
- Transmission electron microscopy (FEI Titan, JEOL 2100)
- Scanning electron microscopy (FEI Verios XHR, Zeiss 1555, Tescan Vega3)
- X-ray powder diffraction (Panalytical Empyrean)
- X-ray micro-CT (Xradia)
- Confocal Raman imaging with AFM (WiTec Alpha 300RA+)
- NMR spectroscopy (2 Bruker Avance and 2 Varian spectrometers)
- X-ray crystallography (Oxford Diffraction)
- GC and HPLC mass spectrometry
- Bioimaging, flow cytometry, cell sorting, and laser micro-dissection
- Optical and confocal microscopy
- Biological sample cryo-preparation and ultramicrotomy

THE AMMRF FLAGSHIP ION PROBE FACILITY

The CAMECA IMS1280 and NanoSIMS 50 are flagship instruments of the 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, and secondary ion imaging on a wide range of samples.

The IMS1280 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). UWA's Ion Probe Facility can currently lay claim to being the best-equipped SIMS lab in the world, as no other facility has two NanoSIMS alongside an IMS1280.


The CAMECA NanoSIMS 50L.

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, 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 2017:

The Ion Probe Facility has continued to contribute to various projects in the context of CCFS. The CAMECA IMS1280 clocked up 4261 hours, far in excess of the '*full-utilisation target*' of 1800 hours. The lab contributed to 44 individual projects, originating from CCFS partners, other Australian research institutes, and overseas. In addition, 8 new development projects were initiated to extend the lab's capabilities, including S isotopes in apatite and ion imaging. 15 journal articles were published in 2017 featuring data acquired using the IMS1280 at UWA, of which 10 were directly related to CCFS projects.

In late 2017, the IMS1280 received a $700k upgrade with the installation of a Hyperion-II RF plasma source for the generation of oxygen primary ions. The new source has a very high brightness compared to the conventional duoplasmatron, improving the spatial resolution and mass resolving power when analysing positive secondary ions. It is also more stable and requires little maintenance, increasing data quality and throughput. The funding for the upgrade came via the Government's NCRIS Agility Fund.

With the new CAMECA NanoSIMS 50L coming online in late 2015, the NanoSIMS lab saw a further increase in the number of projects - 49, spread across 6037 hours. Projects originated mostly from Australian institutions, with 3 projects from overseas, and several industry collaborations. Several new development projects that utilise the RF plasma ion source were initiated, focusing predominantly on isotope mapping in minerals. The NanoSIMS lab contributed to 12 publications in 2017, of which 5 were Earth science-related. One high impact paper (*Barra et al., Scientific Reports*) featured EPMA and NanoSIMS imaging of Re and Os in sulfide minerals to shed light on potential discrepancies in *in situ* Re-Os dating techniques. The project was a collaboration between UWA, Murdoch University and the University of Chile.

CMCA was successful in winning an ARC LIEF grant for a new EPMA to support the characterisation of minerals and materials for researchers in Western Australia. It is anticipated that the new instrument will be installed in late 2018.

For further information on CMCA facilities please consult http://www.cmca.uwa.edu.au/

JOHN DE LAETER CENTRE

The John de Laeter Centre (JdLC) is a collaborative research venture involving Curtin University, the University of Western Australia, CSIRO and the Geological Survey of Western Australia.

It hosts over $28M in infrastructure supporting research in: geosciences (geochronology, thermochronology and isotope studies); environmental science; isotope metrology; forensic science; economic geology (minerals and petroleum); marine science; and nuclear science.

The mission of the Centre is to *"build world-class research infrastructure in Western Australia for the benefit of Earth, Environment and Materials Science research"*. The JdLC is headquartered in the Faculty of Science and Engineering at Curtin University but has a governing board consisting of members of the joint venture partners as well as representatives from the mining, petroleum and environment sectors.

The facility website provides detailed information on the new facilities, instrumentation and research staff (http://www.jdlc.edu.au).

The components of the JDLC are organised into fourteen major facilities including:

(GAP) Geoscience Atom Probe Facility:
GAP is a node of the Advanced Resources Characterisation Facility (ARCF) funded by a $12,400,000 Science and Industry Endowment Fund grant to Curtin, UWA and CSIRO. The GAP hosts a Cameca LEAP 4000X HR microscope capable of carrying out atom probe tomography (APT), a recent development in the geosciences, that provides high spatial resolution with time-of-flight mass spectrometry to provide 3-dimensional chemical information at the atomic scale. More commonly used to study semiconductors and metal alloys, the GAP is the first atom probe facility in the world to be dedicated to the study of geological materials (http://www.geoscienceatomprobe.org). The ARCF also commissioned a Tescan Lyra focused ion beam scanning electron microscope (FIB-SEM), with a Ga+ gun capable of micro-milling out a 100 nm wide needle of a mineral sample prior to APT analysis. The Lyra system is a highly advanced platform for 2D and 3D microanalysis with time of flight mass spectrometry (TOF-SIMS) and electron back scattered diffraction (EBSD) detectors. By correlating the analytical outputs of both the LEAP and the Lyra instruments, the ARCF provides an unprecedented capability of characterising highly complex materials on a wide range of length scales.

(DMH) Digital Mineralogy Hub Facility:
The Facility hosts a Tescan Integrated Mineral Analyzer (TIMA GM) - a fully automated, high throughput, analytical Field Emission Gun Scanning Electron Microscope (FEGSEM) for automated analysis of sample composition. TIMA measures mineral abundance, liberation properties, mineral association and grain size automatically on multiple samples of grain mounts, thin sections or polished sections. Applications include ore characterisation, process optimisation, remediation and the search for precious metals and strategic elements. The facility is being used by a broad spectrum of researchers: geologists and archaeologists are using the facility in petrological characterisation, sample classification and lithofacies studies; while geochemists and geochronologists are using the mineral classification outputs as targeting maps for further ion, electron or laser microprobe analysis.

(CEG) Curtin Experimental Geochemistry Facility:
CEG provides a facility for experimental petrology, geochemistry and hydrogeochemistry at pressures and temperatures that range from those at the Earth's surface to those at the base of the Earth's crust. The Facility contains:

- 2 x 150 ton end loaded piston cylinder presses
- Coretest hydrothermal apparatus
- Assorted furnaces to 1400 degrees C
- Assorted titanium and Teflon-lined bombs

(GHF) GeoHistory Facility:
The GHF houses state-of-the-art laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) equipment, in addition to a low temperature thermochronology laboratory. The LA-ICPMS comprises a Resonetics S-155-LR 193nm excimer laser ablation system coupled to an Agilent 7700x quadrupole ICPMS. The Excimer laser is also coupled to a RESOchron helium analysis line for *in situ* (U-Th-Sm)/He, U-Pb and trace element analysis of single crystals. The facility also has a separate Alphachron helium line with a diode laser and furnace in order to facilitate conventional (U-Th)/He dating on single mineral crystals and larger samples. A Nu Plasma II multi-collector was integrated into the facility to facilitate split stream analysis.

(MMF) Microscopy and Microanalysis Facility:
The MMF houses a broad range of advanced microanalysis instrumentation providing high quality chemical, mineralogical and microstructural information, and high resolution images for research and technical publications. The facility staff have expertise in Materials and Earth Science research which is used to support both academic research and applied projects for the Western Australian minerals and energy sector. Techniques and instrumentation available include:

- High resolution imaging (TEM) - A new FEI Talos F200X S/TEM system will be commissioned in early 2017 to complement ongoing research at the nanoscale. The system combines high resolution S/TEM and TEM imaging with EDS and 3D chemical characterisation.

  The JEM is a transmission electron microscope (TEM) with a LaB6 filament. The TEM is equipped with an EDS detector and a scanning TEM attachment. This instrument is capable of elemental and microstructural analysis at extremely high magnifications.

- Spatially resolved elemental analysis (EDS) and phase and orientation analysis (EBSD) - The MIRA3 is a variable pressure field emission scanning electron microscope (VP-FESEM) that features sensitive EDS and EBSD detectors and integrated software for high quality microstructural analysis of crystalline samples.
- Quantitative mineral analysis (Q-XRD) - The D8A is an X-ray Diffractometer (XRD) with a copper X-ray source and an automated 45 position sample changer. It features a LynxEye position sensitive detector that is 200 times faster than a conventional scintillator detector, allowing collection of superior data in a short time-frame.
- Ion beam sample manipulation including TEM & TKD lamella preparation (FIB) - The NEON is a dual beam focused ion beam scanning electron microscope (FIB-SEM) equipped with a field emission gun and a liquid metal Ga+ ion source. This instrument combines high resolution imaging with precision ion beam ablation of focused regions, allowing for site specific analysis of the surface and subsurface of samples in 2D or 3D.

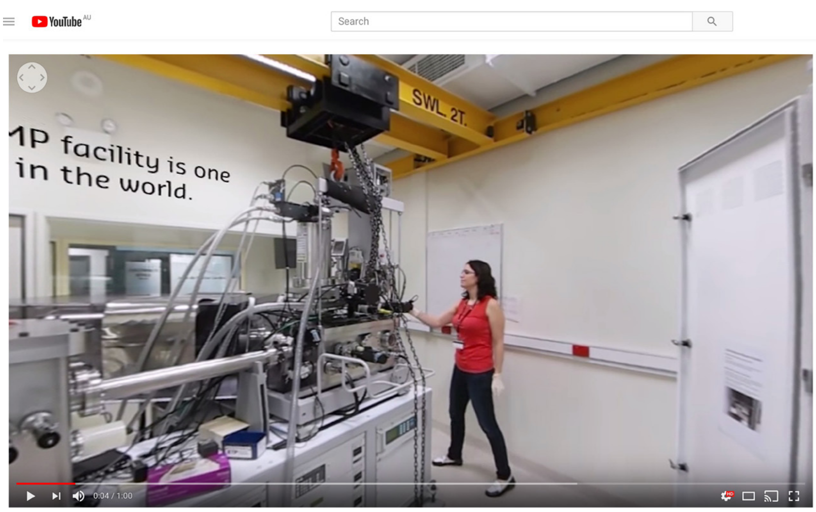
The MMF also houses a suite of equipment that includes light microscopy, vacuum mount impregnation, manual and automated polishers, mills and coaters that are used to prepare samples for electron microscopy and X-ray diffraction.

(SAXS) Small Angle X-Ray Scattering Facility:
Small angle X-ray scattering can be used to characterise the size, shape and distribution of objects between 1 and 100 nm. In 2016, LIEF funding was used to upgrade the instrumentation in the facility. The WA SAXS facility houses a Bruker NANOSTAR SAXS instrument comprising an Excillum MetalJet high-intensity X-ray source, in-vacuum specimen chamber, and a two-dimensional photon counting detector, capable of covering a q-range of 0.008 – 1.25 Å-1.

SHRIMP) Sensitive High Resolution Ion Micro Probe Facility:
The SHRIMP are large mass spectrometers that allow *in situ* isotopic and trace element micro-analysis of complexly zoned minerals in grain mounts and thin section plugs, with a spatial resolution of 5-20 microns. The facility at Curtin has two automated SHRIMP II ion microprobes capable of 24-hour operation, together with a preparation laboratory that was remodelled in 2014. The main application of the SHRIMP instruments at Curtin is for U-Th-Pb geochronology of zircon and other U-bearing minerals, including monazite, xenotime, titanite, allanite, rutile, apatite, baddeleyite, cassiterite, perovskite and uraninite where multiple growth zones commonly require analyses with high spatial resolution. SHRIMP II is fitted with a Cs source, electron gun and 5 channel M/C.

(SMS) SelFrag & Mineral Separation Facility:
A SelFrag facility, supported by an ARC LIEF grant, has been installed within the Department of Applied Geology at Curtin University. High voltage electrodynamic disaggregation of materials in gram- to kilo-scale batches, along with downstream mineral separation processing, to deliver mineral concentrates, separates, mounts for SHRIMP and LA-ICPMS analysis. The facility provides electric pulse disaggregation for mineral separation, which allows mineral grains to be separated from rock samples without the damage associated with standard crushing techniques.

(TIMS) Thermal Ionisation Mass Spectrometry Facility:
TIMS Facility provides highly accurate and precise measurements of the isotopic composition of elements using TIMS TritonTM instrument, including sample preparation in a clean, contamination-free environment. 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 geochemistry (Re/Os, U/ Pb, Pb/Pb, Sm/Nd, Rb/Sr) the TIMS instruments can be applied to a variety of isotope fingerprinting, such as forensics and the environmental impact of human activities. The TIMS instruments are also used for the calibration of isotopic standards and the calculation of isotopic abundances and atomic weights. The facility has recently installed a Thermo Scientific Triton™ mass spectrometer, facilitating a new range of geochemical, geological and environmental research applications.



(TRACE) TRACE Research Advanced Clean Environment Facility:
This consists of a ~400 m^2 class 1000 containment space housing 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 filtration at each stage.

Tour Curtin's Ion Micro Probe (SHRIMP) Facility in 3D via the 360° virtual experience at https://www.youtube.com/watch?v=O8VeGzxZ46I&feature=youtu.be.

(WAAIF) Western Australian Argon Isotope Facility: This is located at Curtin and is equipped with A MAP215-50 mass spectrometer with a low-blank automated extraction system coupled with a New Wave Nd-YAG dual IR (1064 nm) and UV (216 nm) laser, an electromultiplier detector and Niers source. The ultra-violet laser is capable of high-resolution (up to 10 µm beam size) ablation of any mineral, allowing detailed analysis of individual mineral grains. The facility also houses an Argus VI Multi-Collector Noble Gas Mass Spectrometer.

The $^{40}Ar/^{39}Ar$ method is used to date a myriad of geological events such as volcanism, tectonic plate movements, mountain building rates, sediment formation, weathering and erosion, hydrothermal fluid movements, and alteration and diagenesis of minerals.

(WA-OIG) WA Organic and Isotope Geochemistry Facility: WA-OIG is an internationally-recognised group contributing to world-class research in the fields of organic and stable isotope geochemistry, paleogenomics and geomicrobiology. Available techniques are listed here: http://jdlc.edu.au/wa-organic-and-isotope-geochemistry-facility-wa-oig/.

For further information on JDLC facilities please consult http://www.jdlc.edu.au

WESTERN AUSTRALIA PALEOMAGNETIC AND ROCK-MAGNETIC FACILITY

The Western Australia Paleomagnetic and Rock-magnetic Facility, recently upgraded and relocated to Curtin University's Bentley campus, is a national research infrastructure with the latest upgrade co-funded by the Australian Research Council and collaborating institutions including Curtin University, the University of Western Australia (UWA), the Australian National University, Macquarie University and University of Queensland. The facility was established at UWA in 1990 by CCFS CI Z.X. Li, and has been progressively upgraded over the years.

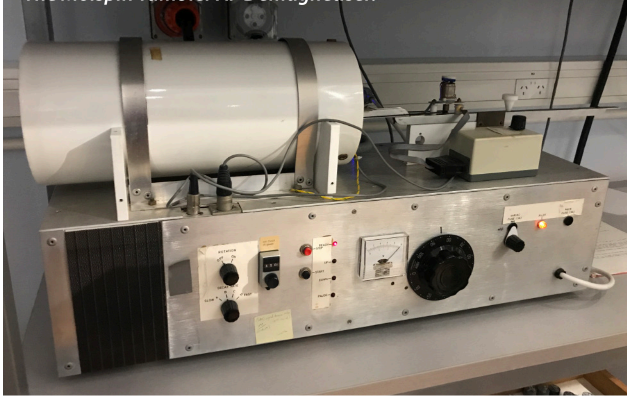
The latest upgrade includes the construction of a magnetically shielded room in mid-2015 by Dr Gary Scott's team, which provides a laboratory space with ambient magnetic fields less than 0.5% of the local geomagnetic field. Within this shielded room we now have a new 2G 755 superconducting rock magnetometer with a vertical Model 855 automated sample handler (the RAPID system) and other accessories attached to it (automated AF demagnetiser, susceptibility meter, etc.). The RAPID system, the first and only one in Australia, was installed and commissioned in February 2017, and has been used by multi-institutional users to collect data since. Other systems now operating inside the shielded room include an AGICO JR-6A spinner magnetometer and ASC TD-48SC and MAGNETIC MEASUREMENTS thermal demagnetisers. The AGICO MFK-1FA Kappabridge was relocated to the new Curtin facility from UWA in 2017, and the Petersen Instruments Variable Field Translation Balance (VFTB) along with the remainder of minor items in the UWA lab will all be co-located within the Curtin facility in early 2018. Arrangements have been made to add the temperature-susceptibility apparatus to the Kappabridge and to upgrade the VFTB system, both expected to be completed in mid-2018. We are planning to conduct a national workshop toward the end of 2018 on paleomagnetism, rock magnetism and applications to tectonics, paleoclimate research, and Earth resource exploration, and will include a training session on the operation of instruments within the Curtin facility.

The new purchases, upgrading and co-location of all instruments represent a major enhancement to the productivity and capabilities of the facility. Apparatus in the facility include:

- a 2G 755 superconducting rock magnetometer with a vertical Model 855 automated sample handler (the RAPID system) and other accessories (including; AF coils, susceptibility meter, and ARM system)
- a second 2G 755 cryogenic magnetometer upgraded to a 4K DC SQUID system (with a recent minor upgrade carried out by 2G enterprises, including the repair of the lightning-damaged cold head; expected to be recommissioned during 2018)
- An AGICO JR-6A spinner magnetometer
- 1x MMTD80, 2x MMTD18 and a TD-48-SC thermal demagnetiser
- a Petersen Instruments Variable Field Translation Balance (VFTB)
- an AGICO MFK-1FA Kappabridge with K-T capacity
- a MAGNETIC MEASUREMENTS MMPM5 pulse magnetiser

The facility supports a wide range of research topics, including reconstruction of global paleogeography (the configuration and drifting history of continents) through Earth's history, studying the evolving geomagnetic field (e.g. paleointensity) through time, analyses of regional and local structures and tectonic histories, dating sedimentary rocks and thermal/chemical (e.g. mineralisation) events, studying past climate changes, and orienting rock cores from drill-holes.

The Molspin Tumbler AF Demagnetiser.



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 "*Infrastructure and 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).

CCFS supports the national UNCOVER initiative:

http://www.uncoverminerals.org.au/

SUPPORT SOURCES

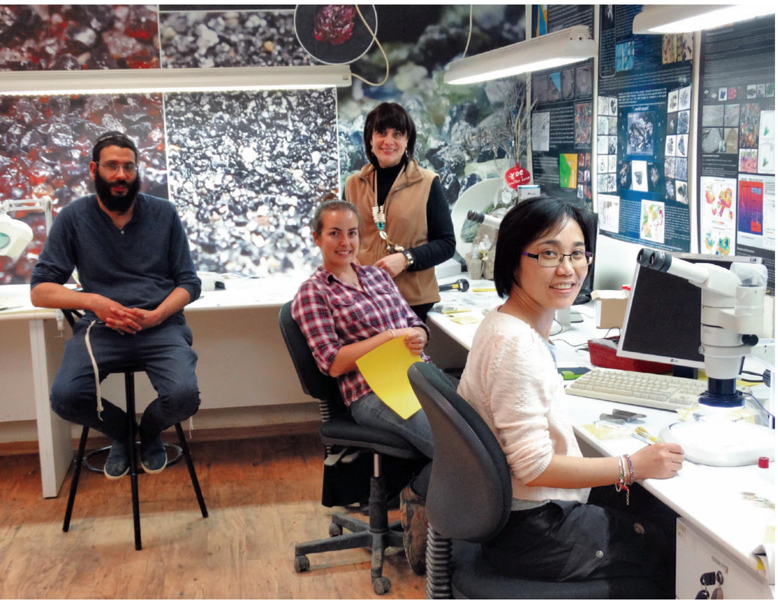
CCFS industry support includes:

- 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 2017

- *TerraneChron*® studies (see *p. 93* and 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). The unique extensive database (over 31,600 zircon U-Pb and Hf-isotope analyses) in the Macquarie laboratory allows unparalleled contextual information in the interpretations and reports provided to industry.
- The Distal Footprints of Giant Ore Systems: UNCOVER Australia, (supported by CSIRO ex Science & Industry Endowment Fund (SIEF), MRIWA and industry collaborators) continued. The project aims to develop a toolkit with a workflow to identify the distal footprints of the Giant Ore Systems in order to overcome the fundamental limitation in current exploration methodologies; Australia's thick cover of weathered rock and sediment.

- The CCFS collaboration with Shefa Yamim (A.T.M.) Ltd. (Akko, Israel) continued and expanded in 2017. Bill Griffin and Sue O'Reilly visited Israel in January to give talks at the annual congress of the Israeli Geological Society (IGS) in Eilat. There was also a very active and vibrant poster session. Following the meeting they returned to the Mt Carmel area to examine and sample several localities of the Cretaceous volcanic rocks, and to visit the alluvial exploration sites under the guidance of Dr John Ward, an expert on alluvial mining. Laboratory work on the remarkable super-reduced mineral associations continued, including collaboration with Prof Martin Saunders in the TEM lab at CMCA in Perth.



Sarah Gain and Jinxiang Huang searching for exotic minerals in the Shefa Yamim (A.T.M) Ltd. mineral sorting facitlity in Akko, with COO Vered Toledo and assistant Mendi Taub in the background.

- CET held their annual *"Corporate Members Day"* on the 5th of December 2017, to showcase its research to its Corporate Members. The day provided an audience of over 70 representatives from CET Member companies with the opportunity to discuss the innovative work of the CET, including its involvement in CCFS, and gave CCFS ECR and postgraduate students a chance to interact with industry. Posters and poster presentations by CET staff and students showcased the width and breadth of research activities. CCFS participant, Crystal LaFlamme presented a talk on *"Mapping deposit footprint, tracing fluid sources and deposition processes orogenic gold deposit in the Yilgarn Craton: new application of sulfur isotope geochemistry"*
- 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-licensing agreement with Minerals Targeting International accommodates 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 2017 as part of the close collaborative working pattern for this project.
- The Linkage Project *"Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia"* continued between CCFS Associate Investigator Elena Belousova, the University of Tasmania, ANU, the Geological Survey of NSW, Geoscience Australia, Rio Tinto Limited, Alkane Resources Ltd, Sandfire Resources NI, IMEX Consulting, Evolution Mining Limited, Heron Resources Limited and the Department of State Growth. The project aims to look at ore deposits and the tectonic evolution of the Lachlan Orogen in SE Australia.

  The outcomes of this project will be used to identify areas of high potential for economically valuable ore deposits, enabling more efficient prioritisation of mineral exploration efforts in South-Eastern Australia.
- 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 collaborative projects. It played a significant role in Montgarri Castillo-Oliver's PhD study of Angolan kimberlites, carried out in collaboration with the mineral exploration industry in Angola.
- A collaborative research project continued in 2016 with the GSWA as a formal CCFS Flagship Program, 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.
- Following Professor Bill Griffin's Noumea workshop on new approaches to exploration and minor-element exploitation in ophiolitic complexes, a collaborative project was established with Jervois Mining, involving a cotutelle PhD student (Mathieu Chassé) jointly supervised by Professor George Callas, Pierre et Marie Curie University, Paris, France. This project continued in 2017, culminating in Mathieu receiving his PhD. The project has led to significant advances in understanding the speciation and mineral residence of the element Scandium (Sc) in lateritic weathering profiles developed on mafic and ultramafic rocks. It also has helped to characterise and define a world-class Sc resource in western New South Wales, and to provide indicators for further exploration. Mathieu has gone on to take up an Assistant Lecturer position at Pierre and Marie Curie University, France.

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)

Contact: Elena Belousova, Bill Griffin or Suzanne O'Reilly
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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 km²) scales. It is based on U-Pb, Hf-isotope and trace-element analysis of single zircon grains by laser-ablation ICPMS (single- and multi-collector) methods.

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

What kind of samples?

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

Applications to mineral exploration

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

Applications to oil and gas exploration

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

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

- Industry partners provided mentoring and both logistical and financial support for CCFS postgraduate research projects in 2017. Participating organisations include: BHP Billiton (BHP Chile Inc.), Barrick Exploration (Compania Minera Barrick Chile Ltd.), Northern Star (Kanowna) Pty ltd., Teck Resources Ltd, CSIRO, ANSTO and MRIWA. See *CCFS Postgraduates* (*p. 75*) for a full list of postgraduate projects.
- Industry visitors spent varying periods at Macquarie, Curtin and UWA (CET) in 2017 to discuss our research and technology development (see visitor list, *Appendix 7*). This face-to-face interaction has proved highly effective both for CCFS researchers and industry colleagues.
- 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, and convening sessions relevant to mineral exploration at national and international industry peak conferences in 2017 (see Abstracts, *Appendix 6*).

A full list of previous CCFS publications is available at http://ccfs.mq.edu.au/Publications/Publications.html

CURRENT INDUSTRY-FUNDED COLLABORATIVE RESEARCH PROJECTS

These are brief descriptions of current CCFS projects that have direct cash support from industry, most with combinations from ARC, internal University or State Government support. Projects are both national and global. In addition to these formal projects, many shorter projects are directly funded by industry, 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. AccessMQ Limited, at Macquarie).

CCFS industry collaborative projects are designed to develop the strategic aspects and applications stemming from the fundamental research programs; 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. The basic research strands that have given rise to strategic applications include the use of geochemical data integrated with tectonic analyses and large-scale datasets (including geophysical) 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 (*TerraneChron*®) have been developed as regional isotopic mapping tools for integration with geophysical modelling.

This integrated approach, has been widely adopted by a significant proportion of the mineral exploration industry and has resulted in granting of licence to use methodologies developed. CCFS Chief and Associate Investigators, collaborating researchers and Board members have been instrumental in shaping UNCOVER Australia (https://www.uncoveraustralia.org.au/) and in shaping the 2017 AMIRA "*Undercover Roadmap*" (ROADMAP). Indeed the 4-D Lithosphere Mapping approach, established by GEMOC and CCFS with industry partners, forms the robust conceptual basis for UNCOVER, contributed significantly to the AMIRA Roadmap process, and has become part of the vernacular in smart exploration strategies.

CCFS PROJECTS FUNDED BY INDUSTRY (INCLUDING ARC LINKAGE)

Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia	***Linkage Project (LP160100483)*** ***Industry Collaborators: Rio Tinto Limited; Alkane Resources Ltd; Sandfire Resources Nl; IMEX Consulting; Evolution Mining Limited; Geoscience Australia; Geological Survey of NSW; Heron Resources Limited; Department of State Growth*** ***CIs: Meffre, Whittaker, Norman, Cracknell, Belousova, Collins, Arundall, Cooke, Maas, Huston, Musgrave, Greenfield*** ***Summary:*** This project aims to develop and test models to evaluate past tectonic processes and configurations in South-East Australia, using both new and existing geological, geophysical and isotopic data. Over the past 550 million years, plate tectonic processes have formed metal-rich mineral deposits in South-East Australia. The project will identify areas of high potential for economically valuable ore deposits, enabling more efficient prioritisation of mineral exploration efforts. This is expected to increase the probability of significant ore deposit discoveries leading to national economic benefit.

Reducing 3D geological uncertainty via improved data interpretation methods	***Linkage Project (LP140100267)*** ***Industry Collaborators: Western Mining Services Australia Pty Ltd, Geological Survey of Western Australia*** ***CIs: Jessell, Holden, Baddeley, Kovesi, Ailleres, Wedge, Lindsay, Gessner, Hronsky*** ***Summary:*** The integrity of 3D geological models heavily relies on robust and consistent data interpretation. This project proposes an innovative workflow for 3D modelling to minimise geological uncertainty. Advanced visualisation and intelligent decision support methods will be combined to assist geological interpretation. Feedback on interpretation will be provided based on data evidence and consistency with expert knowledge and previous interpretations. The process can be considered as a spelling and grammar checker for geological interpretation. The outcome of this study aims to achieve an improved workflow that reduces model uncertainty, resulting in a broad and significant impact on the management of Australian mineral, energy and water resources.
Lithospheric architecture mapping in Phanerozoic orogens	***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 programs 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.
Distal footprints of giant ore systems: UNCOVER Australia	***Supported by CSIRO ex Science & Industry Endowment Fund (SIEF)*** ***Industry Collaborators: CSIRO, UWA, CU, Geological Survey of Western Australia*** ***CIs: Hough, Reddy, McCuaig, Tyler, Dentith, Shragge, Miller, Fiorentini, Aitken*** ***Summary:*** Australia is an old continent with much of its remaining mineral wealth masked by a thick cover of weathered rock and sediments that pose a formidable challenge for future mineral exploration. This project aims to develop a toolkit with a workflow to identify the distal footprints of the Giant Ore Systems to address a fundamental limitation in current exploration methodologies.
Distal footprints of giant ore systems: Capricorn WA case study	***Supported by MRIWA M436*** ***Industry Collaborators: CSIRO, MRIWA, Northern Star Resources Ltd, Thundelarra, Sandfire Resources NL, MMG, Golden Phoenix Resources LTD, Marindi Metals Pty Ltd, Independence Group NL, RNI*** ***CIs: Hough, McCuaig, Reddy, Clark, Fiorentini, Gray, Miller*** ***Summary:*** This study investigates the distal footprint of mineral systems by examining the indelible nature of the mass-independent fractionation of sulfur (MIF-S), which was imparted to different sulfur-bearing reservoirs prior to 2.4 billion years ago, in the Archean eon. This fractionation process led to the unique preservation of this anomalous sulfur isotope signature (as $\Delta^{33}S$) in the Archean sedimentary rock record (Farquhar et al. 2000). Subsequently, as this signature was recycled through different geological processes operating at various scales in space and time, we are now in the privileged position to be able to use it as an indelible tracer and marker of different geological processes.

Magmatic sulfide mineral potential in the East Kimberley	***Supported by MRIWA M459*** ***Industry Collaborators: CSIRO, MRIWA, Panoramic Resources Ltd and Kind River Copper Ltd.*** ***CIs: Barnes, Fiorentini*** ***Summary:*** Magmatic sulfide mineral potential in the East Kimberley igneous intrusions of broadly basaltic composition are the hosts for some of the world's most valuable ore deposits of Ni, Cu and PGE, and indeed some of the most valuable ore deposits of any type on the planet. Exploration for this style of deposit in Proterozoic mobile belts has recently received a major boost in Australia following the discovery of the Nova deposit in greenfields-terrane in Western Australia, and also with exciting new discoveries and deposit extensions in the Musgrave province also in WA. However, detailed camp-scale targeting and exploration for these deposits remains extremely challenging and new approaches are required. The project will investigate the prospectivity of mafic igneous intrusive rocks in the East Kimberley based on age, internal differentiation and geochemistry of parent magmas, and isotope fingerprinting of ore minerals. The centerpiece of this extension of the project will be an investigation of the relationship between multiple small intrusions in the Savannah district, including the ore-hosting Savannah intrusion itself. We will also investigate similar attributes of the neighbouring Hart Dolerite suite and its potential for PGE-enriched magmatic sulfides. Results will be applied to an assessment of potential exploration targets within the East Kimberley region and other greenfield areas in Proterozoic mobile belts elsewhere in Western Australia.
Mineral systems on the margin of cratons: Albany-Fraser Orogen/ Eucla Basement case study	***Supported by MRIWA M470*** ***Industry Collaborators: GSWA and Ponton Minerals*** ***CIs: Kirkland, Clark, Kiddie, Tyler, Spaggiari, Smithies, Wingate*** ***Summary:*** Modern exploration requires a new integrated approach, utilising a broad range of techniques, which can collectively enhance the geological knowledge of a region's mineral endowment. Craton margins host significant lithospheric discontinuities that focus fluids and heat and which, under favourable circumstances, may become mineralised corridors. Additionally, high-grade terrains are frequently viewed as less prospective for some mineralisation (e.g. gold) than lower-grade regions. However, recent discoveries in the Albany-Fraser Orogen highlight that many common models for mineral endowment are lacking and their resolution through cover limited. This program of research will focus on the partially covered terrain of the Albany-Fraser Orogen and the covered Eucla Basement of Western Australia. The project will utilise a lithosphere-scale mineral systems approach to establish the fundamentals (timing, scale, material) of mass transfer processes within the crust. The project will utilise a broad range of geochronology techniques to enhance GSWA's regional U-Pb zircon coverage and will apply crustal evolution studies via novel analytical equipment to rapidly delimit domains of enhanced mantle input.
Gold pathways: evolution of the lithospheric to crustal architecture of the El Indio Belt, Chile-Argentina	***Industry Collaborator: Barrick Gold Corporation*** ***CI: Fiorentini*** ***Summary:*** The study of mineral deposits from a Mineral System perspective is a recent approach, whereby the clustering of major deposits is considered to be the result of conjunction in time and space of four geological factors: whole lithosphere architecture, transient favourable geodynamics, fertility, and preservation of the depositional zone. This study will test this hypothesis in one of the most highly Au-endowed provinces of the Andes Cordillera: the El Indio Belt (EIB, Chile-Argentina 29° 00'–30° 30'S), which holds >45Moz Au mainly hosted in world-class epithermal systems. It intends to define: 1. The trans-lithospheric architecture that acted as the magma/fluids pathway, linking the fertile source with the deposits location; 2. The architecture's geodynamic evolution related to metallogenic events.

The role of whole-lithosphere architecture on the genesis of giant gold systems in the El-Indio region, Chile-Argentina	***Industry Collaborator: Barrick Gold Corporation*** ***CIs: McCuaig, Fiorentini*** ***Summary:*** The overall aim of the project is to establish and link the near-surface, basement and sub-continental lithospheric structures in an integrated structural architecture and geodynamic model for the El Indio-Pascua belt to identify the fundamental controls of the location and formation of giant HS gold deposits. The research will focus on two main objectives: 1. Define the structural framework that acts as the magma/hydrothermal fluids pathway from the deep fertile source region to the shallow-crustal location of the major HS deposits. Specifically, the concept is to build a multi-scale interpretation of the fundamental structural framework and how the conduit structures are linked from surface through the lithosphere. 2. Link the Miocene metallogenic events to the geodynamic evolution of this segment of the Andean subduction system. The aim here is to document the proposed transient nature of the geodynamic evolution and its linkages to metallogenic / mineralisation pulses.
Improving zircon morphology and chemistry as a tool for assessing and ranking the relative prospectivity for Cu porphyry deposits in "*greenfield*" terrains	***Industry Collaborator: BHP Billiton*** ***CIs: Fiorentini, Loucks*** ***Summary:*** A substantial exploration and research problem remains outstanding: although all porphyry copper ore-forming magmas are adakites (distinguished from ordinary calc-alkalic arc magmas by high Sr/Y ratio and spoon-profile rare-earth-element patterns), many adakites are apparently unmineralised or have weak, subeconomic copper mineralization. Then, how to distinguish a hydrothermally altered adakitic igneous complex that is weakly mineralised or barren from a hydrothermally altered adakitic igneous complex that is likely to contain a major copper deposit? This study is set to address this very question.
Nickel sulfide prospectivity of the King Leopold Orogen, Kimberley	***Industry Collaborator: Buxton Resources*** ***CIs: LaFlamme, Fiorentini*** ***Summary:*** This study focuses on the Double Magic Project, which is a current Ni-Cu-PGE exploration target, located within the Western King Leopold Orogen, Western Australia. This body is comprised of a series of intrusive mafic sills, collectively known as the Ruins Dolerite, that have intruded into the turbidite meta sedimentary Marboo Formation. The Ruins Dolerite hosts distinct Ni-Cu sulfide mineralisation within its multiple flows but has not been previously exploited. The Ruins Dolerite is one of the earliest units within the King Leopold Orogen, with an estimated age of 1872-1861 Ma. The age of the Ruins Dolerite is analogous to that of the Tickalara Metamorphics, which similarly hosts significant Ni-Cu-PGE mineralisation at Savannah. This relative age proximity and similarity in mineralisation style question 1) whether the Souble Magic and Savannah systems are genetically related and 2) how mineralisation associated with the Ruins Dolerite fits into the current understanding of the formation of the Central and Eastern Kimberley Regions.
Geology and ore genesis of the Nova-Bollinger Ni deposit, WA	***Industry Collaborators: IGO Independence Group*** ***CIs: Barnes, Fiorentini*** ***Summary:*** This study focuses on unravelling the multiple sulfur isotope architecture of the Nova-Bollinger deposit. Expected outcomes from this work will help to define the ore genesis of the most significant Australian nickel sulfide discovery in decades as well as provide a new framework for the exploration of mafic-hosted systems along the margins of Archean cratons.
Fluid evolution monitored by stable isotopes at the Kanowna Belle deposit	***Industry Collaborator: Northern Star Resources*** ***CIs: Thébaud, Fiorentini, LaFlamme, Sugiono*** ***Summary:*** This project has Northern Star Resources as the sole sponsor. The project will apply stable isotopes, focusing on multiple sulfur isotopes in the Kanowna Belle orogenic gold deposit. This application of stable isotopes will incorporate paragenetic sequence and deformation episodes of the deposit to further understand the evolution of hydrothermal fluids in Archean orogenic gold deposits.

International links in CCFS

BACKGROUND

CCFS' International links 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 collaborations. Other international activity includes funded projects and substantial collaborative programs with major exchange-visit programs in France, Norway, Germany, United Kingdom, New Zealand, Canada, USA, Taiwan, Italy, Spain, South Africa, South America, China, Brazil, Mexico, Japan, Thailand and Russia.

FORMAL MEMORANDA OF UNDERSTANDING (MOU)

Formal MOU between international institutions promote the Centre's collaborative research and facilitate visits by Centre staff and postgraduates as well as joint PhD research projects. CCFS has agreements with the following international institutions:

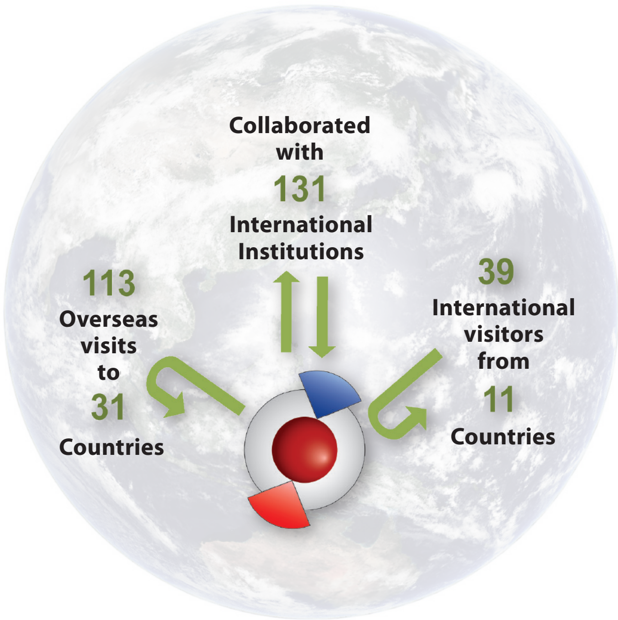
- China University of Geosciences (Wuhan) - 2011 (& Cotutelle)
- Constitution of the International University Consortium in Earth Science - 2012
- University of Science and Technology of China, Hefei - 2012 (& Cotutelle)
- Institute of Geology and Geophysics, China University of Geosciences (IGGCAS, Beijing) - 2014 (& Cotutelle)
- Institute of Tibetan Plateau Research, CAS (Beijing) - 2014
- Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Germany - 2015

COTUTELLE MOU

Cotutelle MOU aim to establish deep, continuing relationships with international research universities through joint research candidate supervision. CCFS has agreements with the following international institutions:

- China University of Petroleum, Beijing, China
- Durham University, United Kingdom
- Eötvös Loránd University, Hungary
- Friedrich-Alexander-University of Erlangen, Nuremberg, Germany
- Nanjing University, China
- Pierre and Marie Curie University, PARIS VI
- Peking University, China
- São Paulo University, Brazil
- University of Barcelona, Catalonia, Spain
- Universidad de la Republica, Uruguay
- Université Montpellier 2, France
- Université Paul Sabatier, France
- Université Jean Monnet, France
- University of Zaragoza, Spain

2017 COLLABORATIVE ACTIVITY

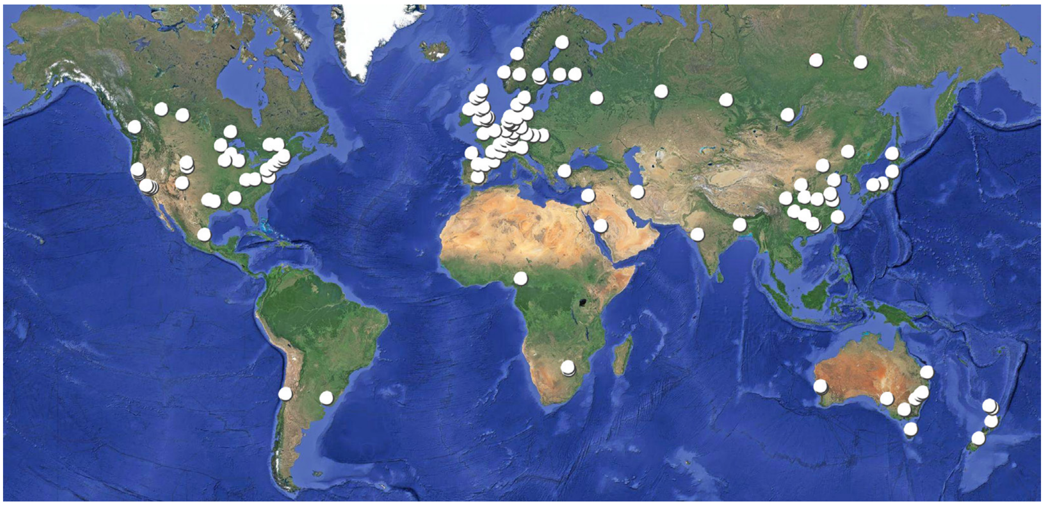


INTERNATIONAL LINKS - 2017 SELECTED HIGHLIGHTS

- A collaborative project between the Institute of Geology and Geophysics, China Academy of Science, Beijing (IGG CAS), CCFS, Geoscience Australia, and ANSIR (Australian facilities for Earth sounding) has resulted in a 4-year passive seismological deployment (CANPASS) along a 900 km profile across Western Australia from Port Hedland to the southwestern border of the Kimberly Craton. The station spacing is 10-15 km, using 80 broadband seismic stations and extends beyond the continent margin using ocean-bottom seismometers.

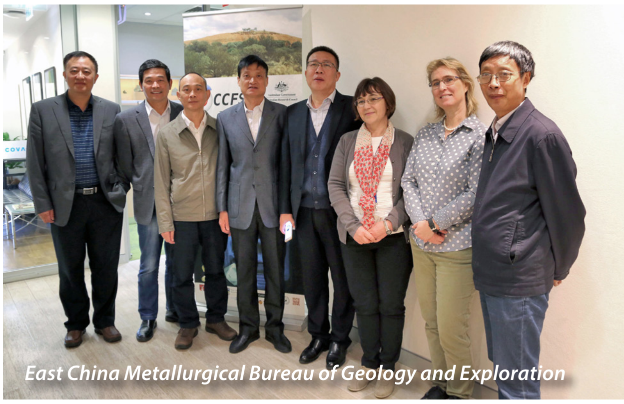
The CWAS Team at work.

CCFS INTERNATIONAL COLLABORATIVE NETWORK



China University of Geosciences, Beijing

Shaanxi Geological Survey

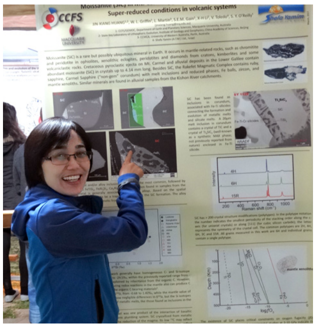

East China Metallurgical Bureau of Geology and Exploration

- Delegates from a range of international institutions visited CCFS in 2017 to discuss programs including the exchange of staff, joint research activities and the exchange of students. These included representatives from China University of Geosciences Beijing (January), Shaanxi Geological Survey (May) and the East China Metallurgical Bureau of Geology and Exploration (September). *Pictured left*

- A collaborative research agreement continued with the China University of Geosciences (Wuhan) with funding by the Chinese Scholarship Council (CSC). This grant provides a living allowance and travel between China and Australia for students and visiting scholars. Students and researchers funded by this project will study and work under the project's aims, integrating geological, geochemical, geophysical and experimental techniques to study the structure, composition, geodynamics and metallogeny of the deep lithosphere and beyond.

Dr Xianquan Ping undertook 12 months of research at CCFS MQ, funded by a CSC Postdoctoral Fellowship, focusing on U-Pb and Hf isotopic analysis of zircons separated from mafic granulite xenoliths in Mesozoic-Cenozoic basalts from the North China Craton. This study revealed the presence of ancient (≥3.5 Ga) lower crust.

- CCFS's very successful engagement with Shefa Yamim (A.T.M.) Ltd and their placer-gemstone exploration program in the Mt Carmel-Yizre'el Valley area of northern Israel continued in 2017 (see *Research highlights pp. 55-57, 67-69*). A group from GEMOC (Sue O'Reilly, Bill Griffin, Sarah Gain and Jinxiang Huang) visited the Shefa Yamim sample processing facility in Akko and spent time examining new finds and selecting mineral grains for further analysis. The group then traveled out to Mitzpe Ramon in the Negev Desert for the annual meeting of the Israel Geological Society, where they presented talks and posters about their recent findings.



Jinxiang demonstrates her poster on the origins of moissanite (SiC) at the meeting of the Israel Geological Society meeting.

Bill Griffin and Sarah Gain in the Yoqneam Road Tunnel, Israel (Photo: Vered Toledo, Shefa Yamim (A.T.M.) Ltd.)

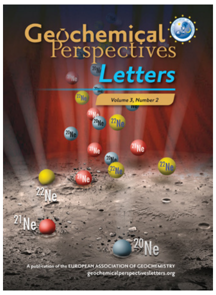
Dr John Ward, Jinxiang Huang, Sue O'Reilly, Bill Griffin and Sarah Gain in the field.

Dr John Ward, an expert on alluvial deposits of diamonds and other commodities, took the group into the field at Akko. His wonderful ability to visualise and explain landscape evolution and geomorphology really gave new insights into the nature of the deposits under exploration. New tuff localities were sampled and the group were able to access a new road tunnel under construction, just as it was exposing the innards of one of the Cretaceous volcanoes that carry the sapphire, ruby, hibonite, moissanite and one of the main research targets, the remarkable Carmel Sapphire™. Shefa Yamim is now processing a bulk sample from this tunnel face. After the conference, Bill and Sue held discussions and seminars at the Hebrew University of Jerusalem. Later in the year Bill Grifin contributed a video interview explaining the science of the mineral assemblages, which became part of Shefa Yamim's highly successful launch on the London Stock Exchange.

JInxiang, Sarah, Mendy Taub and John Ward take in the spectacular scenery at Mitzpe Ramon in the Negev Desert, Israel.

- CCFS had a very high profile at the Goldschmidt Conference in Paris in August 2017. The many CCFS presentations included eight PhD, seven ECR and eighteen senior researcher orals, with several keynotes. CCFS researchers convened two sessions. One of these, Session 5e "*Lithosphere* *evolution during subduction and collision*" attracted an all-time record number of 88 abstract submissions. As a consequence, oral presentations for this extended over 2.5 days of the 5-day conference, with concurrent poster sessions.

Other CCFS highlights included papers presenting the large body of work resulting from the TARDIS Flagship Program. Pictured above are many of the multi-national collaborations team involved in TARDIS. Serendipitously, the Geochemical Perspectives issue (Volume 3, Number 2) containing Mathieu Chassé's paper on "*Scandium speciation in a world-class lateritic deposit*" linking mantle garnets with Sc deposits formed by lateritic weathering) was distributed as part of the conference material. Mathieu's paper was, at that time, the 5th most downloaded paper (over 3,300) in the past year for *Geochemical Perspectives*.



- The UNESCO-IUGS IGCP Project 648, Supercontinent cycles and global geodynamics continued in 2017. The project brings together a diverse range of geoscience expertise from around the world, including three CCFS CIs, to explore the occurrence and evolution history of supercontinents through time and construct global databases of geotectonics, mineral deposits and the occurrences of past mantle plume events. Zheng-Xiang Li organised and co-conducted the first IGCP 648 Database Workshops in Beijing, China, (24 February 2017), a two-day workshop examining how to establish the East Asia part of the IGCP 648 geotectonic and mineral deposit database using the existing 1:2.5 million and 1:5 million digital geological maps. An equally successful database workshop was conducted on 9-10 June 2017 in Townsville, Queensland, Australia, prior to the Rodinia 2017 conference. See http://geodynamics.curtin.edu.au/igcp-648-china-national-working-group-kick-started-compilation-asian-database/.

IGCP 648 Database Workshops, Beijing, China.

  The 2018 IGCP 648 Field Symposium "*From Rodinia to Pangea: Geodynamics, Life and Climate*" will visit the Yichang, Three Gorges Region, China on the 1-9 November 2018. For more information visit http://geodynamics.curtin.edu.au/igcp-648-2018-field-symposium/.

- CCFS has collaborated with the ion-microprobe laboratories at IGG-CAS (Dr Li Xianhua) to develop standards for the analysis of oxygen isotopes in Cr-bearing and Ca-rich garnets; this was necessary because the SIMS technique is sensitive to matrix effects arising from compositional differences between sample and standard. Another important outcome was the development of a synthetic standard SiC, which now enables the *in situ* analysis of both Si isotopes (a world-first) and C isotopes in natural SiC. This development was supported by Dr Paul Savage and Dr Anita Andrews, who analysed the Si isotopes and C isotopes, respectively, of the standard material by '*conventional*' means. A survey of SiC from Russian kimberlites, Tibetan ophiolites and Israeli basalts has been completed and will soon be published. In a new project, IGG-CAS and CCFS are developing standards that will allow the *in situ* analysis of Ti isotopes in a variety of matrices, to investigate the isotopic fractionation of Ti as a function of oxygen fugacity.

- Dr Yongjun Lu continued his collaboration with the Chinese Academy of Geological Sciences (CAGS) and the China University of Geosciences in Beijing (CUGB) to investigate the porphyry copper systems in the Tibetan plateau and surrounding region. Yongjun was Invited to visit CAGS by Professor Zhiming Yang. He was also invited to give presentations at Peking University (PKU) and CUGB.

- Prof Zheng-Xiang Li continued as Co-director of the Australia-China Joint Research Centre for Tectonics and Earth Resources (ACTER). ACTER is a joint research centre led by the Institute for Geoscience Research at Curtin University, and the Institute of Geology and Geophysics of the Chinese Academy of Sciences, with participants from collaborating institutions from the two countries. CET, TIGeR and GEMOC are all Key Australian Partner Institutions (http://tectonics.curtin.edu.au/).

The 2017 ACTER annual field workshop (Photos: Zheng-Xiang Li).

ACTER aims to facilitate: collaborative research and research training in geotectonics and mineral and hydrocarbon resources, the exchange of staff and joint supervision of research students, shared access to analytical facilities, the organisation of joint conferences and annual focused field-based workshops and the exchange of academic materials and information.

The 2017 ACTER annual field workshop "*Tectonics of the Lachlan Fold Belt and granite petrogenesis*" was held on the 23-29 October 2017. The event was led by Professor Bill Collins (Curtin). Among the 42 attendees were representatives from international institutions including the Chinese Academy of Sciences (CAS), Guangzhou Institute of Geochemistry, the Chinese Academy of Geological Sciences, Sun Yat-Sen University, Peking University, Chang'an University and Zhejiang University. See http://geodynamics.curtin.edu.au/2017-acter-field-symposium-23-29-october-2017/.

The 2018 ACTER Field Symposium "*Tectonic evolution of the North Qilian Mountains: From Paleozoic oceanic subduction to Cenozoic plateau expansion*" will be held along the Qilian Mountains, Gansu province, China from the 25th August to the 2nd September 2018. The field trip will focus on (1) the Early Paleozoic North Qilian Orogen featuring oceanic subduction and arc-continent collision, and (2) the Cenozoic fold-and-thrust belt in relation to the uplift and expansion of the Tibetan Plateau. For more information see http://tectonics.curtin.edu.au/acter-2018-field-symposium/.

The 2017 ACTER annual field workshop (Photo: Zheng-Xiang Li).

CCFS PhD graduate Yu Wang and PhD candidate Bo Xu attended a presentation of Associate Professor Dejan Prelević (University of Belgrade) in Beijing related to European ultrapotassic rocks. Dejan is a long-time CCFS Collaborator.

- CCFS is a partner in, and Professor Sue O'Reilly a co-leader of, the new 2018-2022 international IGCP-Project 662 *"Orogenic Architecture and Crustal Growth from Accretion to Collision"*, led by Prof Tao Wang (CAGS in Beijing) and sponsored by UNESCO and IUGS. More than 13 developing and developed countries /regions will be involved, enhancing the cooperation of scientists from diverse social and political environments.

  The main objectives of this proposal are: (1) to characterise differences in crustal formation and architecture between accretionary and collisional orogens; (2) to establish the relative proportions of juvenile vs. reworked crust; and (3) to better understand the role of orogenic compositions on metallogenesis. Participants plan to conduct comparative studies on the Central Asian Orogenic Belt (CAOB), the world's largest Phanerozoic accretionary orogeny, and the Tethyan orogenic belt, the world's youngest extensive collisional and metallogenic belt, as well as other composite orogens.

  The first IGCP-662 workshop and field excursion will be held on 16-22 September 2018 in China. A 5-day pre-workshop field discussion and training course will investigate ophiolites, granitoids, tectonics and crustal growth in the Beishan area of NW China. This will be followed by a one day work-shop at the Chinese Academy of Geological Sciences (CAGS), Beijing (21 September) and a day of post-workshop training on 22 September.

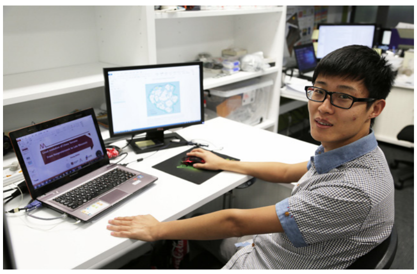
- CCFS fosters many of its international links through visits by collaborators to undertake defined short-term projects, or short-term visits to give lectures and seminar sessions.

  CCFS provides funds to international visitors who will add value to CCFS programs and contribute to the high visibility of research in the Centre. In 2017, CCFS co-sponsored Hadyn Williams Fellow, Professor Brendan Murphy (St. Francis Xavier University, Nova Scotia, Canada).

  During his very productive visit, Professor Brendan Murphy collaborated with members of Flagship Program 5 on a large number of co-authored papers. He also conducted a series of workshops and public lectures:
  - What makes a research leader? Empowering the next generation of Research Leaders
  - How to publish in geological journals (postgraduate students and ECRs)
  - Why do Geology?: Orientation (incoming 1st-year students)
  - Hadyn Williams Lecture: Why leprechauns know how mountains are built (May 2017)
  - Geological Society of Western Australia: Mantle plumes, Mountains and Mineralisation (February 2017)
  - University of Western Australia: Mantle plumes, Mountains and Mineralisation (March 2017)
  - Curtin University: Ophiolite Complexes: a woofer in tweeter's clothing? (March 2017)
  - The supercontinent cycle. Earth Dynamics Research Group, Mandurah, Western Australia

- Many visitors took the opportunity to utilise the internationally recognised concentrations of analytical geochemistry infrastructure available at the three CCFS analytical nodes. See *Infrastructure and technology development p. 82.*

Dr Fatma Kourim, Institute of Earth Science, Academia Sinica, Taiwan.



Xiang Zhou, China University of Geosciences, Wuhan.

International visitors are listed in Appendix 7.

CCFS funding

Financial accounting for allocated funds is carried out at each node. MQ is responsible for the final reporting to ARC through the DVC Research, and is audited through the Macquarie University process.

STRATEGY FOR CCFS FUNDING LEVERAGE

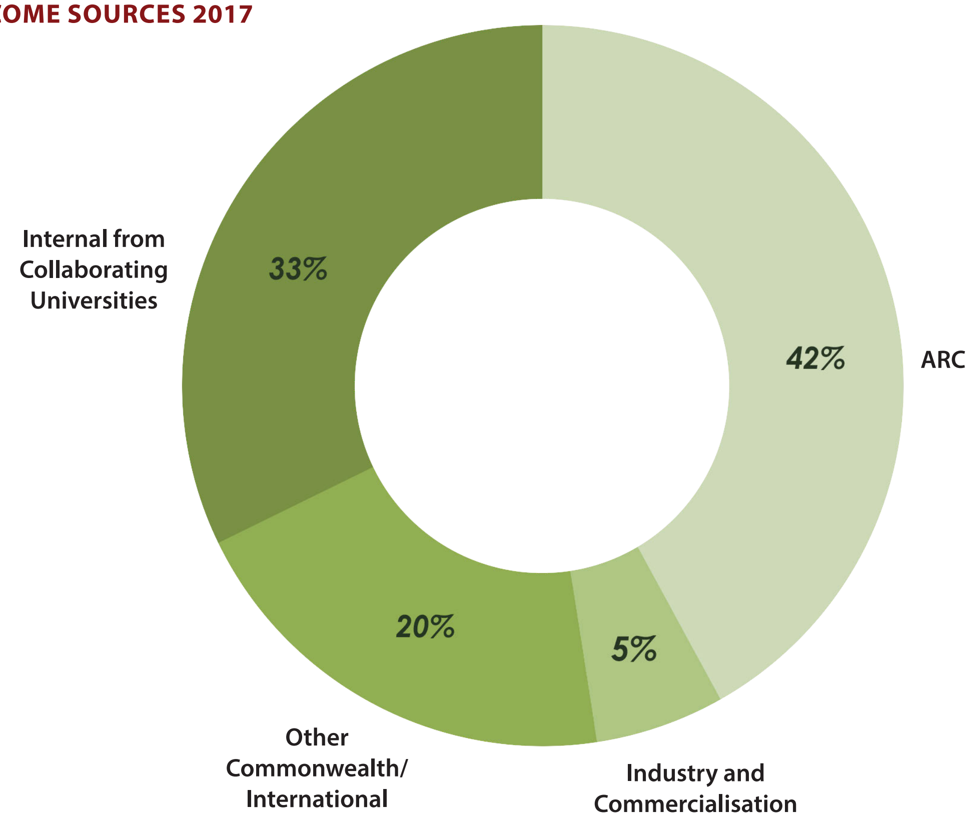
ARC anticipates that Centres of Excellence will develop a profile of basic and strategic research outcomes that provides an attractor for leveraging resources. Active strategies within CCFS include:

- Collaborative project building with industry partners
- Applications to funding schemes for matching funds for new infrastructure purchases and partner co-investment
- 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 relevant ARC funding schemes for projects not funded from the ARC CCFS allocation, but aligned with CCFS goals
- 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 2011-2017 income and expenditure. A full, audited statement of detailed expenditure and income is prepared by Macquarie University. No in-kind support is included here.

CCFS Income & Expenditure Statement 2011-2017							
Source	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Income							
ARC	$1,828,350	$2,004,179	$1,971,746	$2,031,333	$1,952,842	$1,986,040	$2,015,831
MQ	$626,705	$1,032,004	$1,822,748	$1,464,360	$1,925,076	$1,621,113	$1,845,829
UWA	$133,500	$763,500	$415,000	$415,000	$453,539	$415,000	$931,756
Curtin	$727,725	$608,055	$851,244	$611,290	$523,292	$1,027,772	$1,133,376
GSWA	$150,000	$150,000	$150,000	$150,000	$150,000	$150,000	$185,000
SLF Income	$500,000						
SLF Interest	$13,744	$12,530	$5,790	$1,811	$336	$405	
ECR Income from ARC	$1,250,000						
ECR Interest		$24,734	$16,118	$6,566	$1,841		
TOTAL INCOME	**$5,230,024**	**$4,595,003**	**$5,232,646**	**$4,680,360**	**$5,006,926**	**$5,200,330**	**$6,111,792**
ACCUMULATED FUNDS		$3,702,071	$4,960,194	$5,181,390	$4,776,770	$4,378,094	$4,020,390
Expenditure							
Salary	$783,390	$1,608,470	$2,263,183	$2,402,327	$2,423,825	$2,828,977	$3,299,846
Equipment	$90,128	$220,548	$785,851	$512,413	$93,008	$86,061	$44,275
Travel	$91,305	$280,795	$388,431	$404,572	$440,158	$398,178	$585,554
Maintenance/Consum.	$42,433	$459,530	$487,255	$494,580	$640,889	$461,139	$383,845
Scholarships	$520,697	$767,538	$1,086,730	$1,271,088	$1,807,722	$1,783,678	$2,775,961
TOTAL EXPENDITURE	**$1,527,952**	**$3,336,880**	**$5,011,450**	**$5,084,980**	**$5,405,602**	**$5,558,034**	**$7,089,482**
ACCUMULATED FUNDS	$3,702,071	$4,960,194	$5,181,390	$4,776,770	$4,378,094	$4,020,390	$3,042,701

INCOME SOURCES 2017



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

- 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)
- Implementation of significant parts of the UNCOVER initiative set out in: "*Searching the deep earth: a vision for exploration geoscience in Australia*" published by the Australian Academy of Science (2012; https://www.science.org.au/supporting-science/science-sector-analysis/reports-and-publications/searching-deep-earth-vision). CCFS addresses initiatives (ii) - (iii): investigating Australia's lithospheric architecture, 4D geodynamic and metallogenic evolution, and distal footprints of ore deposits.

Lago Argentino, El Calafate, Patagonia - Argentina (Photo: Gonzalo Henriquez).

Appendix 1: Flagship Programs aims and progress for 2017

1. DEEP-EARTH FLUIDS IN COLLISION ZONES AND CRATONIC ROOTS (TARDIS II)

Themes 1, 2 and 3, Early Earth, Earth's Evolution and Earth Today, contributing to understanding Earth's Architecture and Fluid Fluxes.

AIMS

This program investigates the role of fluids in the deep mantle and lithosphere, using studies of kimberlites and other volcanic rocks, xenoliths of mantle and crustal rocks in volcanic rocks, ophiolites, and ultra-high pressure terrains related to subduction zones. Super-reducing, ultra-high pressure (SuR-UHP: 400-600 km) mineral assemblages in some ophiolites carry implications for the evolution of fluid compositions, reactions and redox states in subduction environments from the surface to the Transition Zone, and suggest a newly recognised geodynamic collision process that may improve mineral exploration concepts for paleosubduction regimes. The recent discovery of similar exceptionally reduced mineral assemblages in ejecta from Cretaceous volcanoes in Israel suggests a previously unrecognised process of interaction between deep mantle fluids and ascending basaltic magmas. We aim to produce an experimentally testable model for the generation of such fluids in the mantle, to quantify constraints on the geochemical and tectonic processes that produce SuR-UHP assemblages, and to formulate a geodynamic model for their formation.

2017 Report

A comprehensive investigation of microstructures and mineralogy in Tibetan ophiolites has defined their evolution, including formation in ancient SCLM within subduction-zone settings, followed by subduction into the upper transition zone and exhumation to the sea floor prior to final emplacement by thrusting during continental collision. Studies of ophiolites in Mexico have revealed similar recycling processes, though not extending all the way to the transition zone.

Dr Hadi Shafaii Moghadam continued his investigations into the portion of the Tethyan Belt that lies in Iran, integrating field studies, petrology and isotopic geochemistry of granitoid rocks (as probes of the deep crust), volcanic rocks and ophiolites. The evolution of this '*soft collision zone*' can then be compared and contrasted with the '*hard collision*' between India and Asia, exposed in Tibet. The project has established a geochemical and geochronological framework, shown the existence of buried Archean-Paleoproterozoic crust in the east-central part of the orogeny, and defined major magmatic flare-ups (Neoproterozoic and Cenozoic) related to major collisions and subduction.

Studies of the suite of highly reduced minerals in the ejecta from Cretaceous volcanoes in Israel (industrial collaboration with Shefa Yamim (A.T.M) Ltd. labs in Akko) led to the development of a model involving interaction of mantle-derived methane and hydrogen with basaltic magmas in conduits near the crust-mantle boundary. Detailed mineralogical studies included further TEM analysis, in collaboration with Prof Martin Saunders (CMCA, UWA). Analyses of microstructures and mineralogy have demonstrated that moissanite in the Israeli ejecta and in Siberian kimberlites has grown from carbon-rich Fe-silicide melts, immiscibly separated from silicate melts. This model offers a possible explanation for the wide range of Si isotopes in SiC analysed by SIMS (Perth and Beijing (courtesy of collaborator Professor Li Xian-Hua)). There are clear linkages between the silicide melts that have crystallised SiC and those found within the corundum aggregates found in the Israeli volcanics. Analysis of zircons from the different Cretaceous volcanic bodies revealed an unexpectedly long history of magmatism in the mantle beneath Mount Carmel, extending back to the Permian, and analysis of the distribution of zircon populations among the Cretaceous volcanos generated a map of the temporal and spatial evolution of the magmatic underplate beneath the region.

The work on other mantle rocks continued, with studies of pyroxenites from SE Australia, the Pannonian Basin in Hungary, Cabo Ortegal (Spain) and the Trinity ophiolite (California). Work continued on kimberlites and diamonds in Angola, Siberia and South Africa, including studies of conventional (S, C, O, N) and unconventional (Mg, Fe) isotopes. A major study on the petrography and Sr-C-O isotopes of carbonates in kimberlites worldwide produced consistent criteria for the identification of primary magmatic carbonates and elucidated their role in kimberlite petrology. Work on the deep crust and its reworking continued in China, with petrological studies of xenoliths and adakites, and geophysical imaging.

See *Research highlights pp. 38-40, 44-45, 47, 51, 55-57, 65-66, 67-69.*

Published outputs for 2017

CCFS publications: #628, 825, 835, 856, 862, 863, 864, 875, 878, 880, 933, 936, 942, 959, 965, 968, 969, 972, 975, 991, 998, 1001, 1002, 1004, 1007, 1010, 1018, 1046, 1047, 1048

<25 Conference Abstracts

2. GENESIS, TRANSFER AND FOCUS OF FLUIDS AND METALS

Themes 2 and 3, Earth's Evolution and Earth Today, contributing to understanding Earth's Fluid Fluxes.

AIMS

This program embodies a holistic approach to ore deposit research, acknowledging that the genesis of mineral occurrences requires the conjunction in time and space of three main independent parameters: fertility, lithosphere-scale architecture, and favourable transient geodynamics. In this context, the integrated studies in this Flagship program address the critical link between metal source fertility and four-dimensional evolution of multi-scale fluid pathways that ensure efficient mass and fluid flux transfer between the mantle and the upper crust. Our studies test the hypothesis that the genesis of sizeable mineral deposits is the end product of self-organised critical systems operating from the scale of the planet all the way to the very focused environments where ore deposits can form. This Flagship Program is not commodity-focused but rather looks at the basic commonalities among various mineral systems to unravel the main constraints in the formation of ore systems.

2017 Report

In 2017, the ongoing integrated projects reached some important milestones. The projects in Module 1 (Fertility) focused on unravelling the global cycle of metals. Outcomes include the definition of a new calibrated oxybarometer that may be indirectly applied to discriminate the copper fertility of porphyry belts and unravel the secular oxygen fugacity evolution of the planet from the Hadean through the Eoarchean, as well as the definition of new fertility indicators for porphyry copper mineralisation based on the trace element composition of zircon. This work is fully integrated with other ongoing porphyry studies in South America and in the Macquarie Arc of New South Wales. Finally, from a fertility point of view, recent work completed in east Greenland suggests that nickel sulfide mineralisation associated with the Ammassalik Intrusive Complex (Fig. 1) may be genetically related to the highly endowed ca. 1.9 Ga Kotalhati belt in the Svecofennian Province of Scandinavia, thus opening up the prospectivity of that region for Ni-Cu intrusion-hosted deposits.

Ongoing projects in Module 2 (Architecture) have made significant progress in defining and imaging the key pathways that connect geochemical reservoirs and permit the efficient multi-scale flux of energy and fluids in space and time. Within Module 2, the high-precision TIMS work focused on the Kohistan Arc Complex of northeast Pakistan provided a refinement of current models describing continental crust formation in island arc settings, with crucial implications for the understanding of the architecture of magma plumbing networks in the lower crust.

Finally, in Module 3 (Transient Geodynamics), it was possible for the first time to couple recently produced solidii for carbonated basalts and sediments at pressures and temperatures relevant to upper mantle conditions with geodynamic modelling. This was accomplished through a robust thermomechanical and petrological modelling framework previously applied to decarbonation of subducting slabs and decarbonation within intracratonic settings.

See *Research highlights pp. 42-43, 43, 49-50, 60-61, 62-63, 63, 73-74.*

Published outputs for 2017

CCFS Publications: #635, 846, 870, 879, 890, 926, 954, 955, 957, 973, 986, 988, 997, 1000, 1019, 1027, 1086, 1151

> 20 Conference Abstracts

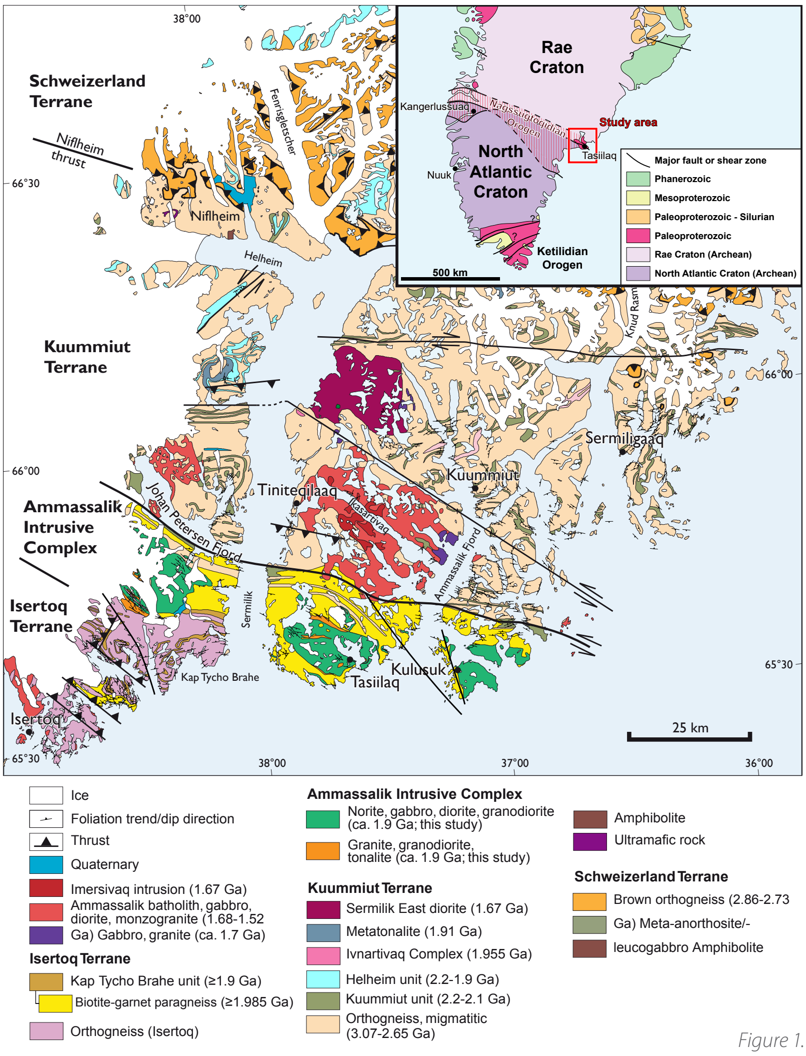


Figure 1.

3. MODELLING FLUID AND MELT FLOW IN MANTLE AND CRUST

Themes 2 and 3, Earth's Evolution and Earth Today, contributing to understanding Earth's Architecture and Fluid Fluxes.

AIMS

Many aspects of Earth Science, from ore deposits to giant earthquakes, depend critically on the complex interaction of solids and fluids. Numerical simulation of these processes and effective visualisations of the results is critical to understanding how these Earth system components work, but our ability to do this is currently very limited. Flagship Program 3 is developing the next generation of numerical codes and aims to refine the thermodynamic parameters involved by integrating high-pressure experiments to handle these complex problems. This will lead to important improvements in the quantification and visualisation of Earth processes, and will be applied to a variety of geodynamic situations.

The new high-pressure experimental group at Macquarie joins this initiative to provide input on physico-chemical parameters of minerals, melts and fluids in the deep mantle, the composition of melts that infiltrate the lithosphere, and their effects on its geodynamics and stability.

2017 Report

2017 saw some of the final development implementations of fluid flow in the code Aspect implemented. This includes a sophisticated melt-transport capacity based on a statistical treatment of melt migration, allowing for melt emplacement and crustal production in global-scale simulations. These are now being implemented in simulations of continental lithospheric evolution, and flood basaltism. Many previously published physical implementations we have developed (e.g. magnetic field evolution, see dealii.org/aspect) have been rolled into the main Aspect community code, and other modules (e.g. impacting) are freely available for download. The latter module resulted in a Nature Geoscience paper, published in 2017, entitled "*Impact-driven subduction on the Hadean Earth*" The material model implemented in Aspect has also been used to simulate the long-term survival of Hadean mantle reservoirs (observed from ^{142}Nd data). The models show that despite a vigorous convecting regime, lateral variations in mantle composition may be sustained over periods of >800 Myrs, due to limited transfer of material between convecting cells in a stagnant-lid regime (Fig. 1). The work formed the basis of a Gordon Conference Keynote presentation, and is currently in review.

The development of a full multiphase flow methodology has resulted in a key paper outlining the approach in Geophysical Journal International (*Oliveira et al., 2017*). The underlying engine (LitMod) has also been applied to problems in dynamic topography of southern Africa, and in linking Pleistocene volcanism in Angola to a deep mantle upwelling.

The progression of the seismology arm of the project in China has led to a paper on the origin, and emplacement, of Quaternary volcanism in Northeast China, as well as further technical developments in, for instance, phase-velocity stacking.

The development and expansion of the high-pressure laboratory is underway, and building works and renovations have begun.

See *Research highlights pp. 44-45, 45-46, 54-55, 64-65.*

Published outputs for 2017

CCFS Publications: #996, 1003, 1012, 1029, 1102 1118, 1119, 1152

15 Conference Abstracts

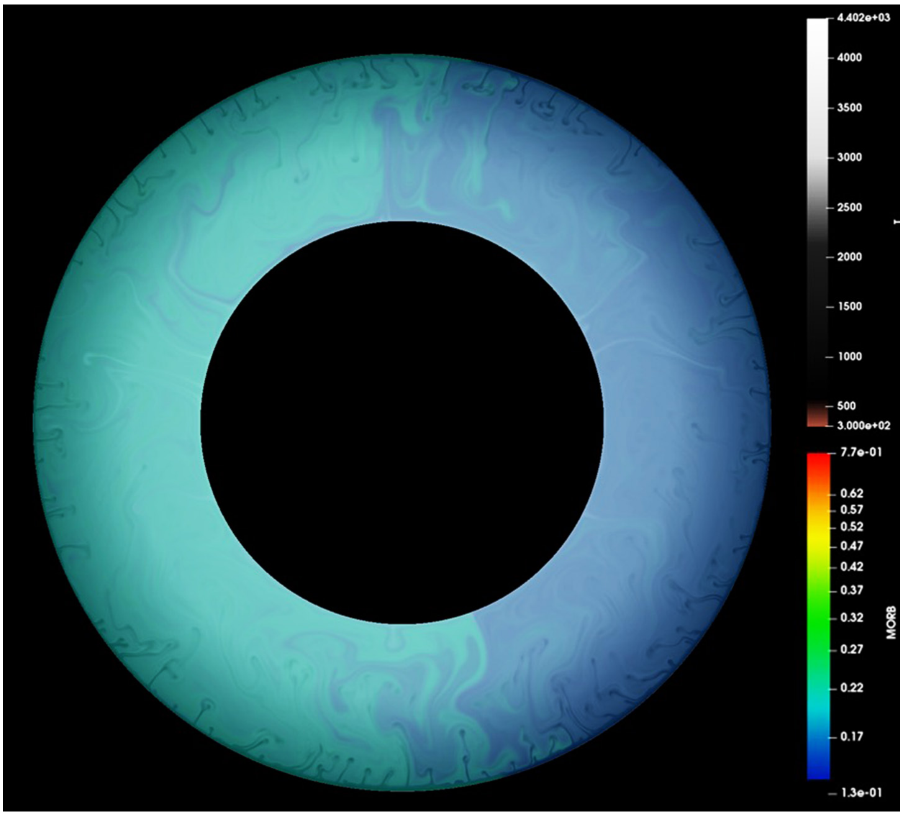


Figure 1. Simulation after 700 Myrs evolution, showing the survival of a primordial heterogenous mantle anomaly over that interval. The timescale is consistent with the survival of distinct Hadean ^{142}Nd mantle reservoirs into the Eoarchaean.

4. ATMOSPHERIC, ENVIRONMENTAL AND BIOLOGICAL EVOLUTION

Theme 1 Early Earth, contributing to understanding Earth's Architecture and Fluid Fluxes.

AIMS

We investigate how the evolution of life and ore deposits were linked to the changing whole-Earth System, focusing on planetary driving forces that affected all the different shells of the planet, to develop a 4-dimensional conceptual framework of Earth evolution. Given the broadly comparable petrological evolution of Earth and Mars, we also aim to put forward new working hypotheses on how life and mineral systems may have formed and evolved on the red planet.

This program will test the hypothesis that the evolution of life and the genesis of sizeable mineral deposits are the end products of systems operating at the scale of the planet all the way down to the specific environments where life flourished and mineral deposits formed. We evaluate the relative importance of: (1) the threshold barriers that form in specific environments, creating strong chemical and energy gradients in the crust, and the self-organised behaviour of mineral systems and life;
(2) the evolving nature of '*traps*' at the lithosphere-hydrosphere boundary, where life and ore deposits developed through time;
(3) the global-scale cycles of key elements and heat transfer essential for the evolution of life and formation of ore deposits and
4) the 4-D evolution of pathways that connect geochemical reservoirs through time, linked to the changing tectonic style of the planet.

2017 Report

In 2017, CCFS Flagship Program 4 was engaged in a wide range of research activities, from continuing investigations of the habitats and biogenicity of the earliest evidence of life on Earth, to the adaptation of life across the Great Oxygenation Event, and global tectonics.

The publishing highlight was a *Nature Communications* paper by Tara Djokic on the discovery of terrestrial hot spring deposits that harboured microbial life in 3.48 billion-year-old rocks of the Pilbara Craton (see *CCFS Communications p. 34*).

Raphael Baumgartner's amazing work on tiny samples of drillcore material from the Dresser Formation stromatolites will be the new benchmark for definitive evidence of the oldest life on Earth (Fig. 1.). The work points to a new taphonomy involving microbial sulfidisation that is important in the search for ancient life on not only Earth, but elsewhere in the solar system. The work is being written up for publication in *Nature*. See *Research highlight pp. 58-60*.

Early in 2017, three FP4 members participated in NASA's 3rd landing site workshop, Los Angeles, for the upcoming Mars2020 mission to search for life on Mars. CI Van Kranendonk gave a presentation on why Columbia Hills, and hot spring sites in general, are good targets in this search, and helped to make this site one of the top three remaining in contention as the landing site for this exciting, $2Billion scientific experiment.

A highlight of 2017 was the field trip to west Greenland with Martin Van Kranendonk, Allen Nutman (U. Wollongong), Darren Dougan (UNSW), and Clark Friend (self-funded) to map the area around the stromatolites discovered by our team and published in *Nature* in 2016. This field trip provided a more thorough geological context for the stromatolite discovery and located an additional outcrop, though these stromatolites were not as well preserved. It also confirmed the initial interpretation, that the stromatolites are bona fide signatures of microbial activity at 3.7 Ga. Mapping the area's metamorphic fluid gradient identified areas where primary structures had been preserved, despite metamorphism and regional high strain. Most importantly, we identified a stratigraphy for the stromatolites, which showed a classic transgression sequence from pebble conglomerate at the base (lying on pillow basalts), through the stromatolitic carbonates interbedded with calc-silicates and quartz-rich sandstones, passing up into deep water facies iron-rich cherts.

Another highlight was the discovery of unique branching siliceous structures in the 2.4 Ga Turee Creek Group that are of undoubted, but enigmatic, biological origin (See *Research highlight p. 69*). These structures are the focus of the PhD study by Georgia Soares at UNSW and could well be the oldest evidence of eukaryotic life, in addition to complex microfossils discovered by Erica Barlow. Brendan Nomchong is looking into the environmental aspects of this reef in order to identify conditions that led to the flourishing of life at this time.

See *Research highlights pp. 37, 52, 58-60, 69*.

Published outputs for 2017

CCFS Publications: #726, 855, 873, 956, 1070, 1075, 1133

11 Conference Abstracts

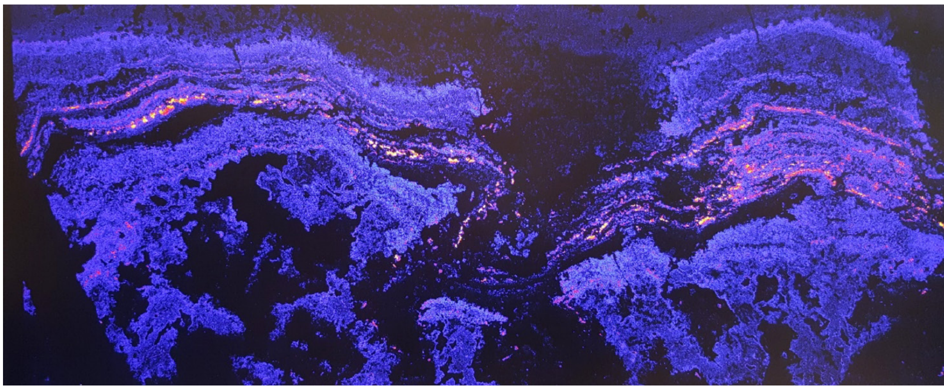


Figure 1. Australian Synchrotron X-Ray Fluorescence image of 3.48 Ga Dresser Formation pyritised stromatolites, showing Ni enrichment in thin laminae that wrap across individual branching structures. Width of view is ~1.5 cm.

5. AUSTRALIA'S PROTEROZOIC RECORD IN A GLOBAL CONTEXT

Themes 2 and 3, Earth's Evolution and Earth Today, contributing to understanding Earth's Architecture.

AIMS

Earth's history is considered to have been dominated by cycles of supercontinent formation and breakup. This program tests this hypothesis and its relevance to Australia's geological evolution, assessing Australia's positions during the supercontinent cycles by examining the paleomagnetic, petrological and detrital provenance record of the Australian and adjacent continents. By studying primarily Australian rocks and comparing the results with global analogues, we aim to extend our knowledge about supercontinent cycles and the evolution of the Australian continent to the Paleoproterozoic or even further back in time. Such knowledge is fundamental for understanding the first-order fluid cycles that controlled the formation and redistribution of Earth resources, and the establishment of a 4D global geodynamic model covered in other Flagship Programs.

2017 Report

Research on the Yilgarn dyke swarms by two PhD students, Camilla Stark and Yebo Liu, have made breakthrough discoveries. In addition to the previously known dyke swarms of 2.4 Ga, 1.2 Ga and 0.75 Ga mafic dyke swarms, our work on newly identified 2.6 Ga, 1.9 Ga and 1.4 Ga mafic dyke swarms will provide key information for the evolution of the Australian continent and positions of the Yilgarn craton relative to other old cratons. Papers reporting on the age, geodynamic setting, palaeomagnetism, and a likely connection between Yilgarn and India at 1.9 Ga, are coming out in Precambrian Research (*CCFS publications #1123 and #1068*).

Palaeomagnetic analyses of the 1.8 Ga Hart dolerite from the Kimberley Craton also led to a new conceptual model of how the Proterozoic supercontinent Nuna was formed. In a paper currently under review, we propose that Nuna experienced a two-stage assembly process: between ca. 1.8 Ga and 1.73 Ga, Australia-East Antarctica was close to Laurentia but still separated by a relatively small ocean, and they appear to have shared similar plate motions. This small ocean only moved closed after 1.6 Ga, leading to the final assembly of Nuna by ca. 1.6 Ga. See *Research highlight p. 53*.

The northern Queensland team, supported by Li's ARC Laureate Fellow project, is also starting to make breakthrough discoveries regarding Australia's position in Nuna and Nuna's assembly process. Provenance analysis of detrital zircons from the Georgetown region, led by PhD student Adam Nordsvan, revealed the first solid geological evidence for a connection between northern Australia and northwestern Canada in Nuna (C*CFS publication #1043*). The work shows that that the Georgetown terrane originated from North America, and only joined Australia at ca. 1.6 Ga during the final assembly of supercontinent Nuna. This work has generated huge global publicity. See *Research highlight pp. 40-41.*

A sedimentary provenance analysis of mid-Cambrian clastic rocks from the Ord Basin in north-western Australia gave surprise findings – the sediments were mostly derived from a non-Australian origin that bears similarities to northern India. This led to a revised palaeogeographic model in which clastic rocks from Indian Gondwana margin travelled along the north-eastern Gondwanan continental margin via longshore currents to northern Australia soon after the assembly of Gondwana.

In 2017, the first Neoproterozoic global reconstruction with full-plate topology was published through collaborations with the University of Sydney and the University of Adelaide, offering an exciting first glimpse into the future of paleogeography (*CCFS Publication #925*).

See *Research highlights pp. 40-41, 53*.

Published outputs for 2017

CCFS Publications: #790, 802, 840, 882, 883, 888, 897, 898, 920, 925, 952, 966, 985, 1011, 1033, 1043, 1068, 1123, 1131, 1134

28 Conference Abstracts

6. FLUID REGIMES AND THE COMPOSITION OF EARLY EARTH

Themes 1 and 3, Early Earth and Earth Today, contributing to understanding Earth's Architecture and Fluid Fluxes.

AIMS

Zircon crystals are currently the only material that records events in the first 500 million years of Earth's history, since no rocks have survived from this period and no other minerals have been established as Hadean in age. There is growing evidence from the study of these zircon crystals that the Earth stabilised rapidly after accretion and that both solid rock and liquid water were present within 150 million years of its formation. This program uses the geochemical signatures of zircon crystals from all known Hadean and early Archean localities, together with geochemistry of the oldest known rocks and the application of geophysical and geochemical modelling, to establish how the first crust formed, why it was destroyed, and the role fluids played in this process. The changes that took place throughout the Archean are being evaluated as crustal processes evolved and plate tectonics became the dominant regime. A key component is determining the interaction between the mantle and the evolving crust. In addition, work undertaken on Martian meteorites and lunar samples is providing further constraints on the early history of the Solar System, especially the role played by fluids.

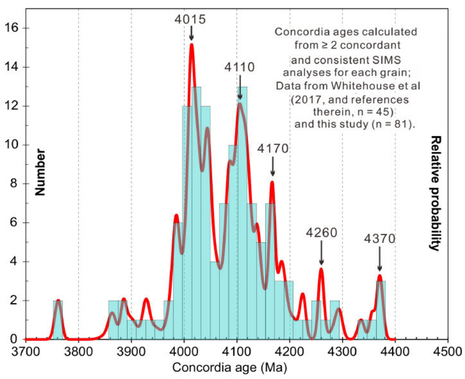


Figure 1. Compilation of all the available Concordia data from single zircon crystals, identifying the key age peaks within the Hadean.

2017 Report

CCFS post-doctoral fellow Dr Rongfeng Ge is re-evaluating the Jack Hills detrital zircon suite, focusing on identifying the most pristine portions in order to assess their original characteristics. Major advances include the recognition of radiogenic lead (Pb*) mobility on a nanometre to micron scale using ion imaging techniques. This led to the discovery of a concordant grain recording the oldest age known on Earth (4481+/-17 Ma), which nonetheless proved to be spurious due to Pb* mobilisation: the results were published in *Geology*. Other work published during the year included that of former CCFS PhD student, Dr Qian Wang, based on her traverse through the entire Jack Hills belt. A highlight of this study was the identification of a quartzite unit near the northern margin of the belt that contained ~20% Hadean grains. Work on the identification of CO_2 and graphitic carbon inclusions in Jack Hills' zircons, in conjunction with German colleagues, was also published.

The Nd study of 3.8-3.0 Ga TTG rocks from the Anshan area of the North China Craton (NCC) identified variations in ^{142}Nd, suggesting evolution of the host rocks at c.a. 4.4 Ga. Work on the Kuruktag area of the Tarim Craton identified a tonalite recording an age of 3.7 Ga, making it one of the oldest rock-units in China: this work has been published in Science Advances.

Lu-Hf analyses were undertaken on samples from Aker Peaks in Kemp Land, Antarctica, to better characterise their age and provenance and the results are currently being evaluated. The metallic lead nanospheres identified in ancient zircons from the Napier Complex, Antarctica, have been investigated by both NanoSIMS and atom probe and work will continue into 2018.

A field trip was made to the Saglek Bay area of Labrador, Canada, to further investigate the ancient gneisses where vestiges of life at 3.9 Ga have been reported by Japanese scientists. Detailed studies were undertaken in several selected areas and a suite of 140 samples collected for geochemical and isotopic investigation in association with the Polish Academy of Sciences.

Further analysis of lunar basalts helped to revise the stratification of basaltic sequences at the Apollo landing sites and also helped in developing a reference framework for crater counting chronology. Analyses of millimetre-sized lithic clasts in lunar impact breccias demonstrated that their Pb isotope systems were completely reset during the impacts, hence providing a means of defining the ages of both the breccias and the impacts that formed them. Some basaltic clasts analysed in lunar meteorites and dated at around 4.33-4.36 Ga confirm for the first time that basaltic magmatism started on the Moon immediately after solidification of the Lunar Magma Ocean and basalts were not formed after ~3.8 Ga. A coherent Pb isotope evolution model of the Martian mantle was formulated that is consistent with the results obtained from other isotope systems, including Rb-Sr, Sm-Nd, Lu-Hf and Re-Os.

Published outputs for 2017

CCFS Publications: #962, 963, 1087, 1111, 1116, 1120, 1127, 1128, 1130, 1131, 1132, 1137, 1138, 1139, 1140, 1142, 1143, 1144, 1145, 1146, 1147, 1148, 1149, 1156

9 Conference Abstracts

Ripple-marked sandstone in the Cuddapah Basin, India (See CCFS publication #1127).

7. PRECAMBRIAN ARCHITECTURE AND CRUSTAL EVOLUTION IN WA

Themes 1, 2 and 3, Early Earth, Earth's Evolution and Earth Today, contributing to understanding Earth's Architecture.

AIMS

Iron, Gold and Nickel deposits are of global economic significance, and the Neoarchean Yilgarn Craton and the Proterozoic orogens around its margins constitute one of Earth's greatest mineral treasure troves. Whereas the Yilgarn Craton is one of the best-studied Archean cratons, its enormous size and limited outcrop are detrimental to a deep understanding of what controls the distribution of resources and which geodynamic processes were involved in the tectonic assembly of the Australian continent. This program combines geological, geochemical and geophysical techniques to develop a 3D structural model of the lithosphere of the Yilgarn Craton and its margins. The Yilgarn Craton is a highly complex piece of Archean crust with a long history extending from 4.4-2.6 Ga: amalgamation of terranes is thought to have occurred around 2.65 Ga. The program includes the Capricorn Orogen Passive Array (COPA), a passive-source experiment that studies the structure of the deep crust and shallow lithosphere using earthquake seismology. The data from this experiment will be the main source for the local ambient noise inversion, the receiver function common convection point (CCP) stacking techniques, and possibly a body-wave tomography study. Given the fact that the passive source site coverage in Western Australia is sparse and that the available permanent sites in the region provide nearly 10 years of data at isolated locations, several techniques that focus on crust and upper mantle structure beneath single stations will also be applied. This approach has the potential to provide quick access to the crustal and lithospheric structure from these representative sites.

2017 Report

We completed the Capricorn Orogen Passive-source Array (COPA) field deployment in late 2017, and data analysis is currently under way. In 2016, the data collected from previous services were analysed with a focus on the seismic structure of the Capricorn Orogen crust. The Canning land (CWAS; 20 sites) and ocean-bottom-seismic (CANPASS; 11 sites) arrays were successfully deployed in September 2017 in collaboration with the Institute of Geology and Geophysics of the Chinese Academy of Sciences (IGG-CAS). A 40-site Perth Basin Seismic (PBS) array started operation in 2017.

Recent work on the Hf isotopic composition of the unexposed Proterozoic crystalline basement to the Bight and Eucla Basins in Western Australia has revealed the existence of a huge tract

CWAS Team work: a selfie after finishing a portable seismic station at Wallal Downs, Canning.

of predominantly juvenile material. The observed isotopic evolution pattern is comparable to other central Australian Proterozoic provinces, including the Musgrave Province, the northern margin of the Gawler Craton, and components within the Rudall Province. New zircon Hf isotope and whole-rock Nd isotope data from the Pilbara Craton, Western Australia do not support a model of modern-style subduction, instead being consistent with vertical tectonic processes in a volcanic plateau-type setting for the East Pilbara Terrane prior to ~3.2 Ga. New zircon O, U-Pb and Hf isotope data from magmatic rocks across the Rudall Province outline two potential scenarios for the Paleo- to Mesoproterozoic geodynamic evolution of the Rudall Province. An early cratonic amalgamation between the West and North Australian Cratons ca. 1680 Ma followed by Mesoproterozoic intraplate events or, more likely, a later assembly ca. 1377–1275 Ma (Yapungku Orogeny).

See *Research highlights pp. 48-49, 57-58, 70-71, 72-73.*

Published outputs for 2017

CCFS Publication: #971, 1135, 1060, 1061, 1064, 1076

2 Conference Abstracts

IGG-CAS visitors Kun Wang, and Baolu Sun install a portable seismic station at the abandoned airstrip of Anna Plains Station during the Sept 2017 CWAS deployment.

WHOLE OF CENTRE TECHNOLOGY DEVELOPMENT

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

Themes 1, 2 and 3, Early Earth, Earth's Evolution and Earth Today, contributing to understanding Earth's Architecture and Fluid Fluxes.

AIMS

The Ion Probe Facility within the CMCA at UWA is one of the best-equipped Secondary Ion Mass Spectrometry (SIMS) labs in the world. It houses a CAMECA IMS 1280 large-radius ion microprobe, for the high-precision analysis of stable isotopes in minerals, and two CAMECA NanoSIMS 50s for imaging mass spectrometry at the sub-micron scale. This program provides a dedicated Research Associate to facilitate CCFS activities and lead the development of standards and analytical protocols at the CMCA. This greatly benefits CCFS by increasing the capacity of the Facility, enabling a higher degree of interaction and participation on research projects, facilitating standards and protocols development, and allowing greater synergy with other CCFS node facilities.

For progress in 2017 and plans for 2018, please see pp. 82-86 in Technology Development.

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

Themes 1, 2 and 3, Early Earth, Earth's Evolution and Earth Today, contributing to understanding Earth's Architecture and Fluid Fluxes.

AIMS

The overall aim is to develop new analytical methods for *in situ* measurement of trace elements and isotope ratios to support and enable CCFS research programs and to provide new directions of research. Specific objectives include:

(1) combined trace element and isotope analysis - '*split-stream*' analysis

(2) development of '*non-traditional*' stable isotopes

(3) characterisation of reference materials for elemental and isotope ratio measurement

(4) development of data reduction software for combined trace element and isotope analysis

For progress in 2017 and plans for 2018, please see pp. 86-87 in Technology Development.

Appendix 2: CCFS workplan 2018

1. DEEP-EARTH FLUIDS IN COLLISION ZONES AND CRATONIC ROOTS (TARDIS II)

Activities planned include:

- completing and publishing the remaining studies on the Iranian Tethys
- continuing the detailed analytical work on the Mt Carmel magmatic system
- carrying out analytical work on an analogue from Devonian kimberlites from the Azov area, Ukraine
- publishing work on the Mt Carmel system in at least three papers
- completing and publishing the work on material from Pannonian Basin, Cabo Ortegal and SE Australia
- continuing work on kimberlitic carbonates, and publishing at least one paper.

2. GENESIS, TRANSFER AND FOCUS OF FLUIDS AND METALS

The work plan for 2018 aims to complete the various projects that are still in progress in the three modules. In Module 1, the focus will be on unravelling the genesis of adakites by looking at the natural laboratory provided by Patagonia. In order to provide the necessary constraints to the working hypotheses that are being developed as part of the PhD project of Gonzalo Javier Henriquez, a modelling project will be carried out in parallel in Module 3. The study will examine the style of emplacement of magmas in the crust under a compressive regime and model the evolution of the subducting Nazca plate during the opening of the slab window. In Module 2, we expect to complete the multiple sulfur isotope dataset from the Yilgarn Craton granitoids, with the intent to produce the very first sulfur isotope map of an Archean Craton. It is anticipated that further high-precision TIMS dating, as well as the completion of pending trace element analyses on apatite and zircon crystals from selected porphyry copper systems globally, will elucidate the key constraints on ore genesis in magmatic arcs. It is expected that the work carried out in 2018 will lay the foundations for new collaborations into the future.

3. MODELLING FLUID AND MELT FLOW IN MANTLE AND CRUST

During 2018 the foundation project will see the maturation of many of its numerical approaches and the application to a wide range of CCFS projects. For instance, J.C. Afonso, Beñat Oliveira (PostDoc) and Marti Burcet (new PhD student) will adapt our recently developed Multiphase and Multicomponent Reactive Transport model to simulate and explain the origin and evolution of transcrustal magmatic systems. In addition, we will expand the capabilities of the current numerical platform with both disequilibrium trace-element and isotopic modelling. We foresee immediate applications to a multitude of problems through collaborations across CCFS nodes.

The development of a statistical approach to modelling the transport of melt and crustal production in global mantle convection models will extend into simulations on the interaction of mantle melts, eclogitisation, and lithosphere recycling, planned by C. O'Neill and S. Zhang.

Further seismic imaging combining surface waves and body waves will be performed in NE China to investigate the origin of intraplate volcanism in NE China. This work will be carried out in collaboration with China University of Geosciences (Wuhan) and Southern University of Science and Technology of China.

The experimental laboratory at MQ is closed in the period February to December 2018 for renovations. Some experiments will be carried out in the laboratories of partner institutions (e.g. Australian National University, University of Mainz, China University of Geosciences, Wuhan), whereas other projects will concentrate on data collection and analysis from experiments already run. Current projects include volatile-induced melting of mantle peridotite, carbonate/silicate rock reactions in subduction zones, the deep Earth nitrogen cycle, trace elements in mantle orthopyroxenes, and trace elements in olivine phenocrysts from eastern Australian volcanic rocks.

4. ATMOSPHERIC, ENVIRONMENTAL AND BIOLOGICAL EVOLUTION

Research will continue on established CCFS FP4 projects, including:

A project on the evidence of early life in the Dresser Formation of the North Pole Dome has been funded by an ARC DP (Van Kranendonk, Fiorentini, "*A terrestrial hot spring setting for the origin of life? Darwin's Warm Little Pond revisited*") and a nearly $1M NZD Marsden Fund grant to Prof Kathy Campbell (U Auckland) and CI Van Kranendonk, including a significant component for a new diamond drilling program through the Dresser. Tara Djokic will continue her PhD research into hot spring deposits of the Dresser, and Raphael Baumgartner's results from the Dresser Formation will be written up as part of his new post-doc position at UNSW, resulting in at least four major papers.

Results from West Greenland fieldwork on the oldest known stromatolites will be written up.

Writing up and further research on the development of complex life in the immediate aftermath of the Great Oxygenation event will continue; with papers from Erica Barlow, Georgia Soares, and Brendan Nomchong (two submitted, three more in progress). Erica is due to complete her PhD this year on the microfossil assemblage of the Turee Creek Group. A new UNSW PhD student, Bonnie Teece (MRes MU), will undertake organic geochemical studies of these complex life-bearing rocks.

Van Kranendonk aims to complete the second edition of Earth's Oldest Rocks, due for publication in late 2018, and write two major papers on: "*The chemistry for Life on Land*" (*Nature*), and "*A Planetary Driver of Atmospheric, Biological and Environmental Change through the Precambrian*"; a summary of many years work.

The Australian Centre for Astrobiology will co-host Astrobiology Australasia 2018, Rotorua, New Zealand, in collaboration with the New Zealand Astrobiology Network. This meeting will be followed by our "*Grand Tour*" field trip across Western Australia, from the living stromatolites of Shark Bay back through time to the ancient fossil stromatolites of the Pilbara.

5. AUSTRALIA'S PROTEROZOIC RECORD IN A GLOBAL CONTEXT

Palaeomagnetic analyses and writing up for Yilgarn, northern Kimberley, the Gawler craton and East Antarctica will continue in 2018. Geochronological and geochemical results from the Yilgarn and East Antarctica mafic dykes will also be written up for publication during the year.

6. FLUID REGIMES AND THE COMPOSITION OF EARLY EARTH

Work in Australia will remain focused on Jack Hills. The characterisation of the oldest zircons from the W74 site will continue with the aim of placing tighter constraints on the nature of Earth's oldest crust. The database acquired in 2017 will be interrogated, and new results on Pb mobility will be prepared for publication. The quartzite locality with ~20% Hadean grains will be re-investigated and detailed characterisation of the new grains undertaken.

The atom probe investigation of lead (Pb) nanospheres in ancient zircons from the Napier Complex, Antarctica, will continue in order to precisely determine their distribution and isotopic composition. Work on the Kemp Land samples has now been extended to include new samples provided by Geoscience Australia.

Another field trip to Labrador will be undertaken in mid-2018 to focus on the distribution of the most ancient gneissic components identified in the 2017 field season.

Work will continue on both lunar rocks and Martian meteorite samples with the aim of constraining the age of the oldest crust and the precise timing of events in the early solar system.

7. PRECAMBRIAN ARCHITECTURE AND CRUSTAL EVOLUTION IN WA

In the eastern Capricorn region, 12 new COPA stations will be in operation until April to fill gaps in the Capricorn deployment. The 40-station Perth Basin Seismic Array will be finished in February 2018. The Ocean Bottom Seismometer deployment is scheduled to end in May 2018. In September 2018, 40 more sites will be deployed during the second phase of the Canning Land project. New seismic models of the crust and sub-crustal lithosphere of the Capricorn Orogen to be submitted for publication include the crustal and shallow upper mantle shear-wave velocity model using ambient noise imaging, the Moho and intra-crustal discontinuity topography mapping using receiver functions and the lithosphere-scale body-wave tomographic model of the Capricorn orogenic mantle. A visiting post-doc will start working on the Perth Basin Seismic array data using ambient noise tomography, receiver function imaging, body wave tomography and auto-correlation. An MSc student from UWA will help in this project. A whole-Yilgarn ambient-noise velocity modelling will start this year, combining existing datasets.

Appendix 3: 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. For Industry funded projects see *Industry Interaction pp. 91-97.*

A terrestrial hot spring setting for the origin of life? Darwin's Warm Little Pond revisited	**M. Van Kranendonk**, **M. Fiorentini**, K.A. Campbell, D. Deamer: *Support by ARC DP (commencing 2018)* ***Summary:*** This Project aims to test the proposal that a terrestrial hot spring field could have been the setting for the origin of life, in preference to the currently favoured site at deep sea vents. This will be achieved by: 1) detailed characterisation of the only known, truly ancient, inhabited terrestrial hot spring analogue in the geological record – the 3.5 billion-year-old Dresser Formation, Western Australia; 2) comparison of this ancient analogue with active hot spring fields in New Zealand; and 3) experimental research on prebiotic organic chemistry using Dresser materials and active hot spring fluid chemistries. Results will be used to develop a terrestrial origin of life setting and assist in the search for life on Mars.
Establishing the critical physical-chemical factors in the early surface environment and tectonic regime that supported early life and continuing habitability	A. Nutman, V. Bennett, **M. Van Kranendonk**: *Support by ARC DP (commenced 2017)* ***Summary:*** Engineering planetary habitability: Earth's first billion years. This project aims to establish the critical physical-chemical factors in the early surface environment and tectonic regime that supported early life and continuing habitability. Life was established on Earth within the first billion years of its 4.56-billion-year history. This project's integrated geological and geochemical study will investigate this period's rare sedimentary and volcanic record, including the oldest fossiliferous sequences discovered recently, to show how the early Earth's chemistry supported life and evolution. The project expects to enhance understanding of why life prospers on some habitable zone planets but not on others
Rehydration of the lower crust, fluid sources and geophysical expression	M. Hand, **C. Clark**, D. Hasterok, **T. Rushmer**, **S. Reddy**, B. Hacker: *Support by ARC DP (commenced 2016)* ***Summary:*** This project aims to explore a long-standing mystery: the origin of deep crustal electrical conductors detected by magnetotelluric imaging of tectonically stable crust. These features occur in cratons of all ages, and commonly cross-cut structures and lithologies. This project aims to investigate the hypothesis that such features are the record of ancient deep crustal fluid flow, which modified the rocks' electrical properties. Using an exceptionally exposed natural laboratory preserving large-scale rehydration of anhydrous lower crust, the project plans to determine the source of fluids and the compositional changes they induced. It then plans to experimentally determine changes in resistivity induced by fluid flow and use that data to model the magnetotelluric response at crustal scale.
To develop a geophysically relevant proton conduction model for the Earth's upper mantle	**S. Clark**, **J.C. Afonso**, A. Jones: *Support by ARC DP (commenced 2016)* ***Summary:*** The aim of this project is to develop a geophysically relevant proton conduction model for the Earth's upper mantle. This will allow the robust interpretation of conductivity maps of the interior of the Earth and the discovery of major new mineral deposits. This advance will be achieved through four major initiatives based on recently developed experimental and computational facilities. This project will develop new methods for determining rock conductivities and subsurface mapping from combined datasets. We will obtain new insights into the structure and dynamics of the upper mantle as well as providing key data necessary for a national effort aimed at reestablishing Australia as a primary target for mineral exploration.

Just add water: a recipe for the deformation of continental interiors	**A. Putnis**, T. Raimondo, **N. Daczko**: *Support by ARC DP (commenced 2016)* ***Summary:*** By integrating geochemical, geochronological and microstructural datasets, this project aims to provide a novel framework for fluid-rock systems in the lithosphere. Plate tectonics argues that continental interiors are usually stable, rigid and undeformable, yet mountain belts have formed in these locations. Their existence suggests that strong crust can be weakened to allow the accommodation of deforming forces, but the underlying causes for this change in behaviour are not clear. This project aims to investigate the largely unexplored impact of fluid flow on the characteristics of intraplate deformation. This would improve our understanding of what modulates the strength of continental crust, including its susceptibility to seismic activity, and the ways in which fluids interact with the deep crust, including their mineralisation potential.
Mechanisms of proxy uptake in biominerals	**D. Jacob**, S. Eggins, R. Wirth: *Support by ARC DP (commenced 2016)* ***Summary:*** This project plans to combine nano-analytical and aquaculture methods to develop new models that improve the reliability of paleoclimate reconstructions. The compositions of shells and skeletal materials of marine invertebrates are essential archives for quantifying temperatures and environmental conditions before modern climate records began. However, their reliability relies on understanding their formation. Emerging knowledge from material sciences indicates that these biocarbonates form via transient precursors rather than direct precipitation from seawater, profoundly affecting their interpretation. This project plans to transfer this new understanding to the earth sciences using nanoscale analytical methods including in vitro geochemical partitioning experiments. This would enable realistic models for geochemical proxy behaviour to be developed, significantly improving paleoclimate interpretations and assessments of ocean acidification effects on marine calcifiers.
Timescales of mixing and volatile transfer leading to volcanic eruptions	**H. Handley**, **S. Turner**, M. Reagan, J. Barclay: *Supported by ARC Discovery (commenced 2015)* ***Summary:*** The short-lived lead isotope, ^{210}Pb, has the unique ability to place timescale constraints on volcanic processes, such as the input, mixing and degassing of magma. These processes are believed to be of fundamental importance in the triggering of volcanic eruptions. This project will measure ^{210}Pb isotopic compositions and elemental diffusion profiles in crystals of volcanic rocks that represent the end members of mixed magmas to constrain the volume and timescale of volatile transfer from magmatic recharge and also the time between magma mixing events and eruptions. The project aims to test the paradigm that magma recharge triggers volcanic eruptions and aims to yield significant outcomes for understanding eruption triggers at hazardous volcanoes.
The global consequences of subduction zone congestion	**L. Moresi**, P. Betts, J. Whittaker, M. Miller: *Supported by ARC Discovery (commenced 2015)* ***Summary:*** This project will use a combination of 3D geodynamic modelling, plate kinematic reconstruction and geological and geophysical synthesis to determine how congested subduction zones influence plate kinematics, subduction dynamics and tectonic evolution at orogen and global scales. The project aims to deliver a transformation change in understanding the links between congested subduction, mantle flow, trench migration, crustal growth, transitions between stable convergent margin configurations and deformation in the overriding plates of subduction zones. Determining these relationships is significant because it will provide dynamic context to interpret the geological record of ancient convergent margins, which host a large percentage of Earth's metal resources.

How the Earth works-toward building a new tectonic paradigm	**Z.X. Li**: *Supported by ARC Laureate Fellowships (commenced 2015)* ***Summary:*** This fellowship project aims to build on the latest technological and conceptual advances to establish the patterns of Earth evolution, and use this information to examine a ground-breaking geodynamic hypothesis which links cyclic plate aggregation and dispersion to deep Earth processes. Half a century after the inception of plate tectonics theory, we are still unsure how the Earth '*engine*' works, particularly the forces that drive plate tectonics. The project involves extensive national and international collaboration to potentially create a paradigm shift in our understanding of global tectonics, and hopes to contribute to an understanding of the formation and distribution of Earth resources to provide a conceptual framework for their exploration.
How the Earth moves: Developing a novel seismological approach to map the small-scale dynamics of the upper mantle	**Y. Yang**: *Supported by ARC Future Fellowship (commenced 2013)* ***Summary:*** The concept of small-scale convection currents from about 100-400 km below the Earth's surface is a model proposed to explain the origins of intraplate volcanoes and mountains. However, direct evidence for the physical reality of small-scale convection cells is generally weak. This project will develop a novel seismological approach combining both ambient noise and earthquake data that can image such small-scale upper mantle convection. The outcomes of this project will help to fill the gap left in the Plate Tectonic paradigm by its inability to explain intraplate geological activity (volcanoes, earthquakes, mountains), which would be a significant step towards unifying conceptual models about how the Earth works.
Roles of deep-Earth fluid cycling in the generation of intra-continental magmatism	**X.C. Wang**: *Supported by ARC Future Fellowship and MQ (commenced 2014)* ***Summary:*** This project aims to test a provocative and potentially ground-breaking hypothesis that fluid released from subducted oceanic slabs and stored in the mantle transition zone, may trigger or control some major intra-plate geotectonic phenomena. It aims to provide a self-consistent model that links geological processes occurring at plate boundaries with those far-field effects well away from plate boundaries via deep-Earth fluid cycling. The outcomes of this project aim to help to better understand links between plume and plate tectonic processes in the first-order dynamic system of Earth, and identify ways to improve success in future mineral exploration.
Earth's origin and evolution: a sulphurous approach	**O. Alard**: *Supported by ARC Future Fellowship (commenced 2015)* ***Summary:*** This project aims to shed new light on global element cycles in the deep Earth and how they connect to the evolution of the exospheres - one of the hottest topics in geosciences. It also aims to produce key knowledge on the extraction and transport of elements from the deep Earth to the surface, which may provide valuable information for resource exploration. Using novel integrated elemental and isotopic approaches, this program aims to track the origin and fate of sulfur, selenium and tellurium during accretion and subsequent redistribution in fluids to Earth's surface. This new knowledge is critical to understanding how these and other elements of strategic and economic importance, such as the Platinum Group Elements, are extracted from the deep Earth and transported to the surface.
Measuring mantle hydrogen to map ore fluids and model plate tectonics	**K. Selway**: *Supported by ARC Future Fellowship (commenced 2015)* ***Summary:*** The goal of this project is to use magnetotellurics to measure mantle hydrogen contents to aid in the discovery of new mineral deposits. Hydrogen controls the strength of Earth's mantle and is a vital component of the systems that form giant ore deposits. However, mantle hydrogen content is unconstrained. Ore-forming fluids hydrate the mantle pathways on which they travel. The first aim of this project is to image these fluid pathways to improve mineral exploration techniques. Plate tectonic models assume that the lithospheric mantle is dehydrated but existing data from magnetotellurics and mantle rocks show high hydrogen contents. The second aim of this project is to create a map of the hydrogen content of the plates, which may lead to new models for continental evolution and mantle dynamics.

A new approach to revealing melting processes in the hidden deep Earth	**A. Giuliani**: *Supported by ARC DECRA (commenced 2015)* ***Summary:*** Kimberlite magmas are very rich in volatiles (for example carbon dioxide and water); they are the major host of diamonds and provide the deepest samples from Earth's mantle. The primary compositions of these melts can provide unique information on the nature of the deep mantle. However, kimberlite melts mix and react with wall rocks on the way up, obscuring their primary composition. To see through these secondary processes, the project aims to use a novel approach integrating the study of melt inclusions in magmatic minerals with analysis of radiogenic and stable isotopes, and investigating reactions between kimberlite magmas and wall-rock fragments. The project aims to provide new understanding of the constraints on melting processes and recycling of crustal material in the deep mantle.
IGCP project: Supercontinent cycles and global geodynamics	**Z.X. Li**, D. Evans, S. Zhong and B. Eglington and Co-Leaders, and around 170 members from around the world: *Supported by UNESCO-IUGS IGCP (commenced 2016)* ***Summary:*** In this project, we will bring together a diverse range of geoscience expertise to explore the occurrence and evolution history of supercontinents through time, in the process to construct global databases of geotectonics, mineral deposits, and the occurrences of past mantle plume events. We will further utilise all information collected to conduct better-constrained geodynamic modelling on how the Earth's engine works in the first order, and how the supercontinent cycles interacted with the mantle to produce episodic and unevenly distributed Earth resources.
Australian membership of the International Ocean Discovery Program	R. Arculus, D. Cohen, S. Gallagher, P. Vasconcelos, C. Elders, J. Foden, M. Coffin, O. Nebel, H. McGregor, M. Clennell, C. Sloss, A. Heap, A. Webster, A. Kemp, **S. George**: *Supported by ARC LIEF (commenced 2016)* ***Summary:*** This project is for an Australian membership of the International Ocean Discovery Program. The Program will recover drill cores, situate observatories, and conduct down-hole experiments in all the world's oceans from lowest to highest latitudes to address fundamental questions about Earth's history and processes within four high-priority scientific themes: climate and ocean change - reading the past and informing the future; biosphere frontiers - deep life, biodiversity, and environmental forcing of ecosystems; Earth connections - deep processes and their impact on Earth's surface environment; Earth in motion - processes and hazards on a human time scale.
Femtosecond laser micropyrolysis gas chromatograph-mass spectrometer	**S. George**, J. Paterson, **M. Van Kranendonk**, J. Brocks, N. Sherwood, **D. Jacob**, A. Fuerbach, G. Brock, S. Löhr, S. Sestak: *Support by ARC LIEF (commencing 2018)* The project aims to build a femtosecond-laser, micropyrolysis gas-chromatograph-mass spectrometer. The facility will have the capability to selectively analyse very small petrographically-recognisable organic components, hence bridging the analytical gap between organic petrography and organic geochemistry. The project aims to understand the early evolution of life, the response of the biosphere to mass extinction, the migration of fluids in petroleum reservoirs, the heterogeneity of organic matter in shale gas reservoirs, and the composition of macromolecules in biominerals and macerals. The facility will contribute to a broad range of Australia's theoretical and applied problems in geoscience and geobiology.
China-Western Australia Seismic Survey (CWAS)	L. Zhao, **H. Yuan**: *Supported by the Institute of Geology and Geophysics, Chinese Academy of Sciences (commenced 2016)* ***Summary:*** IGGCAS, Macquarie and GWSA will install a 900 km-long dense (station spacing of 10-15 km) seismic profile across the Western Australia from Port Hedland to the southwestern border of the Kimberley Craton. The project will include 80 broadband seismic stations for 18 months from April 2017 to October 2018 with IGGCAS to provide seismic instruments for 60 stations. A test station was installed in Oct 2016.

Cutting-edge electron probe microanalysis driving Western Australia's resource geosciences	D. Sampson, S. Barnes, **M. Fiorentini**, I. Fitzsimons, S. Johnson, A. Kemp, **M. Kilburn**, M. Martyniuk, A. Putnis, **S. Reddy**, R. Smithies, Y. Uvarova: *Support by ARC LIEF (commencing 2018)* ***Summary:*** The overwhelming demand for electron probe microanalysis from outstanding research groups in Western Australia requires renewal of over-subscribed, aging facilities to drive innovation and alleviate bottlenecks in advanced geosciences multi-capability workflows. A new generation electron microprobe, with advances in trace element mapping and cathodoluminescence analysis, will enable superior characterisation of a wide range of materials. The electron probe will drive underpinning geoscience, resources science and economic geology, as well as support a broad range of disciplines and diverse fields, such as nanotechnology, microelectronics and aquatic sciences.
Genesis of comb quartz layers: case studies from porphyry Cu deposits at Qulong, Tibet and Now Chun, Iran	Z. Yang, **Y. Lu**: *Supported by NSFC (commenced 2015)* ***Summary:*** Two hypotheses have been proposed to account for the formation of comb quartz layers (also unidirectional solidification textures, UST). One concept proposes that these textures have grown from pockets of exsolved magmatic fluid located between the magma and its crystallised border, but the other proposes that they have precipitated directly from a crystallising silicate melt. To test these hypotheses, as well as to investigate the nature and source of primitive ore-forming fluids in porphyry Cu systems, comb-layered quartz from Qulong and Now Chun porphyry Cu deposits has been selected for the following studies. Features to be studied include: (1) their distribution, occurrence and petrographic characteristics; (2) their spatial and genetic relationships with Cu mineralisation; (3) characteristics of melt/fluid inclusions (e.g. composition, formation temperature, Cu content) in comb-layered quartz; and (4) their elemental and oxygen isotopic geochemistry. The aims of this study are to: (1) document the nature and variation of initial ore-forming fluids in the two deposits; (2) clarify the genesis of comb quartz layers; and (3) identify the sources of ore-forming fluids for porphyry Cu system.
Magmatic oxidation state, water content, and volatile nature: New insights into genesis of porphyry copper mineralisation at Zhunuo in the Gangdese belt, southern Tibet	X. Sun, **Y. Lu**: *Supported by NSFC (commenced 2017)* ***Summary:*** Many models about the genesis of porphyry copper mineralisation in the Gangdese collisional zone of southern Tibet have been advanced based on abundant elemental and isotopic analyses. However, some issues remain unclear, including the source of magmatic water and the contribution of ultrapotassic and high-Mg dioritic magmas to porphyry copper mineralisation. The Zhunuo porphyry Cu deposit in the western part of the Gangdese copper belt is characterised by the occurrence of many Miocene igneous rocks including fertile high Sr/Y monzogranite and monzogranite porphyry, high-Mg dioritic rocks (enclaves and diorite porphyry), ultrapotassic rocks (lamprophyre), and barren low Sr/Y granite porphyry, and by the enriched or curst-like Nd-Hf isotopes of high Sr/Y rocks. These features are rarely present in the porphyry copper deposits in the eastern Gangdese, and thus the Zhunuo deposit offers a new window into the genesis of porphyry Cu mineralisation in continental collision zones. This project is aimed at analysing compositions of some minerals such as zircon, apatite, amphibole, and plagioclase by Electron microprobe analysis (EMPA) and LA-ICP-MS, and in-situ sulfur isotopes of sulfides, studying magmatic oxidation state, water content and volatile (e.g., S, F, Cl) and their evolution during magma mixing, and constraining the source of magmatic water and contribution of different magmas for porphyry copper mineralization. The results will not only be helpful for further understanding porphyry copper mineralisation and evaluate the fertility of igneous rocks in the Gangdese belt but also provide new insights into improving porphyry copper metallogenic theory in collisional zones.

Maintaining and upgrading the Global Palaeomagnetic Database	**S.A. Pisarevsky**: *Supported by NSFC University of Oslo (commenced 2015)* ***Summary:*** Maintaining and upgrading the Global Palaeomagnetic Database (GPMDB) (*http://www.ngu.no/geodynamics/gpmdb/*), which was originally developed by McElhinny and Lock (*1996, Surv. Geophys. 17, 575*). Updated versions of the GPMDB will be delivered electronically in Microsoft Access database format twice a year (June and December). At Oslo University the updated versions will subsequently be incorporated in both the GPMAP (*Torsvik and Smethurst 1999, Computers & Geosciences 25, 395-402*) and GPlates (*www.gplates.org*) software and made available electronically online.
The Ediacaran-Silurian palaeogeography of western Yangtze Block and its tectonic linkage with the Gondwana assembly	**W. Yao**, J. Wang, X. Zhou: *Supported by the China Geological Survey and CU (commenced 2015)* ***Summary:*** This project targets the Ediacaran-Silurian sedimentary packages on the western margin of the Yangtze Block, by analysing their sedimentary facies and environments, tracking the provenances of the targeted sedimentary detritus as well as the basin fillings. Based on the sedimentary facies and provenance results, it aims at correlating the western Yangtze Ediacaran-Silurian sedimentary strata with the coeval sedimentary packages of other continents on the northern Gondwana margin (e.g. north India, western Australia etc.), and investigating the paleogeographic linkages amongst those areas. Together with the well-known paleogeographic link between the Cathaysia Block and northern Gondwana during the Ediacaran-Silurian, this project will evaluate the paleogeography of South China in the supercontinent assembly and its geodynamic significance.
3D Earth	**J.C. Afonso**, J. Ebbing: *Supported by European Space Agency and MQ University (commenced 2017)* ***Summary:*** The goal of this project is establish a global 3D reference model of the crust and upper mantle based on the analysis of satellite gravity and (electro-)magnetic data in combination with seismological models and analyse the feedback between processes in Earth's deep mantle and the lithosphere. Selected case examples will provide the possibility to test these approaches on a global and regional scale. This will result in a framework for consistent models that will be used to link the crust and upper mantle to the dynamic mantle.
Multiscale inversion of porous rock physics	**J. C. Afonso**: *Supported by Research Innovation Staff Exchange (commenced 2017)* ***Summary:*** We will develop and exchange knowledge on applied mathematics, high-performance computing (HPC), and geophysics to better characterise the Earth´s subsurface. We aim to better understand porous-rock physics in the context of elasto-acoustic wave propagation phenomena. We will develop parallel high-continuity isogeometric analysis (IGA) simulators for geophysics. We will design and implement fast and robust parallel solvers for linear equations to model multi-physics electromagnetic and elasto-acoustic phenomena. We seek to develop a parallel joint inversion workflow for electromagnetic and seismic geophysical measurements. To verify and validate these tools and methods, we will apply the results to: characterise hydrocarbon reservoirs, determine optimal locations for geothermal energy production, analyse earthquake propagation, and jointly invert deep-azimuthal resistivity and elasto-acoustic borehole measurements. Our target computer architecture for the simulation and inversion software infrastructure consists of distributed-memory parallel machines that incorporate the latest Intel Xeon Phi processors. Thus, we will build a hybrid OpenMP and MPI software framework. We will widely disseminate our collaborative research results through publications, workshops, postgraduate courses to train new researchers, a dedicated webpage with regular updates, and visits to companies working in the area. Therefore, we will perform a significant role in technology transfer between the most advanced numerical methods and mathematics, the latest super-computer architectures, and the area of applied geophysics.

Appendix 4: Participants list

Chief Investigators

- Professor Suzanne Y. O'Reilly (Centre Director, MQ)
- Professor Simon Wilde (Node Director, CU)
- Associate Professor Marco Fiorentini (Node Director, UWA)
- Dr Elena Belousova (MQ)
- Associate Professor Simon Clark (MQ)
- Professor Stephen Foley (MQ)
- Professor William Griffin (MQ)
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- Professor Zheng-Xiang Li (CU)
- Associate Professor Alexander Nemchin (CU)
- Associate Professor Craig O'Neill (MQ)
- Associate Professor Norman Pearson (MQ) *until 1 July 2017*
- Professor Martin Van Kranendonk (UNSW)
- Associate Professor Yingjie Yang (MQ)

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- Dr Olivier Alard (MQ)
- Associate Professor Nathan Daczko (MQ)
- Professor Simon George (MQ)
- Dr Richard Glen (Adjunct Professor)
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- Professor Dorrit Jacob (MQ)
- Associate Professor Mary-Alix Kaczmarek (University Paul Sabatier Toulouse III)
- Associate Professor Christopher Kirkland (CU)
- Professor Jochen Kolb (GEUS and KIT, Germany)
- Dr Yongjun Lu (GSWA at UWA)
- Dr Louis-Noel Moresi (University of Melbourne)
- Professor Steven Reddy (CU)
- Associate Professor Tracy Rushmer (MQ)
- Associate Professor Bruce Schaefer (MQ)
- Professor Paul Smith (MQ)
- Professor Simon Turner (MQ)
- Dr Michael Wingate (GSWA)
- Professor Shijie Zhong (University of Colorado at Boulder, USA)

Partner Investigators

- Dr Ian Tyler (CCFS Leader, GSWA)
- Professor Michael Brown (University of Maryland, USA)
- Dr Klaus Gessner (Geological Survey of Western Australia)
- Professor David Mainprice (Université de Montpellier, France)
- Professor Catherine McCammon (Bayreuth University, Germany)
- Professor T. Campbell McCuaig (BHP Billiton)
- Professor Fuyuan Wu (Chinese Academy of Science, China)

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- Ms Sally-Ann Hodgekiss, Reporting & Comms. Manager (MQ)
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- Mrs Anna Wan, Centre Admin Officer (MQ)
- Mr Yacoob Padia, Business Manager (CU)
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- Mr Sean Webb, Business Manager (CMCA, UWA)
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- Mr Steven Craven (MQ)
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Professor Jim Everett	Dr Louisa Lawrance	Dr John Vann
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Dr Richard Goldfard	Dr Franco Pirajno	Professor Xisheng Xu
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Dr Debora Araujo	Dr Jeff Harris	Dr Yvette Poudjom Djomani
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Dr Graham Begg	Dr Bram Janse	Dr Peter Robinson
Dr Christoph Beier	Dr Felix Kaminsky	Dr Giovanna Sapienza
Dr Phillip L. Blevin	Dr Christoph Lenz	Dr Takako Satsukawa
Professor Hannes Brueckner	Ms Qian Liu	Dr Ed Saunders
Mr Robert Bultitude	Mr Qingyong Luo	Dr Simon Shee
Dr Mei-Fe Chu	Dr Viktor Makhlin	Dr Thomas Stachel
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Mr Jason Bennett (UWA)	Ms Kim Jessop (MQ)	Mr Gregory Poole (UWA)
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Mr Bruno Colas (MQ)	Mr Yebo Liu (Curtin)	Mr Dennis Sugiono (UWA)
Ms Daria Cyprych (MQ)	Mr Kai Liu (Curtin)	Mr Mehdi Tork Qashqai (MQ)
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Ms Katherine Farrow (MQ)	Ms Erin Martin (Curtin)	Mrs Silvia Volante (Curtin)
Mr Michael Förster (MQ)	Mr Samuel Matthews (MQ)	Mr Alexander Walker (Curtin)
Mr Hamed Gamal El Die (Curtin)	Mr Keith McKenzie (MQ)	Mr Chong Wang (Curtin)
Ms Robyn Gardner (MQ)	Miss Holly Meadows (Curtin)	Mr Kai Wang (MQ)
Mr Hindol Ghatak (MQ)	Miss Uvana Meek (MQ)	Mr Jonathon Michael Wasiliev (MQ)
Miss Louise Rebecca Goode (MQ)	Ms Stephanie Montalvo Delgado (Curtin)	Mr Shucheng Wu (MQ)
Mr Kui Han (MQ)	Mr Jonathan Munnikhuis (MQ)	Mr Bo Xu (MQ)
Mr Michael Hartnady (Curtin)	Ms Stephanie Nichols (MQ)	

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Mr Richard Blake (UNSW)	Mr Byron Gear (MQ)	Mr Luke Smith (MQ)
Mr Cameron Brown (MQ)	Mr Mitchell Gerdes (MQ)	Mr Morgan Stewart (MQ)
Mr Christopher Corcoran (MQ)	Mr Hindol Ghatak (MQ)	Mr Jack Stirling (UWA)
Mrs Victoria Elliott (MQ)	Mr Tasman Gillfeather-Clark (MQ)	Mr Sahand Tadbiri (UNSW)
Mr Omar Elkhaligi (MQ)	Mr Harrison Jones (MQ)	Mr Alexander Tunnadine (MQ)
Mr Michael Farmer (MQ)	Miss Angela Mabee (MQ)	Mr Harry West (MQ)
Mr Anthony Finn (MQ)	Ms Carla Raymond (MQ)	Mr Haoming Wu (MQ)
Mr Lucas Gamertsfelder (MQ)		

Appendix 5: 2017 Publications

A FULL LIST OF CCFS PUBLICATIONS IS UPDATED AT: http://www.ccfs.mq.edu.au/

628. **González-Jiménez, J.-M.**, Proenza, J.A., Martini, M., Camprubí, A., **Griffin, W.L.**, **O'Reilly, S.Y.** and **Pearson, N.J.** 2017. Deposits associated with ultramafic-mafic complexes in Mexico: the Loma Baya case. *Ore Geology Reviews, 81, 1053-1065.*

635. **Fougerouse, D.**, Micklethwaite, S., Ulrich, S., Miller, J.M., Godel, B., Adams, D.T. and **McCuaig, T.C.** 2017. Evidence for two stages of mineralization in West Africa's largest gold deposit: Obuasi, Ghana. *Economic Geology, 112, 3-22.*

762. **Baumgartner, R.J.**, Baratoux, D., Gaillard, F. and **Fiorentini, M.L.** 2017. Numerical modelling of erosion and assimilation of sulfur-rich substrate by martian lava flows: Implications for the genesis of massive sulfide mineralization on Mars. *Icarus, 296, 257-274.*

790. Goddéris, Y., Le Hir, G., Macouin, M., Donnadieu, Y., Hubert-Théoud, L., Dera, G., Aretz, M., Fluteau, F., **Li, Z.X.** and Halverson, G.P. 2017. Paleogeographic forcing of the strontium isotopic cycle in the Neoproterozoic. *Gondwana Research, 42, 151-162.*

802. Ma, L., Wang, Q., **Li, Z.-X.**, Wyman, D.A., Yang, J.-H., Jiang, Z.Q., Liu, Y.S., Goua, G.-N. and Guo, H.F. 2017. Subduction of Indian continent beneath southern Tibet in the latest Eocene (~35 Ma): Insights from the Quguosha gabbros in southern Lhasa block. *Gondwana Research, 41, 77-92.*

805. Kuznetsov, N.B., **Belousova, E.A.**, Krupenin, M.T., Romanyuk, T.V. and Maslov, A.V. 2017. The results of geochronological and isotope-geochemical study of zircons from tuffs of Sylvitsa Group (western slope of the Middle Urals): the origin of ash layers in Vendian strata of the East European Platform. *Doklady Earth Sciences, 473, 359-362.*

825. **Shafaii Moghadam, H.**, Li, X.-H., **Griffin, W.L.**, Stern, R.J., Thomsen, T.B., Meinhold, G. and Aharipour, R. 2017. Early Paleozoic tectonic reconstruction of Iran: Tales from detrital zircon geochronology. *Lithos, 268-271, 87-101.*

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835. Lu, J.G., **Xiong, Q.**, **Griffin, W.L.**, **Huang, J.X.**, **O'Reilly, S.Y.**, Satsukawa, T., Zheng, J.P. and **Pearson, N.J.** 2017. Uplift of the southeastern Australian lithosphere: thermal-tectonic evolution of garnet pyroxenite xenoliths from western Victoria. *In G. Bianchini, J.L. Bodinier, R. Braga and M. Wilson (eds), The crust-mantle and lithosphere-asthenosphere boundaries: insights from xenoliths, orogenic deep sections and geophysical studies. Special Paper of the Geological Society of America, 526, 27-48.*

836. Abersteiner, A., **Giuliani, A.**, Kamenetsky, V.S. and Phillips, D. 2017. Petrographic and melt-inclusion constraints on the petrogenesis of a magmaclast from the Venetia kimberlite cluster, South Africa. *Chemical Geology, 455, 331-341.*

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846. Rosing-Schow, N., **Bagas, L.**, **Kolb, J.**, Balic-Zunic, T., Korte, C. and **Fiorentini, M.L.** 2017. Hydrothermal flake graphite mineralisation in Paleoproterozoic rocks of South-East Greenland. *Mineralium Deposita, 52, 769-789.*

853. **Wang, Y.**, Prelević, D., Buhre, S. and **Foley, S.F.** 2017. Constraints on the sources of post-collisional K-rich magmatism: The roles of continental clastic sediments and terrigenous blueschists. *Chemical Geology, 455, 192-207.*

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857. **Spruzeniece, L.**, **Piazolo, S.** and Maynard-Casely, H.E. 2017. Deformation-resembling microstructure created by fluid-mediated dissolution-precipitation reactions. *Nature Communications, 8, 14032.*

858. Gardner, C.J., Graham, I.T., **Belousova, E.**, **Powell, W.**, Booth, G.W., Gardiner, F. and Greig, A. 2017. Evidence for Ordovician subduction-related magmatism in the Truong Son terrane, SE Laos: Implications for Gondwana evolution and porphyry Cu exploration potential in SE Asia. *Gondwana Research, 44, 139-156.*

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861. Brasier, M.D., Norman, D.B., Liu, A.G., Cotton, L.J., Hiscocks, J., Garwood, R.J., Antcliffe, J.A. and **Wacey, D.** 2017. Remarkable preservation of brain tissues in an Early Cretaceous iguanodontian dinosaur. *In A.T. Brasier, D. McIlroy and N. McLoughlin (Eds), Earth System Evolution and Early Life: a Celebration of the Work of Martin Brasier. Geological Society, London, Special Publications, 448, 383-398.*

862. **Xu, B.**, **Griffin, W.L.**, **Xiong, Q.**, Hou, Z.-Q., **O'Reilly, S.Y.**, **Guo, Z.**, **Pearson, N.J.**, **Gréau, Y.**, Yang, Z.-M. and Zheng, Y.-C. 2017. Ultrapotassic rocks and xenoliths from South Tibet: Contrasting styles of interaction between lithospheric mantle and asthenosphere during continental collision. *Geology*, *45*, *51-54*.

863. **Tretiakova, I.G.**, **Belousova, E.A.**, Malkovets, V.G., **Griffin, W.L.**, **Piazolo, S.**, **Pearson, N.J.**, **O'Reilly, S.Y.** and Nishido, H. 2017. Recurrent magmatic activity on a lithosphere-scale structure: crystallization and deformation in kimberlitic zircons. *Gondwana Research*, *42*, *126-132*.

864. **Shafaii Moghadam, H.**, Bröcker, M., **Griffin, W.L.**, Li, X.H., Chen, R.X. and **O'Reilly, S.Y.** 2017. Subduction, high-P metamorphism and collision fingerprints in SW Iran: Constraints from zircon U-Pb and mica Rb-Sr geochronology. *Geochemistry, Geophysics, Geosystems*, *18*, *306-332*.

866. **Spruzeniece, L.**, **Piazolo, S.**, **Daczko, N.**, **Kilburn, M.R.** and Putnis, A. 2017. Symplectite formation in the presence of a reactive fluid: Insights from hydrothermal experiments. *Journal of Metamorphic Geology*, *35*, *281-299*.

869. Eglinger, A., **Thebaud, N.**, Zeh, A., Davis, J., Miller, J., **Parra-Avila, L.**, **Loucks, R.** and **McCuaig, C.** 2017. New insights into the crustal growth of the Paleoproterozoic margin of the Archean Kéména-Man domain, West African craton (Guinea): Implications for gold mineral system. *Precambrian Research*, *292*, *258-289*.

870. He, W., Yang, L., Brugger, J., **McCuaig, T.C.**, **Lu, Y.**, Bao, X., Gao, X., Lu, Y. and Xing, Y. 2017. Hydrothermal evolution and ore genesis of the Beiya giant Au polymetallic deposit, western Yunnan, China: evidence from fluid inclusions and H-O-S-Pb isotopes. *Ore Geology Reviews*, *90*, *847-862*.

871. **Giuliani, A.**, Tappe, S., Rooney, T.O., McCoy-West, A.J., Yaxley, G.M. and Mezger, K. 2017. Editorial: The role of intraplate magmas and their inclusions in Earth's mantle evolution. *Chemical Geology*, *455*, *1-5*.

873. **Baumgartner, R.J.**, **Fiorentini, M.L.**, Baratoux, D., Ferriere, L., Locmelis, M., Tomkins, A. and Sener, K.A. 2017. The variability of ruthenium in chromite from chassignites and olivine-phyric shergottites: new insights into the behaviour of PGE and sulphur in martian magmatic systems. *Meteoritics & Planetary Science*, *52333-350*, *333-350*.

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877. **Lara, P.**, Oyhantcabal, P. and **Dadd, K.** 2017. Post-collisional, Late Neoproterozoic, high-Ba-Sr granitic magmatism from the Dom Feliciano Belt and its cratonic foreland, Uruguay: petrography, geochemistry, geochronology, and tectonic implications. *Lithos*, *277*, *178-198*.

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879. Yeats, C.J., Hollis, S.P., Halfpenny, A., Corona, J-C., **LaFlamme, C.**, Southam, G., **Fiorentini, M.**, Herrington, R.J. and Spratt, J. 2017. Actively forming Kuroko-type volcanic-hosted massive sulfide (VHMS) mineralization at Iheya North, Okinawa Trough, Japan. *Ore Geology Reviews*, *84*, *20-41*.

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Appendix 6: 2017Abstract titles

A FULL LIST OF CCFS ABSTRACTS FOR CONFERENCE PRESENTATIONS IS AVAILABLE AT: http://www.ccfs.mq.edu.au/

XLIX (49) Tectonic meeting, Tectonics of modern and ancient oceans and their margins, Москва, Russia, January 31- 4 February 2017	Results of a study of detrital zircons from the Bakal and Shalinskoi suites of the typical Riphean section (Bashkir uplift, the southern Urals) using the *TerraneChron®* method T.V. Romanyuk, N.B. Kuznetsov, V.M. Gorozhanin, E.N. Gorozhanina, **E.A. Belousova** and E.S. Pyzhova (in Russian)
Granitoids Through Time, Monash University, Australia, 2 February 2017	Post-collisional, Late Neoproterozoic, high-Ba-Sr granitic magmatism from the Dom Feliciano Belt and its cratonic foreland, Uruguay **P. Lara**, P. Oyhantcabal and K. Dadd
The 48th Lunar and Planetary Science Conference, The Woodlands, Texas, 20-24 March 2017	The hunt for shocked zircon in the Jack Hills: 21,000 and counting M.A. Cox, A.J. Cavosie, **S.M. Reddy**, P.A. Bland, J.W. Valley
3rd Deep Carbon Observatory International Science Meeting, University of St. Andrews, Scotland, 23-25 March 2017	Insights into diamond formation from polycrystalline diamond aggregates **D. Jacob**, R.A. Stern, S. Piazolo, J. Chapman and J. Czas
Conference of the Israeli Geology Society, Mitzpe Ramon, Israel, 21 March 2017	The hibonite-grossite-vanadium assemblage in Mt Carmel corundum: extreme desilication and reduction in a volcanic plumbing system **W.L. Griffin**, **S.E.M. Gain**, **J.X. Huang**, V. Toledo and **S.Y. O'Reilly** The Mt. Carmel birdshot assemblage: Immiscibility of metal, metal-oxide and silicate melts during basalt-methane interaction in a volcanic plumbing system **W.L. Griffin**, **S.E.M. Gain**, **J.X. Huang**, V. Toledo and **S.Y. O'Reilly** Moissanite (SiC) in Mt Carmel pyroclastics and alluvial deposits: Super-reduced conditions in volcanic systems **J.-X. Huang**, **W.L. Griffin**, **S.E.M. Gain**, V. Toledo and **S.Y. O'Reilly**
International Symposium on Zircon Geochronology and Crustal Evolution, Kunming, China, 12-20 April 2017	Can too much information spoil a good story? S.A. Wilde **Keynote**
TARGET 2017: Innovating Now for Our Future, Perth, Western Australia, 19-21 April 2017	Rutile as an indicator mineral in gold exploration A. Agangi, **S.M. Reddy**, D. Plavsa, **D. Fougerouse**, **C. Clark**, M. Robert and T.E. Johnson Structural controls on the localization of Au and Ni deposits in the Halls Creek Orogen, insight from geodynamic numerical modeling and geophysical interpretation F. Kohanpour, M.D. Lindsay, **W. Gorczyk** and S. Occhipinti Fingerprinting ore forming processes with sulfur isotopes: craton to camp scale **C. LaFlamme**, **M. Fiorentini**, **V. Selvaraja** and **S. Caruso** Ground truthing remote sensing maps – mineralogical composition of regolith and its implications to hydrothermal alteration **H. Lampinen**, C. Laukamp, S. Occhipinti, V. Metelka and S. Spinks Recent advances and potential leads in lithogeochemical exploration for magmatic nickel sulphide deposits **M. Le Vaillant**, **M.L. Fiorentini** and S.J. Barnes

TARGET 2017: Innovating Now for Our Future, Perth, Western Australia, 19-21 April 2017 *cont...*	Terrane-scale porphyry Cu fertility in the Lhasa terrane, southern Tibet **Y-J. Lu**, Z.Q. Hou, Z.M. Yang, **L.A. Parra-Avila**, **M. Fiorentini**, **T.C. McCuaig** and **R. Loucks** Methods of targeting across all scales – what important elements to consider? T.C. McCuaig **Keynote** Controls and genesis of high-grade ore-shoots at Callie world-class gold deposit, Northern Territory, Australia L. Petrella, **N. Thébaud**, **C. LaFlamme** and S. Occhipinti The future(s) of minerals exploration J.P. Sykes, A. Trench and **T.C. McCuaig** Tracing sulfur-sources in the Agnew gold camp: an illustration of Archean orogenic gold deposits diversity **N. Thébaud**, **D. Sugiono**, **C. LaFlamme**, F. Voute, J. Miller and **M. Fiorentini**
European Geosciences Union General Assembly 2017, Vienna, Austria, 23-28 April 2017	Linking geodynamics and geophysical inversion with multiobservable probabilistic tomography **J.C. Afonso**, N. Rawlinson, **Y. Yang**, S. Zlotnik and O. Ortega Preservation of a 2.4 Ga ecosystem in the Kazput formation of the Turee Creek Group, Western Australia **E.V. Barlow** and **M.J. Van Kranendonk** Ubiquity and diversity of nodular and digitate micro-stromatolites in New Zealand's siliceous hot springs: relevance for Mars biosignature exploration K.A. Campbell, K.M. Handley, C. Sriaporn, S.W. Ruff, **M.J. Van Kranendonk**, D.M. Guido and **T. Djokic** The behaviour of monazite at high temperature and high stress in the lower crust **C. Clark**, R. Taylor, **T. Erickson**, **S. Reddy**, **D. Fougerouse**, I. Fitzsimons and M. Hand Redistribution of iron and titanium in subduction zones: insights from high-pressure serpentinites R. Crossley, K. Evans, **S. Reddy** and G. Lester An origin of life in terrestrial fresh water hydrothermal pools B.F. Damer, D.W. Deamer, **M.J. Van Kranendonk** and **T. Djokic** Exceptional Preservation of Biosignatures in c. 3.48 Ga Terrestrial Hot Spring Deposits, Pilbara, Western Australia **T. Djokic**, **M.J. Van Kranendonk**, K.A. Campbell and M.R. Walter Astrobiology 'Down Under': A comprehensive virtual field trip of the c. 3.48 Ga Dresser Formation, Pilbara Craton, Western Australia **T. Djokic**, **M.J. Van Kranendonk**, C. Oliver, S. Guan and A. Ong Rehydration reactions and microstructure development in lower crustal granulites from the Bergen Arcs, Norway **T. Erickson**, **S. Reddy**, **C. Clark**, M. Hand, K. Bhowany and A. Prent The topography of the Iberian Peninsula from coupled geophysical-petrological inversion of multiple data sets J. Fullea, A. Negredo, M. Charco, I. Palomeras, A. Villaseñor and **J.C. Afonso** Continental geodynamics and mineral exploration-the Western Australian perspective **K. Gessner**, R. Murdie, **H. Yuan**, L. Brisbout, C. Sippl, **I. Tyler**, **C. Kirkland**, **M. Wingate**, S. Johnson, C. Spaggiari, H. Smithies, **Y. Lu**, **C. Gonzalez**, M. Jessell, E.-J. Holden, **W. Gorczyk** and S. Occhipinti Peering into the deep: Illuminating the crustal evolution of the Eucla basement and its relationship to the Albany-Fraser Orogen of southwest Australia **M. Hartnady**, **C. Kirkland**, **C. Clark**, C. Spaggiari and H. Smithies Keep it real and visual: Dissecting social media engagement and its potential to influence trust in space science Y.L. Hwong, C.A. Oliver and **M.J. Van Kranendonk** Long term evolution of Earth's magnetic field strength: Supercontinent cycles and nucleation of the inner core **U. Kirscher**, **R.N. Mitchell**, G. Cox, P. Asimow, **N. Zhang** and **Z.-X. Li** **Highlight** Ignimbrites of Armenia – Paleomagnetic constraints on flow direction and stratigraphy of pyroclastic activity of Mount Aragats **U. Kirscher**, K. Meliksetian, H. Gevorgyan, G. Navasardyan and V. Bachtadse The importance of the Gurian stage: magnetostratigraphic correlation of the Calabrian in the southern Caucasus and its paleoclimatic implications **U. Kirscher**, O. Oms, A.A. Bruch, I. Shatilova, G. Chochishvili and V. Bachtadse Tracing Archean sulfur across stitched lithospheric blocks **C. LaFlamme**, **M. Fiorentini**, M. Lindsay, B. Wing, **V. Selvaraja**, S. Occhipinti, S. Johnson and H. Thi Bui Tracing sulfur across lithospheric boundaries **C. LaFlamme**, **M. Fiorentini** and B. Wing **Invited**

European Geosciences Union General Assembly 2017, Vienna, Austria, 23-28 April 2017 *cont...*	Numerical Modelling of Multi-Phase Multi-Component Reactive Transport in the Earth's Interior **B. Oliveira**, **J.C. Afonso**, S. Zlotnik and **R. Tilhac** Model order reduction for the fast solution of 3D Stokes problems and its application in geophysical inversion O. Ortega Gelabert, S. Zlotnik, **J.C. Afonso** and P. Díez How 'cyclic' is the Supercontinental Cycle **S.A.Pisarevsky** Mechanism and duration of plutonic processes in oceanic crust: the example of the South Rallier du Baty intrusive complex, Kerguelen Archipelago L. Ponthus, D. Guillaume, M. de Saint Blanquat, M. le Romancer, **N. Pearson**, M. Grégoire and **S.Y. O'Reilly** Nano is the next big thing: Revealing geochemical processes with atom probe microscopy **S. Reddy**, D. Saxey, W. Rickard, **D. Fougerouse**, E. Peterman, A. van Riessen and T. Johnson Thermochronology across tectonic contacts in southwest Turkey defines extensional South Menderes Monocline U. Ring, S. Thomson and **K. Gessner** Very broad band seismic constraints on the LAB and lithospheric layering in the north American Craton B. Romanowicz, **H. Yuan**, P. Clouzet, M. Caló, C. Roy, T. Bodin and S. Maurya Unravelling the complexities of a high-grade Paleoarchean terrane: Saglek Block, Labrador, Canada A. Salacinska, **M. Kusiak**, D. Dunkley, M. Whitehouse and **S. Wilde** Crustal structure of a Proterozoic craton boundary: east Albany-Fraser Orogen, Western Australia, imaged with passive seismic and gravity C. Sippl, L. Brisbout, C. Spaggiari, **K. Gessner**, H. Tkalcic, B. Kennett and R. Murdie Seismic structure of a late-Archean microcontinent in the middle of the Western Australian Craton **H. Yuan**, S. Johnson, M. Dentith, R. Murdie, **K. Gessner**, F. Korhonen and T. Bodin Geochemical, zircon U-Pb and Hf isotopic study on metabasalt in the Cathaysia Block: Implications of Paleozoic migmatization of Precambrian crustal and mantle materials in South China W. Zeng, H. Zhou, **Z.-X. Li**, I.C.W. Fitzsimons, Z. Zhong, H. Xiang, R. Liu and S. Jin
Astrobiology Science Convention (Abscicon), Mesa, USA, 24-28 April 2017	Preservation of a 2.4 Ga ecosystem in the Kazput Formation of the Turee Creek Group, Western Australia **E.V. Barlow** and **M.J. Van Kranendonk**
AIG Workshop, Perth, WA, 2 May 2017	Crustal structure of the Capricorn Orogen inferred from passive source seismology **H. Yuan**
Deformation Mechanisms, Rheology and Tectonics, Inverness, Scotland, 30 April - 7 May 2017	Recognition of melt flux through shear zones **N.R. Daczko**, **S. Piazolo**, **D. Da Silva**, **U. Meek**, **C. Stuart** and **H. Ghatak** Melt flux through the root of a magmatic arc under static versus dynamic conditions **N.R. Daczko**, **S. Piazolo**, **C.A. Stuart** and **U. Meek** Flow behaviour of the middle and lower crust: Insights from field observations and numerical modelling **R. Gardner**, **S. Piazolo** and **N. Daczko** Patterns of strain localization in heterogeneous, polycrystalline rocks – a numerical perspective **R. Gardner**, **S. Piazolo** and **N. Daczko** Microstructural indicators of channelled melt flow through the lower crust **U. Meek**, **N. Daczko** and **S. Piazolo** Earthquakes at depth: Insights from high resolution orientation and chemical analysis **S. Piazolo**, P. Trimby, **N.R. Daczko** and C. Kong Deformation-resembling microstructure created by fluid-mediated dissolution-precipitation reactions **L. Spruzeniece**, **S. Piazolo** and H.E. Maynard-Casely
EMAS-15 / IUMAS-7, Konstanz, Germany, 7-11 May 2017	Integration of Electron Backscatter Diffraction, Transmission Kikuchi Diffraction and Atom Probe Microscopy: A superior workflow for nanoscale geochemistry **S.M. Reddy**, D.W. Saxey, W.D.A. Rickard, **D. Fougerouse** and A. van Riessen High-resolution imaging, EBSD analysis and isotope mapping of experimentally produced micro and nanocrystalline geological materials **L. Spruzeniece**, **S. Piazolo**, **M.R. Kilburn** and A. Putnis

JPGU-AGU Joint Meeting 2017, Chiba, Japan, 20-25 May 2017	South China in the assembled Gondwana **W. Yao**, **Z.X. Li**, W.X. Li and X.H. Li **Invited**
GAC-MAC Annual Meeting, Kingston, Ontario, Canada, 21-23 May 2017	Post-accretionary uplift of the Meguma Terrane relative to the Avalon Terrane in the Canadian Appalachians D.B. Archibald, J.B. Murphy, N.S. Antigonish, F. Jourdan and **S.M. Reddy**
2017 GSA Cordilleran Section Annual Meeting, Honolulu, Hawaii, 23-25 May 2017	The influence of hydrous melting on the electrical conductivity in feldspar labradorite **G.M. Amulele**, **S.M. Clark** and **A.W. Lanati**
2017 Interior of the Earth, Gordon Research Conference, Mount Holyoke College, South Hadley, MA, USA, 4-9 June 2017	The long legacy of deep mantle processes C. O'Neill **Keynote**
FUTORES II (Future Understanding of Tectonics, Ores, Resources, Environment and Sustainability) Townsville, Queensland, Australia, 4-7 June 2017	Atmospheric sulfur in the orogenic gold deposits of the Archean Yilgarn Craton **V. Selvaraja**, **S. Caruso**, **M.L. Fiorentini** and **C.K. LaFlamme** Metallogeny of the Capricorn Orogen, Western Australia S.P. Johnson, I.O.H. Fielding, B. Rasmussen, J. Zi, J.R. Muhling, **M.T.D. Wingate** and S. Sheppard **Invited** The effect of magmatic oxidation state, hydration state and temperature on incorporation of cerium in zircon: bad news for Ce-in-zircon oxybarometry **R.R. Loucks**, **M.L. Fiorentini** and B.D. Rohrlach Calibration of a new magmatic oxybarometer using uranium, cerium and titanium in zircon as a pathfinder to Cu-fertile arc igneous complexes **R.R. Loucks** and **M.L. Fiorentini**
ARCF Project Workshop, Perth, Australia, 7 June 2017	Nanoscale characterisation of trace element mobility: implications for rutile as a pathfinder mineral **R. Verberne**, **S. Reddy**, D. Saxey, W. Rickard, **D. Fougerouse**, D. Plavsa and A. Agangi
Rodinia 2017: Supercontinent Cycles and Global Geodynamics, Townsville, Queensland, Australia, 11-14 June 2017	A full-plate global reconstruction of the Neoproterozoic: An essential step in quantifying ancient geodynamics A.S. Collins, A.S. Merdith, **S.A. Pisarevsky**, S. Williams and D.R. Müller **Keynote** The Derim Derim Event of Northern Australia - Geochemical characterisation and impact on hydrocarbon development G.M. Cox, J. Foden, A.S. Collins, **U. Kirscher** and **R.N. Mitchell** Does the Earth have a fundamental frequency? G.M. Cox, **R.N. Mitchell**, A.S. Collins, D. Hasterok and J. Foden Precambrian mantle plume centres and breakup margins identified using the large igneous province record R.E. Ernst, **Z.-X. Li** and **S.A. Pisarevsky** **Keynote** Gulf of Nuna: Mesoproterozoic hydrocarbon burial during supercontinent Breakup **U. Kirscher**, **R. Mitchell**, G.C. Cox, **W. Yao**, C.J. Spencer and M. Kunzmann Decoding Earth's rhythm: Modulation of supercontinent cycles by longer superocean cycles **Z.-X. Li**, **R.N. Mitchell**, C.J. Spencer, R. Ernst, **S.A. Pisarevsky** and B. Murphy Palaeomagnetism of the Boonadgin Dyke Suite, Yilgarn Craton: Implications for the assembly of the Western Australian Craton and possible connection with India **Y. Liu**, **Z.-X. Li**, **S. Pisarevsky**, **U. Kirscher**, **R. Mitchell** and **C. Stark** Evaluation of full-plate reconstructions of the Neoproterozoic using Hf isotopes in zircon **E.L. Martin**, W.J. Collins, A.S. Collins and C.J. Spencer Girdle Earth: The snowball Earth arc magmatism system **R.N. Mitchell**, C.J. Spencer, T.D. Raub, G. Cox, **E. Martin**, **U. Kirscher**, J.B. Murphy, **S. Pisarevsky**, A. Collins, W. Collins and **Z.-X. Li**

Rodinia 2017: Supercontinent Cycles and Global Geodynamics, Townsville, Queensland, Australia, 11-14 June 2017 *cont...*	Laurentian crust in NE Australia: A critical tie-point during the assembly of the supercontinent Nuna **A.R. Nordsvan**, B.J. Collins, **Z.-X. Li**, C.J. Spencer, **A. Pourteau**, I. Withnall, P.G. Betts and **S. Volante** New progress and constraints on supercontinent reconstructions S. Pisarevsky **Keynote** Tectonic evolution of NE Australia during the assembly of supercontinent Nuna: a multi-disciplinary reappraisal **A. Pourteau**, **S. Volante**, **A. Nordsvan**, **J. Li**, **Z.X. Li** and W.J. Collins A multi-scale structural and metamorphic study of the Georgetown Inlier, NE Queensland –– Implications for the assembly of the supercontinent Nuna **S. Volante**, **A. Porteau**, W.J. Collins, **Z.X. Li**, I. Withnall and **A. Nordsvan** Long-travelled sediments from India to Australia in the assembled Gondwana **W. Yao**, **Z.X. Li** and **E. Martin** Ca. 750–720 Ma tectonic transition recorded in the Bemarivo terrane balances the global plate kinematic budget during Rodinia break-up J.-L. Zhou, R. Tucker, **Z.-X. Li**, G.-Q. Tang, L.-G. Wu and X.-H. Li
ECROFI 2017, Nancy, France, 23-29 June 2017	Silicate melt inclusions recording metasomatism in an upper mantle lherzolite xenolith from the northern Pannonian Basin **N. Liptai**, M. Berkesi, L. Patko, L.E. Aradi, R. Kaldos, **S.Y. O'Reilly**, **W.L. Griffin**, **N.J. Pearson** and C. Szabo Tracking wehrlitization process using silicate melt inclusions in upper mantle xenoliths from Nógrád-Gömör Volcanic Field (Northern Pannonian Basin) L. Patkó, L.E. Aradi, **N. Liptai**, M. Berkesi, R.J. Bodnar, E. Sendula, R. Klébesz and C. Szabó
5th Australian Atom Probe Workshop, Magnetic Island, Australia, 27-30 June 2017	Trace element nanocluster in natural rutile (TiO_2) and their geological significance **R. Verberne**, **S. Reddy**, D. Saxey, W. Rickard, **D. Fougerouse**, D. Plavsa and A. Agangi
Shock Metamorphism in Terrestrial and Extra-Terrestrial Rocks Workshop, Perth, Australia, 26 June - 2 July 2017	Nanoscale trace element analysis of shocked zircon using FIB-ToF-SIMS and atom probe microscopy W.D.A. Rickard, **S.M. Reddy**, **S.D. Montalvo**, D.W. Saxey, **D. Fougerouse** and A.J. Cavosie
6th Augen Conference, Sydney University, 5-6 August 2017	Meeting tomorrow's needs: The national decadal plan for Earth Sciences, and implementing it in the classroom C. O'Neill **Plenary**
IAVCEI 2017 Scientific Assembly, Portland, Oregon, USA, 14-18 August 2017	The remnant Paleoproterozoic Hart-Carson LIP of north Western Australia K. Orth, J. Hollis, C. Phillips and **M.T.D. Wingate**
Goldschmidt 2017 Conference, Paris, France, 13-18 August 2017 *cont...*	Changes in clinopyroxene crystal structure and chemistry as functions of pressure, temperature, and dissolved H_2O concentrations in coexisting basanitic melts: implications for thermobarometry and the compositions of near-solidus mantle melts **J. Adam**, R. Oberti, F. Camara, T. Green and **T. Rushmer** Reappraisal of MORB redox state using both Fe and S speciation **O. Alard**, C. Baudouin, **M. Chassé**, F. Parat, M. Muñoz, H. Nguyen and H. Ananuer Origin of zircons from the Kondyor Platinum-Bearing Massif (Russia): Evidence from U-Pb and Hf-O isotopic data I. Badanina, **E. Belousova**, K. Malitch, **W. Griffin** and **L. Martin** The role of sulfides in the fractionation of highly siderophile and chalcophile elements during the formation of shergottite meteorites **R.J. Baumgartner**, **M.L. Fiorentini**, J.-P. Lorand, D. Baratoux, F. Zaccarini, L. Ferriere and S. Kerim Halogen and Cl Isotope compositions of martian phosphates: implications for surface chemistry and bulk Mars J. Bellucci, M. Whitehouse, T. John, **A. Nemchin** and J. Snape

Goldschmidt 2017 Conference, Paris, France, 13-18 August 2017

U-Pb and Lu-Hf Isotopic systems in zircon within Ediacaran – Paibian Granitoid "*Taourirt*" ring-complexes (Silet Terrane, Tuareg Shield, Algeria, West Africa): Implications for tectonic setting and regional correlation
B. Bonin, A. Azzouni-Sekkal, P. Bowden, **E. Belousova**, **Y. Greau**, **W.L. Griffin** and F. Bechiri-Benmerzoug

Scandium speciation in a world-class lateritic deposit
M. Chassé, **W.L. Griffin**, **S.Y. O'Reilly** and G. Calas

Occurrence of Ge-bearing accessory minerals within the Variscan Pb-Zn deposits of the Bossost Dome, French Pyrenean Axial Zone
A. Cugerone, B. Cenki-Tok, A. Chauvet, E. Le Goff, L. Bailly, **O. Alard**, E. Oliot and M. Alard

Re-Os geochronology of sub-micrometre meteoritic alloys through atom probe microscopy
L. Daly, P.A. Bland, S. Tessalina, D.W. Saxey, **S.M. Reddy**, **D. Fougerouse**, W.D.A. Rickard, L.V. Forman, P.W. Trimby, L. Yang, A. La Fontaine, J. Cairney, S.P. Ringer and **B.F. Schaefer**

Eoarchean crust in the Napier Complex of East Antarctica: Isotopic insights from U-Pb-Hf in zircon
D. Dunkley, **M. Kusiak**, **S.A. Wilde**, Kemp and M. Whitehouse

New constraints on MARID- and PIC-Style mantle metasomatism and their relationship to continental alkaline magmatism
A. Fitzpayne, **A. Giuliani**, D. Phillips, J. Hergt and P. Janney

Partitioning of nitrogen during partial melting of phlogopite-rich metasomes
M.W. Förster, D. Prelević, S. Buhre and **S. Foley**

Zircon O-Li isotopic constraints on the origins of the Cretaceous Low-$\delta^{18}O$ Nianzishan Granite, NE China
Y.-Y. Gao, **W. Griffin**, **M.-F. Chu**, **S.Y. O'Reilly**, **N.J. Pearson**, Q.-L. Li and X.-H. Li

Southwestern Africa on the burner: Pleistocene carbonatite volcanism linked to mantle upwelling in Angola
A. Giuliani, M. Campeny, V.S. Kamenetsky, R. Maas, J.C. Melgarejo, B.P.P. Kohn, E.L. Matchan, J. Mangas, A.O. Goncalves and J. Manuel

Recycling and growth of zircons in chromitites from the subcontinental lithospheric mantle
J.M. Gonzalez-Jimenez, C. Marchesi, **W.L. Griffin**, F. Gervilla, **E. Belousova**, C.J. Garrido, R. Romero, C. Talavera, M. Leisen, **S.Y. O'Reilly** and F. Barra

Recrystallisation and short-lived lattice disruptions along mantle fluid pathways
Y. Gréau, **H. Henry**, **J.-X. Huang**, **W.L. Griffin** and **S.Y. O'Reilly**

CH_4 interaction with basalt magma: Super-reducing conditions beneath Mt Carmel, Israel
W.L. Griffin, **S.E.M. Gain**, **J. Huang**, V. Toledo and **S.Y. O'Reilly**

The unexplored potential impact of pyroxenitic layering on upper mantle seismic properties
H. Henry, **J.C. Afonso**, T. Satsukawa, **W.L. Griffin**, **S.Y. O'Reilly**, **M.-A. Kaczmarek**, **R. Tilhac**, M. Gregoire and G. Ceuleneer

Moissanite in volcanic systems: super-reduced conditions in the mantle
J. Huang, **Q. Xiong**, **W. Griffin**, **L. Martin**, V. Toledo and **S.Y. O'Reilly**

Insights into diamond formation from polycrystalline diamond aggregates
D. Jacob, R. Stern, J. Chapman and **S. Piazolo**

Zircon O isotope ($^{18}O/^{16}O$) single grain mapping using LG-SIMS
H. Jeon, **M. Kilburn** and **L. Martin**

Microstructural investigations of Ureilite Meteorite Sayh Al Uhaymir 559
M.-A. Kaczmarek, A. Bouvier, S. Shieh and T. Withers

Zircon below the micron scale: on the trail of errant elements
M.A. Kusiak **Keynote**

A monazite and zircon record of Neoarchean polymetamorphism in the Saglek Block of Labrador
M.A. Kusiak, D.J. Dunkley, **S.A. Wilde**, P. Konecny, A. Salacinska and M.J. Whitehouse

Tracing the final collision of accretionary orogens: Terminal magmatic activities in the southern Central Asian Orogenic Belt (CAOB)
S. Li, S.-L. Chung, **S. Wilde**, B.-M. Jahn, W.-J. Xiao and T. Wang

Role of deep-Earth water cycling in Cretaceous magmatism in southeast China
Z. Li, **X.-C. Wang**, **S.A. Wilde**, L. Liu, W.-X. Li and X.M. Yang

Deformation and tectonic evolution of the upper mantle in the Northern Pannonian Basin
N. Liptai, K. Hidas, L. Patkó, **S.Y. O'Reilly**, **W.L. Griffin**, **N.J. Pearson** and C. Szabó

Garnet pyroxenites in Southeastern Australia: Tracing deep lithospheric events
J.G. Lu, **W.L. Griffin**, **Q. Xiong**, **S.Y. O'Reilly**, J.-P. Zheng and **N.J. Pearson**

Goldschmidt 2017 Conference, Paris, France, 13-18 August 2017 *cont...*	Evaluation of full-plate reconstructions of the Neoproterozoic using Hf isotopes in zircon **E.L. Martin**, W.J. Collins, A.S. Collins and C.J. Spencer Textural, chemical and isotopic record of fluid-rock interactions in lawsonite-eclogite from Port Macquarie (Australia) **L. Martin**, A. Galtier, **M. Kilburn** and P. Guagliardo Chronology of the lunar magma ocean **A. Nemchin**, J. Snape and M. Whitehouse **Invited** Geodynamic processes during heroic collisions revealed from geochemical, microstructural and geodynamic information **S.Y. O'Reilly**, **W. Griffin**, **Q. Xiong**, **J.C. Afonso** and T. Satsukawa Numerical modelling of Multi-Phase Multi-Component Reactive Transport in the Earth's interior **B. Oliveira**, **J.C. Afonso**, S. Zlotnik and **R. Tilhac** Model order reduction for the fast solution of 3D Stokes problems and its application in geophysical inversion O. Ortega Gelabert, S. Zlotnik, **J.C. Afonso** and P. Díez Studying sub-crustal reflectors in SW-Spain with wide-angle profiles I. Palomeras, P. Ayarza, R. Carbonell, **J.C. Afonso** and J. Diaz The Paleoproterozoic Baoulé-Mossi domain, West African Craton: plate tectonics at 2.3-2.0 Ga? **L.A. Parra-Avila** Using U-Th-Pb monazite geochronology to constrain emplacement ages and melt production rates of leucocratic granites A.M. Piechocka, C.J. Gregory, J.-W. Zi, S. Sheppard, **M.T.D. Wingate** and B. Rasmussen Archean to Permian zircons in Cretaceous mantle-hosted ophiolitic chromitites from Eastern Cuba J.A. Proenza, J.M. González-Jiménez, A. Garcia-Casco, **E. Belousova**, **W.L. Griffin**, C. Talavera, Y. Rojas-Agramonte, T. Aiglsperger, D. Navarro-Ciruana, N. Pujol, F. Gervilla, C. Lazaro and **S.Y. O'Reilly** Atmospheric sulfur in the orogenic gold deposits of the Archean Yilgarn Craton **V. Selvaraja**, **S. Caruso**, **M. Fiorentini**, **C. LaFlamme** and T-H. Bui Amphibole as a proxy for the volatile content of the Archean mantle G. Sessa, M. Tiepolo, **M. Fiorentini**, M. Moroni, E. Deloule, L. Ottolini, A. Langone and E. Ferrari Tracing the sources of lunar volcanism with Pb isotopes J. Snape, **A. Nemchin**, J. Bellucci and M. Whitehouse **Invited** Fluid Induced transition from banded kyanite- to bimineralic eclogite and implications for the evolution of cratons H. Sommer, **D. Jacob**, R. Stern, D. Petts, D. Mattey and G. Pearson Radiogenic isotope geochemistry of Cabo Ortegal Pyroxenites: Origin and age of a sub-arc mantle domain **R. Tilhac**, **W.L. Griffin**, **S.Y. O'Reilly**, G. Ceuleneer, **B.F. Schaefer**, **H. Henry** and M. Grégoire Remnant ancient lithospheric fragments in Proterozoic Dunzhugur Ophiolites in Southern Siberia K.-L. Wang, M.A. Gornova, V. Kovach, Z. Chu, V.A. Belyaev, K.-Y. Lin and **S.Y. O'Reilly** Episodic subduction of Tethyan slabs recorded in a Tibetan Ophiolite **Q. Xiong**, **W.L. Griffin**, J.-P. Zheng, **N.J. Pearson** and **S.Y. O'Reilly** Ultrapotassic rocks and xenoliths from South Tibet: Contrasting styles of interaction between lithospheric mantle and asthenosphere during continental collision **B. Xu**, **W. Griffin**, **Q. Xiong**, Z. Hou, **S.Y. O'Reilly**, Z. Guo, **N.J. Pearson**, **Y. Gréau**, Z.-M. Yang and Y. Zheng Tracing an intraoceanic Paleozoic subduction zone in Western Junggar of China by geophysical imaging Y. Xu, Y. Liu, S. Wu, B. Yang, S. Zhang, R. Huang, **Y. Yang**, Q. Wang and L. Zhu 3D crustal structure of the Tibetan Plateau revealed by ambient noise tomography: Implications for the deformation and growth of tibet **Y. Yang**, **C. Jiang** and Y. Zheng Crustal structure of the Capricorn Orogen of Western Australia – The role of a microcontinent during Paleoproterozoic dubduction and intra-cratonic crust reworking **H. Yuan**, S. Johnson, M. Dentith, P. Varas, R. Murdie, **K. Gessner** and F. Korhonen
14th SGA Biennial Meeting, Quebec, 20-23 August 2017	Proterozoic West African gold: why 'When' leads to 'Where' A-S. André-Mayer, A. Eglinger, E. Le Mignot, A. Fontaine, L. Reisberg, C. Zimmerman, J. Miller, J. Jessell, **T.C. McCuaig**, **N. Thebaud**, Q. Masurel, E. Lebrun, **L.A. Parra-Avila**, **D. Fougerouse**, L. Siebenaller, S. Perrouty, D. Beziat, L. Baratoux, S. Salvi, Y. Bourassa and S. Naba

14th SGA Biennial Meeting, Quebec, 20-23 August 2017 *cont...*	The bimodal fluid evolution of the Nimbus Zn-Ag deposit: an Archean VHMS with epithermal characteristics **S. Caruso**, **M.L Fiorentini**, **C. LaFlamme**, S.P. Hollis, **L.A.J. Martin**, S.J. Barnes and D. Savard Form and emplacement of chonoliths A.R. Cruden, S. Barnes, C. Magee, J. Van Otterloo, A. Bunger, **M. Fiorentini** and S. Micklethwaite Zircon composition: indicator of fertile igneous rocks related to porphyry copper deposits K. Hattori, J. Wang, **R. Baumgartner**, C. Kobylinski, S. Morfin and P. Shen Gold metallogeny of Greenland **J. Kolb**, **N. Thébaud**, **E. Lebrun**, **M. Fiorentini** and T. Nielsen Multiple sulfur isotopes monitor fluid evolution in MIF-S-bearing orogenic gold **C. LaFlamme**, **D. Sugiona**, **N. Thébaud**, **M. Fiorentini**, **S. Caruso**, **V. Selvaraja** and F. Voute Southern Mali crustal evolution, a geochemical and isotopic study and its implications for the petrogenesis and metallogenesis of the Rhyacian Baoulé-Mossi domain, southern West African Craton **L.A. Parra-Avila**, **M.L. Fiorentini** and A. Eglinger Controls on high-grade ore-shoots at Callie world-class gold deposit, Northern Territory, Australia L. Petrella, **N. Thébaud**, **C. LaFlamme**, S. Occhipinti, **S. Turner** and S. Perazzao The making of Archean orogenic gold deposits: tracing sulfur sources in the Agnew gold camp **N. Thébaud**, **D. Sugiono**, **C. LaFlamme**, F. Voute and **M. Fiorentini**
12th International Eclogite Conference. High- and ultrahigh-pressure rocks - Keys to lithosphere dynamics through geologic time, Åre, Sweden, 26-29 August 2017	Major and trace element fluxes at carbonated metabasite-peridotite interface: insight from experimental modeling A.L. Perchuk, V.O. Yupaskurt, **W.L. Griffin**, M.Yu. Shur and **S.E.M. Gain** Peridotites and eclogites in the SCLM: The evolution of an understanding **W.L. Griffin** and **S.Y. O'Reilly** **Keynote** Major and trace element fluxes at carbonated metabasite-peridotite interface: insight from experimental modeling A.L. Perchuk, V.O. Yupaskurt, **W.L. Griffin**, M.Yu. Shur and **S.E.M. Gain** Tectonostratigraphy, structure and petrology of the Averøy layered eclogite and relations to the Nordøyane UHP domain, W Norway S. Auglænd, S., P. Robinson, P., S.A. McEnroe, M.P. Terry, **N. Daczko**, T.E. Krogh, T, S.L. Kamo and K. Hollocher Modeling of Rare Earth Elements redistribution in HP/LT metamorphic rocks: Record of lawsonite, titanite and epidote breakdown by garnet H. Ditterová, M. Konrad-Schmolke, L. Erpel and **A. Pourteau**
24th Congress and General Assembly of the International Union of Crystallography, Hyderabad, India, 21-28 September 2017	Determination of proton conduction in olivine and hydrogarnet **S.M.P.G.S. Kumara**, **S.M. Clark**, R.A. Mole and N. de Souza
SIMS 21, 21st International Conference on Secondary Ion Mass Spectrometry, Krakow, Poland, 10-16 September 2017	Stable isotope labelling as a tool to investigate mineral-fluid interaction **M. Kilburn**, **M. Fiorentini**, **S. Piazolo** and **T. Rushmer**
Comparative Tectonic Analysis of Melanges, Accretionary Orogens, and Arc-Continent Collisions Through Time; Wuhan, China; 16-21 September 2017	Permo-Triassic to Cretaceous Magmatism along the northern margin of the North China Craton: Implications for the junction of the Central Asian Orogenic Belt **S.A. Wilde** and M.L. Grant **Invited**

SEG 2017. Ore Deposits of Asia: China and Beyond, Beijing, China, 17-20 September 2017	Fe-Ti-V deposits of China and Russia: Tectonic setting, geochemistry and paleomagnetic data N. Krivolutskaya, R. Veselovskiy, X. Song, L.-M. Chen, S.-Y. Yu, B. Gongalsky, **E. Belousova**, Y. Bychkova, K. Malitch and N. Svirskaya Porphyry Cu fertility in the Lhasa Terrane, southern Tibet: Insights from terrane-scale whole-rock geochemistry and zircon trace element and Hf-O isotopes **Y-J. Lu**, Z. Hou, Z. Yang, **L.A. Parra-Avila**, **M. Fiorentini**, **T.C. McCuaig**, **R.R. Loucks** Zircon compositions as fertility indicator of Archean granites **Y-J. Lu** and H. Smithies Zircon characterization as a pathfinder for porphyry Cu deposits **L.A. Parra-Avila**, **M.L. Fiorentini**, **Y. Lu**, **R. Loucks** and S. Garwin Mass dependent fractionation in pyrite from the Golden Mile: Evidence for a mantle connection during gold mineralization M.G. Rodriguez, S. Hagemann, **C. LaFlamme** and **M. Fiorentini** Large copper and gold systems of Kazakhstan and Tienshan: Geodynamics and metallogeny revisited R. Seltmann, A. Dolgopolova, D. Konopelko, R. Creaser, **E. Belousova**, A. Miroshnikova, A. Mizerny, M. Mizernaya, M. Kokkuzova and D. Makat Ultrapotassic rocks and xenoliths from South Tibet: Contrasting styles of interaction between lithospheric mantle and asthenosphere during continental collision **B. Xu**, **W.L Griffin**, **Q. Xiong**, Z.-Q. Hou, **S. O'Reilly**, Z. Guo, **N. Pearson**, **Y. Gréau**, Z.-M. Yang and Y.-C. Zheng
11th International Kimberlite Conference, Gaborone, Botswana, 18-22 September 2017	New constraints on the origin of carbonates in kimberlites using petrography, mineral chemistry and *in situ* stable isotope analysis **M. Castillo-Oliver**, **A. Giuliani**, **W.L. Griffin**, **S.Y. O'Reilly**, E. Thomassot and R.N. Drysdale Metasomatic evolution of the SCLM beneath the Lunda Norte province (NE Angola) **M. Castillo-Oliver**, **W.L. Griffin**, J.C. Melgarejo, S. Galí, N.J. Pearson, V. Pervov and **S.Y. O'Reilly** Mineralogy, geochemistry, and petrogenesis of paleoproterozoic alkaline magmas in the Yilgarn Craton, Western Australia **E. Choi**, **M.L. Fiorentini**, **A. Giuliani**, A. Kemp, F. Pirajno and **S. Foley** Melt evolution of the Finsch orangeite, South Africa H. Farr, **A. Giuliani** and D. Phillips New constraints on the origins of MARID and PIC rocks based on mineral and bulk-rock geochemical data: Implication for mantle metasomatism and alkaline magmatism A. Fitzpayne, **A. Giuliani**, J. Hergt, D. Phillips and P. Janney Multiple metasomatic events recorded in MARID xenoliths A. Fitzpayne, **A. Giuliani**, D. Phillips, J. Hergt, J. Farquhar and R.N. Drysdale The carbon cycle in the continental lithosphere and the generation of alkaline mafic melts in cratonic and rift regions **S.F. Foley** and T.P. Fischer Olivine zoning and the evolution of kimberlite systems **A. Giuliani**, A. Soltys, E. Lim, H. Farr., D. Phillips, K. Goemann and **W.L. Griffin** **Keynote** Tracing mantle metasomatism using combined stable (C, O, N) and radiogenic (Sr, Nd, Hf, Pb) isotope geochemistry: case studies from mantle xenoliths of the Kimberley kimberlites **A. Giuliani**, D. Phillips, R. Maas, J.D. Woodhead, C. Harris, **M.L. Fiorentini**, J. Farquhar, E. Thomassot, C. Cheng and A. Fitzpayne Complex zoning of olivine in archetypal kimberlites provides new insights into the evolution of kimberlite magmas E. Lim, **A. Giuliani** and D. Phillips A comparison of geochronology methods applied to kimberlites and related rocks from the Karelian Craton, Finland D. Phillips, D. Zhong, E.L. Matchan, R. Maas, H. Farr, H. O'Brien and **A. Giuliani** Primitive melt composition of the Bultfontein Kimberlite A. Soltys, **A. Giuliani** and D. Phillips Apatite from the Kimberley Kimberlites (South Africa): Petrography and mineral chemistry A. Soltys, **A. Giuliani** and D. Phillips

11th International Kimberlite Conference, Gaborone, Botswana, 18-22 September 2017 *cont...*	Tracking continental-scale modification of the Earth's mantle using Hf-isotopes in zircon megacrysts J.D. Woodhead, J. Hergt, **A. Giuliani**, D. Phillips and R. Maas Ilmenite as a recorder of the kimberlite history from mantle to surface: examples from Indian kimberlites J. Xu, J.C. Melgarejo and **M. Castillo-Oliver** Magma mingling at the Menominee pipe, USA? Contributions from texture and mineral chemistry J. Xu, J.C. Melgarejo, L. Torró i Abat and **M. Castillo-Oliver** Styles of alteration of Ti oxides of the kimberlite groundmass: implications on the petrogenesis and classification of kimberlites and similar rocks J. Xu, J.C. Melgarejo and **M. Castillo-Oliver** Ilmenite generations in a mixed orangeite-kimberlite from Banankoro, Guinea: implications for exploration J. Xu, J.C. Melgarejo, **M. Castillo-Oliver**, L. Arqués and J. Santamaria
Exploration 17: Sixth Decennial International Conference on Mineral Exploration, Toronto, Ontario, Canada, 21-25 October 2017	Exploration targeting **T.C. McCuaig** and R.L. Sherlock **Keynote**
FAMOS (From Arc Magmas to Ores) Conference, University of Bristol, UK, 2 November 2017	Applications of zircon chemistry to mineral exploration **R. Loucks** **Invited**
Third Lithosphere Dynamics Workshop, CET UWA, Perth, November 5-6 2017	From Archean craton to Tibet: application of isotopic mapping, whole-rock fertility indicator and zircon compositions to understanding lithospheric evolution and mineral systems **Y.-J. Lu** Deep mantle processes: rheology, mixing, and how it's changed **C. O'Neill** **Invited** Finite-frequency P wave tomography of the upper mantle beneath Capricorn Orogen and adjacent areas X.B. Xu, **H.Y. Yuan** Bayesian transdimensional inversion for a probabilistic shear wave velocity model of the crust in the central West Australian Craton **H. Yuan** and **T. Bodin**
Asian Orogeny and Continental Evolution: New Advances from Geologic, Geophysical and Geochemical Perspectives, Taipei, Taiwan, 6-12 November 2017	Extrusion-style growth of the Tibetan Plateau since 40 Ma: New insights from the Longmenshan Fault Zone **Z.-X. Li** **Keynote** How extensive are microcontinents within the Chinese segment of the Central Asian Orogenic Belt? **S.A. Wilde** **Keynote**
Specialist Group in Tectonics and Structural Geology, The Geological Society of Australia, Denmark, WA, 8-12 November 2017	Emplacement mechanisms for small mafic-ultramafic intrusions hosting Ni-Cu sulfide ores: evidence from the Savannah (Sally Malay) deposit S. Barnes, D. Mole, **M. Le Vaillant** and **S. Denyszyn** Our blind side – Aligning structural geology, tectonics, and a whole of lithosphere reality G. Begg, **W. Griffin**, **S. O'Reilly** and **L. Natapov** Deep density structure of the Albany-Fraser Orogen and Yilgarn Craton margin from constrained 3D gravity modelling L. Brisbout, R. Murdie and **K. Gessner** Structural and fluid mechanical controls on the formation of Ni-Cu-PGE trapping chonoliths A. Cruden, J. van Otterloo, S. Barnes, C. Magee, A. Bunger, S. Micklethwaite and **M. Fiorentini** Melt flux through the root of a magmatic arc under static versus dynamic conditions **N. Daczko**, **S. Piazolo**, **C. Stuart** and **U. Meek**

Specialist Group in Tectonics and Structural Geology, the Geological Society of Australia, Denmark, WA, 8-12 November 2017 *cont...*	Patterns of strain localization in heterogeneous, polycrystalline rocks – a numerical perspective **R. Gardner**, **S. Piazolo** and **N. Daczko** Uncovering the Yilgarn Craton's hidden crustal structure by integrating geochemistry and geophysics **K. Gessner**, R.H. Smithies, **Y. Lu**, **C. Kirkland** and **H. Yuan** Distinguishing hydration in shear zones by aqueous fluid versus silicate melt **H. Ghatak**, **N. Daczko**, **S. Piazolo** and T. Raimondo Reactivation of an Archean craton margin – Albany–Fraser Orogen numerical case study **W. Gorczyk** and C. Spaggiari Uncovering terra incognita: new insights into the evolution of Antarctica and constraints for ice sheet models J. Halpin, J. Whittaker, **N. Daczko**, I. Fitzsimons, A. Reading, A. Maritati, T. Staal, S. Watson, J. Mulder, T. Noble, Z. Chase, S. Tooze and I. Sauermilch **Keynote** Structural controls on Au and Ni mineralization in the Halls Creek Orogen, insight from geodynamic numerical modeling and geophysical interpretation F. Kohanpour, Lindsay, M.D., **W. Gorczyk** and S. Occhipinti Terrane-scale porphyry Cu fertility in the Lhasa terrane, southern Tibet **Y-J. Lu**, Z.Q. Hou, Z.M. Yang, Z.M., **L.A. Parra-Avila**, **M. Fiorentini**, **T.C. McCuaig** and **R. Loucks** An Australian source for Pacific-Gondwanan zircons: Implications for the assembly of northeastern Gondwana **E. Martin**, W. Collins and **C. Kirkland** Localisation of high strain and high temperature into the Chalba Shear Zone, Gascoyne Province **H. Meadows**, **S. Reddy**, **C. Clark**, D. Plavsa and T. Johnson Microstructural and microchemical evidence for deep crustal melt-rock interaction in mass transfer zones, Finero Complex, Ivrea Verbano Zone, Italy poster **J. Munnikhuis**, **N. Daczko** and A. Langone Multifractal topography: a case study of structurally-controlled landforms across the Menderes Massif, western Turkey M. Munro, **K. Gessner**, A. Ord and B. Hobbs Advances in geodynamic modelling **C. O'Neill** **Keynote** High-T, low-P c. 1.7 Ga tectonism in the West Australian Craton triggered by magma flux into the crust A. Piechocka, F. Korhonen, C. Gregory, J.-W. Zi, S. Sheppard, S. Johnson, **M. Wingate**, I. Fitzsimons and B. Rasmussen 500 Ma of post-Mesoproterozoic intracontinental reactivation in the west Musgrave Province, Central Australia R. Quentin de Gromard, H. Howard, **C. Kirkland**, R. Smithies, **M. Wingate**, F. Jourdan, B. McInnes, M. Danišík, N.J. Evans and B. McDonald Variations in regional stresses, geometry and shape of low strength zones controls the periodic Alice Springs orogeny **D. Silva**, **S. Piazolo**, **N. Daczko**, T. Raimondo and G. Houseman The recognition of former melt flux through high-strain zones **C. Stuart**, **S. Piazolo** and **N. Daczko** The geometry of hydrothermal veins in the 3.5 Ga Dresser Formation, North Pole Dome, Western Australia **S. Tabiri**, **M.V. Kranendonk** and P. Lennox Tectono-metamorphic evolution of the Georgetown Inlier, NE Australia and its implications for the assembly of the supercontinent Nuna **S. Volante**, **A. Pourteau**, **Z.-X. Li** and W. Collins Crustal structure of the Capricorn Orogen of Western Australia and its role in Paleoproterozoic craton assembly and reworking: a high-density passive seismic receiver function study **H. Yuan**, S.P. Johnson, M. Dentith, P. Piña-Varas, R. Murdie, **K. Gessner** and F.J. Korhonen
Geological Society of Australia (GSA) Earth Science Student Symposium (GESSS) Sydney, Australia, 10 November 2017	Physical artefacts or biological structures: the difficulty in interpreting Precambrian fossils **E.V. Barlow** and **M.J. Van Kranendonk** The origin and mantle dynamics of Quaternary intra-plate volcanism in Northeast China from joint inversion of surface wave and body wave Z. Guo, **K. Wang**, **Y. Yang** and Y.J. Chen

Geological Society of Australia (GSA) Earth Science Student Symposium (GESSS) Sydney, Australia, 10 November 2017 *cont...*	Silica phases and the effects of phase transformation on electrical conductivity – Just another mineral to test or a major player in the Earth's field? **A.W. Lanati**, **G.M. Amulele** and **S.M. Clark** Hydrous melting of Labradorite: An electrical conductivity investigation **A.W. Lanati**, **G.M. Amulele** and **S.M. Clark** Time-frequency domain phase weighted stacking and its application to phase velocity extraction from ambient noise's empirical Green's functions F. Niu, G. Li, **Y. Yang** and J. Xie The composition of melts in the incipient melt regime **Z. Pintér**, **S. Foley**, G.M. Yaxley and **T. Rushmer**
TIGeR Conference 2017, Timescales of Geological Processes, Curtin University, Perth, 13-15 September 2017	Gigayear periodicity of mantle circulation on Earth W.J. Collins, **E.L. Martin**, **R. Mitchell**, C.J. Spencer and J.B. Murphy Insights into sulphur cycling at subduction zones from in-situ isotopic analysis of sulphides in high-pressure serpentinites and 'hybrid' rocks from alpine Corsica R.J. Crossley, K.A. Evans, **H. Jeon** and **M.R. Kilburn** Melting Earth's Ancient Mantle **N.J. Gardiner**, T.E. Johnson, **C.L. Kirkland** and R.H. Smithies Visualizing temporal and spatial patterns of U-Pb disturbance **C. Kirkland** Detrital zircon grain shape analysis in 3D and the effect on preservation bias (Murchison River, Western Australia) V. Markwitz, **C.L. Kirkland**, **K. Gessner**, A. Mehnert and J. Shaw Is true polar wander a thermometer? **R. Mitchell**, J. Korenaga and B. Steinberger Dating monazite to constrain emplacement ages and melt production rates of leucocratic granites A.M. Piechocka, C.J. Gregory, J.-W. Zi, S. Sheppard, **M.T.D. Wingate** and B. Rasmussen 500 Ma of a magmatic intracontinental reactivation: a case study from the west Musgrave Province, central Australia R. Quentin de Gromard, H. Howard, **C. Kirkland**, R. Smithies, **M. Wingate**, F. Jourdan, B. McInnes, M. Danišík, N.J. Evans and B. McDonald Time-resolved, microstructurally-controlled, trace element mobility in deformed Witwatersrand pyrite **S.M. Reddy**, **D. Fougerouse**, **C.L. Kirkland**, D.W. Saxey, W.D. Rickard and R.M. Hough Dating basalts by pyroxene $^{40}Ar/^{39}Ar$ with implications for large igneous provinces and correlations of Precambrian basins J.-W. Zi, F. Jourdan, **X.-C. Wang**, P.W. Haines, B. Rasmussen, G.P. Halverson and S. Sheppard
17th Australian Space Research Conference, Sydney, Australia, 15-17, November 2017	Hydrothermal systems, early life on Earth and implications for astrobiology **T. Djokic** **Plenary**
CCFS Whole-of-Centre Meeting, Cairns, Australia, 27-29 November 2017	**116 abstracts** The CCFS Whole-of-Centre Meeting Abstract Volume ISSN:2209-1351 (Online) is available for download http://ccfs.mq.edu.au/WoCMeeting17/2017WoCMAbstractVolume.pdf
AGU Fall Meeting, New Orleans, USA, 11-15 December 2017	Extended Late-Cretaceous magnetostratigraphy of the James Ross Basin Island, Antarctica T.M. Chaffee, **R. Mitchell**, S.P. Slotznick, J. Buz, J. Biasi, J. O'Rourke, F. Sousa, D. Flannery, R.R. Fu and J.L. Kirschvink Looking for the edge: Does lateral change in azimuthal anisotropy mark the limit of the North American Craton? X. Chen, V.L. Levin, Y. Li and **H. Yuan** Numerical geodynamic modelling of slab derived carbonate melting at upper mantle condition **C. Gonzalez**, **W. Gorczyk** and **M. Fiorentini**

AGU Fall Meeting, New Orleans, USA, 11-15 December 2017 *cont...*	Magma emplacement in 3D **W. Gorczyk** and K. Vogt
	Water and metasomatism in the Slave cratonic lithosphere (Canada): an FTIR study M. Kilgore, A.H. Peslier, A.D. Brandon, L.A. Schaffer, D.G. Pearson, **S.Y. O'Reilly**, M.G. Kopylova and **W.L. Griffin**
	Palaeomagnetism of the Palaeoproterozoic Boonadgin Dyke Suite, Yilgarn Craton: Possible connection with India **Y. Liu**, **Z.-X. Li**, **S. Pisarevsky**, **U. Kirscher**, **R. Mitchell** and **J.C. Stark**
	Adjoint tomography of empirical Green's functions from ambient noise in Southern California **K. Wang**, Q. Liu, **Y. Yang**, P. Basini and C. Tape
	Mountain building in central and western Tien Shan orogen: Insight from joint inversion of surface wave phase velocities and body wave travel times **S. Wu**, **Y. Yang** and **K. Wang**
Franco-Australian Astrobiology and Exoplanet Workshop (FAAbExo), Canberra, Australia, 16-20 December 2017	Towards an understanding life on early Earth: microfossils from the c. 2.4 Ga Turee Creek Group, Western Australia **E.V. Barlow** and **M.J. Van Kranendonk**
	High-pressure silicate phases in exoplanets: Implications for dynamics and thermal evolution C. O'Neill **Invited**

Appendix 7: CCFS visitors

CCFS VISITORS 2017 (Excluding participants in conferences and workshops)

VISITOR	ORGANISATION	COUNTRY
Dr Chris Adams	Lower Hutt	New Zealand
Dr Graham Begg	Minerals Targeting International	Australia
Dr Helen Brand	Australian Synchrotron, Clayton, Victoria	Australia
Miss Valentina Brombin	University of Ferrara	Italy
Mr Marc Buisson	Université Toulouse III Paul Sabatier	France
Mr Chunfei Chen	Chinese University of Geosciences, Wuhan	China
Miss Ying Chen	Institute of Geology and Geophysics, Chinese Academy of Sciences	China
Mr Hong-Kun Dai	Chinese University of Geosciences, Wuhan	China
Ms Lauren Elliott	University of South Australia	Australia
Mr Yousong Fang	Vice Director of Human Resource Department, East China Metallurgical Bureau of Geology and Exploration	China
Ms Olga Galabert	LaCAN, Universitat Politècnica de Catalunya (UPC)	Spain
Ms Alyssa Galtier	Institut Polytechnique LaSalle Beauvais	France
Mr Qisheng Jiang	Chief Expert of Science and Technology, East China Metallurgical Bureau of Geology and Exploration	China
Dr Cheng Jin	China University of Geosciences (Beijing)	China
Ms Patricia Kang	University of Minnesota	USA
Miss Zakie Kazemi	Shahrood University of Technology	Iran
Dr Fatma Kourim	Institute of Earth Science, Academia Sinica	Taiwan
Mr Hua Li	Director of Comprehensive Geology Brigade, East China Metallurgical Bureau of Geology and Exploration	China
A/Professor Xiangdong Lin	Earthquake Administration of Beijing Municipality	China
Professor Dameng Liu	China University of Geosciences (Beijing)	China
Dr Luke Milan	University of New England, Armidale, NSW	Australia

VISITOR	ORGANISATION	COUNTRY
Dr Katarina Miljkovic	Department of Applied Geology, Curtin University	Australia
Professor Brendan Murphy	St. Francis Xavier University	Canada
Mr Jahaziel Nkere	University of Cape Town	South Africa
Mr Folker Pappa	Kiel University	Germany
Dr Xian-Quan Ping	China University of Geosciences (Wuhan)	China
Professor Malcolm Sambridge	ANU	Australia
A/Professor Eric Sandvol	Department of Geological Sciences, University of Missouri	USA
Professor Ying Tong	Chinese Academy of Geological Sciences	China
Mr Jialou Wang	Chief Engineer of East China Metallurgical Bureau of Geology and Exploration	China
Mr Zhongwei Wang	China University of Geosciences (Wuhan)	China
Mr Gang Wang	China University of Geosciences (Wuhan)	China
Mr Kai Wang	Chinese Academy of Geological Sciences	China
Dr Kuo-Lung Wang	Institute of Earth Science, Academia Sinica	Taiwan
Mr Biao Wang	Vice Director of East China Metallurgical Bureau of Geology and Exploration	China
Professor Gerhard Wörner	University of Göttingen	Germany
Mr Rong Xu	China University of Geosciences (CUG)	China
Mr Xiaobing Xu	Institute of Geology and Geophysics, Chinse Academy of Sciences	China
Dr Huajun Xu	Zhejiang University of Science and Technology	China
Mr Mugang Yan	Assistant Director of East China Metallurgical Bureau of Geology and Exploration	China
Miss Anqi Zhang	China University of Geosciences (Wuhan)	China
Professor Chuanheng Zhang	China University of Geosciences (Beijing)	China
Dr Yongqian Zhang	Institute of Mineral Resources, Chinese Academy of Geological Sciences	China
Dr Yuanchuan Zheng	China University of Geosciences (Beijing)	China
Mr Xiang Zhou	China University of Geosciences (Wuhan)	China
A/Professor Sergio Zlotnik	LaCAN, Universitat Politècnica de Catalunya (UPC)	Spain

Appendix 8: Research funding

GRANTS AND OTHER INCOME FOR 2017

Investigators	2017 Funding Source	Project Title	Amount
O'Reilly	ARC Centre of Excellence (CE1101017)	Core to Crust Fluid Systems	$2,015,831
Wilde	ARC CoE (CU contribution)	Core to Crust Fluid Systems	$280,000
GSWA	ARC CoE (GSWA)	Core to Crust Fluid Systems	$185,000
O'Reilly	ARC CoE (MQ contribution)	Core to Crust Fluid Systems	$440,000
O'Reilly	ARC CoE (MQ FSE contribution)	Core to Crust Fluid Systems	$110,000
Fiorentini	ARC CoE (UWA contribution)	Core to Crust Fluid Systems	$415,000
Moresi, Betts, Whittaker, Miller	ARC Discovery Project (DP150102887)	The global consequences of subduction zone congestion	$180,000
Handley, Turner, Reagan, Barclay	ARC Discovery Project (DP150100328)	Timescales of mixing and volatile transfer leading to volcanic eruptions	$115,582
Jacob, Eggins, Wirth	ARC Discovery Project (DP160102081)	Mechanisms of proxy uptake in biominerals	$110,643
Putnis, Raimondo, Daczko	ARC Discovery Project (DP160103449)	Just add water: a recipe for the deformation of continental interiors	$108,000
Clark, Afonso, Jones	ARC Discovery Project (DP160103502)	To develop a geophysically relevant proton conduction model for the Earth's upper mantle	$101,292
Hand, Clark, Hasterok, Rushmer, Reddy, Hacker	ARC Discovery Project (DP160104637)	Rehydration of the lower crust, fluid sources and geophysical expression	$137,600
Nutman, Bennett, Van Kranendonk	ARC Discovery Project (DP170100715)	Establishing the critical physical-chemical factors in the early surface environment and tectonic regime that supported early life and continuing habitability	$100,000
Li	ARC Australian Laureate Fellowship (FL150100133)	How the Earth works - Toward building a new tectonic paradigm	$630,510
Li	ARC Australian Laureate Fellowship (CU contribution)	How the Earth works - Toward building a new tectonic paradigm	$493,899
Yang	ARC Future Fellowship (FT130101220)	How the Earth moves: Developing a novel seismological approach to map the small-scale dynamics of the upper mantle	$94,735
Wang	ARC Future Fellowship (FT140100826)	Roles of deep-Earth fluid cycling in the generation of intra-continental magmatism	$333,361
Alard	ARC Future Fellowship (FT150100115)	Earth's origin and evolution: A sulphurous approach	$204,118
Selway	ARC Future Fellowship (FT150100541)	Measuring mantle hydrogen to map ore fluids and model plate tectonics	$178,671

Investigators	2017 Funding Source	Project Title	Amount
Arculus, Cohen, Gallagher, Vasconcelos, Elders, Foden, Coffin, Nebel, McGregor, Clennell, Sloss, Heap, Webster, Kemp, George	ARC LIEF (LE160100067)	Australian membership of the International Ocean Discovery Program	$2,000,000
Jessell, Holden, Baddeley, Kovesi, Ailleres, Wedge, Lindsay, Gessner, Hronsky	ARC Linkage Project (LP140100267)	Reducing 3D geological uncertainty via improved data interpretation methods	$43,300
Meffre, Whittaker, Norman, Cracknell, Belousova, Collins, Arundell, Cooke, Maas, Huston, Musgrave, Greenfield	ARC Linkage Project (LP160100483) (MQ contribution)	Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia	$164,000
Giuliani	ARC DECRA (DE150100510)	A new approach to revealing melting processes in the hidden deep Earth	$130,292
Hough, McCuaig, Reddy, Clark, Fiorentini, Gray, Miller	SIEF/MERIWA M436	Distal footprints of giant ore systems	$260,698
Hough, Reddy, McCuaig	SIEF RP	The distal footprints of giant ore systems: UNCOVER Australia	$169,401
Barnes, Fiorentini	MERIWA M459	Magmatic sulfide mineral potential in the East Kimberley	$35,000
Kirkland, Clark, Kiddie, Tyler, Spaggiari, Smithies, Wingate	MRIWA M470	Mineral systems on the margin of cratons: Albany-Fraser Orogen/Eucla Basement case study	$150,000
O'Reilly	NCRIS AuScope	AuScope Project Plan 3.53 – Earth composition and evolution	$245,970
O'Reilly	NCRIS AuScope (MQ contribution)	AuScope Project Plan 3.53 – Earth composition and evolution	$50,000
O'Reilly	RAAP	Interest - AuScope – Earth composition and evolution	$6,890
Kirkland	Department of Mines and Petroleum	Crustal evolution project Geological Survey of Western Australia	$44,173
Lampinen, Occhipinti	ASEG Research Foundation	Research Grant	$3,000
Huang	Australian and New Zealand International Ocean Discovery Program Consortium	Mg-isotope composition of altered oceanic crust	$20,000
Afonso	MQ	Safety Net Scheme	$16,782
Afonso	MQ	DVCR Discretionary Fund	$99,879
Griffin, O'Reilly, Pearson, Belousova	MQ Enterprise Partnership Pilot Research Grant (Minerals Targeting International Pty Ltd)	Lithospheric architecture mapping in phanerozoic orogens	$60,000
Clark	MQ Enterprise Partnership Scheme	Pilot Research Grants – Sydney Water	$100,000
Clark	MQ Enterprise Partnership Scheme	Pilot Research Grants – MQ contribution	$50,000
LaFlamme	UWA	Research impact award	$10,000
Jacob	Australian Synchrotron – Access Program	H_2O and CO_2 distribution along grain boundaries	$1,112

Investigators	2017 Funding Source	Project Title	Amount
Daczko	University of Tasmania - AAD Subcontract Agreement	Reconstructing East Antarctica in Gondwana: Ground-truthing a new tectonic model	$12,000
Kirkland	Ministry of Mineral Resources (Greenland)	Geochronology for the Greenland Ministry of Mineral Resources	$76,138
Yuan, Zhao	Institute of Geology and Geophysics, Chinese Academy of Sciences	China-Western Australia Seismic Survey Canning Passive Seismic Survey	$300,000
Yang, Lu	National Natural Science Foundation of China	Genesis of comb quartz layers: Case studies from porphyry Cu deposits at Qulong, Tibet and Now Chun, Iran	$50,000
Sun, Lu	National Natural Science Foundation of China	Magmatic oxidation state, water content, and volatile nature: New insights into genesis of porphyry copper mineralization at Zhunuo in the Gangdese belt, southern Tibet	$40,000
Pisarevsky	University of Oslo	Maintaining and upgrading the global palaeomagnetic database	$10,000
Yao, Wang, Zhou	China Geological Survey	The Ediacaran–Silurian palaeogeography of western Yangtze Block and its tectonic linkage with the Gondwana assembly	$10,000
Afonso, Ebbing	European Space Agency	3D Earth	€85,000
Afonso, Ebbing	European Space Agency (MQ contribution)	3D Earth	$17,200
Afonso	Research Innovation Staff Exchange	Multiscale inversion of porous rock physics using high-performance simulators: Bridging the gap between mathematics and geophysics	€765,000
Fiorentini	Barrick Gold Corporation	Gold pathways: evolution of the lithospheric to crustal architecture of the El Indio Belt, Chile-Argentina	$100,000
McCuaig, Fiorentini	Barrick Gold Corporation	The role of whole-lithosphere architecture on the genesis of giant gold systems in the El-Indio region, Chile-Argentina	$215,000
Fiorentini, Loucks	BHP Billiton	Improving zircon morphology and chemistry as a tool of assessing and ranking the relative prospectivity for Cu porphyry deposits in *"greenfield"* terrains	$202,000
LaFlamme, Fiorentini	Buxton Resources	Nickel sulfide prospectivity of the King Leopold Orogen, Kimberley	$10,000
Barnes, Fiorentini	IGO Independence Group	Geology and ore genesis of the Nova-Bollinger Ni deposit, WA	$160,000
LaFlamme, Thebaud, Fiorentini, Sugiono	Northern Star Resources	Fluid evolution monitored by stable isotopes at the Kanowna Belle deposit	$76,718
O'Reilly	GLITTER software	Core to Crust Fluid Systems	$44,410
Clark	ANSTO	Scholarship	$91,354
CCFS Postgraduates	MQ, CU and UWA Scholarships	Scholarships	$2,775,961
Meek	MQPGRF Round 1	Melt metasomatism within the lower crust	$5,000
Forster	MQPGRF Round 2	Experimental melting of rocks of ultramafic and sedimentary origin in accretionary orogens	$3,866
Liptai	MQPGRF Round 2	Nature of the mantle beneath the Carpathian-Pannonian basin, Hungary - A mantle xenolith study	$4,697

GRANTS AND OTHER INDICATIVE INCOME FOR 2018

Investigators	2018 Funding Source	Project Title	Amount
GSWA	ARC CoE (GSWA)	Core to Crust Fluid Systems	$185,000
Handley, Turner, Reagan, Barclay	ARC Discovery Project (DP150100328)	Timescales of mixing and volatile transfer leading to volcanic eruptions	$115,582
Moresi, Betts, Whittaker, Miller	ARC Discovery Project (DP150102887)	The global consequences of subduction zone congestion	$150,000
Jacob/Eggins	ARC Discovery Project (DP160102081)	Mechanisms of proxy uptake in biominerals	$110,643
Putnis, Raimondo, Daczko	ARC Discovery Project (DP160103449)	Just add water: A recipe for the deformation of continental interiors	$55,000
Clark, Afonso, Jones	ARC Discovery Project (DP160103502)	To develop a geophysically relevant proton conduction model for the Earth's upper mantle	$72,675
Hand, Clark, Hasterok, Rushmer, Reddy, Hacker	ARC Discovery Project (DP160104637)	Rehydration of the lower crust, fluid sources and geophysical expression	$101,826
Nutman, Bennett, Van Kranendonk	ARC Discovery Project (DP170100715	Establishing the critical physical-chemical factors in the early surface environment and tectonic regime that supported early life and continuing habitability	$100,000
Van Kranendonk, Fiorentini, Campbell, Deamer	ARC Discovery Project (DP180103204)	A terrestrial hot spring setting for the origin of life?	$193,000
Li	ARC Australian Laureate Fellowship (FL150100133	How the Earth works - Toward building a new tectonic paradigm	$609,068
Li	ARC Australian Laureate Fellowship (CU contrib)	How the Earth works - Toward building a new tectonic paradigm	$493,899
Wang	ARC Future Fellowship} (FT140100826)	Roles of deep-Earth fluid cycling in the generation of intra-continental magmatism	$333,361
Alard	ARC Future Fellowship (FT150100115)	Earth's origin and evolution: A sulphurous approach	$192,240
Selway	ARC Future Fellowship (FT150100541)	Measuring mantle hydrogen to map ore fluids and model plate tectonics	$161,338
Arculus, Cohen, Gallagher, Vasconcelos, Elders, Foden, Coffin, Nebel, McGregor, Clennell, Sloss, Heap, Webster, Kemp, George	ARC LIEF (LE160100067)	Australian membership of the International Ocean Discovery Program	$2,000,000
Meffre, Whittaker, Norman, Cracknell, Belousova, Collins, Arundell, Cooke, Maas, Huston, Musgrave, Greenfield	ARC Linkage Project (LP160100483)	The distal footprints of giant ore systems: UNCOVER Australia	$20,829 (to MQ)
George, Paterson, Van Kranendonk, Brocks, Sherwood, Jacob, Fuerbach, Brock, Lohr, Sestak	ARC LIEF (LE180100060)	Femtosecond laser micropyrolysis gas chromatograph-mass spectrometer	$297,463
Sampson, Barnes, Fiorentini, Fitzsimons, Johnson, Kemp, Kilburn, Martyniuk, Putnis, Reddy, Smithies, Uvarova	ARC LIEF (LE180100070)	Cutting-edge electron probe microanalysis driving Western Australia's resource geosciences	$966,283

Investigators	2018 Funding Source	Project Title	Amount
O'Reilly	NCRIS AuScope	AuScope Project Plan 3.53 – Earth composition and evolution	$245,970
O'Reilly	NCRIS AuScope (MQ contribution)	AuScope Project Plan 3.53 – Earth composition and evolution	$50,000
O'Reilly	RAAP	AuScope – Earth composition and evolution	$200,000
Yang, Lu	National Natural Science Foundation of China	Genesis of comb quartz layers: Case studies from porphyry Cu deposits at Qulong, Tibet and Now Chun, Iran	$50,000
Sun, Lu	National Natural Science Foundation of China	Magmatic oxidation sate, water content, and volatile nature: New insights into genesis of porphyry copper mineralization at Zhunuo in the Gangdese belt, southern Tibet	$40,000
Yuan, Zhao	Institute of Geology and Geophysics, Chinese Academy of Sciences	China-Western Australia Seismic Survey	$99,690
LaFlamme, Thebaud, Fiorentini, Sugiono	Northern Star Resources	Fluid evolution monitored by stable isotopes at the Kanowna Belle Deposit	$254,483
Fiorentini	Barrick Gold Corporation	Gold pathways: evolution of the lithospheric to crustal architecture of the El Indio Belt, Chile-Argentina	$100,000
Barnes, Fiorentini	IGO Independence Group	Geology and ore genesis of the Nova-Bollinger Ni deposit, WA	$160,000
Fiorentini, Loucks	BHP Billiton	Improving zircon morphology and chemistry as a tool of assessing and ranking the relative prospectivity for Cu porphyry deposits in "*greenfield*" terrains	$202,000

Appendix 9: Standard performance indicators

All values maximised at double target

Area	Category	Code	Indicator		Value
RESEARCH	Number & quality of outputs	R1	*Research outputs*	*Actual*	183
				Target	40
		R2(a)	*Journals with Impact Factor >2.5*	*Actual*	84%
				Target	70%
		R2(b)	*Journals with impact Factor >3 Note: (14%>6)*	*Actual*	78%
				Target	50%
		R2(c)	*Journals with specific target audiences*	*Actual*	14%
				Target	20%
		R2(d)	*Book chapters / international conference proceedings*	*Actual*	6%
				Target	10%
		R3(a)	*Number of presentations / talks / papers / lectures given at major international meetings*	*Actual*	343
				Target	40
		R3(b)	*Number of invited or keynotes given at major international meetings*	*Actual*	25
				Target	10
		R4	*Number & nature of commentaries on Centre's achievements in general/specialist publications*	*Actual*	>100
				Target	8
		R5	*Citation data for publications: at least 4 CIs in top 200 Geoscientists*	*Actual*	4
				Target	4
	Research training and professional education	R6	*Number of attended professional training courses for staff and postgraduate students*	*Actual*	11
				Target	10
		R7	*Number of Centre attendees at all professional training courses*	*Actual*	64
				Target	20
		R8	*Number of new postgraduates working on core Centre research, supervised by CoE staff (PhD, Mast.)*	*Actual*	27
				Target	8
		R9	*Number of new postdoctoral researchers recruited to the CoE working on core Centre research*	*Actual*	6
				Target	4
		R10	*Number of new Honours/MRes students working on core Centre research & supervised by CoE staff*	*Actual*	13
				Target	6
		R11(a)	*Number of postgraduate completions working on core Centre research and supervised by CoE staff*	*Actual*	27
				Target	6
		R11(b)	*Postgraduate completion times: students working on core CoE research, supervised by Centre staff*	*Actual*	3.5
				Target	3.5
		R12	*Number of Early Career Researchers (within 5 years of completing PhD) working on core CoE research*	*Actual*	21
				Target	6
		R13	*Number of students mentored*	*Actual*	110
				Target	24
		R14	*Number of mentoring programs*	*Actual*	4
				Target	3
	Build int. national and regional links/networks	R15	*Number of international visitors and visiting fellows*	*Actual*	39
				Target	20
		R16	*Number of national and international workshops held / organised by Centre*	*Actual*	9
				Target	3
		R17	*Number of visits to overseas laboratories and facilities*	*Actual*	33
				Target	20
		R18	*Examples of relevant interdisciplinary research supported by the Centre*	*Actual*	100%
				Target	>50%

RESEARCH

Build end-user links

Code	Indicator		Value
R19	*Number of government, industry & business community briefings*	*Actual*	10
		Target	6
R20	*Number and nature of public awareness programs*	*Actual*	6
		Target	5
R21	*Currency of information on the Centre's website*	*Actual*	12
		Target	4
R22	*Number of website sessions*	*Actual*	13,671
		Target	10,000
R23	*Number of public talks given by centre staff*	*Actual*	12
		Target	6

ORG SUPPORT

Generate cash & in-kind contributions from partners & other sources & build collab. & infrastructure support

Code	Indicator		Value
O1	*Annual new and existing cash contributions from collaborating organisations*	*Actual*	4,872,284
		Target	1,790,000
O2	*Annual in-kind contributions from collaborating organisations*	*Actual*	12,877,059
		Target	12,418,100
O3	*Annual cash contributions from partner organisations*	*Actual*	185,000
		Target	150,000
O4	*Annual in-kind contributions from partner organisations*	*Actual*	1,920,567
		Target	1,229,300
O5	*Other research income secured by Centre staff*	*Actual*	10,974,538
		Target	140,000
O6	*Number of new organisations collaborating with, or involved in, the Centre*	*Actual*	11
		Target	6
O7	*Level and quality of infrastructure provided to the Centre*	Documented *pp. 82-90*	

GOVERNANCE

Intersect the right set of expertise to guide the Centre

G1	*Breadth, balance and experience of the members of the Advisory Board*	The Advisory Board includes senior representatives from industry and other end users such as Geoscience Australia (documented *p. 9*), and was endorsed by the Mid-term Review Panel.
G2	*Frequency, attendance and value added by Advisory Committee meetings*	A very productive Advisory Board meeting was held in November 2018. Attendance at the meeting was over 87.5%. Input from the board has been invaluable, providing a different perspective on Centre activities. The CCFS board has been very engaged in workshopping key aspects of Centre business, in realigning the CCFS Vision and planning for the Centre's post-funding future and Legacy.
G3	*Vision and usefulness of the Centre strategic plan*	Strategic plan was reviewed mid 2014 and endorsed by the CCFS Board and executive.
G4	*Adequacy of the Centre's performance measure targets*	Centre's performance measure targets are discussed with the board annually. CCFS has consistently performed well against the current measures. As a result of feedback and reassessment post review, they continue to be revised on a regular basis.
G5	*Effectiveness of the Centre in bringing researchers together to form an interactive and effective research team*	Jointly authored presentations and publications as well as co-supervised postgraduates (see *Appendix 5 and pp. 75-81*)
G6	*Capacity building of the Centre through scale and outcomes*	Recruitment of staff: 5 (see *pp. 11-13*) Recruitment of postgraduate students: 22 (see *pp. 75-81*) International Linkages: 39 visitors (see *pp. 98-103*)

BENEFIT	Contribute to the national research agenda; expand the national capability in Earth Science	*N1*	*Industry Seminars*	*Actual*	4
				Target	4
			Number of industry / end-user collaborations		18
		N2	*Postgraduate units established by end year 3*	*Actual*	6
				Target	2
			Number of honours and Postgraduate students		110

CCFS KPI	Outcomes	*C1*	*Linkage of geochemical / petrologic / geological data with geophysical datasets / modelling* *2014 - Convene international conference on integration of geophysics / geology*	*Actual*	Complete
				Target	Complete
		C2	*Technology & method development related to NCRIS infrastructure* *2013 -1st results submitted for publication / conference presentation*	*Actual*	Complete
				Target	Complete
	Training	*C3*	*Establishment of formal postgraduate units & training within host and collaborating university frameworks*	*Actual*	Complete
				Target	Complete
	End-user	*C4*	*Establishment of linkages and collaborative projects with end-users relevant to external core business of the Centre* *2013 - proceed with projects*	*Actual*	Complete
				Target	Complete

Appendix 10: 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:

- **Research Training Program (RTP) -** available to both domestic and international students from 2017 (https://www.education.gov.au/research-training-program). The scheme is administered by individual universities on behalf of the Department of Education and Training. Applications for a RTP Scholarships can be made directly to participating universities.
  Each university has its own application and selection process:

  MQ - http://www.mq.edu.au/research/phd-and-research-degrees/scholarships/hdr-main-scholarship-rounds

  Curtin - http://research.curtin.edu.au/postgraduate/rtp-scholarship-policy/

  UWA - http://www.scholarships.uwa.edu.au/
- **China Scholarship Council - Postgraduate Study Abroad Program** is a national scholarship program financing outstanding Chinese students (Chinese citizens) to study at top universities around the world. Curtin, Macquarie and UWA are partner universities in this program (http://www.csc.edu.cn/).

CCFS also provides research funding through competitive internal schemes; 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, Greenland and other locations globally (see the map on *p. 21* 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
- Paleomagnetism and supercontinent reconstruction
- Geodynamic modelling
- 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 enquiries can be sent to: ccfs.admin@mq.edu.au; or 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
(RSES) ANU	(Research School of Earth Sciences) Australian National University
ANSTO	Australian Nuclear Science and Technology Organisation
APA	Australian Postgraduate Award
ARC	Australian Research Council
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
COPA	Capricorn Orogen Passive-source Array
CSIRO	Commonwealth Scientific Industrial Research Organisation
CU	Curtin University
CWAS	China-Western Australia Seismic Survey
DECRA	Discovery Early Career Researcher Award
DEST	Department of Education, Science and Training
DP	Discovery Project
EBSD	Electron Backscatter Diffraction
ECR	Early Career Researcher
EPS	Earth and Planetary Sciences (Department, Macquarie University)
EMP	Electron Microprobe
FIM	Facility for Integrated Microanalysis
FSE	Faculty of Science and Engineering (MQ)
FTIR	Fourier Transfer Infrared Spectroscopy
GAC-MAC	Geological Association of Canada-Mineralogical Association of Canada
GAU	Geochemical Analysis Unit (EPS, Macquarie University)
GEMOC	Geochemical Evolution and Metallogeny of Continents
GET	Géosciences Environnement Toulouse, France
GEUS	Geological Survey of Denmark and Greenland
GIS	Geographic Information System
GLAM	Global Lithospheric Architecture Mapping
GLITTER	GEMOC Laser ICPMS Total Trace Element Reduction software
GSWA	Geological Survey of Western Australia
ICPMS	Inductively Coupled Plasma Mass Spectrometer
(C)IPRS	(Curtin) International Postgraduate Research Scholarship
KIT	Karlsruhe Institute of Technology, Germany
LAM-ICPMS	Laser Ablation Microprobe - ICPMS
LIEF	Linkage Infrastructure, Equipment and Facilities
ING PAN	Institute of Geological Sciences, Polish Academy of Sciences
MC-ICPMS	Multi-Collector - ICPMS
MQGA	Macquarie University GeoAnalytical (formerly GAU)
MRIWA	Minerals Research Institute of Western Australia
(i)MQRES	(International) Macquarie University Research Excellence Scholarships
MOU	Memoranda of Understanding
NASA	National Aeronautics and Space Administration
NCRIS	National Collaborative Research Infrastructure Scheme
PGE	Platinum Group Element
RAAP	NSW Research Attraction and Acceleration Program
RTPS	Research Training Program Stipend (formerly APA)
SAC	Science Advisory Committee
SEM	Scanning Electron Microscope
SIEF	Science & Industry Endowment Fund
SIRF	UWA Scholarship for International Research Fees
TIGeR	The Institute for Geoscience Research
UM	University of Melbourne
UNSW	University of New South Wales
UWA	University of Western Australia

Australian Government
Australian Research Council

MACQUARIE University

Curtin University

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GEOLOGICAL SURVEY WESTERN AUSTRALIA

ARC Centre of Excellence for Core to Crust Fluid Systems

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