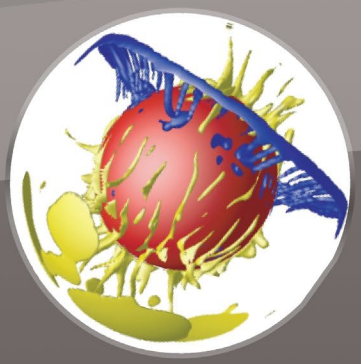
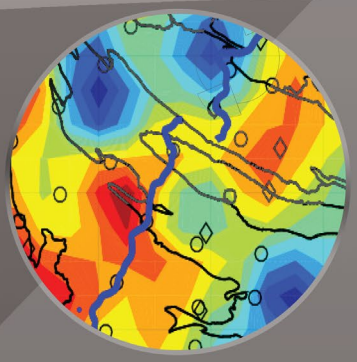
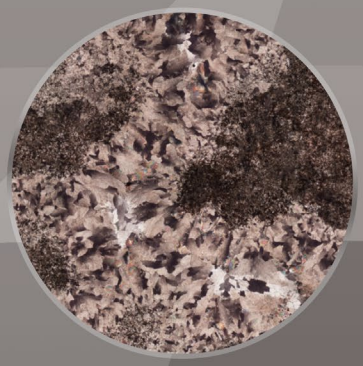
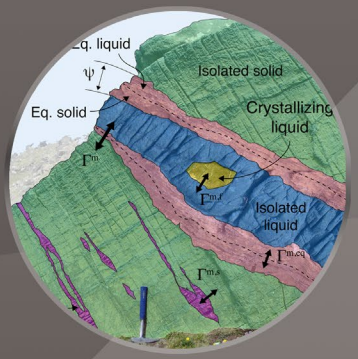
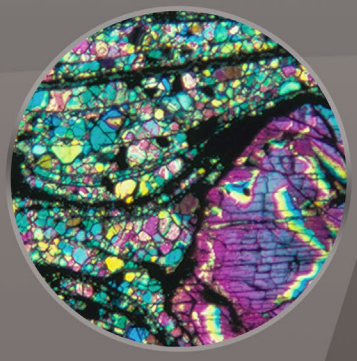
2019
Annual Report

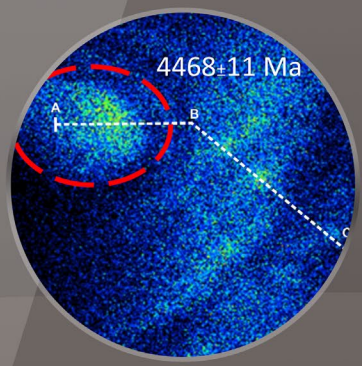


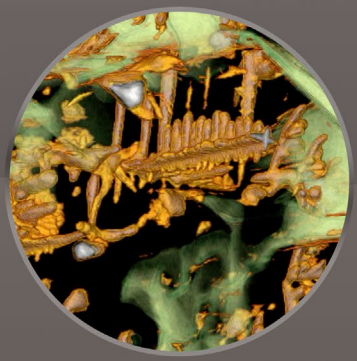












CCFS

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.

Front Cover: The cover depicts the CCFS impression of the 'downward-looking telescope' recommended as a priority for Geoscience research in the next decade, in the Australian Academy of Science Decadal Plan for Australian Geoscience (https://www.science.org.au/supporting-science/science-policy-and-sector-analysis/decadal-plans-science/australian-geoscience). This virtual telescope could look at least 300 km beneath Earth's surface to unlock Australia's hidden mineral wealth. This concept emerged from the CCFS vision of "Delivering the fundamental science needed to sustain Australia's resource base", by making deep Australia visible and delivering a transformative framework for the discovery of new critical mineral deposits to enable a sustainable future for Australia.

Continuing achievements of CCFS are given under "Flagship Programs," p. 29, and the cumulative Research Highlights compilation at http://ccfs.mq.edu.au/Research%20Highlights/

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 2019 (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: GEMOC from Macquarie University (Administering Institution), Curtin University (TiGeR) and CET at the University of Western Australia (Collaborating Institutions). The Geological Survey of Western Australia is a Partner Institution and researchers from Monash University, the University of Melbourne and the University of New South Wales are formally affiliated.

The 7-year allocated Centre funding from the ARC ceased at the end of 2018, but ARC formally granted continuation of the status of CCFS as an ARC Centre of Excellence for three years, contingent on demonstration of a relevant, funded continuing research program and retention of key researchers. As highlighted in the 2018 CCFS Report, eight of the Future Fellows awarded in CCFS transitioned to continuing academic positions and the two Laureate Fellowships (awarded 2015 and 2018) across two nodes of CCFS have increased our critical research mass within areas fundamental to understanding "*Core to Crust Fluid System*". These prestigious Fellowships with generous grants thus help to underpin funding, expertise and research personnel resources to continue the frontline research characteristic of CCFS aimed at better defining Earth's 4D evolution and its composition and architecture today - the Earth framework that enables our civilisation to inhabit this amazing planet.

How has CCFS made a difference?
Selected examples are listed below:

Pioneering Integrative approach to understanding Earth across deep time and space (4D)

The conceptual framework of integrating geochemical, geophysical, geological, tectonic and geodynamic datasets in a GPS environment has revolutionised our holistic understanding of the inaccessible deep Earth, leading to the predictive modelling of the location of large economic deposits and enhanced understanding of how the Earth works and has evolved. CCFS advances in these geoscience disciplines seamlessly incorporate Bayesian mathematical approaches and innovative imaging techniques to probe planetary, global terrain and nanoscales advancing geoscience capabilities.

Outstanding Fundamental Research

Clarivate/Thomson Reuters have recognised CCFS' frontline research through citation, innovation and highly cited awards to CCFS researchers, in addition to the Google Australian Researcher of the Year award, and recognition of a CCFS Chief Investigator as one of the "*World's Most Influential Minds*" across several years. Numerous awards of "*annual best paper*" in prestigious journals, a constant flow of keynote presentations and awards of best posters and talks at peak and influential conferences and international workshops, by senior, early-career and postgraduate CCFS researchers, all provide evidence of peer recognition internationally.

Frontline advances in geophysics include: development of ambient-noise adjoint-tomography; LitMod's 3D multi-observable probabilistic inversion for the compositional and thermal structure of the lithosphere and upper mantle; new inversion techniques to understand earthquake generation in Western Australia; revolutionary multiphase multicomponent reactive transport modelling of disequilibrium melt-rock processes and geochemical geodynamics. All of these seminal contributions embed geochemical, tectonic, geological and/or advanced imaging and modelling components, emphasising integration across diverse datasets and methodologies.

One example (among many in CCFS) of research that could not have been achieved without the funding, scale and focus of a Centre of Excellence is the "*Tibet Project*" that involves all nodes, more than 30 CCFS researchers from Chief Investigators to PhD students and international collaborators, and three Flagship Programs, and has generated four IGCP (International Geological Correlation Project) Programs. Outcomes so far include breakthroughs in understanding in detail: the tectonic history of the Himalayas from palaeomagnetic evidence; the sources and mechanisms for mineralisation (e.g. copper, gold, chromite and critical minerals) in different collision zone scenarios, not only in Tibet but along the entire Tethyan Belt and analogue tectonic environments; identifying domains of highly-reduced mantle environments; demonstrating that some collision zone domains are excavated from Earth's transition zone 450 km beneath the surface, and recognising the analogue relevance for mineral exploration in the Australian Tasmanides.

International Collaborations

Global alliances with leading international geoscience groups have been forged through formal collaborative partnerships, programs and exchanges across multiple institutions (including China, Spain, France, Canada, Norway, Germany, South Africa, Taiwan, India, USA). These collaborations leverage the Centre funding, expertise and researcher resources and commonly include cotutelle PhD programs which provide the basis for a new generation of productive global research alliances. At the 2019 Goldschmidt Conference in Barcelona, a reunion of CCFS affiliates demonstrated the amazing diaspora of our postgraduates, early-career researchers and continuing senior alliances representing more than 10 countries.

Training a new generation

CCFS has so far graduated 102 PhD students and 47 early-career researchers have participated in CCFS. 57 PhD students undertook research aligned with CCFS in 2019. CCFS postgraduates are producing world-class research with authorship of 41 publications (27 first-authored) in high-impact journals in 2019 and 39 presentations at peak international workshops and conferences.

This cohort forms the future generation of frontline researchers and professionals with comprehensive experience in solving difficult problems with tantalisingly incomplete datasets, into a world future with increasingly complex problems requiring clever integrative approaches.

Technology Development and New Directions

The Technology Development section of this Report documents the ongoing frontline developments related to *in situ* geochemical analysis and imaging technologies using the outstanding array of advanced instrumentation accessible across CCFS nodes. Of increasing value is the co-registration of data across all types of datasets so that overlays of multiple datasets provide new insights into the distribution of specific elements and chemical domains in the Earth and relationships to the physical properties detected in seismic, magnetotelluric, gravity and magnetic surveys.

A step-change in the impact of geochemical data presentation has been a major achievement (e.g. *CCFS Publications #456, 530, 862, 942, 1046*). Where datasets are sufficiently comprehensive, elemental and isotopic data can be presented as contoured images on regional scales. This transformation in the presentation of geochemical data (traditionally presented as multi-element diagrams and plots) is as user-friendly and as accessible as geophysical tomography images, and has led to the national goal of geochemical mapping of Australia's lithosphere recommended in the Australian Academy of Science Geoscience Decadal Plan. AuScope (and NCRIS Capability) is coordinating a national program to achieve this visionary world-first national resource, part of the downward-looking telescope imaged on the cover of this Report (https://www.auscope.org.au/ece).

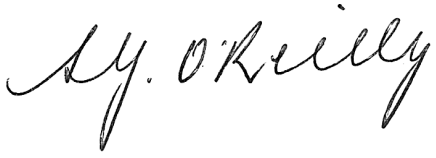
Igniting a renaissance in Australian experimental geoscience: CCFS has been an incubator driving new directions. As an example, the Laureate Fellowship of Prof Stephen Foley has enabled a framework for leading-edge experimental simulations of high-pressure and temperature conditions at varying depths within the Earth, building on the distributed national experimental infrastructure network established previously with funding from the ARC LIEF scheme and new instrumentation and associated laboratories at Macquarie.

Industry and end-user engagement

Industry interaction has been an integral component of CCFS. Collaborative projects with industry input (including guidance from CCFS Board members) has shaped the relevance of the fundamental research directions, and enabled continuation of relevant CCFS activities. These include the ongoing work in CET (UWA) in training courses and in research responses relevant to industry needs. Geophysical research has attracted significant industry and end-user collaborations. One example is the large-scale fully funded collaboration with IGG CAS to undertake a 900-km-long dense (station spacing of 10-15 km) seismic profile across Western Australia from Port Hedland to the southwestern border of Kimberly Craton, using 60 broadband seismic stations from IGG CAS, and 20 from ANSIR. Other funded examples (detailed in the *Industry interaction* section) include: the multi-institution ESA-funded project "*3D Earth*" with researchers from the two centres of excellence, CCFS (Australia) and CEED (Norway), creating a world reference lithospheric model and a high-resolution thermochemical model of the North Atlantic region; a de Beers-resourced "*Multiobservable Thermochemical Tomography of Central and South Africa*"; "*Developing thermochemical models of Australia's lithosphere*" with Geoscience Australia; and a Linkage Project "*Illuminating AusLAMP*", targeted at joint interpretation of magnetotelluric and seismic datasets.

Shaping International and National Science policy

CCFS researchers are now sought as thought-leaders globally for research related to Earth's lithosphere and the integrated use of large datasets across geochemistry, geology and geophysics. CCFS researchers nationally provide advice to local, state and federal departments and members of parliaments, and through Australian Academy formal reports and reviews to the Chief Scientist and the Australian government on a wide range of geoscience-related issues. CCFS has indeed fulfilled its Vision of "*Delivering the fundamental science needed to sustain Australia's resource base*" and its new generation of researchers are a vital part of the CCFS legacy and continuation.



Professor S.Y. O'Reilly

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 integrates information across geology, tectonics, experimental and analytical geochemistry, petrophysics, geophysics, and petrophysical and dynamical modelling. These disciplines have traditionally represented '*research silos*', but CCFS has brought them together to provide a significant increase in our national research capability.

CENTRE RESEARCH

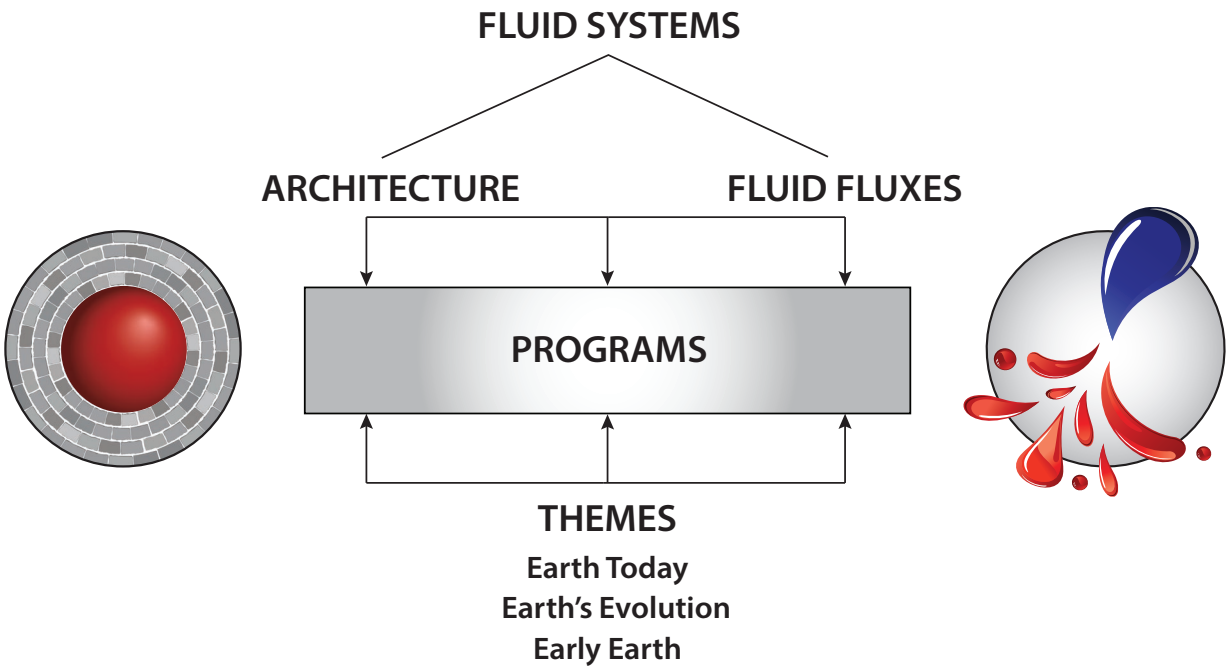
Research programs within the Centre are focused to provide maximum synergy for the scope enabled by the resource base. As it is not possible to encompass the full range of research about the Earth's fluid cycle and deep Earth dynamics, all applied and mature strategic research is carried out in parallel, 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. 14*) 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"*.

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 and Programs are 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 allows us to test the involvement of biological processes in ancient deposits.

The earliest record of Earth's magnetic field provides new information on when the core's geodynamo formed and the geometry and intensity of its field and is used to track the movement of Archean tectonic plates. The geochemical nature and dynamic behaviour of the mantle in the early Earth continues to 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 define the rates of continental growth *vs* recycling through time and test linkages between crust and mantle events. Geophysical imaging and dynamic modelling have been used to build 3D models of subduction dynamics, thermal evolution and geodynamic cycles. Stable-isotope studies track water and other fluids in their cycles through the Earth and the hydrosphere.

THEME 3: EARTH TODAY

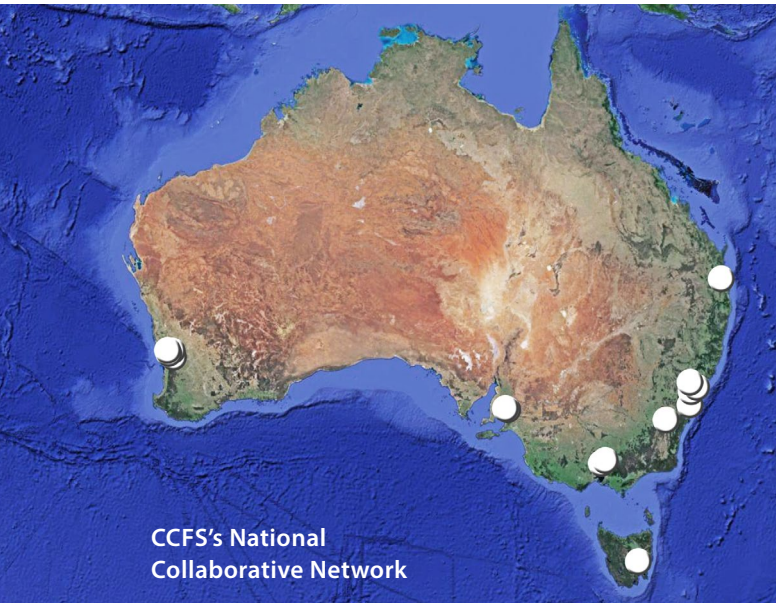
Earth Today - Dynamics, decoding geophysical imaging, and Earth resources. Geophysical imagery gives us a snapshot of the current status of the deep Earth but also carries the imprints of past processes. Realistic interpretation of these data provide us with new insights into Earth's internal dynamics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

Measurements of the physical properties of potential deep Earth materials at extreme conditions 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 provides new ways to interpret observations on fluid/melt inclusions in minerals. CCFS is investigating 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.

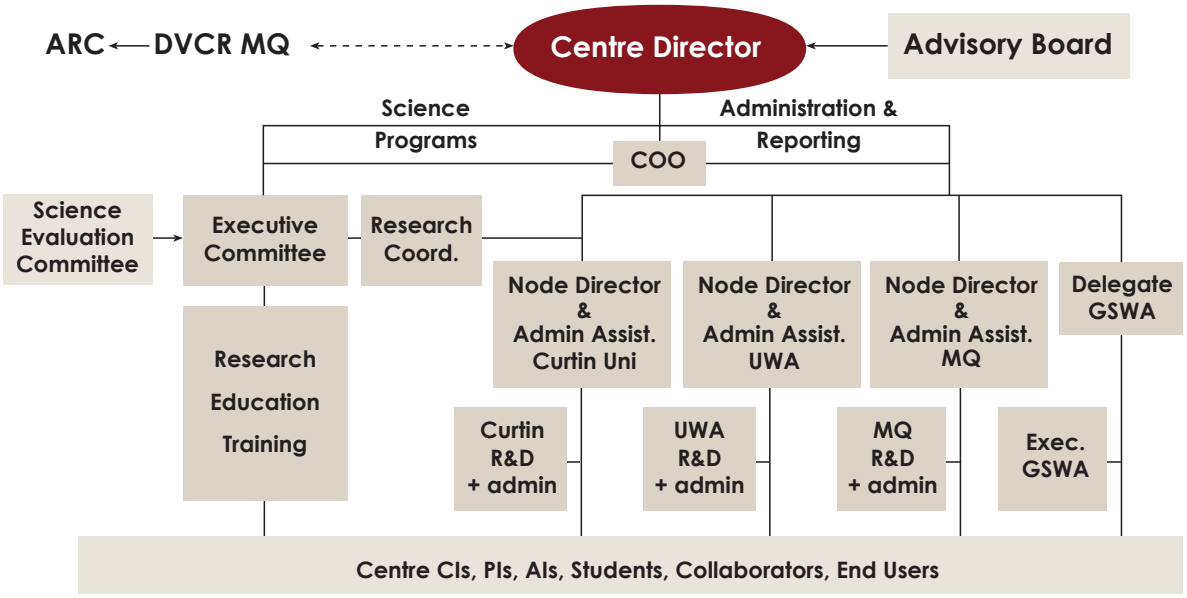
Reading background seismic noise at Lake Dora, Punmu Community, Canning Stock Route. (L-R) Ruth Murdie, Lucy Brisbout (GSWA) and Tingzi Li (IGG-CAS) (photo Huaiyu Yuan)

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. 64*). 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*).



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.

During the ARC funding period, the Advisory Board's external membership comprised senior representatives from industry and other end-users such as Geoscience Australia. This model had proven highly productive during the lifetimes of the GEMOC Key Centre and CET. The Board met at least annually to provide advice on the research program and governance, and any other matters relevant to CCFS.

The Science Advisory Committee had a rotating membership and provided valuable evaluations of 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

Associate Professor 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

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 2* 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

Professor Juan Carlos Afonso - MQ

Dr Olivier Alard - MQ

Associate Professor Nathan Daczko - MQ

Dr Richard Glen - MQ

Dr Masahiko Honda - Australian National University

Professor Dorrit Jacob - MQ

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

Associate Professor Christopher Kirkland - CU

Professor Jochen Kolb - GEUS

Dr Yongjun Lu - GSWA

Professor Louis-Noel Moresi - University of Melbourne

Professor Steven Reddy - CU

Dr Svyatoslav Shcheka - MQ

Associate Professor Bruce Schaefer - MQ

Dr Michael Wingate - GSWA

Professor Shijie Zhong - University of Colorado, USA

Early Career Researchers

Dr Raphael Baumgartner - UWA

Dr Montgarri Castillo-Oliver - MQ

Dr Chunfei Chen - MQ

Dr Denis Fougerouse - CU

Dr Michael Förster - MQ

Dr Hadrien Henry - MQ

Dr Johannes Hammerli - UWA

Dr Uwe Kirscher - CU

Dr Hugo Olierook - CU

Dr Beñat Oliveira Bravo - MQ

Dr Romain Tilhac - MQ

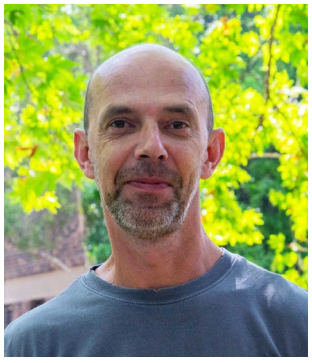
Dr Lei Wu - CU

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. Eleven Future Fellows; Associate Professor Elena Belousova, Associate Professor Marco Fiorentini, Associate Professor Heather Handley, Professor Dorrit Jacob, Associate Professor Craig O'Neill, Professor Sandra Piazolo, Associate Professor Yingjie Yang, Dr Xuan-Ce Wang, Dr David Wacey, Dr Olivier Alard and Dr Kate Selway, 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. Their profiles can be accessed from the "*Participants*" section of our previous reports (http://www.ccfs.mq.edu.au/AnnualReport/Index.html).

Those of this outstanding cohort who have completed their Fellowship, have now transitioned to permanent high-level positions and become international research leaders in roles 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.

NEW STAFF



Dr Svyatoslav Shcheka completed his MSc in Geochemistry at the Moscow State University, Russia, before moving to Far East Geological Institute in 1992, where he experimentally studied the petrology of Pt-bearing ultramafic intrusions of Russian Siberia and Far East. He started his PhD project on carbon solubility in major mantle minerals at University of Tuebingen in 2001 and completed it in 2006. In late 2005 he moved to the Bavarian Research Institute of Experimental Geochemistry and Geophysics (BGI) at the University of Bayreuth, a partner institute of CCFS, where he mainly focused on experimental study of volatile elements in the Earth's interior at high pressure and temperature until 2019.

In October 2019 Svyatoslav joined Macquarie University as a high pressure experimental scientist where he is setting up the new experimental laboratory, contributing to CCFS Flagship Program 3.

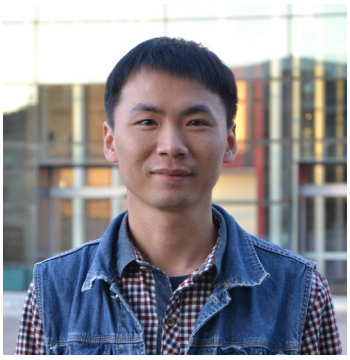
EARLY CAREER RESEARCHERS (ECR)

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 2019 ECRs and summarise their expertise and research areas.

NEW 2019



Dr Chunfei Chen completed his PhD in Earth Sciences at China University of Geosciences, Wuhan in December 2018, in which he studied the mantle recycling of limestone. During his PhD he visited Macquarie University and joined the CCFS research group where he used high-pressure experiments to reveal the melting behaviour of limestone in subduction zones and mantle wedges. Since mid-2018, he has also focused on studying high temperature Ca isotope geochemistry, especially for tracing carbonatite activity and recycled carbon in the mantle. In May 2019, Chunfei returned to Macquarie University as a Postdoctoral Research Fellow. Now he is engaged in the study of the physical and chemical behaviour of carbon in subduction zones and its role in driving mantle evolution.

Dr Michael Förster studied geology at the Johannes Gutenberg University Mainz and joined CCFS at Macquarie University in 2016 as a PhD student in Prof Stephen Foley's experimental petrology group. In 2019 he completed his PhD with the thesis entitled "*Subduction Zone Metasomatism and its Consequences for Potassium-rich Magmatism and Deep Nitrogen Cycling*", where he investigated the geochemical behaviour of nitrogen and potassium in magma and mantle rocks. As a postdoctoral researcher, he is examining the fate of nitrogen

during subduction and recycling to Earth's mantle. The various reactions of nitrogen, forming reduced and oxidised species, are known as the nitrogen cycle. Nitrogen is also part of high-pressure fluids, and atmospheric nitrogen is continuously fixed and deposited in marine sediments which are recycled to Earth's mantle in subduction zones. This recycling process is thought to be associated with potassium-bearing silicates, where micas play an integral role, for example through the substitution of ammonium for potassium in phlogopite. Using an experimental geological approach Michael is investigating the partitioning of nitrogen between minerals and fluids as well as minerals and melts by performing high-pressure piston cylinder-, belt-, and multi-anvil experiments on synthetic and natural mineral and rock samples. The experimental run products are analysed using electron the microprobe (EPMA) and secondary ion mass spectrometry (SIMS). His research contributes to CCFS Flagship Program 3.

CONTINUING

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 focused on the 3.5 Ga old stromatolites at North Pole Dome, Dresser Formation, Pilbara (WA) and their link to hydrothermal fluids.

Raphael examined whether such fluids 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. He also examined the micron- to nano-scale textural 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.

In 2018 Raphael took up a postdoctoral position at UNSW to continue his work with Martin Van Kranendonk's group. Raphael's research contributes to CCFS Flagship Program 4.

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. During her PhD, Montgarri characterised several Angolan kimberlites of the Las Lundas province, as well as their diamond indicator minerals (predominantly ilmenite and garnet). She also studied mantle xenoliths to better understand the structure and metasomatic evolution of the subcontinental lithospheric mantle in NE Angola. In 2016, she graduated with a PhD from both universities.

Since then, Montgarri has been employed as a Research Associate by CCFS at Macquarie University. Her postdoctoral research is based on the use of *in situ* techniques ((MC)-LA-ICPMS and SIMS) to characterise primary and secondary carbonates in kimberlites worldwide, combining textural information with *in situ* compositional and isotopic (C, O and Sr) analysis. This integrated approach provides new insights into the isotopic composition of the parental kimberlite melt, and thus that of the Earth's mantle. It also allows discrimination between the different processes that led to carbonate formation in kimberlites (i.e. magmatic and deuteric crystallisation, degassing, weathering etc.). By studying the C isotope variation of the deep mantle with space and time, Montgarri aims to contribute to the current understanding of the deep Earth's carbon cycle in cratonic roots. 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.

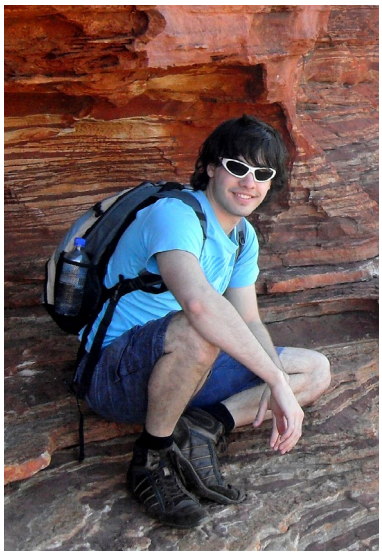
Dr Hadrien Henry is a Research Associate at CCFS, Macquarie University. He completed his BSc and MSc at the Université Paul Sabatier Toulouse III. In 2015, he commenced a cotutelle PhD degree between Macquarie University and Université Paul Sabatier, Toulouse III. Hadrien's thesis focused on the microstructure and petrophysics of pyroxenites and mantle using samples from the Cabo Ortegal Complex, Spain and the Trinity ophiolite, California, USA. In 2018, he graduated from Université Paul Sabatier Toulouse III and Macquarie University in early 2019. As a Research Associate in CCFS at Macquarie University, Hadrien works on the microstructure of olivine megacrysts from the Åheim peridotite body in western Norway and takes part in multiple collaborations involving Electron BackScattered Diffraction (EBSD) and the study of microstructures. Hadrien is also part of the *TerraneChron®* team at CCFS. This research contributes to CCFS Flagship Program 1.

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 used the microanalysis of accessory minerals, in particular apatite from magmatic systems, to unravel processes which lead to the fertile systems feeding ore deposits.

In mid-2019, Johannes returned to the University of Bern, where he commenced an Ambizione fellowship. His research contributes to CCFS Flagship Program 2.

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.

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 used his expertise in geochronology, geochemistry, tectonics and geodynamics to understand the 3 billion year history of the Capricorn Orogen and its mineral endowment. In 2019 Hugo continued at Curtin University as the manager of geochronology and geochemistry projects for the mining and mineral exploration industry, liaising with geological surveys around the globe.



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 multi-phase 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. This research contributes to CCFS Flagship Program 3.

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 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 November 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.

In November 2019 Romain took up a short-term postdoctoral position (until April 2020) at Kanazawa University with a Japan Society for the Promotion of Science (JSPS) Fellowship. In May 2020 he will commence a postdoctoral position at the Instituto Andaluz de Ciencias de la Tierra (IACT), Granada / Consejo Superior de Investigaciones Científicas (CSIC) with a Juan de la Cierva Fellowship.

Dr Lei Wu received his PhD in 2017 from the University of Alberta, Canada where he reconstructed the amalgamation history of East Asia using paleomagnetic and seismological data. After his PhD, Dr Wu conducted a nine-month postdoc applying the shear wave splitting and receiver functions methods to determine the upper lithospheric mantle / crustal anisotropy in the Western Canada Sedimentary Basin. In 2018, Dr Wu commenced a two-year postdoc position with CCFS at Curtin University, working with Zheng-Xiang Li to build a new global full-plate paleogeographic model. His research interests involve geophysics, paleogeographic reconstruction, seismology and paleomagnetism. This research contributes to CCFS Flagship Program 5.

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. 14*) 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 targeted the research goals through to 2019, providing a new focus and realigned strategies to deliver vital new knowledge about Australia's geological evolution to guide smart new mineral exploration. They have provided the basis for continuing mature research strands underpinned by two Technology Development Programs designed to deliver more leading-edge geochemical breakthroughs, capitalising on the outstanding geochemical instrumental infrastructure across CCFS.

Projects are detailed in *Flagship Programs.*

Independently funded basic research projects are listed in *Appendix 1.*

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**, Kilburn, Martin, Alard, Huang, Giuliani, Gréau, Castillo-Oliver, Lu, Tilhac, Henry (ECRs) Takenaka de Oliveira, Greene (PhDs)
2. Genesis, transfer and focus of fluids and metals Themes 2 and 3 Fluid Fluxes	**Fiorentini**, Foley, O'Reilly, Griffin, Reddy, Lu, Bagas, Kilburn, Loucks Fougerouse, Gonzalez, Hammerli, LaFlamme, Parra-Avila (ECRs) Bennett, Dering, Jara, Poole (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, O'Reilly, Griffin, Shcheka Jiang, Oliveira Bravo, Förster, Chen (ECRs) Lanati, Manassero, Pinter, Wasilev, Wang, Wu, Zhang (PhDs)
4. Atmospheric, environmental and biological evolution Theme 1 Earth's Architecture and Fluid Fluxes	**Van Kranendonk**, Fiorentini, Foley, Kirkland, Kilburn, Alard, LaFlamme, Baumgartner (ECRs) Barlow, Caruso, Djokic, Nomchong, Soares, Teece (PhDs)
5. Australia's Proterozoic record in a global context Themes 2 and 3 Earth's Architecture	**Li**, Pisarevsky, Wang, Wingate, O'Reilly, Griffin, Belousova, McCuaig, Mitchell, Kirscher, Yao (ECRs) 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, Martin, O'Neill 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 Wu (ECR) Dering (PhD)

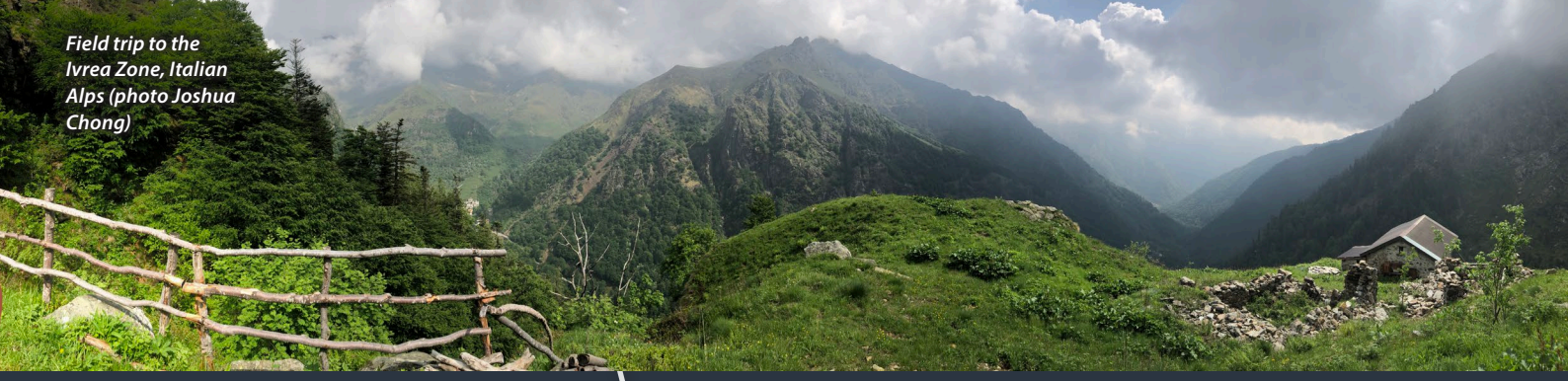
TECHNOLOGY DEVELOPMENT

Cameca Ion microprobe development Themes 1, 2 and 3 Earth's Architecture and Fluid Fluxes	**Kilburn**, Martin, Fiorentini, 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	**Alard**, Griffin, O'Reilly, Gréau, Kilburn, Martin, Huang Henry (ECR)

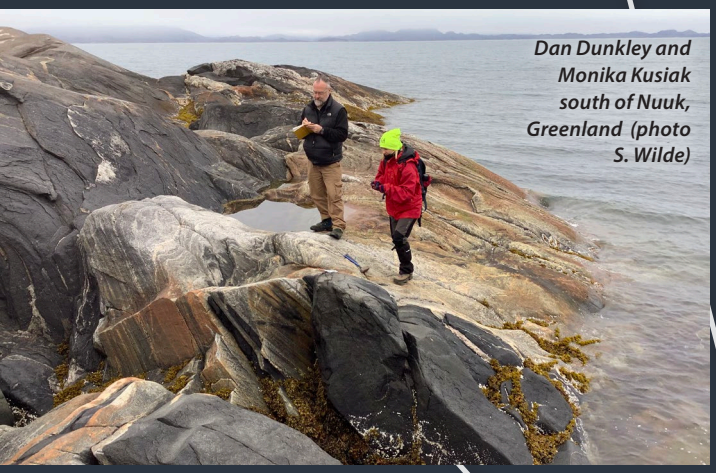
Where out of this world is CCFS?

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.

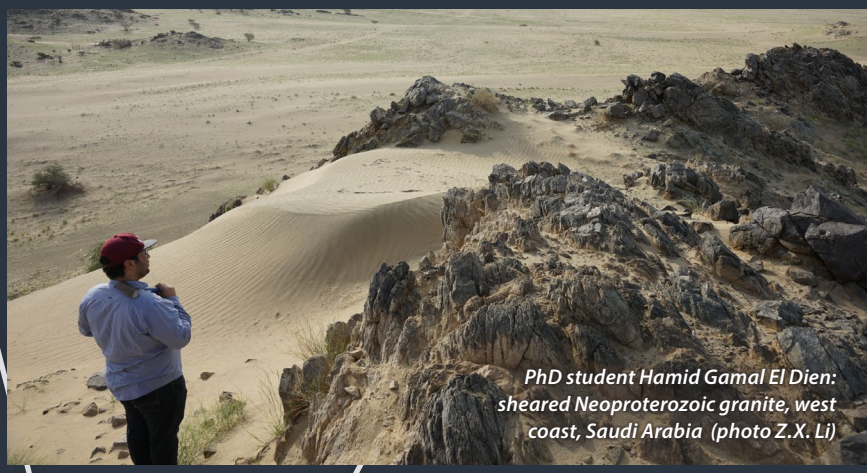
Moon Mars Venus



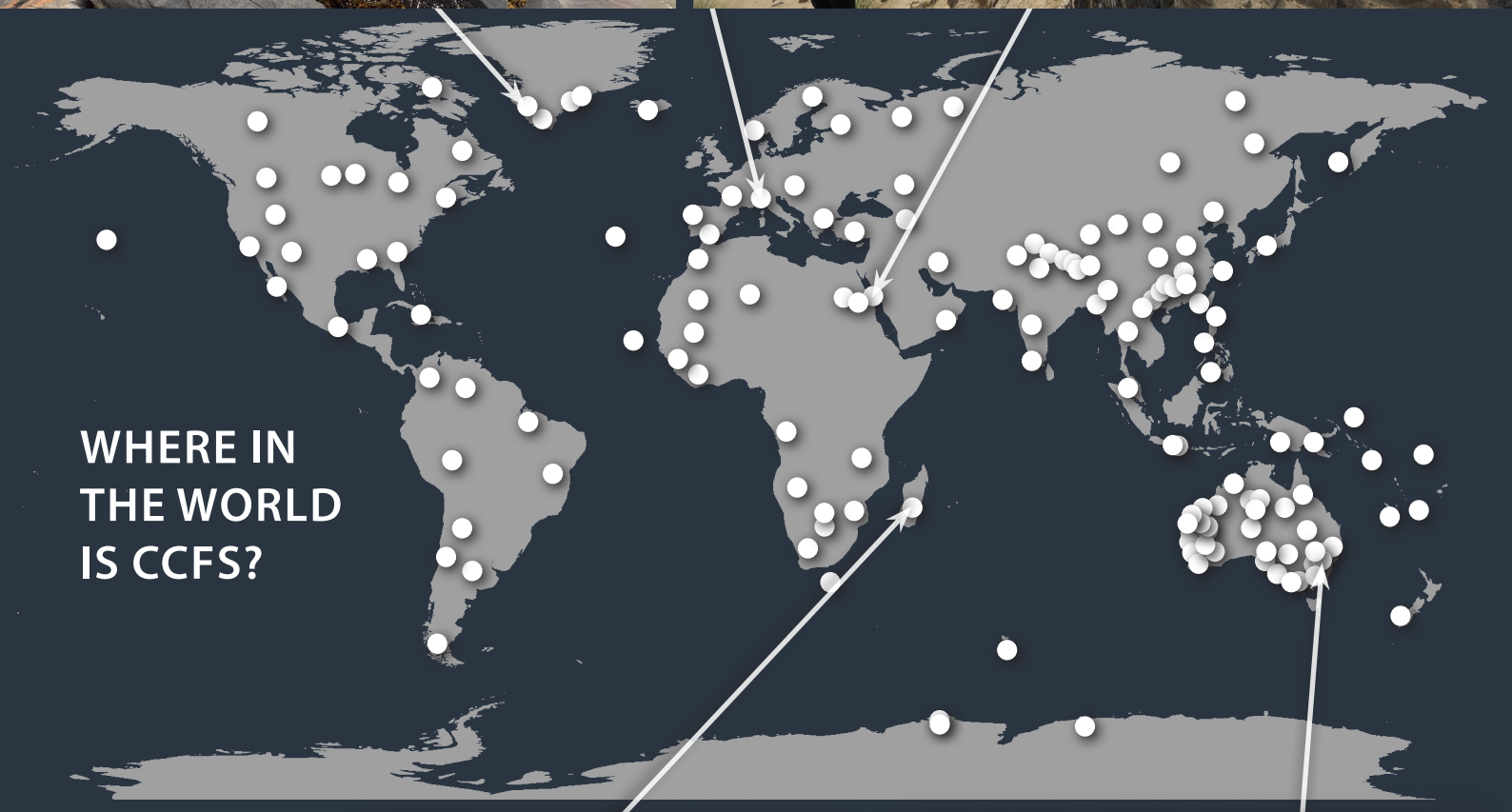
Field trip to the Ivrea Zone, Italian Alps (photo Joshua Chong)



Dan Dunkley and Monika Kusiak south of Nuuk, Greenland (photo S. Wilde)



PhD student Hamid Gamal El Dien: sheared Neoproterozoic granite, west coast, Saudi Arabia (photo Z.X. Li)



WHERE IN THE WORLD IS CCFS?

IGCP 648 field symposium, Madagascar (photo Z.X. Li)

Luc Doucet working on Cambrian ophiolite along the foreshore of Port Macquarie, NSW (photo Z.X. Li)

Communications 2019

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 2019 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 2019 are given in Appendix 3.

The 155 CCFS publications that were published in 2019 are predominantly 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 has a LinkedIn Group - Join the conversation at http://www.linkedin.com/groups/6969996

PARTICIPATION IN WORKSHOPS, CONFERENCES AND INTERNATIONAL MEETINGS IN 2019

CCFS Investigators, associated staff, early-career researchers and postgraduates had a high profile at 24 peak geophysical, metallogenic, geodynamic and geochemical conferences as convenors, invited speakers, or presenters, with 138 presentations including:

- Melt Evolution in Space and Time Symposium, Melbourne, Australia, 14-15 February 2019
- EGU General Assembly 2019, Vienna, Austria, 7-12 April 2019
- GACMAC 2019, Quebec, Canada, 11-13 May 2019
- Japan Geoscience Union Meeting 2019, Chiba, Japan, 26-30 May 2019
- ABSCICON, Seattle, USA, 24-28 June 2019
- DRT: 22nd Deformation Mechanisms, Rheology and Tectonics Meeting "*From Microtectonics To Plate Tectonics*", Tubingen, Germany, 11-14 June 2019
- 2nd IGCP 662 Workshop and Field Excursion, Ulaanbaatar, Mongolia, 5-8 July 2019
- XIII International Symposium on Antarctic Earth Sciences, Incheon, Republic of Korea, 22-26 July 2019
- AOGS 16th Annual Meeting, Singapore, 28 July - 2 August 2019
- Goldschmidt 2019, Barcelona, Spain, 18-23 August 2019

Some of the large contingent of CCFS participants who attended Goldschmidt 2019 in Barcelona.

- 2019 Ada Lovelace Workshop on Modelling Mantle and Lithosphere Dynamics, Siena, Italy, 25-30 August 2019
- 15th Biennial Meeting SGA 2019, Glasgow, Scotland, 27-30 August 2019
- The Second Australasian Exploration Geoscience Conference (AEGC), Perth, Australia, 2-5 September 2019
- 7th International Large Igneous Provinces Conference 2019, Tomsk, Russia, 28 August - 8 September 2019
- SIMP, SGI, SOGEI Joint Conference, Parma, Italy, 16-19 September 2019
- Selwyn Symposium 2019, GSA Victoria Division: The Co-Evolution of Life and Precambrian Environments, Melbourne, Australia, 30 September 2019
- SEG 2019 South American Metallogeny: Sierra to Craton, Santiago, Chile, 7-10 October 2019
- International Symposium on Deep Earth Exploration and Practices, Beijing, China, 24-26 October 2019
- GESSS NSW 2019, UNSW, Sydney, 31 October- 1 November 2019

- 5th IGCP-649 Diamonds and Recycled Mantle Workshop and Field Trip in Oman, 13-22 November 2019
- Biennial Meeting of the Specialist Group for Tectonics and Structural Geology and The Specialist Group in Solid Earth Geophysics, Port Lincoln, WA, Australia, 18-22 November 2019
- GESSS-WA 2019, Perth, Australia, 29 November 2019
- AGU Fall Meeting 2019, San Francisco, USA, 9-13 December 2019

CCFS participants at Goldschmidt 2019, Barcelona, Spain.

INVITED TALKS AT MAJOR CONFERENCES

2ND IGCP 662 WORKSHOP AND FIELD EXCURSION, ULAANBAATAR, MONGOLIA 5-8 JULY 2019	Does continental crust grow significantly by collision and/or subduction **S.Y. O'Reilly** and **W.L. Griffin** **Invited**
15TH BIENNIAL MEETING SGA 2019, GLASGOW, SCOTLAND, 27-30 AUGUST 2019	Reactivation and enrichment of a Gondwana margin Ni-Cu-PGE - (Te-Au) mineral system during the breakup of Pangea **M. Fiorentini**, **S. Denyszyn**, **G. Dering**, D. Howell, D. Blanks, R. Maas, M. Locmelis and **C. Laflamme** **Keynote**
GOLDSCHMIDT 2019, BARCELONA, 18-23 AUGUST 2019	An SCLM control on the metallogenic DNA of the continental lithosphere D. Holwell, **M. Fiorentini**, I. McDonald I, Y. Lu, **A. Giuliani**, D. Smith, M. Keith and M. Locmelis **Invited** *TerraneChron®*'s trajectory 2000-2030 **E. Belousova**, **W.L. Griffin** and **S.Y. O'Reilly** **Keynote** The lithosphere and metallogeny: A 40-year evolution of concepts **W.L. Griffin** and **S.Y. O'Reilly** **Keynote**
2019 ADA LOVELACE WORKSHOP ON MODELLING MANTLE AND LITHOSPHERE DYNAMICS, SIENA, ITALY, 25-30 AUGUST 2019	Hadean mantle dynamics, tectono-volcanic regimes, and the role of impacts **C. O'Neill** **Keynote**
7TH INTERNATIONAL LARGE IGNEOUS PROVINCES CONFERENCE 2019, TOMSK, RUSSIA, 28 AUG - 8 SEPT 2019	LIPs and supercontinent reconstructions **S.A. Pisarevsky** **Keynote**
AGU FALL MEETING 2019 - SAN FRANCISCO, UNITED STATES, 9-13 DECEMBER 2019	Was the Tethys ocean a legacy of the Nuna and Rodinia superocean? - a new perspective from the point of supercontinent-superocean cycles **Z.X. Li** **Invited** Seismic observations of ponding plumes beneath the mantle transition zone L. Waszek, B. Tauzin, N.C. Schmerr, M. Ballmer and **J.C. Afonso** **Invited** New seismic observations in Western Australia from dense array deployments **H. Yuan**, X. Xu, R. Murdie, M.C. Dentith, S. Johnson, K. Gessner and L. Zhao **Invited**

OTHER CONFERENCE/WORKSHOP ROLES

IGCP 648 DATABASE WORKSHOP 2019, PERTH, AUSTRALIA, 24-30 MARCH 2019	*Organiser:* Zheng-Xiang Li
IGCP 648 2019 FIELD SYMPOSIUM, TOLIARA, MADAGASCAR, 22 JUNE – 6 JULY 2019	*IGCP 648 Co-leader:* Zheng-Xiang Li
GOLDSCHMIDT 2019, BARCELONA, SPAIN, 18-23 AUGUST 2019	*Co-convenor:* Olivier Alard Session: 03E *"The Abundance and Mobility of Chalcophile/Siderophile Elements in the Mantle and Crust"* *Co-convenor: Andrea Giuliani* Session: 03I *"Origin and Evolution of Continental Mantle Lithosphere and its Resource Endowment"*
2019 ADA LOVELACE WORKSHOP ON MODELLING MANTLE AND LITHOSPHERE DYNAMICS, SIENA, ITALY, 25-30 AUGUST 2019	*Co-convenor:* Craig O'Neil Session: 2 *"Plate-mantle dynamics in the Early Earth"*
PILBARA GEOHERITAGE WORKSHOP KARRATHA, WA, AUSTRALIA, 26-28 AUGUST 2019	*Organiser/Leader:* Martin Van Kranendonk
15TH BIENNIAL MEETING SGA 2019, GLASGOW, SCOTLAND, 27-30 AUGUST 2019	*Short course organiser:* Marco Fiorentini Course title: *"Advances in exploration targeting for magmatic Ni-Cu-PGE mineral systems" (pictured right)*
GESSS NSW 2019, UNSW, SYDNEY, AUSTRALIA, 31 OCTOBER - 1 NOVEMBER 2019	*Abstract Manager, Equity and Diversity Manager/ website creation:* Georgia Soares
AGU FALL MEETING 2019 - SAN FRANCISCO, USA, 9-13 DECEMBER 2019	*Convenor:* Michael Forster Session: D141B *"Quantities, Movements, Forms, and Origins of Carbon and Other Volatile Elements in Earth and Planetary Bodies I"* *Co-convenor:* Juan Carlos Afonso Session: S22C *"Using Observables to Infer Mantle Physical State I"* *Co-convenor:* Juan Carlos Afonso Session: S23G *"Using Observables to Infer Mantle Physical State II Posters"Lead convenor:* Huaiyu Yuan Session: T23B *"Tethys Dynamics"* *Lead convenor:* Huaiyu Yuan Session: T31HB *"T31H - Tethys Dynamics II Posters"* *Convenor:* Zheng-Xiang Li *Co-Chairs:* Zheng-Xiang Li, Nan Zhang Session: T060 *"The Tectonics and Geodynamics of Supercontinents"*

A full list of abstracts for Conferences and Workshops attended is given in Appendix 4 and on the CCFS website.

ESTEEM

AWARDS

Participant	Activity
Juan Carlos Afonso	Awarded a 2019 Early Career Scientist Award by the International Union of Geodesy and Geophysics. The award was presented at the XXVII General Assembly of the IUGG, Montreal, Canada, July 2019. The award recognises Juan Carlos's outstanding research in Earth and space sciences and international research cooperation 
Steve Foley	 Received an MQ Faculty of Science and Engineering Award for Excellence in Research Awarded the title of Distinguished Professor (Macquarie University)
Andrea Giuliani	Awarded a Swiss National Science Foundation Ambizione Fellowship
Bill Griffin	Named *'Australia's Most Influential Researcher'* in the field of Geochemistry and Mineralogy by The Australian 2019 Research Magazine. Awarded a SIMP-Honorary Fellowship (Italian Society of Mineralogy and Petrology) *See p. 20*
Bill Griffin & Sue O'Reilly	Awarded Visiting Professorships by You-Hong Sun, the president of China University of Geoscience Beijing   Life-time recognition of the geoscience research, teaching and mentoring careers of Sue O'Reilly and Bill Griffin was honoured in a dedicated Session and celebratory joint keynote at Goldschmidt 2019, in Barcelona
Zheng-Xiang Li	 Awarded a 2019 American Geophysical Union Fellowship: Fellowships are awarded to those whose visionary leadership and scientific excellence have fundamentally advanced research in their respective fields.

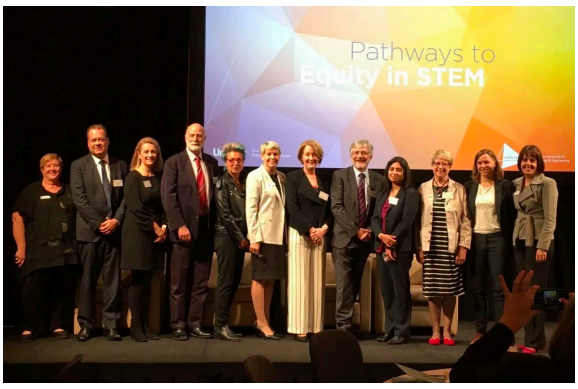
AWARDS *cont...*

Participant	Activity
Kate Selway	 Named in 2019's list of the superstars of STEM, announced 11 December 2018 by Science & Technology Australia (STA) https://scienceandtechnologyaustralia.org.au/list/2019-superstars/
Simon Wilde	Awarded the Gibb Maitland Medal from the Geological Society of Australia (WA Division)

For Postgraduate awards see the "*Postgraduate*" section *p. 41.*

2019 NEW APPOINTMENTS AND POSITIONS

Bill Griffin	Honorary Fellow of the Italian Society for Mineralogy and Petrology (SIMP). The award was given *"in recognition of internationally relevant scientific and organising contributions to the advancement of the Mineralogical Sciences and an invaluable support to strengthen the scientific relationships between the nominee's country and Italy". (pictured with Piergiulio Cappelletti, President of SIMP).*
Anthony Lanati	Governing Councillor - NSW Division, Geological Society of Australia National Executive Committee Honorary Treasurer and Chair of Finance and Risk Committee
Zheng-Xiang Li	Principal Project Leader - IGCP 648: Supercontinent Cycles and Global Geodynamics Member of the Overseas Advisory Committee, China State Council
Yongjun Lu	Appointed Councillor for Society for Geology Applied to Mineral Deposits (SGA) in 2016-2019 Secretary of the 6th International Archean Symposium (6IAS), Perth 2020 Treasurer, Specialist Group in Geochemistry, Mineralogy & Petrology (SGGMP), Geological Society of Australia Mentor, Society of Economic Geologists (SEG)
Craig O'Neill	Member of the Australian Academy of Science National Committee for Earth Sciences
Sue O'Reilly	Member, Expert Working Group for the Women in STEM Decadal Plan (and the Decadal Plan launch speaker for the Australian Academy of Science in April 2019 (*pictured right*)



2019 NEW APPOINTMENTS AND POSITIONS *cont...*

Sue O'Reilly *cont...*	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*" Australian Member, IUGG Nominations Committee Project Leader - IGCP 622: "*Orogenic architecture and crustal growth from accretion to collision*" Chair, Equity and Diversity Reference Group, Australian Academy of Science
Kate Selway	Guest Editor - "*Earth, Planets and Space*" (24th EM Induction workshop special issue)
Martin Van Kranendonk	Mars2020 Sample Return team member

EDITORIAL APPOINTMENTS	
Acta Geologica Sinica	Wilde
American Journal of Science	Wilde
Cogent Geosciences	O'Neill
Earth and Planetary Physics (EPP)	Yang
Earth, Space and Planets EM Induction Workshop Spec. Issue	Selway
Exploration Geophysics	Selway, Yang
Geodynamics & Tectonophysics	Pisarevsky
Geol. Society of America Bulletin	Griffin, Kirkland, Li
Geophysical Journal International	Afonso

EDITORIAL APPOINTMENTS	
Geosphere	Yuan
Journal of Earth Sciences	Wang
Lithos	Foley, Griffin
Mineralium Deposita	Fiorentini
Nature Scientific Reports	Daczko, Jacob, Li
Precambrian Research	Pisarevsky
Russian Geology and Geophysics	Pisarevsky
Science China - Solid Earth	Yuan
Solid Earth Sciences	Griffin
Tectonophysics	Li

OUTREACH

Forum	Participant/s	Date
Women in STEM Decadal Plan launch	Sue O'Reilly	April 2019
Presentation: University of Tasmania and Institute of Marine and Antarctic Studies *"Using geophysics to measure glacial isostatic adjustment"*	Kate Selway	16-17 March 2019
Women in Research - Podcast and interview https://www.womeninresearch.org.au/sue-oreilly	Sue O'Reilly	June 2019
Workshop for HDR students at the University of Milan, Italy: *"Advances in exploration targeting for magmatic Ni-Cu-PGE mineral systems"*	Marco Fiorentini	10-11 June 2019

OUTREACH *cont...*

Forum	Participant/s	Date
National Science Week, Victoria guest speaker – Melbourne Museum, Lilydale School, Parliament House	Kate Selway	9-11 Aug 2019
"Life on Mars" public event, Perth Convention Centre	Martin Van Kranendonk	10 Aug 2019
"Microscopic Earth" outreach at the Australian Museum during the Sydney Science Festival 	Nathan Daczko	15 Aug 2019
ABC Ockham's Razor Live, Powerhouse Museum, Sydney	Kate Selway	15 Aug 2019
NASA-ESA Pilbara fieldtrip to Instrument principle scientist for Mars2020 and ExoMars rover missions to Mars	Martin Van Kranendonk	19-25 Aug 2019
Collaboration with French NGO training geology students from West African countries - Field traverse through the French and Italian Alps: How do you form an orogen?	Marco Fiorentin	Sept 2019
Presentation to group members of Prof Jian-Ping Zheng in CUGW	Hong-Kun Dai	12 Sept 2019
Presentation and Field Trip at *'Astro-Rocks Fest'* in Mount Magnet, Western Australia. Theme: *'Earthquakes in Western Australia: Present, Past and Way Back'* 	Klaus Gessner *As part of the 2019 AstroRocks Fest in September 2019, Klaus Gessner led a field trip to the Moyagee Fault, near Mount Magnet in Western Australia, the site of an Archean Earthquake.*	20-22 Sept 2019
Meeting with President of German Science Foundation (DFG) DFG Delegation to Australia, German Ambassador	Foley	Oct 2019
Series of Distinguished Lectures at China University of Geosciences (Beijing) on *"An Overview of Earthquake Surface Wave Tomography and Ambient Noise Tomography"* to approx. 40 HDR students 	Yingjie Yang	21-25 Oct 2019
Published article for STEM teaching material with Futurum https://futurumcareers.com/movers-and-shakers-using-supercomputers-to-understand-how-supercontinents-form-and-drift-apart	Zheng-Xiang Li	Nov 2019
Report to Canning Council about the Canning seismic project	Huaiyu Yuan	17 Nov 2019
Invited seminar, Faculty of Geophysical and Astronomical Sciences, University of La Plata, Argentina	Maria Constanza Manassero	20 Dec 2019

MEDIA

Activity	Participant/s	Date, Forum	Web address
Carmeltazite recognised as a new and rare mineral	Bill Griffin	7/1/19, Mining weekly	http://www.miningweekly.com/article/carmeltazite-recognised-as-a-new-and-rare-mineral-2019-01-07
New mineral found inside gemstones in Israel	Bill Griffin	8/1/19, Mining.com	http://www.mining.com/new-mineral-found-inside-gemstones-israel
Israeli company finds new 'outer space' mineral on Earth	Bill Griffin	8/1/19, Haaretz - Israel News	https://www.haaretz.com/israel-news/israeli-company-finds-new-outer-space-mineral-on-earth-1.6823868
Mapping a mineral future	Sue O'Reilly	9/1/19, National Mining Chronicle	http://www.nationalminingchronicle.com.au/61-agenda/service-and-supply/18786-products-technology-14
Israeli mining company unearths rare mineral	Bill Griffin	10/1/19, BBC News	https://www.bbc.com/news/blogs-news-from-elsewhere-46816297
Carmeltazite: A new unique gemstone from Israel	Bill Griffin	14/1/19, FORBES	https://www.forbes.com/sites/davidbressan/2019/01/14/carmeltazite-a-new-unique-gemstone-from-israel/#28f4dbc5570a
"Ancient Earth rock found on the moon"	Craig O'Neill	29/1/19, Science Magazine	https://www.sciencemag.org/news/2019/01/ancient-earth-rock-found-moon
Academy welcomes priority investment in critical minerals projects	Sue O'Reilly	13/2/19, Australian Academy of Science	https://www.science.org.au/news-and-events/news-and-media-releases/academy-welcomes-priority-investment-critical-minerals
Academy welcomes Australian Future Mines Centre commitment	Sue O'Reilly	13/2/19, Australian Academy of Science	https://www.science.org.au/news-and-events/news-and-media-releases/academy-welcomes-australian-future-mines-centre-commitment
How the dinosaurs went extinct: asteroid collision triggered potentially deadly volcanic eruptions	Craig O'Neill	22/2/19, The Conversation	https://theconversation.com/how-the-dinosaurs-went-extinct-asteroid-collision-triggered-potentially-deadly-volcanic-eruptions-112134
Carmeltazite: new gemstone on the block	Bill Griffin	4/19, Mine	https://mine.nridigital.com/mine_apr19/carmeltazite_new_gemstone_on_the_block
A 'seiche' wave can outpace a tsunami, and both can be triggered by meteorites and earthquakes	Craig O'Neill	4/4/19, The Conversation	https://theconversation.com/a-seiche-wave-can-outpace-a-tsunami-and-both-can-be-triggered-by-meteorites-and-earthquakes-114753
Moonquakes measured during Apollo missions suggest the Moon may still be tectonically active	Craig O'Neill	14/5/19, ABC News	https://www.abc.net.au/news/science/2019-05-14/moon-tectonic-activity-moonquake-study/11106794
Diamonds, volcanoes and a rock star: what a new map of the Earth's interior will reveal	Juan Carlos Afonso	23/5/19, The Lighthouse	https://lighthouse.mq.edu.au/article/may-2019/Diamonds,-volcanos-and-a-rock-star-what-a-new-map-of-the-earths-interior-will-reveal
Diamonds are cooked up as Earth recycles minerals below the ocean floor: Study	Craig O'Neill	30/5/19, Firstpost	https://www.firstpost.com/tech/science/diamonds-are-cooked-up-as-earth-recycles-minerals-below-the-ocean-floor-study-6724091.html
Saturn's rings and their propellers, waves, speckles and secrets come into focus with Cassini's final images	Craig O'Neili	15/6/19, ABC News	https://www.abc.net.au/news/science/2019-06-14/saturn-rings-up-close-in-latest-cassini-images/11202460
ABC is an Australian public broadcast service. Wikipedia: Q&A Science Special (Featuring Brian Cox)	Martin Van Krenendonk	17/6/19, ABC TV Q&A program	https://www.youtube.com/watch?v=TNvUhbLfDt4

MEDIA *cont...*

Activity	Participant/s	Date, Forum	Web address
If these rocks could talk	Tara Djokic	22/7/19, TEDxSydney	https://www.youtube.com/watch?v=pVbJYQBUmV4 
Diamonds point to existence of ancient rocks from the birth of the Earth	Stephen Foley	16/8/19, ABC News	https://www.abc.net.au/news/science/2019-08-16/super-deep-diamonds-give-us-window-into-the-deep-earth/11412730
Today no one got eaten	Kate Selway	1/9/19, ABC Radio: Ockham's razor	https://www.abc.net.au/radionational/programs/ockhamsrazor/no-one-got-eaten-by-a-polar-bear/11455896
The greatest treasure hunt	Martin Van Krenendonk	1/9/19, ABC News online	https://www.abc.net.au/news/2019-09-01/nasa-in-western-australia-looking-for-clues-to-mars-mission/11452250
NASA research in Western Australia could hold key to finding life on Mars	Martin Van Krenendonk	1/9/19, ABC TV National News	https://m.youtube.com/watch?feature=youtu.be&v=Zl4yLJpMGcc
Interview: Channel 9 Today Weekend Breakfast	Martin Van Krenendonk	8/9/19, Channel 9 Today Weekend Breakfast	https://wetransfer.com/downloads/e07f59cf1774711745bb997f8c64aedd20190911033226/4c0506541a26829e8a79a1f3ce6993e620190911033226/0ec148
Kate Selway - Science at the extreme	Kate Selway	29/9/19, Climactic podcast	https://www.climactic.fm/80
Life Sciences & Earth Sciences: Australia's Research field leaders	Bill Griffin	1/10/19, The Australian	https://specialreports.theaustralian.com.au/1540291/life-sciences-earth-sciences/
CPRM researcher presents data on geochemistry of the subcontinental lithospheric mantle at the Goldschmidt 2019	Lynthener Bianca Takenaka	1/11/19, Geological Survey of Brazil News	https://www.cprm.gov.br/publique/Noticias/Pesquisadora-da-CPRM-apresenta-dados-sobre-geoquimica-do-manto-litosferico-subcontinental-no-Goldschmidt-2019-5960.html

MEDIA - FEATURED PAPERS

1242. **Li, Z.X.**, **Mitchell, R.N.**, Spencer, C.J., Ernst, R., **Pisarevsky, S.**, **Kirscher, U.** and Murphy, J.B. 2019. Decoding Earth's rhythms: modulation of supercontinent cycles by longer superocean episodes. *Precambrian Research*, *323*, *1-5*.

Activity	Date, Forum	Web address
Curtin study finds billion-year superocean cycles in Earth's history	31/1/19, CU News and Events	https://news.curtin.edu.au/media-releases/curtin-study-finds-billion-year-superocean-cycles-in-earths-history/
Study finds billion-year superocean cycles in Earth's history	31/1/19, PhysOrg	https://phys.org/news/2019-01-billion-year-superocean-earth-history.html
Curtin study finds billion-year superocean cycles in Earth's history	31/1/19, Mirage News	https://www.miragenews.com/curtin-study-finds-billion-year-superocean-cycles-in-earth-s-history/
Research finds billion-year superocean cycles in Earth's history	2/2/19, Tech Explorist	https://www.techexplorist.com/research-finds-billion-year-superocean-cycles-earths-history/20674/

MEDIA - FEATURED PAPERS *cont..*

Activity	Date, Forum	Web address
Study finds billion-year superocean cycles in Earth's history	3/2/19, Watts up with that?	https://wattsupwiththat.com/2019/02/03/study-finds-billion-year-superocean-cycles-in-earths-history/
Earth once swallowed its own superocean. Could it happen again?	7/2/19, Live Science	https://www.livescience.com/64707-earth-swallowed-superocean.html
Earth might form a superocean every billion years	8/2/19, IFLScience	https://www.iflscience.com/environment/earth-might-form-a-superocean-every-billion-years/all/

1331. **Förster, M.W.**, **Foley, S.F.**, Marschall, H.R., **Alard, O.** and Buhre, S. 2019. Melting of sediments in the deep mantle produces saline fluid inclusions in diamonds. *Science Advances*, *5*, *eaau2620*. *(see Fig. 1, p. 27)*

Activity	Date, Forum	Web address
Earth recycles ocean floor into diamonds	24/4/19, Long Room	https://www.longroom.com/discussion/1503671/earth-recycles-ocean-floor-into-diamonds
Earth recycles ocean floor into diamonds	29/5/19, EurekAlert!	https://www.eurekalert.org/pub_releases/2019-05/mu-ero052919.php
Confirmed: Earth is crushing the ocean into salty diamonds	29/5/19, LiveScience	https://www.livescience.com/65589-diamonds-come-from-the-sea.html
Earth recycles ocean floor into diamonds	29/5/19, Phys.org	https://phys.org/news/2019-05-earth-recycles-ocean-floor-diamonds.html
Earth recycles ocean floor into diamonds	29/5/19, Science Daily	https://www.sciencedaily.com/releases/2019/05/190529145104.htm
Interview about the discovery that many diamonds are formed when the Earth's mantle crushes ancient seabed minerals.	30/5/19, ABC Illawarra Mornings	
Interview about the discovery that many diamonds are formed when the Earth's mantle crushes ancient seabed minerals.	30/5/19, ABC Newcastle Drive	
Earth is compressing its oceans into salty diamonds	30/5/19, Mind Guild	http://themindguild.com/earth-is-compressing-its-oceans-into-salty-diamonds/
Most diamonds formed from ancient seabeds	30/5/19, Business Standard	https://www.business-standard.com/article/news-ians/most-diamonds-formed-from-ancient-seabeds-119053000536_1.html
Earth recycles ocean floor into diamonds	30/5/19, Environmental News Network	https://www.enn.com/articles/58218-earth-recycles-ocean-floor-into-diamonds
News story from Eurasia Review	30/5/19, Eurasia Review	
Ancient seabed buried deep in Earth can create diamonds, study says	30/5/19, FOX News	https://www.foxnews.com/science/ancient-seabed-in-earth-create-diamonds
Earth's seafloor may be destined to become diamonds	30/5/19, National Geographic	https://www.nationalgeographic.com.au/science/earths-seafloor-may-be-destined-to-become-diamonds.aspx
Earth recycles ocean floor into salty diamonds	30/5/19, TECH Explorist	https://www.techexplorist.com/earth-recycles-ocean-floor-salty-diamonds/23661/
How Earth recycles ocean floor into diamonds	30/5/19, The Deccan Herald	https://www.deccanherald.com/science-and-environment/how-earth-recycles-ocean-floor-into-diamonds-737095.html
Earth has an ocean floor recycling system which produces diamonds	30/5/19, Value Walk	https://www.valuewalk.com/2019/05/earth-ocean-floor-recycling-system-diamonds/
Diamanten aus recyceltem meeresgrund	31/5/19, FOCUS Online	https://www.scinexx.de/news/geowissen/diamanten-aus-recyceltem-meeresgrund
Earth recycles ocean floor into diamonds	31/5/19, Lab Manager	https://www.labmanager.com/news/earth-recycles-ocean-floor-into-diamonds-1749

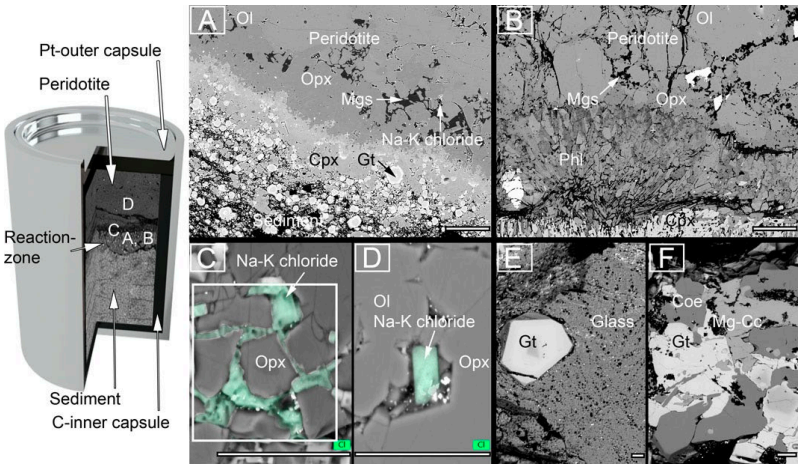
MEDIA - FEATURED PAPERS *cont..*

Activity	Date, Forum	Web address
Most diamonds formed from ancient seabeds	31/5/19, New Kerala	https://www.newkerala.com/news/read/150336/most-diamonds-formed-from-ancient-seabeds.html
Ancient seabed buried deep in Earth can create diamonds	31/5/19, New York Post	https://nypost.com/2019/05/31/ancient-seabed-buried-deep-in-earth-can-create-diamonds/
Study: Salts trapped inside fibrous diamonds came from ancient seabeds	31/5/19, Sci-News	http://www.sci-news.com/geology/salts-fibrous-diamonds-07241.html
Scientists detect ancient sea salt in diamonds, proving their extraordinary origins	31/5/19, ScienceAlert	https://www.sciencealert.com/most-diamonds-are-made-from-billion-year-old-recycled-sea-floor-cooked-deep-beneath-us
Bildung aus subduziertem Meeressediment erklärt salzhaltige Einschlüsse von Bort-Diamanten Diamanten aus recyceltem Meeresgrund	31/5/19, Scinexx	https://www.scinexx.de/news/geowissen/diamanten-aus-recyceltem-meeresgrund/
Minerale: Rätsel salzhaltiger diamanten gelöst	31/5/19, Spektrum	https://www.spektrum.de/news/raetsel-salzhaltiger-diamanten-geloest/1648688
Earth cooks rare diamonds out of recycled ocean floor	31/5/19, Tech Times	https://www.techtimes.com/articles/243964/20190530/earth-cooks-rare-diamonds-out-of-recycled-ocean-floor.htm
El fondo marino podría convertirse en una 'fábrica' de diamantes	1/6/19, RT Network	https://actualidad.rt.com/actualidad/316727-antiguos-fondos-marinos-crear-tierra
Ocean floor sediments recycle to form salty diamonds	2/6/19, Sciencehook	https://sciencehook.com/chemistry/ocean-floor-sediments-recycle-to-form-salty-diamonds-1856
O planeta está a engolir o fundo do mar (e a cuspir diamantes)	3/6/19, ZAP	https://zap.aeiou.pt/planeta-engolir-fundo-mar-cuspir-diamantes-259597
Earth recycles ocean floor into diamonds	5/6/19, Space Daily	https://www.enn.com/articles/58218-earth-recycles-ocean-floor-into-diamonds
Salty diamonds formed from recycled ocean floor, researchers say	6/6/19, CTV news	https://www.ctvnews.ca/sci-tech/salty-diamonds-formed-from-recycled-ocean-floor-researchers-say-1.4454771
News: Salty diamonds formed from recycled ocean floor, research says	8/6/19, BrainFeed Magazine	https://brainfeedmagazine.com/salty-diamonds-formed-from-ocean-floor/
Neues aus der kinderstube der diamanten	18/6/19, Informations-dienst Wissenschaft	https://idw-online.de/de/news717690
Neues aus der kinderstube der diamanten	18/6/19, Jura Forum	https://www.juraforum.de/wissenschaft/neues-aus-der-kinderstube-der-diamanten-659370
News from the diamond nursery	19/6/19, EurekAlert!	https://www.eurekalert.org/pub_releases/2019-06/guf-nft061919.php
News from the diamond nursery	19/6/19, Informations-dienst Wissenschaft	https://idw-online.de/de/news717829
Extreme pressure and heat in Earth's mantle simulated	19/6/19, Long Room	https://www.longroom.com/discussion/1529902/extreme-pressure-and-heat-in-earths-mantle-simulated
Extreme pressure and heat in Earth's mantle simulated	19/6/19, Science Daily	https://www.sciencedaily.com/releases/2019/06/190619130313.htm
Diamonds: Salty pieces of oceanic history?	10/7/19, Science 101	https://www.science101.com/diamonds-salty-pieces-oceanic-history/
News from the diamond nursery	11/7/19 Innovations Report	https://www.innovations-report.de/html/berichte/geowissenschaften/neues-aus-der-kinderstube-der-diamanten.html
Sedimentschmelzen im erdmantel als quelle für salzhaltige einschlüsse in diamanten identifiziert	13/8/19, Informations-dienst Wissenschaf	https://idw-online.de/de/news720494

MEDIA - FEATURED PAPERS *cont..*

Activity	Date, Forum	Web address
Sedimentschmelzen im erdmantel als quelle für salzhaltige einschlüsse in diamanten identifiziert	13/8/19, Jura Forum	https://www.juraforum.de/wissenschaft/sedimentschmelzen-im-erdmantel-als-quelle-fuer-salzhaltige-einschluesse-in-diamanten-identifiziert-663938
Sedimentschmelzen im erdmantel als quelle für salzhaltige einschlüsse in diamanten identifiziert	14/8/19, Inovations report	https://www.innovations-report.de/html/berichte/geowissenschaften/sedimentschmelzen-im-erdmantel-als-quelle-fuer-salzhaltige-einschluesse-in-diamanten-identifiziert.html

Figure 1. Backscattered electron images of experimental charges. Locations of images A-D from sediment-peridotite reaction experiments are schematically shown in capsule on left. For full figure caption see 2018 CCFS Research highlight: Reaction of subducted marine sediment with peridotite produces saline fluid inclusions in diamonds (http://ccfs.mq.edu.au/AnnualReport/18Report/ResHigh.html#Reaction).



1379. **Baumgartner, R.J.**, **Van Kranendonk, M.J.**, Wacey, D., **Fiorentini, M.**, Saunders, M., **Caruso, S.**, Pages, A., Homann, M. and Guagliardo, P. 2019. Nano–porous pyrite and organic matter in 3.5-billion-year-old stromatolites record primordial life. *Geology*, *47*, *1039-1043*.

Activity	Date, Forum	Web address
Fossilised microbes from 3.5 billion years ago are oldest yet found	25/9/19, New Scientist	https://www.newscientist.com/article/2217747-fossilised-microbes-from-3-5-billion-years-ago-are-oldest-yet-found/
Earliest signs of life: Scientists find microbial remains in ancient rocks	25/9/19, ScienceDaily	https://www.sciencedaily.com/releases/2019/09/190926105844.htm
Confirmed. Fossils that formed 3.5 billion years ago, really are fossils. The oldest evidence of life found so far	30/9/19, Universetoday	https://www.universetoday.com/143561/confirmed-fossils-that-formed-3-5-billion-years-ago-really-are-fossils-the-oldest-evidence-of-life-found-so-far/
Organic matter found in 3.5-billion-year-old stromatolites	3/10/19, Sci-News	http://www.sci-news.com/paleontology/organic-matter-dresser-formation-stromatolites-07657.html
Ancient rock remains reveal signs pointing to earliest life on Earth	3/10/19 UWA News	http://www.news.uwa.edu.au/2019100311643/international/ancient-rock-remains-reveal-signs-pointing-earliest-life-earth
Pilbara rock find key to early life	30/10/19 The West Australian	Print

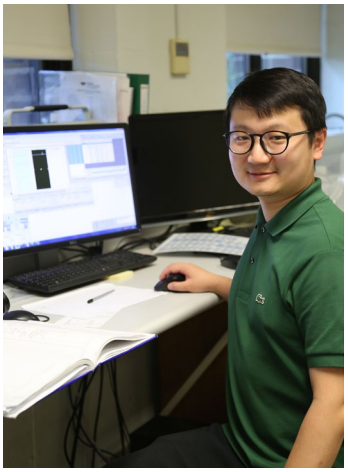
VISITORS

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 5. 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*.

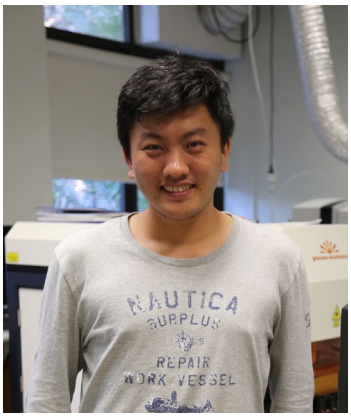
Dr Ed Saunders, University of New England, Armidale, NSW.

Dr Fan Yingjie of the Bureau of International Cooperation, Dr Yupeng Yao, Deputy Director of the Department of Earth Science, National Natural Science Foundation of China (NSFC), Prof Zengqian Hou, Vice-President National Science Foundation of China (NSFC), Sue O'Reilly and Yingjie Yang.

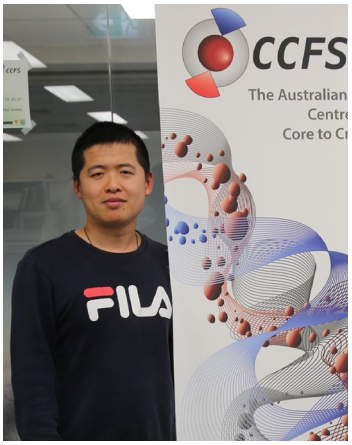


Dr Bo Xu, China University of Geosciences (Beijing).

Huaiyu Yuan and Miss Tingzi Li, Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS), Beijing.



Mr Jue Hou, Institute of Geophysics, China Earthquake Administration.



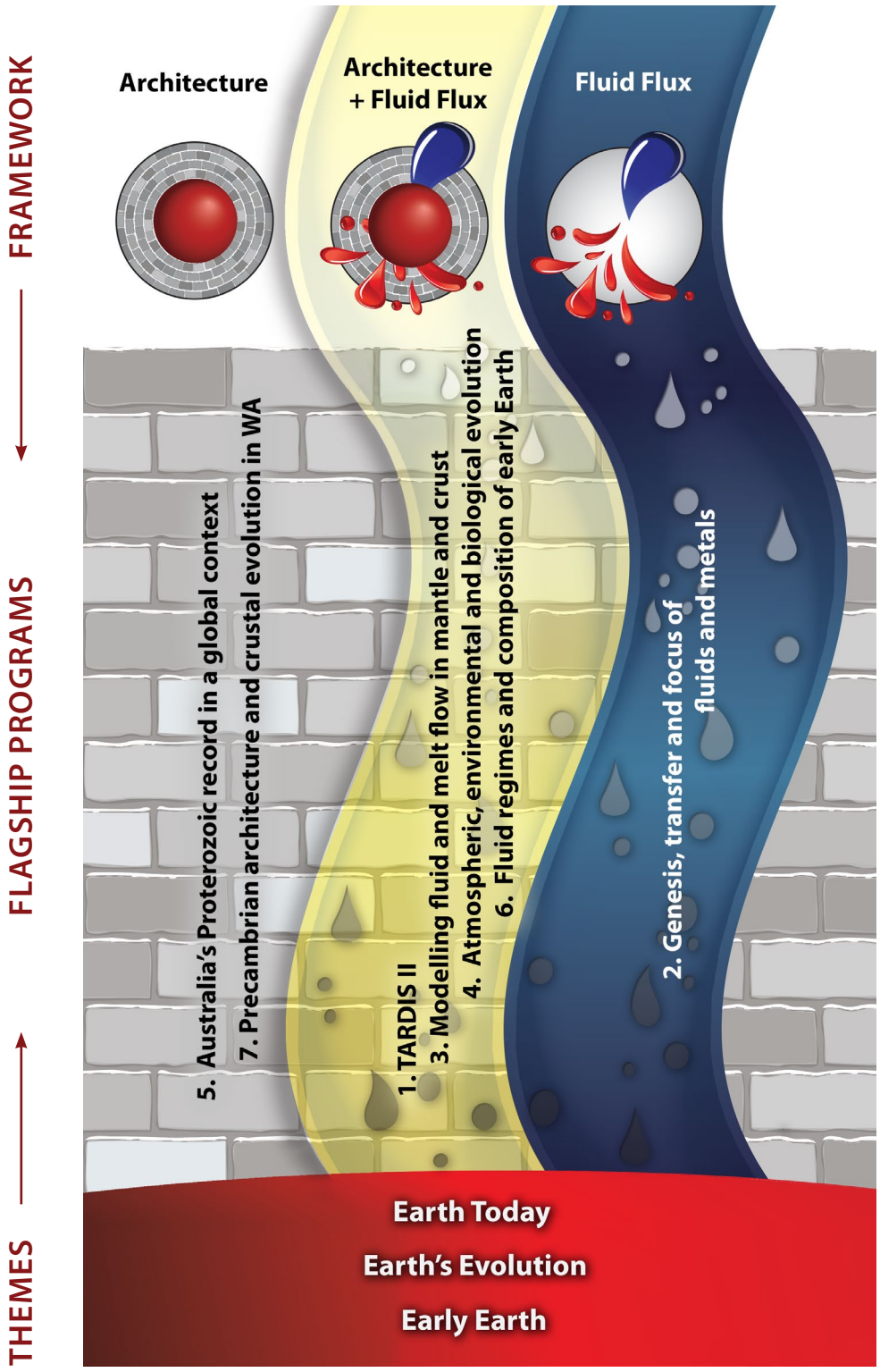
Dr Yunshuai Li, Institute of Surface-Earth System Science, Tianjin University.

Sue O'Reilly, Prof Karl Karlstrom and Prof Laura J. Crossey (Dept Earth & Planetary Sciences, University of New Mexico) and Graham Begg (Minerals Targeting International).

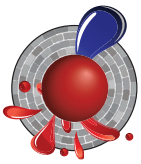
Dr Wei Guo, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing.

Flagship Programs

Following the conceptual framework outlined on *page 4,* these Flagship Programs 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.



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

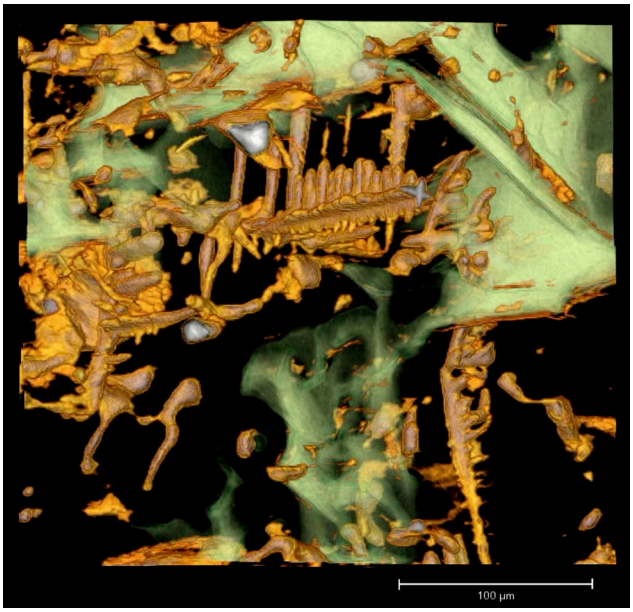
This program investigates the role of fluids in the deep mantle and lithosphere, using studies of kimberlites and other volcanic rocks, xenoliths of mantle and crustal rocks in volcanic rocks, ophiolites, and UHP terrains related to subduction zones. Super-reducing, ultra-high-pressure (SuR-UHP: 400-600 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 new geodynamic collision process that may improve mineral exploration concepts for paleosubduction regimes. The recent discovery of similar ultra-reduced mineral assemblages in ejecta from Cretaceous volcanoes in Israel suggests a previously unrecognised process of interaction between highly reducing deep-mantle fluids and ascending basaltic magmas. We aim to produce an experimentally testable model for the generation of such fluid conditions in the mantle, to quantify constraints on the geochemical and tectonic processes that have produced SuR-UHP assemblages, and to produce a geodynamic model for these processes.

2019 REPORT

The TARDIS project continued in 2019 to carry out research on significant questions relating to kimberlite genesis, the petrogenesis of super-reduced magmatic systems, the evolution of the North China Craton, magmatism and tectonics in the Tethyan collisional belt, and the mantle beneath the Pannonian Basin in Hungary.

Kimberlites: Andre Giuliani and coworkers (*CCFS publication #1329*) used core-to-rim analyses of oxygen isotopes in olivine macrocrysts in kimberlites to show that most of these olivine grains were derived from peridotites in the subcontinental lithospheric mantle, while their rims crystallised from the kimberlitic melts, which had assimilated variable proportions of mantle material. Building on this basis, they concluded that kimberlites worldwide represent very similar primary magmas, modified to varying degrees by assimilation of SCLM material (*CCFS publication #1488*). This new model greatly simplifies research into the origins of kimberlitic magmas. *Nkere et al.* (*CCFS publication #1354*) and *Batumike et al.* (*CCFS publication #1344*) carried out *in situ* U-Pb dating of groundmass perovskite in kimberlites from the Democratic Republic of the Congo, adding more data on the distribution of some of Earth's youngest kimberlites. One of the standards used in this work, the Mud Tank zircon, was documented by *Gain et al.* (*CCFS publication #1330*), enhancing the use of this widely distributed material in laboratories worldwide. *Montgarri Castillo-Oliver et al.* (*CCFS publication #1421*) followed up last year's major study on the petrography of primary and secondary carbonates (*CCFS publication #1184*) with a detailed petrographic-isotopic study of the famous carbonate parageneses from the Benfontein kimberlite sills in South Africa. Their multi-technique approach not only revealed the petrographic and geochemical complexity of carbonates in kimberlites in unprecedented detail, but also allows identification of the processes that led to their formation. The narrow range of isotopic variation in primary carbonates suggests that kimberlites are derived from a mantle source with little contribution from recycled crustal material, and complements the results of *Giuliani et al.* (*CCFS publication #1488*).

Ultra-reduced magmatic assemblages, Mt Carmel, Israel: Significant progress was made in this subproject this year, most of which will be published or submitted in 2020. 2019 saw the publication of a trio of papers centred on the hibonite-grossite-vanadium assemblage found as complex, coarsely-crystalline grains in the alluvial deposits derived from the Cretaceous pyroclastic volcanoes on Mt Carmel. The main paper (*CCFS publication #1209*) is the first report of a terrestrial magmatic hibonite-grossite assemblage, though these minerals are common in the Calcium-Aluminum Inclusions (CAIs) in carbonaceous chondrite meteorites. The presence of native vanadium in this assemblage testifies to extremely low oxygen fugacity (fO_2), ca 9 log units below the Iron-Wustite buffer that probably controls the fO_2 of Earth's mantle. This very low fO_2 is similar to that of the early Solar nebula, and implies the presence of a fluid phase dominated by H_2. This was spectacularly confirmed when sharp-eyed collaborator Luca Bindi (University of Florence) identified a tiny grain of



3D-micro CT image of a small piece of Carmel Sapphire, part of the ultra-reduced magmatic assemblages, Mt Carmel, Israel. This image shows the distribution of corundum (black), silicate melt (green), fluid-filled voids (red) and metallic melts, including Ti oxynitrides (orange). View the 3D rotating image here: http://ccfs.mq.edu.au/AnnualReport/19Report/3DCarmelSapphire.html

vanadium dihydride (VH_2) associated with the native vanadium in one sample (*CCFS publication #1360*). This is the first naturally occurring metal hydride, and has been submitted for approval as a new mineral - kishonite (for the Kishon River from which the sample came). This unique observation was further supported by collaborator Fernando Camara (University of Milan), who used Raman spectroscopy to infer the presence of H_2 in the hibonite adjacent to inclusions of vanadium. These discoveries shed important new light on the transfer of volatiles from the reduced sublithospheric mantle, and represent several more bricks in the construction of a complete model for the Mt Carmel magmatic system.

North China Craton (NCC): Work in 2019 focused on the evolution and nature of the lower crust beneath the craton and adjacent areas. *Dai et al.* (*CCFS publication #1360*) used basalts and xenoliths from the Langshan area to infer the presence of subducted oceanic material beneath the northern edge of the North China Craton (NCC), while *Ping et al.* (*CCFS publication #1396*) showed that the lower crust is younger than the mid- to upper-crust beneath the southeastern part of the NCC. *Ma et al.* (*CCFS publication #1225*) used seismic data and xenolith references to show that the lower crust is similar in composition and thickness beneath the '*disrupted*' NCC and the adjacent '*intact*' Ordos block. This is a powerful argument against the widely promoted idea that the Mesozoic-Cenozoic disruption of the SCLM beneath the NCC was driven by delamination of the lower crust.

Pannonian Basin: The Nógrád-Gömör Volcanic Field (NGVF), in the northern Pannonian Basin in Central Europe, is one of five key localities where the lithospheric mantle of the Carpathian-Pannonian region can be studied using peridotite xenoliths hosted in late Miocene to Pleistocene alkali basalts. *Liptai et al.* (*CCFS publication #1361*) published a major study documenting the regional distribution of microstructural characteristics in the xenoliths. The lateral variations in microstructures record deformation by dislocation creep in a transpressional regime, which is consistent with recent tectonic evolution in the Carpathian-Pannonian region, associated with the convergence of the Adria microplate and the European platform. The microstructures also contribute to a better understanding of the regional seismic data. Despite well-developed fabrics in the xenoliths, which imply a strong seismic anisotropy, the lithospheric mantle alone most likely cannot account for the shear wave splitting delay times measured in the NGVF, indicating that deformation in both the lithosphere and the asthenosphere contributes to the observed shear wave splitting. In a related study, *Patko et al.* (*CCFS publication #1239*) used FTIR spectroscopy to measure hydroxyl contents in the major minerals of NGVF xenoliths, and found them to have unusually low H contents. These probably are not representative of the upper mantle beneath the region, but reflect the loss of H during high-temperature annealing (before and during eruption) and relatively slow cooling in the erupted basalts.

Tethyan Belt: Work in 2019 focused on the petrological and tectonic evolution of the continental crust of northern Gondwana, now found in accretionary terranes in both Iran and Tibet. *Moghadam et al.* (*CCFS publication #1381*) documented the generation of the Cadomian (570-525 Ma) crust of NE Iran in a continental-margin arc under very high magmatic fluxes in a '*crustal hot zone*' that involved interaction between mantle-derived melts and old continental crust. Synthesis of new and published data indicates that this type of interaction is common during periods of high magmatic fluxes. The results indicate that differentiation of mafic melts in the lower crust during prolonged magmatic flare-ups plays a key role in building a stratified continental crust. Using data from Late Cretaceous ophiolites in NE Iran, *Moghadam et al.* (*CCFS publication #1236*) unravelled the processes of the subduction initiation and back-arc opening north of Neo-Tethys, which eventually separated the Cadomian crust from Gondwana and sent it off to join Europe-Asia. *Kazemi et al.* (*CCFS publication #1199*) studied related late Cretaceous subduction along the Lut Block in NE Iran, a largely covered stable crustal block with a history back to the Archean, also once part of Gondwana. In another part of Tethys, *Zhou et al.* (*CCFS publication #1213*) used zircons from Neoproterozoic sedimentary rocks exposed in the basement of the Lhasa Block in Tibet, the last terrane to arrive before the collision of India with Asia, to connect this terrane with the Himalaya and/or the East Africa Orogen. These results show that the Lhasa Block was probably located within a giant convergent plate margin system surrounding the Rodinia supercontinent during its breakup in Tonian time (850-1000 Ma). Continuing geochemical studies related to porphyry copper deposits are revealing the processes and conditions that lead to significant economic deposits (e.g. *CCFS publication #1230*).

WORKPLAN 2020

Kimberlites and related rocks: Work will continue on the isotopic characteristics of kimberlites and related rocks, focusing on two major questions: what does a "*primitive*" kimberlite look like, and how is it generated?

Ultra-reduced magmatic assemblages, Mt Carmel, Israel: The focus of this subproject will be to achieve a complete synthesis of the unusual mineral assemblages from this remarkable locality and the conditions of their formation. This will require studies of mineral assemblages formed at (relatively) oxidising conditions. Further analytical work will be required, but limited in scope. Plans to begin *in situ* studies of the isotopic systematics of Ti, N and O isotopes in the ultra-reduced minerals have been disrupted by the global pandemic, but we hope to make progress during 2020. Further analyses of the isotopic composition of included gasses will be carried out in Beijing, and another Beijing lab will analyse Si and C isotopes in more SiC samples.

North China Craton: A large-scale seismic survey and further studies of xenolith suites will examine the uppermost mantle and lower crust, and the Mantle Transition Zone beneath the NCC, to investigate the effects of repeated subduction beneath the region, and the transfer of fluids and magmas from the MTZ to the crust.

Tethyan Belt: Work will continue on the magmatic and structural evolution of the Tethyan Belt in Iran, leading to a synthesis of the development of the northern edge of Gondwana, the detachment of a series of microcontinents, and their amalgamation to the European continent. Work in Tibet will focus on the role of the lithospheric mantle as a reservoir for volatiles and ore-forming elements concentrated in Cu-Mo-Au porphyries, and the origin of ore deposits in ophiolitic massifs.

Published outputs for 2019

CCFS publications: #1199, 1209, 1213, 1225, 1230, 1236, 1239, 1249, 1245, 1256, 1329, 1330, 1344, 1354, 1360, 1361, 1365, 1367, 1377, 1396, 1399.

>20 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.

Marco Fiorentini (pictured) hiking through the Italian Alps with Postgraduate students Gregory Dering and Joshua Chong to investigate the metallogenic architecture of the magmatic Ni-Cu-PGE sulfide deposits associated with the Jurassic magmas of the Ivrea Zone (see photos pp. 41, 42, photo Joshua Chong).

2019 REPORT

In 2019, this Flagship Project acted as a gravity well, attracting numerous researchers and students from a variety of universities to work with analytical infrastructure based at UWA. Work mainly focused on establishing the cycle of volatiles and metals at the scale of the lithosphere. Past and ongoing projects have significantly contributed to and engaged industry and generated new projects on various mineral systems (*see p. 63*). These include partnerships with:

- Anglo American and CSIRO to investigate the potential of silicate and oxide phases to be used as resistate indicator minerals in the exploration for magmatic nickel sulfide ores
- Panoramic Resources and Innovation Connections, in partnership with the Commonwealth government, investigating the role of high-precision geochronology as a tool to unveil the timescales of ore forming processes in magmatic systems
- IGO to characterise the geochemical and isotopic signature of mafic and ultramafic rocks in the Proterozoic Albany-Fraser Belt, Yilgarn Craton, Western Australia
- Auldana to characterise volcanic and sedimentary records and unravel the convergence and amalgamation of the continental arcs and terranes of north-eastern Thailand

In 2019, overseas field work activities for this Flagship Project focused on the Ivrea Zone (*see photo below*) of northwest Italy, northern Thailand, and along the southern Andes in Chile. In the Ivrea Zone, work focused on the La Balma Monte Capio intrusion, investigating how metals and volatiles are recycled along the margins of continental blocks during subsequent magmatic episodes spanning tens of millions of years. In northern Thailand, the work principally aimed at sampling magmatic suites in order to build an isotopic map of that lithospheric domain. In Chile, the work aimed at establishing the nature of fertility signals in

whole-rock and mineral (zircon, apatite) datasets in relation to ore porphyry systems, with special emphasis on the chronology of events. In Australia, field work focused on the Agnew-Wiluna (AWB) and Fraser belts of the Yilgarn Craton on Western Australia, in the context of the ongoing Yilgarn 2020 project (AWB) and collaboration with IGO (Fraser belt).

WORKPLAN 2020

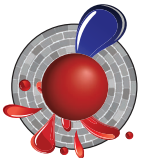
Work in 2020 will be carried out within the framework of a number of ongoing PhD projects, mainly funded by ARC or industry, and the work of ECRs at UWA. Ms Eunjoo Choi will submit her PhD thesis in early 2020. Her work focuses on unravelling the significance of Proterozoic magmatism in the Yilgarn Craton as a probe to unravel the first-order control on its metallogenic fertility and endowment.

Published outputs for 2019

CCFS publications: #1198, 1210, 1214, 1289, 1342, 1343, 1356, 1358, 1359, 1380.

16 Conference Abstracts

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.

2019 REPORT

The two major outcomes from this program have been the development and expansion of Litmod and its subsidiary codes, led by CI Afonso, and the technical implementations of CCFS modules into the community code *Aspect*, leading to new community-available modules for handling complex physical processes.

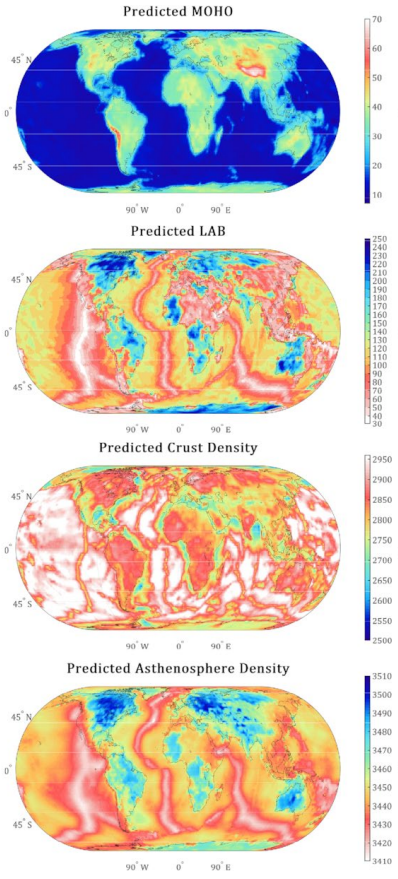


Figure 1. LithoRef18, a new global model for the Earth's lithosphere and upper mantle obtained through a formal joint inversion of 3D gravity anomalies, geoid height, satellite-derived gravity gradients and absolute elevation complemented with seismic, thermal and petrological prior information. The model includes crustal thickness, average crustal density, lithospheric thickness, depth-dependent density of the lithospheric mantle, lithospheric geotherms, and average density of the sublithospheric mantle down to 410 km depth with a surface discretisation of 2°×2°. See CCFS publication #1234.

The science outcomes from these developments in the past year include i) A recognition of meteorite impacts as a geological process in the Archaean record, and a demonstration of the ability of Archaean spherule-bed forming impacts to generate tectonic responses in the Archaean geological record. This has been published in the high-profile journal *Geology* in 2020. ii) The development of *LithoRef18*: A global reference model of the lithosphere and upper mantle from joint inversion and analysis of multiple data sets, presented in *Afonso et al.* (*CCFS publication #1234,* Fig. 1) in the journal *Geophysics Journal International*, and available for download at https://www.juanafonso.com/software. iii) Improved seismic models of

Figure 2. 1000-ton multi-anvil apparatus from Voggenreiter GmbH.

the structure of the Chinese lithosphere and the influence of subduction in this area. Results were published in *Zhang et al.* (*CCFS publication #1481*), and *Xu et al.* (*2020, Geology, CCFS publication #1483*).

Figure 3. Two new piston-cylinder apparatuses from GUKO Sondermaschinenbau GmbH, installed in January 2020.

The newly renovated and expanded high-pressure experimental laboratory was opened in 2019, with two multi-anvil apparatuses (Fig. 2) to add to the existing 500-ton multi-anvil from the old laboratory. In January 2020, two new piston-cylinder apparatuses were delivered and installed by GUKO Sondermaschinenbau (Germany; Fig. 3).

Whilst the laboratory was closed, experiments in this Flagship Program were continued at the ANU, Frankfurt, Mainz and Wuhan, with projects including reaction experiments with sedimentary rocks and mantle peridotites (Michael Förster, Mingdi Gao and Chunfei Chen) and partial melting of mantle peridotites with different mixtures of volatile components (Zsanett Pintér and Zairong Liu). The scope of sedimentary materials included in the experiments has widened considerably and is chosen to represent major contributors to material in subduction zones. Michael Förster has been looking at reactions with marine sediments from the Mediterranean, whereas Chunfei Chen is investigating the behaviour of carbonates. Until now, researchers have used average compositions of sediments, which include just small proportions of carbonates. Chunfei makes the point that most carbonates are subducted as chalk or limestones, and so these need to be investigated directly. Mingdi Gao is focusing attention on collision zones and is using the leucosome of a migmatite in his experiments.

Both Zsanett and Zairong are completing their PhD theses in early 2020: Zsanett has looked at melt compositions produced where the mantle contains oxidised fluid components with CO_2 and H_2O mixtures, whereas Zairong has produced the first-ever melt compositions for melting with CH_4-H_2O mixtures at low mantle pressures of around 2 GPa.

WORKPLAN 2020

Work will continue in 2020 towards developing the next generation of tools for Earth Science simulations - in particular novel techniques to model the interaction of fluid flow with solid geodynamic process, from the crust, to lithosphere, and deeper mantle.

Since the re-opening of the experimental laboratory, we have been joined by laboratory manager Svyatoslav ("Slava") Shcheka (*see p. 9*) and PhD student Chutian Shu (*see p. 47*). Slava joins us after several years at the Bayerisches Geoinstitut in Bayreuth, and Chutian from Guangzhou.

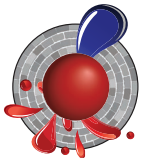
From 2020, the experimental laboratory is being run through the Australian Laureate project "*Deep Earth Cycles of Carbon, Water and Nitrogen*", with support from Macquarie University. Projects include reaction experiments on subduction zones, and the further development of experiments to facilitate the analysis of nitrogen in solid samples. Chutian's project considers the varied origins of hydrous pyroxenites in the mantle and assesses which melts could be produced from them.

Published outputs for 2019

CCFS publications: #1234, 1235, 1270, 1305, 1308, 1317, 1331, 1332, 1334, 1341, 1353, 1357, 1369, 1376, 1393, 1402, 1404, 1406, 1433, 1478, 1481.

>20 Conference Abstracts

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 and are involved in NASA's Mars2020 landing site selection process.

This program tests 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. A component of the program focuses on Mars to investigate whether the evolution of life and the genesis of mineral systems on the red planet operated in a broadly similar fashion. 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 the pathways that connect different geochemical reservoirs through time, linked to the changing tectonic style of the planet, as a guide to understanding biological and ore deposit evolution through time.

2019 REPORT

In 2019, research under the FP4 umbrella took a sharp turn towards studies focused on 1). the Geological Setting for the Origin of Life, as well as continuing investigations on 2). the Earliest Life on Earth, and 3) life's Adaptations to the Great Oxidation Event.

1) A great debate currently exists on the site for the Origin of Life, with implications not only for how life might have gotten started on our own planet, but where to search for life elsewhere in our solar system. This research focuses on two areas - active hot springs in New Zealand, and ancient, fossilised hot springs in NW Australia, hosted by the stromatolitic 3.48 Ga rocks of the Dresser Formation, Pilbara Craton. Specifically, the former informs interpretation of the latter, and the ancient site provides a key suite of information parameters on what an early Earth hot spring site looked like, including element concentrations and variations in the fluid chemistry. Investigations of the active NZ springs is focused on the additional complexity provided by hot springs mixing zones. In the ancient rocks, our focus is on the alteration geochemistry of the footwall and what that provides in terms of element mobility to the surface.

In terms of Astrobiology, this research has potential influence on future missions to search for life elsewhere in the solar system. The reason is that if life started in the deep oceans, as some believe, then the water-worlds of Enceledes and Europa might be interesting places to search for a second genesis. On these lines, Mars might not be so exciting, as it appears never to have had a global ocean and plate spreading. Alternatively, if life started on land, as more and more research now suggests, then these water-ice moons of the giant gas planets may not be so interesting to explore, as they may never have had the conditions necessary to get life started, even though they may present currently habitable environments for life as we know it on Earth. In this model, Mars becomes much a more interesting place to search for life, as it had volcanic heat, water, and known hot springs.

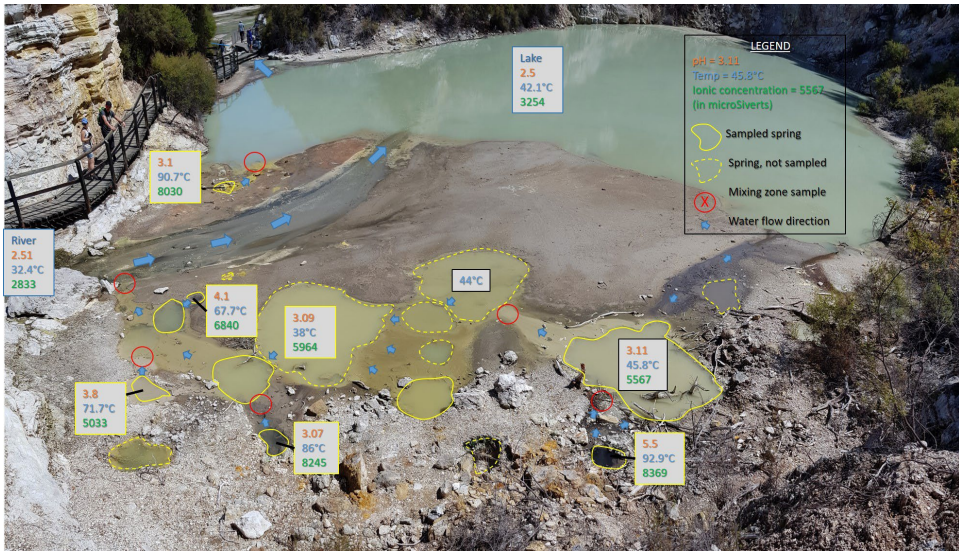
2) The search continues for strong evidence for the oldest life on Earth, from Greenland and the Pilbara region of NW Australia. In Greenland, a number of recent publications over the past 1-2 years supports the original interpretation of stromatolites discovered in 3.7 Ga meta-dolomites. Further study on these contentious rocks, their environment of deposition, context, and strain state continues. In the Pilbara, research continues on the evidence for early life in the 3.48 Ga Dresser Formation, both in terms of a better understanding of known evidence for life, but also in terms of descriptions of novel signs of life and the possible metabolisms they used. In addition is a major new focus on the newly discovered hot springs facies, funded in part by a Marsden Fund grant from New Zealand. An ongoing PhD project is investigating organic geochemistry of preserved organic matter.

3) This project focuses on the adaptation of life to the rise of free oxygen in Earth's atmosphere approximately at ~2.4-2.3 Ga. The study area is also in Western Australia, at a unique microbialite reef complex of the Turee Creek group preserved in the southern Hamersley Ranges. One PhD has been completed (E. Barlow, UNSW 2019), on microfossils, which has documented two new microfossil types - including a possible eukaryotic colonial form, as well as a deep sea, benthic, sulfur-cycling fauna.

WORKPLAN 2020

In 2020, research under the FP4 will continue to focus on the Geological Setting for the Origin of Life, The Earliest Life on Earth, and Life's Adaptations to the Great Oxidation Event.

Investigations into early life in active and ancient hot springs (New Zealand/Dresser Formation) and the oldest life on Earth in Greenland and the Pilbara will continue.



A collection of closely-spaced, diverse hot spring pools at Wai-O-Tapu, Rotorua, New Zealand, showing the chemical complexity present in a small area.

Two PhD studies are expected to complete; one on thrombolites and the general environmental conditions of the reef complex; the other on unique branching kerogenous structures that appear to represent an early attempt of biological complexity, possibly even eukaryotic. The organic matter of this ancient life is also being investigated.

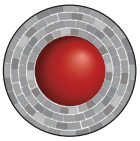
Published outputs for 2019

CCFS publications: #1153, 1154, 1362, 1364, 1379, 1437, 1443, 1448, 1470.

10 Conference Abstracts

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.

2019 REPORT

Since the completion of project funding in 2017, elements of this program have been incorporated within Z.X. Li's Laureate Fellow project. Previously reported palaeomagnetic results from the 1.8 Ga Hart Dolerite and 1.89 Ga Boonadgin dykes were officially published in early 2019 (*CCFS publications #1238 and #1123* respectively). Additional palaeomagnetic poles for the recently discovered 2.62 Ga and 1.39 Ga mafic dyke swarms from the Yilgarn Craton are still to be published and will be finalised in 2020. This work formed a significant part of the PhD thesis of Yebo Liu, which was submitted at the end of 2019.

Some additional palaeomagnetic work, performed in collaboration with a jointly appointed PhD student Wang Chong from the Institute of Geology and Geophysics, Chinese Academy of Sciences (and published in *Science Bulletin*), suggest the long-lived connection of the North Australian Craton to that of North China during the supercontinent Nuna. The work used palaeomagnetic as well as geological constraints to establish the evidence for this connection. One paper was published in *Science Bulletin* (*CCFS publication #1432*), and another paper has just been accepted for publication in *Solid Earth* (*Wang et al., 2020*).

Some other previously reported work (published early in 2019, *CCFS publication #1242*), which posited a global geodynamic model involving the superposition of a 1.2 Ga superocean cycle with a 600 Myr supercontinent cycle, received significant media attention through 2019 with numerous internet media articles (see links at the bottom of web site http://geodynamics.curtin.edu.au/research/research-highlights/decoding-earths-rhythms/). This model also gained additional support from subsequent publications (the paper has already been cited 15 times within one year of publication).

As part of Li's ARC Laureate Fellowship project, some additional significant publications have been generated by the oceanic-LIP sub-project. Together with Prof Li, Dr Doucet and PhD student Gamal El Dien (Fig. 1) we have published numerous high impact publications in 2019 relating to the geochemical signatures of mantle rocks and how they can be used to test

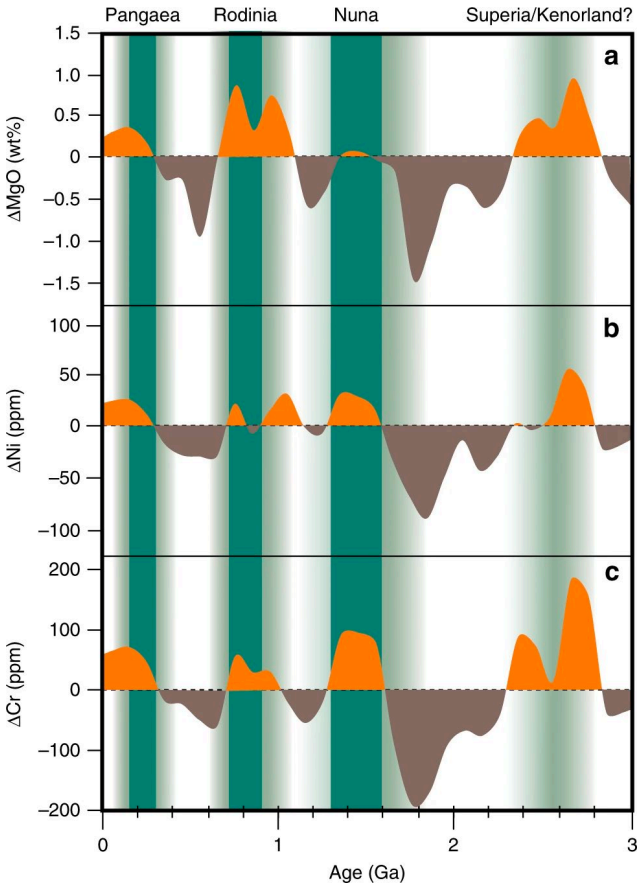


Figure 1. Global geochemical fingerprinting of plume intensity suggests coupling with the supercontinent cycle. The figure shows variability of global mean MgO, Ni and Cr in basalts after detrending the linear secular decreases. The major positive peaks at ~2.8–2.3 Ga, ~1.6–1.3 Ga, ~1.0–0.7 Ga, and ~0.3–0.0 Ga are broadly consistent with the tenures and break-up times of post-2 Ga supercontinents. The assembly and break-up of supercontinents are generally prolonged and multistage processes, which are marked by gradual green shading. See Gamal El Dien et al. Nature Communications, 10, 5270 for full caption (CCFS publication #1445).

the coupling between the supercontinent cycle and mantle dynamics (http://geodynamics.curtin.edu.au/research/research-highlights/shall-dance-600-million-years-long-steps/; http://geodynamics.curtin.edu.au/research/research-highlights/cr-spinel-records-metasomatism-not-petrogenesis-mantle-rocks/; http://geodynamics.curtin.edu.au/research/research-highlights/origin-arc-magmatic-signatures/). This exciting work is continuing to develop, and many more publications are envisaged in 2020 (*Earth Dynamics Research Group photo above).*

Earth Dynamics Research Group

Work has also progressed on a global paleogeographic animation spanning the past two billion years. Initial animations, back to the Neoproterozoic, along with the integration of the geological record (Large Igneous Provices etc.) into the otherwise predominantly palaeomagnetic reconstructions were presented at numerous conferences throughout the year. This work will continue into 2020 with publications to follow.

A significant event of 2019 was the naming of Prof Zheng-Xiang Li as one of 62 new AGU Fellows. This honour was bestowed at the AGU Fall Meeting 2019 in San Francisco, California (*see p. 19*).

WORKPLAN 2020

Numerous new findings, supported by Li's ARC Laureate Fellow project, are due to be published in 2020. Work will continue on the paleogeographic evolution of Australia in the Precambrian during 2020 utilising palaeomagnetism and geological evidence (including detrital zircon geochronology). The new palaeomagnetic poles from the 2.62 Ga and 1.39 Ga mafic dyke swarms of the Yilgarn Craton, a significant portion of Yebo Liu's PhD work, will be published. Palaeomagnetic results obtained from northern WA and the North Australian Craton will also be published to elucidate the Paleoproterozoic assembly of proto-Australia. An additional publication describing a modified SWEAT configuration of Australia and Laurentia during Nuna is also forthcoming.

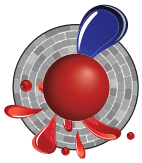
New global paleogeographic reconstructions that stretch into the Paleoproterozoic will be continually reported and published throughout 2020.

Published outputs for 2019

CCFS publications: #1011, 1123, 1182, 1238, 1242, 1306, 1355, 1371, 1432, 1436, 1445, 1447, 1456, 1457, 1459, 1461, 1465, 1467, 1469, 1473, 1474.

>20 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 record 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.

2019 REPORT

Work in 2019 was focused on the key regions on Earth containing examples of the earliest-formed crust (Antarctica, Labrador, Greenland and Tarim) and Hadean zircons (Jack Hills, Western Australia). In addition, work commenced on the 3.8 Ga rocks in the Ukrainian Shield with the appointment of Dr Leonid Shumlyanskyy as a post-doctoral fellow at Curtin, who took up the appointment in March 2019.

Further investigation of the Hadean and Eoarchean zircons from Jack Hills commenced with a number of local and international

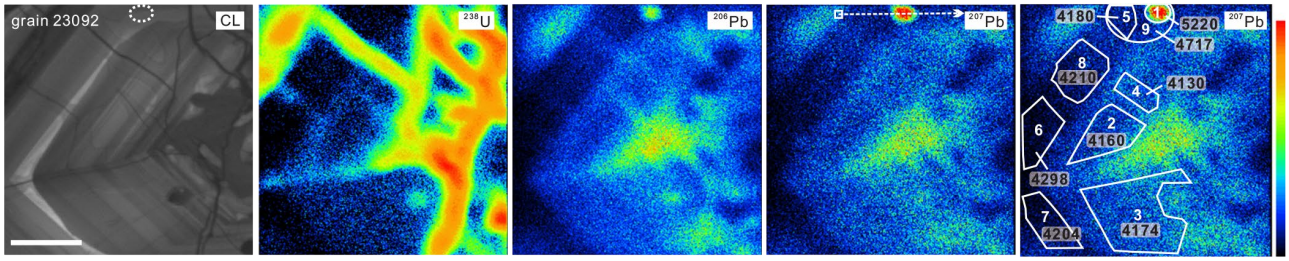


Figure 1. FP6. Pb images showing the internal structures, distribution of U-Pb isotopes, and calculated $^{207}Pb/^{206}$ Pb ages for various regions of interest (ROI) in Hadean zircon grain 23092. Colour scale indicates relative counts/pixel intensity of the ions. Note the first order control of the U, Th and Pb concentrations is by cracks, grain boundaries and CL zoning. Also note the presence of hotspots and patches of high ^{206}Pb and ^{207}Pb that do not correspond to high ^{238}U. These hotspots and patches correspond to different growth zones. They have exceptionally high apparent $^{207}Pb/^{206}Pb$ ages, and incorporating them into ~20 µm elliptical ROIs (similar to SIMS spot) results in spuriously older $^{207}Pb/^{206}Pb$ ages. Scale bar is 20 µm. See CCFS publication #1333.

collaborators. Former CCFS post-doctoral fellow Dr Rongfeng Ge's re-evaluation of the Jack Hills detrital zircon suite with respect to lead mobility was published in *Earth and Planetary Science Letters (CCFS publication#1333,* Fig. 1). In addition, we searched for lead nanospheres in a suite of zircons already investigated for the effects of recent weathering, involving former CCFS Marie Curie fellow Monika Kusiak and Dr Richard Wirth from Potsdam, Germany: the results will be published in 2020. A study of the trace elements in a suite of zircons ranging in age from 3.2 to 4.3 Ga was undertaken with Prof Simon Turner and the results were published in *Nature Communications* in 2020 (more on this next year!).

Further investigations of the distribution of the 3.7 Ga gneisses in the Tarim Craton continued in association with Associate Professor Rongfeng Ge from Nanjing University and a new paper was published in early 2020.

The Lu-Hf investigation of ancient zircon crystals from Aker Peaks in Kemp Land, Antarctica, proved to be more complex than originally envisaged and additional work was undertaken to resolve the issues. Metallic lead nanospheres identified in ancient zircons from the Napier Complex, Antarctica, were investigated by NanoSIMS and the work published in *Scientific Reports*.

Sample preparation and zircon separation continued on the samples collected in 2017 from the Saglek Bay area of Labrador, Canada, to further investigate the ancient gneiss complex. Two papers were published; one on a re-evaluation of the ancient Uivak gneisses (*International Journal of Earth Sciences*) and the other on the Neoarchean events affecting this ancient terrane (*Geological Society of London*).

Work commenced in West Greenland with a fieldtrip to Isua. Unfortunately, the weather was extremely inclement and we had only a limited time on the outcrops. However, a suite of samples was collected and shipped to Poland for initial preparation. The same bad weather that affected Greenland was also experienced on the opposite side of the Atlantic, and a planned trip to Labrador had to be cancelled.

Research continued in Antarctica with a grant from the Australian Antarctic Division to work on the legacy collection housed at Geoscience Australia in Canberra. The main aim is to investigate the extent of Eoarchean rocks across the Napier Complex. An additional aim is to resolve the extent of lead nanospheres in zircon across the complex and to establish how these might be related to the major metamorphic events. This project also involves Prof Martin Whitehouse in Stockholm and Prof Simon Harley in Edinburgh.

Lunar work in 2019 was focused on re-investigating the nature of the rocks at the Apollo landing sites and a series of papers were published. Work also continued on investigating lunar meteorites and also terrestrial impact craters, with special emphasis on the zircon signature. The identification that the lunar surface may possibly contain fragments of the Earth that were ejected when an asteroid struck was published in *Earth and Planetary Science Letters* in March 2019 (*CCFS publication #1494*) and is based on the ongoing study of material collected some 50 years ago from the Apollo 14 site. The sample contained quartz (extremely rare on the Moon) and zircon crystals unlike any previously described from the moon with respect to their geochemical signature.

WORKPLAN 2020

Work in Australia will remain focused on zircon from Jack Hills. Further work on Pb mobility in these grains will be undertaken using the atom probe to determine if lead nanospheres are present.

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. The full extent of Eoarchean rocks across the Napier Complex will be investigated using the legacy collection at Geoscience Australia.

Work will commence on samples collected from Isua, West Greenland in 2019, and continue on samples collected from Labrador in 2017. Work on the Eoarchean rocks of the Tarim Craton in China will likewise continue.

A new investigation of the Eoarchean and Hadean zircons in the Singhbhum Craton in India will commence in association with Dr Rajat Mazumder in Oman.

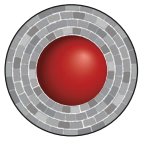
Work will continue on both lunar rocks and Martian meteorite samples with the aim of constraining the age of the oldest crust and the precise timing of events in the early solar system.

Published outputs for 2019

CCFS publications: #1333, 1439, 1440, 1442, 1444, 1446, 1452, 1454, 1455, 1458, 1461, 1462, 1463, 1464, 1466, 1468, 1493, 1494, 1495, 1496, 1497, 1498.

9 Conference Abstracts

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

The enormous size and limited outcrop of the Neoarchean Yilgarn Craton and the Proterozoic orogens around its margins are detrimental to a deep understanding of what controls the distribution of mineral resources and which geodynamic processes were involved in the tectonic assembly of the Australian continent. The principal aim of this program is to combine geological, geochemical and geophysical techniques to propose a 3D structural model of the lithosphere of the Yilgarn Craton and its margins. This aim is predominantly addressed through passive source seismic experiments and integrated analysis of Hf-isotope data.

2019 REPORT

In 2019 the Geological Survey of Western Australia commissioned Velseis Integrated Technologies to conduct a 2D seismic survey along an aggregate 305 km in seven traverses in the Eastern Goldfields of Western Australia. Velseis also undertook an initial interpretation of the data, with input from GSWA geoscientists, to identify major features and structures visible in the data. The data and interpretation were released to the public in September and presented to industry at the annual 'GSWA in the Goldfields' event in Kalgoorlie in November (*see photo below*).

A major task of the seismic component was to wrap up a significant field campaign in late November 2019 in which 60 broadband temporary stations were deployed for over a year in the Canning regions (the Canning Seismic project).

Related to the Canning seismic project, a collaboration to deploy a semi-permanent real-time seismic station along the Canning coastal area was carried out with Geoscience Australia to improve the national network coverage in the region, which will improve the capability in hazard assessment and structural imaging. In November an outreach presentation about the general seismic tools and the purposes of the Canning project was presented to the council members of the Canning Shire.

WORKPLAN 2020

The collected data from the Canning Seismic project will be analysed in 2020 to develop seismic velocity models of the crust and the shallow upper mantle which will provide tighter constraints to regional tectonic development and provide background (deep) knowledge for resources exploration purposes.

A related Chinese NSF proposal funded in 2019, starting in 2020, will expand the Canning project into the Archean cratonic regions. This 4-year project will also seek opportunities to put a second Ocean Bottom Seismic array offshore the Canning coastal region.

Published outputs for 2019

CCFS Publications: #1217, 1378, 1433, 1434, 1435.

8 Conference Abstracts

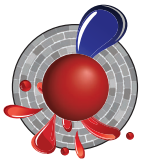
'GSWA in the Goldfields' event in Kalgoorlie

GSWA staff and exploration and mining industry practitioners at GSWA's Goldfields event, Joe Lord Core Library, Kalgoorlie, where new high-resolution seismic data was presented to industry along with relevant drillcore sections.

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.



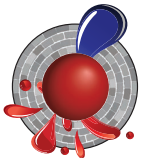
AIMS

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.

See "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 *(presented Goldschmidt 2019, Gréau, Alard, O'Reilly)*

(2) development of '*non-traditional*' stable isotopes

(3) characterisation of reference materials for elemental and isotope ratio measurement (*see CCFS publication #1330*)

(4) development of data reduction software for combined trace element and isotope analysis

See "Technology Development"

CCFS postgraduates

HONOURS

Joshua Chong (Hons): Petrological constraints on the genesis of Ni-Cu- PGE-(Au-Te) mineralisation associated with the La Balma-Monte Capio intrusion, Ivrea Zone, Italy (UWA, commenced 2019) *(pictured below: Ivrea Zone, Italian Alps, photo Greg Dering)*


Joshua Chong

Jessica Morrison (Hons): Thermochronology and Trace Element Characteristics of Apatite from the Nova-Bollinger Magmatic Ni-Cu Sulfide Deposit. (UWA, commenced 2019)

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.

AWARDED 2019

Michael Alderson: Spatially resolved Micro-XRF data for geochemical exploration strategies

Benjamin Alsop: Microstructural evidence of melt-present deformation and its effect on zircon modification

Lou-Andrea Gennatas: Geochronology and provenance of the Late Devonian Canowindra Fish Bed, Lachlan Orogen

Lauren Gorojovsky: Sulfur, selenium, copper, and tellurium systematics in the Manus Back-arc Basin *(pictured top right: Goldschmidt 2019)*

Lauren Gorojovsky

Stephanie Hawkins: Investigating an igneous dyke swarm using Applied Field Magnetics

Angela Mabee: Plume volcanism controls site1172 sediment provenance and deposition pre-Antarctic Circumpolar Current

Joshua Shea: Identifying a source assemblage for Buckland Volcanic Province

Alice Van Tilburg: Exploring lithospheric scale structure in the Southern Yilgarn Craton with 3D magnetotellurics

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 2012-2019. 41 papers with CCFS postgraduates as authors were published in high-profile international journals in 2019 including *Nature Communications, American Mineralogist, Chemical Geology, Geochimica et Cosmochimica Acta, Terra Nova, Geochemistry, Geophysics, Geosystems, Precambrian Research, Lithos, Tectonics, Chemical Geology* and *Journal of Geophysical Research*. 39 presentations were also given at international conferences (see *Appendix 4*).

2019 HIGHLIGHTS

Michael Förster joined CCFS as a postdoctoral researcher to work on the fate of nitrogen during subduction and recycling to Earth's mantle.

Anthony Lanati was awarded Best Presentation (Staff and People's Choice) at the MQ EES HDR Day 20 November 2019.

COMPLETED

Sonia Armandola (PhD): Detrital accessory phase geochemistry and geochronology of Capricorn basins and implications for the evolution of the Capricorn Orogen (WA) (CU 2018)

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

David Barbosa da Silva (PhD): The microchemical and microstructural evolution of fluid and melt transfer in deep crustal shear zones (MQ 2019)

Erica Barlow (PhD): Microfossils of the Paleoproterozoic Turee Creek Group: Biological evolution resulting from atmospheric change? (UNSW 2019)

Raphael Baumgartner (PhD): Ore deposits of the future; magmatic Ni-Cu-PGE sulfide mineral systems on Mars (UWA 2017)

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)

Richard Blake (MPhil): Determining recent organic contamination in ancient rocks (UNSW 2019)

Eleanore Blereau (PhD): Petrochronology of the ultrahigh-temperature (UHT) metamorphic Rogland-Vest Agder Sector, southwestern Norway (CU 2017)

Raul Brens Jr (PhD): Constraints on petrogenesis and elemental recycling of the Tonga-Kermadec Island Arc System and the associated Lau and North Fiji Basins (MQ 2018)

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

Stefano Caruso (PhD): Geological controls on the fractionation of multiple sulfur isotopes in Archean mineral systems; *SIRF & MRIWA Postgraduate Scholarship* (UWA 2019)

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

Mathieu Chassé (PhD): Mechanisms of enrichment of rare earth elements in supergene conditions (MQ 2018)

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)

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 2019) *(pictured below: Ivrea Zone, Italian Alps, photo Joshua Chong)*


Gregory Dering

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)

Raphael Doutre (PhD): Spatial periodicity, self-organisation and controls on large ore deposits (UWA 2018)

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)

Michael Förster (PhD): Experimental melting of rocks of ultramafic and sedimentary origin in accretionary orogens (MQ 2019)

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)

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

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

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

Christopher Gonzalez (PhD): CO_2 devolatilisation and its influence on partial melting, subduction, and metasomatism in the mantle lithosphere (UWA 2016)

Louise Goode (PhD): Investigating the magmatic drivers behind temporal variations in eruption frequency and style at Kelut volcano, Indonesia (MQ 2018) *(pictured below)*

Louise Goode and Hadrien Henry

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)

Michael Hartnady (PhD): Crustal evolution of the Albany-Fraser Orogen (CU 2019)

Hadrien Henry (PhD): Mantle pyroxenites: Deformation and seismic properties (MQ 2018) *(pictured above)*

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)

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

Constanza Jara Barra (PhD): Gold pathways: in the El Indio Belt, Chile-Argentina; *Barrick Exploration* (UWA 2019)

Kim Jessop (PhD): The role of aqueous fluids in the formation of regional-style high-temperature low-pressure (HTLP) metamorphic complexes (MQ 2018)

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

Heta Lampinen (PhD): Defining a base metal mineral systems footprint in the Edmund Basin of the Capricorn Orogen, Western Australia (UWA 2018)

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)

Shaijie Li (PhD): Isotopic dating oil generation and charge events in Canning (Australia) and Sichuan (China) (CU 2019)

Nora Liptai (PhD): Geochemical and physical properties and evolution of the lithospheric mantle beneath the Nógrád-Gömör Volcanic Field (Northern Pannonian Basin, Central Europe) (MQ 2018)

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)

Jianggu Lu (PhD): Mantle xenoliths from SE China and SE Australia: Nature and evolution of the lithospheric mantle (MQ 2018)

Yongjun Lu (PhD): Controls on porphyry emplacement and Porphyry Au-Cu mineralisation along the Red River Fault, Hunan Province, China (UWA 2012)

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)

Samuel Matthews (PhD): Novel applications of gravity gradiometry for the detection and monitoring of sequestered CO_2 (MQ 2019)

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

Holly Meadows (PhD): Mineral geochemistry, deformation and ore-fluid evolution in the Capricorn Orogen, WA (CU 2018)

Vicky Meier (PhD): Metamorphic evolution of the Kerala Khondalite belt, India (CU 2017)

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)

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)

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)

Valerie Roy (MSc): Hydrogeological and hydrogeochemical study of the Peak Hill-Horseshoe Deposit, Capricorn Orogen to identify mineral system footprints (UWA 2018)

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)

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

Camilla Stark (PhD): Decoding mafic dykes in the southern Yilgarn Craton: Significance to Australia's positions in the supercontinent-superplume cycle (CU 2018)

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

Catherine Stuart (PhD): Melt migration in the lower crust by porous melt flow (MQ 2018)

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

Sahand Tadbiri (MSc): The geometry and kinematics of hydrothermal veins in the c. 3.5 Ga Dresser Formation, North Pole Dome, Western Australia (UNSW 2019)

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)

Mehdi Tork Qashqai (PhD): Multi-observable probabilistic inversion for the thermochemical structure of the lithosphere (MQ 2017)

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)

Kai Wang (PhD): Adjoint tomography of surface wave observables from ambient seismic noise (MQ 2018)

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)

Shucheng Wu (PhD): The geodynamic setting of the Western Junggar region during the Late Paleozoic: evidence from seismic tomography (MQ 2019)

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)

Bo Xu (PhD): Mantle-derived igneous rocks from Southern Tibet: Nature and evolution of the lithospheric mantle and implications for mineralisation from subduction to collision (MQ 2019)

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)

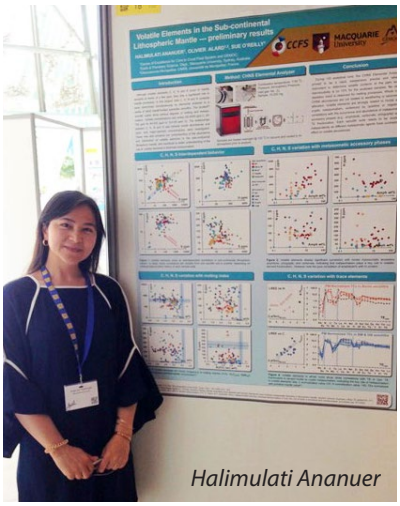
Kongyang Zhu (PhD): Petrogenesis and tectonic setting of Phanerozoic granitic rocks in eastern South China (CU 2014)

CONTINUING

Cameron Adams (PhD): Investigating the relationship between positive magnetic anomalies and nickel-sulphide deposits, Kambalda, Western Australia; *MRIWA* (UWA, commenced 2015)

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

Halimulati Ananuer (PhD): Abundance, Speciation and distribution of volatile elements in the SCLM; *MQRTP* (MQ, commenced 2017) *(pictured right, Goldschmidt 2019)*



Halimulati Ananuer

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)

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)

Maria Cherdantseva (PhD): The role of volatiles in the genesis of nickel-sulfide mineral systems; *CIPRS* (UWA, commenced 2019)

Eunjoo Choi (PhD): Alkaline magmatism as a probe into the lithospheric mantle; *IRPT, MRIWA* (UWA, submitted 2020)

Hongkun Dai (PhD): Nature and evolution of the northwest North China Craton; *iMQRES* (MQ, commenced 2018)

Andrei de Souza (MSc): Petrogenesis and isotopic constraints on the emplacement of discordant ultramafic pipes in the eastern Bushveld Igneous Complex, South Africa (UWA, commenced 2019)

Benedikt Demmert (PhD): Modelling the effect of minority components in biominerals via biomimetic mineralisation; CTIMRTPS (MQ, commenced 2018)

Tara Djokic (PhD): A reconstructed subaerial hot spring field in the ~3.5 billion-year-old Dresser Formation, Pilbara Craton, Western Australia; *APA* (UNSW, commenced 2016)

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; *RTP* (MQ, part time, commenced 2014)


Hamed Gamal El Dien

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

Hindol Ghatak (PhD): Role of fluids in facilitating the intracontinential Alice Springs Orogeny; *iMQRTP* (MQ, commenced 2017)

Markus Gogouvitis (PhD): Distinguishing hydration in shear zones by aqueous fluid versus silicate melt (UNSW, commenced 2018)

Stephanie Greene (PhD): Evolution of the lithospheric mantle sampled by the Jericho kimberlite, northern Slave craton, Canada; *IMRTPS* (MQ, commenced 2017)

Kui Han (PhD): Modelling the physical properties of multi-phase aggregates from the single phases; *IRPT* (MQ, commenced 2017)

Gonzalo Henriquez (PhD): Improving zircon morphology and chemistry as a tool for assessing and ranking the prospectivity for Cu porphyry deposits in greenfield terranes; *Industry - BHP Billiton* (UWA, commenced 2017)

Raham Jalil (PhD): Mineralogy, geochemistry and genesis of ophiolite associated economic minerals (PGEs, gold, silver, base metals and REEs) in Waziristan area, North-West Pakistan; *CFIMRTPT* (MQ, commenced 2018)

Anthony Lanati (PhD): Petrology, geochemistry and origin of the shoshonites; *RTP* (MQ, commenced 2018)

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)

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

Jiangyu Li (PhD): Thermal history of Proterozoic NE Australia: Insights into Nuna assembly and breakup; *CIPRS, CSC* (CU, commenced 2016)

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, submitted 2019)

Zairong Liu (PhD): Identifying source rocks and oxidation states in southern Australian volcanic rocks; *CTiMRTP* (MQ, submitted 2019)

Maria Constanza Manassero (PhD): A reduced order approach for probabilistic inversions of 3D magnetotelluric data; *iMQRES* (MQ, submitted 2019)

Erin Martin (PhD): Understanding Neoproterozoic geodynamics through H isotopes in zircon; *APA* (CU, submitted 2019)

Shiladitya Mazumdar (PhD): Biomineralisation pathways and element partitioning in calcium carbonate; IMRTPS (MQ, commenced 2017)

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

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

Stephanie Montalvo Delgado (PhD): Development and application of atom probe tomography to complex zircon grains; *CIPRS* (CU, commenced 2016)

Jonathan Munnikhuis (PhD): Microchemical and microstructural evolution of fluid and melt transfer in deep crustal shear zones; *iRTP* (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): Depositional environment of the c. 2.4 Ga Turee Creek Group, Western Australia; *RTP* (UNSW, commenced 2017)

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

Sinan Özaydin (PhD): Measuring the mantle hydrogen content of cratons by implementing the magnetotelluric method; *IMRTPS* (MQ, commenced 2018)

Sarath Patabendigedara (PhD): Quantifying the effects of surface and bulk proton transport in mantle materials; *IMRTPS* (MQ, commenced 2016)

Zsanett Pintér (PhD): The composition of melts in the incipient melting regime; *IMRTPS* (MQ submitted 2019)

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

Carla Raymond (PhD): Archaeometric investigations of Egyptian artefacts using novel techniques; *MRTPS* (MQ, commenced 2018)

Matthew Rowe (PhD): late Archaean granitic magmatism related to cratonisation and gold mineralisation in the Yilgarn Craton; *The Robert and Maude Gledden Postgraduate Research Scholarship, GSWA* (UWA, commenced 2017)

Farshad Salajegheh (PhD): 3D multivariable probabilistic inversion for thermochemical structure of Earth; *RTP* (MQ, part time, commenced 2014)

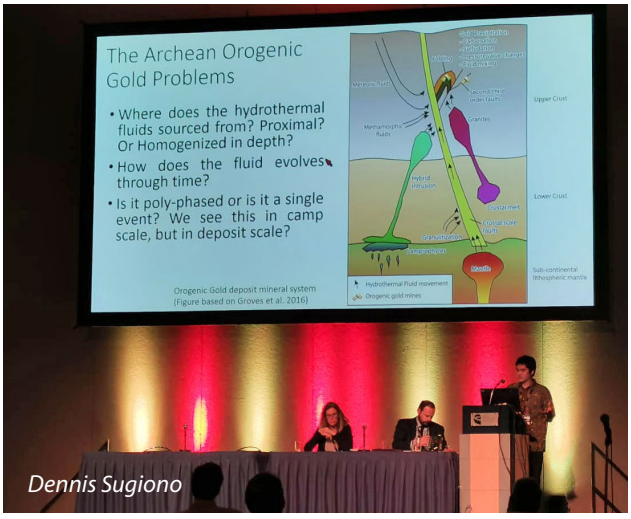

Chutian Shu

Chutian Shu (PhD): The role of hydrous pyroxenites in subduction zone magmas; *CTIMRTPS* (MQ, commenced 2019) *(pictured left)*

Georgia Soares (PhD): Evolution of complex life and the GOE; *RTP* (UNSW, commenced 2017)

Luke Steller (PhD): Movement and concentration of essential pre-biotic elements (with a focus on boron) in both ancient and modern hot spring systems (UNSW, commenced 2019)

Dennis Sugiono (PhD): Sulfur isotope application on the Kanowna Belle Deposit; *RTP-IPRS, Northern Star (Kanowna) Pty Ltd* (UWA, commenced 2017) *(pictured below)*



Dennis Sugiono

Lynthener Bianca Takenaka de Oliveira (PhD): Origin and composition of the subcontinental lithospheric mantle (SCLM) along the lineament of 125 Azimuth, Brazil; iMQRES (MQ, commenced 2019) *(pictured right)*


Lynthener and one of her doctoral supervisors, Professor Miguel Basei (Institute of Geosciences - USP), Goldschmidt 2019 (photo CPRM).

Bronwyn Teece (PhD): Organic geochemistry of complex life at the rise of atmospheric oxygen; *RTP* (UNSW, commenced 2018)

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

Anne Vernes (PhD): Understanding camp-scale crustal architecture and its effect on the channelisation of komatiite lava and Ni-Cu-PGE ore deposition (UWA, commenced 2019)

Marina Veter (PhD): Calibration of geochemical *"scouts"* for mantle processes; *IRTPS* (MQ, 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)

Alexander Walker (PhD): Sulphur isotope and trace element signatures within mineralised occurrences in the Fraser Zone, Western Australia; *CIPRS* (CU, submitted 2019)

Chengyuan Wang (PhD): Modification of mantle lithosphere: reaction between recycled carbonate melt and mantle peridotite; *CTIMRTPS* (MQ, submitted 2020)

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

Jonathon Wasiliev (PhD): Building a Super-Earth: Activation parameters in an alien mantle; (MQ, commenced 2013)

Anqi Zhang (PhD): Joint inversion of multiple geophysical data sets to constrain the evolution of the lithosphere beneath the Junggar and Tianshan, NW China; *CTIMRTPS* (MQ, commenced 2018)

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:

- 2 Cameca SX-100 electron microprobes
- a Zeiss EVO MA15 Scanning electron microscope (with Oxford Instruments Aztec Synergy EDS/EBSD and Horiba HCLUE spectral cathodoluminescence detector)
- JOEL benchtop Scanning electron microscope
- A Nanomin FEI Field Emision SEM
- Micro XRF M4 Tornado from Bruecker
- three Agilent quadrupole ICPMS (industry collaboration; one 7500cs; two 7700cx)
- two Nu Plasma multi-collector ICPMS
- a triple quad (Q3) ICPMS 8900
- a Nu Plasma II multi-collector ICPMS
- a Nu Attom high resolution single-collector sector field ICPMS
- 2 Thermo Finnigan Triton TIMS
- a Photon Analyte LSX213nm laser ablation system
- a Photon Machines Excite Excimer laser ablation system
- a Photon Machines Analyte G2 Excimer laser ablation system
- a Photon Machines Analyte198 Femtosecond laser ablation system
- Thermo Fisher Neptune Plus MC-ICPMS
- a PANalytical Axios 1kW XRF with rocker-furnace sample preparation equipment
- a Vario El Cube CHNS elemental analyser
- AEuro EA3000 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
- MP-AES (Microwave Plasma Mass Spectrometer)
- MAT 253+ Isotope Ratio Mass Spectrometer with IBEX
- 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 GEOCHRONOLGY

This facility has been successively 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.

Peter Weiland in the Clean Labs.

This facility is focused on *in situ* imaging and microanalysis of trace elements and isotopic ratios in minerals, rocks and fluids. A wide range of *in situ* geochronological analytical capabilities has backup from traditional solution methodologies.

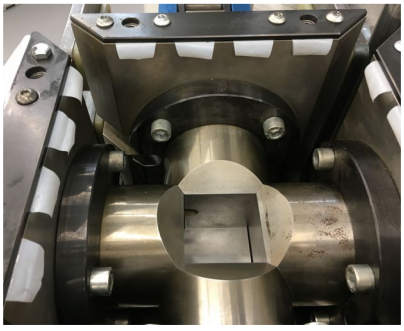
Major instruments were replaced or upgraded, many by joint ventures with national partners including Teledyne Cetac technologies, Nu Instruments, AMETEK and ThermoFisher Scientific.

EQUIPMENT FOR HIGH-PRESSURE EXPERIMENTATION

In April 2019, two multi-anvil presses were lowered into position through a removable roof. The larger MAX2003 is a cubic anvil set-up and is complemented by a Walker module in the smaller 1000 ton-press (*both pictured below*).

The extended laboratory now includes three multi-anvil apparatuses, one diamond-anvil cell and two piston-cylinder apparatuses. Two additional GUKO Sondermaschinenbau rapid-quench piston-cylinder apparatuses are due for delivery in 2020. There are also two Griggs apparatuses, a one-atmosphere quench furnace, a multi-anvil apparatus and a diamond-anvil cell apparatus.

Experimental projects 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.



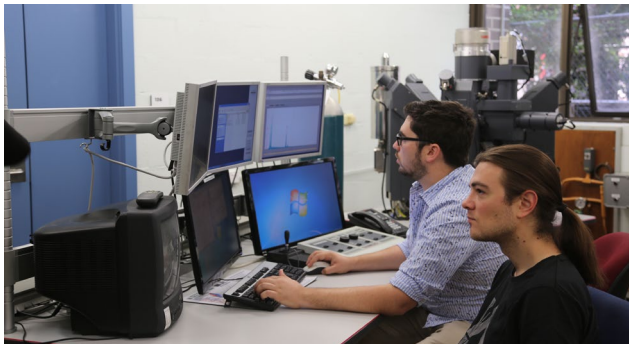
Cubic anvils MAX2003.

The FP3 870 LP1000 being manoeuvred into position

PROGRESS IN 2019:

1. Facility for Integrated Microanalysis

a. Electron Microprobe: Dr Timothy Murphy (*pictured below*), appointed in 2017, oversees the electron microprobe. The SX100 was fully refurbished by Cameca engineers (thanks to Nicolas Boutron and Pierre-Yves Corre) in November 2017 and now performs 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 has been updated with "*Probe*" software developed by John Donovan.



In 2019 a second SX100 (*pictured above*) was acquired from University of Tasmania and installed at MQGA. The instrument complements and expands the current EPMA equipment at MQGA and is set up with Probe for EPMA software and equipped with an anti-contamination stage, 5 WDS spectrometers, a Bruker EDS spectrometer and a Cathodoluminescence Light pipe. The installation of the new instrument will allow us to double our research output and method development as well as improving QA/QC of samples tested in MQGA.

CCFS and AuScope have 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. Earth and 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. Dr Timothy Murphy is leading a group developing new approaches with this instrument.

b. Laser-ablation ICPMS microprobe (LAM): Dr Yi-Jen Lai manages the extensive LA-ICPMS and MC-ICPMS instrument park available at Macquarie. CCFS Research Associate Yoann Gréau provides invaluable technical help and expertise. In 2019 CCFS technical and research staff Romain Tilhac and Hadrien Henry provided generous assistance for users. This will be continued by Montgarri Castillo-Oliver in 2020.

The Photon Machines Excite/G2 laser system and Agilent 7700 ICPMS are used for *in situ* trace element analyses and U-Pb

geochronology. An extremely mobile 213 nm Laser (LSX213, Teldyne) has been purchased to ensure service continuity. The facility is used by Macquarie PhD thesis projects, international visitors, Masters Research students and several in-house funded research projects and industry collaborations. Projects include 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.

Yi-Jen Lai and collaborators have launched an initiative aiming to develop LA-ICP-MS trace-element imaging. These techniques were applied in biological samples (e.g. skin) and archaeological samples (e.g. cattle's teeth). Thanks to an enhanced collaboration with Teledyne – PhotonMachine, an Aerosol Rapid Introduction System (ARIS) was recently installed on the Excite Excimer laser ablation system. Expected outcomes are a reduction in wash-out time and enhanced resolution. The ARIS is currently being integrated and methodologies are under development.

With the addition of trace gases such as N_2 and H_2 in the ablation gas, Olivier Alard and collaborators have obtained a significant increase in terms of sensitivity (counts per ppb multiplied by 2) and a noticeable decrease in detection limit. This breakthrough allows researchers to investigate: (i) olivine trace element abundances (i.e. higher sensitivity means complete REE patterns can now be obtained), (ii) ultratrace element concentrations and distributions between silicates, sulfides and oxides of rarely investigated elements such as metalloids from the d- and p-blocks elements (e.g. Sn, Sb, Cd, Mo, W…). This technique is now being applied by Marina Vetter (PhD), S. Foley and S. Demouchy (CNRS, Géoscience Montpellier). MQGS recently performed extremely well in the international round-robin (G-Probe) proficiency test for *in situ* trace element measurements.

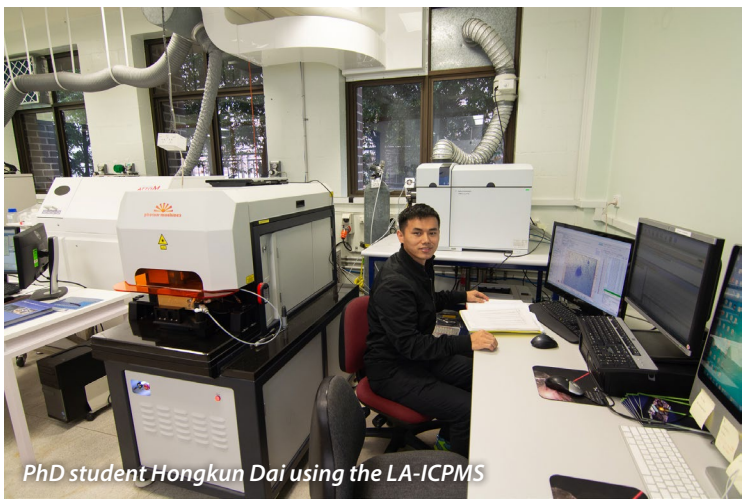
The new Q3-ICPMS (Agilent 8900) was installed in December 2017 and is co-located with the upgraded Nu-Plasma HR. The development of *in situ* Rb-Sr analysis is well underway. Preliminary results were presented by Lauren Gorojovsky and Olivier Alard at the Goldschmidt conference in August 2019 (Barcelona, Spain) and are now being published. In-house reference materials have been characterised to extend the range of material (matrix) analysed. The team led by Olivier Alard is also working on other developments for the precise (interference-free) measurement of chalcophile and siderophile elements for precise S-Se and Te analyses by LA-ICPMS in submarine glasses. Lauren Gorojovsky developed this approach during her MRes with great success. She is now pursuing this research in her PhD.

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-Oliver and Yoann Gréau have refined the measurement of *in situ* Sr isotopes in carbonate and clinopyroxene by LA-MC-ICPMS. The *in situ* measurement of U-Pb isotopes in zircon using a 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*). A UPS and new Daly detectors were installed on the Nu Plasma II MC-ICPMS in early 2020. The larger dynamic range will offer more flexibility and stability, especially for *in situ* techniques requiring simultaneous measurement of abundant and rare isotopes such as *in situ* Re-Os. 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.

In 2015 a third Photon Machines excimer laser microprobe was installed and co-located with the Nu Plasma HR 034. The interface was upgraded, increasing sensitivity between 1.5 and 2 times, and this contributed to an overall improvement in signal stability, as well as precision of single measurements and long-term reproducibility.

CCFS Research Associate Dr Yoann Gréau and Dr Olivier Alard (Future Fellow), have recently made good progress in method development. A novel split-stream approach has been established, involving the simultaneous measurement of Re-Os isotopes on the Nu plasma II and siderophile and chalcophile trace elements on the Agilent 7700. Preliminary results for this world first were presented at the Goldschmidt 2019 conference in Barcelona. Future Fellow Olivier Alard is undertaking studies on worldwide mantle sulfides. The project



PhD student Hongkun Dai using the LA-ICPMS

integrates *in situ* Platinum Group Elements, Re-Os and S isotopes obtained using the newly established Laser splitting system (MU) and ion probe (CAMECA 1280, CMCA Perth) respectively, in collaboration with CCFS Research Associate Laure Martin (UWA). This project pushes the concept of analytical integration to a new level. Planned applications are (i) combined U-Pb and Lu-Hf characterisation of zircons and (ii) simultaneous measurements of Sr isotopes and trace elements in silicates and carbonates. New technique strategies involving splitting with the Q3-ICPMS are also being investigated.

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 were up-scaled in 2019 with the involvement of Dr Romain Tilhac and Hadrien Henry 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). Isotope dilution routines are being implemented by Peter Weiland and will soon be available.

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 2019 a further 4 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 2019 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 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. This year the PANalytical was refurbished to maintain high accuracy and precision. Round-robin tests (GeoPT) show the PANalytica Axios is performing very well.

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 Halimulati Ananuer, Michael Förster). A large suite of reference materials (n≈43), with variable matrix and composition, has been measured and the results were presented at the Geoanalysis Conference (held at Macquarie University in July 2018). The Elementar analyser yields remarkably accurate and reproducible measurements for C, H, N and S at low levels for relatively small samples (i.e. ≈20 mg). Refurbishment of a second Elemental analyser (Euro Vector) is underway. This instrument will be dedicated to the measurement of small samples (i.e. <20 mg).

3. Whole-rock solution analysis

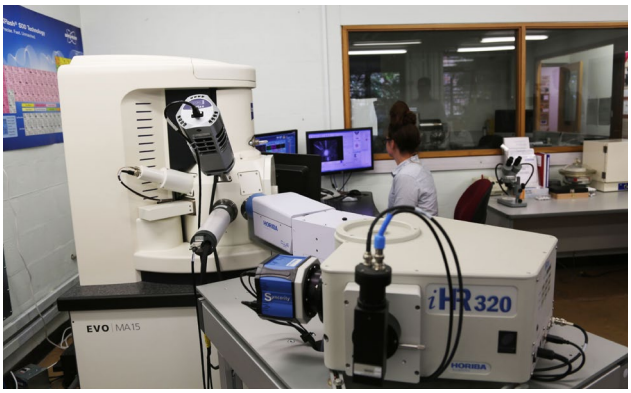
An Agilent 7500cs ICPMS produces trace-element analyses of dissolved rock samples for the projects of CCFS/GEMOC researchers and students and external users, supplementing the data from the XRF. We are testing the performance of the Nu Attom for ultratrace element measurements. The ICPMS dedicated to 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 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. In 2019 the system's capabilities were extended with the loan of a liquid nitrogen cold stage from the Department of Physics. The instrument continued to grow its user base across the Faculty of Science and Engineering at Macquarie University with users from Chemistry, Physics, Biology, Environmental Sciences as well as users from the Faculty of Arts, Department of Ancient History and the Museum of Ancient Cultures.

2019 research and applications of Raman Spectrometry included:

- Earth and Planetary Science, analysis of sulfate speciation in glasses (Dr Oliver Alard and Lauren Gorojovsky)
- Forensics applications, namely ink characterisation on Egyptian papyrus (Prof Damian Gore and Assoc Prof Malcolm Choat)
- Chemistry, surface enhanced Raman spectroscopy (SERS) of nano particle interactions in serum (Dr Alfonso Garcia-Bennett and Inga Kuschnerus)
- Physics and Astronomy, Photoluminescence/ Raman characterisation of UV Laser irradiated diamond surfaces. (Mojtaba Moshkani)
- Physics and Astronomy, localised dehydroxylation in the Muscovite using single ultrafast (fs) laser pulse. (Saurabh Awasthi)
- Physics and Astronomy, analysis of diamond seeded silicon surfaces and structural analysis of diamond thin films grown at low substrate temperature by microwave plasma chemical vapor deposition (MPCVD) (Fatima Zahra).
- Archaeology, oxide and corrosion analysis of ancient lead scrolls (Prof Simon Clark and Carla Raymond)
- Archaeology, identification of pigments used in Egyptian Mummy Carapace (Dr Karin Sowada and Dr Ronika Powers)
- Archaeology, pigment analysis of Amarna Blue used in Egyptian pottery (Prof Martin Bommas, Dr. Tim Murphy, and Penelope Edwell)

7. Computer cluster

Computational geodynamics has been supported throughout this project through a number of in-house machines (Enki and Toto), as well as a Macquarie partnership with NCI, that has enabled large project-based allocations on the national machines. The former resources have enabled the development and testing of in-house computational tools, including Aspect modules (led by Craig O'Neill and former postdoc Siqi Zhang) to model crustal production, impact melting and magmatic melt emplacement, and also Litmod in modelling crustal and lithospheric structure. Our access to the large scale facilities has enabled production-level simulations and has supported > 5 PhD projects, postdocs and numerous Masters projects.

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 (2xJEOL 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)

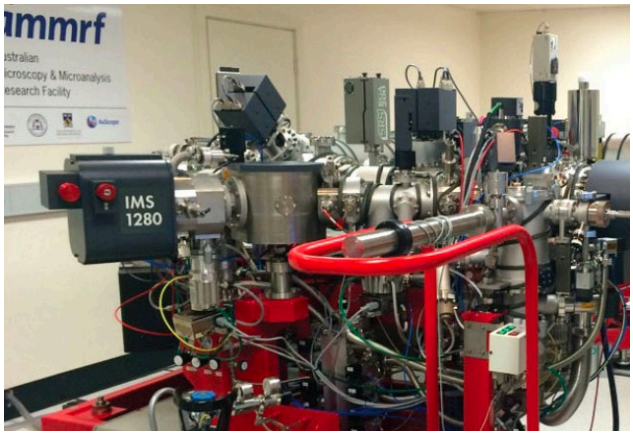
- X-ray micro-CT (Xradia)
- Confocal Raman imaging with AFM (WiTec Alpha 300RA+)
- NMR spectroscopy (2 Bruker Avance and 2 Varian spectrometers)
- X-ray crystallography (Oxford Diffraction)
- GC and HPLC mass spectrometry
- Bioimaging, flow cytometry, cell sorting, and laser micro-dissection
- Optical and confocal microscopy
- Biological sample cryo-preparation and ultramicrotomy

THE AMMRF FLAGSHIP ION PROBE FACILITY

The CAMECA SIMS 1280 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 i*n 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 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 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.



CAMECA SIMS 1280.

PROGRESS IN 2019:

The Ion Probe Facility has continued to contribute to various projects in the context of CCFS. Both 1280 and NanoSIMS laboratories contributed to individual projects in Earth Sciences, originating from CCFS partners, other Australian research institutes and overseas.

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. The new instrument was installed in early 2019.

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 based at Curtin University and forms one of the university's core research centres. The centre houses advanced instrumentation for high-quality chemical, mineralogical and microstructural analysis, and high-resolution imaging. 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 JdLC will soon be home to new equipment vital for gaining a better understanding of the Earth and its place in the Universe after AuScope received $5 million in Federal Government funding. A new replacement Sensitive High-Resolution Ion Microprobe (SHRIMP) age-dating instrument will be installed at the John de Laeter Research Centre at Curtin. Funded through the National Collaborative Research Infrastructure Strategy, the new SHRIMP will enable continued research and innovation. AuScope's SHRIMP instrument forms part of the Earth Composition and Evolution infrastructure located at Curtin University, The University of Melbourne and Macquarie University.

The JDLC website (http://www.jdlc.edu.au) provides detailed information on the multiple facilities, instruments and research staff that make up the centre.

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

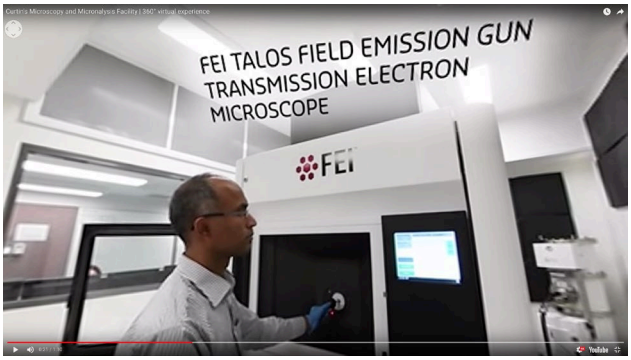
semiconductors and metal alloys, the GAP is the first atom probe facility in the world to be dedicated to the study of geological materials (http://www.geoscienceatomprobe.org). The ARCF also commissioned a Tescan Lyra focused-ion-beam scanning electron microscope (FIB-SEM), with a Ga+ gun capable of 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 backscattered 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 at the nanoscale.

(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.



Take a 360° virtual tour of Curtin's Microscopy and Micronalysis Facility at https://www.youtube.com/watch?time_continue=21&v=mEtg_citH_w.

(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 is available through a FEI Talos F200X transmission electron microscope (TEM), which was 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 instrument is capable of elemental and microstructural analysis at extremely high magnifications.
- Spatially resolved elemental analysis (EDS) and phase and orientation analysis (EBSD) on a Tescan MIRA3 platform - a variable pressure field emission scanning electron microscope (VP-FESEM) that features sensitive EDS and Oxford Symmetry EBSD detectors and integrated software for high quality microstructural analysis of crystalline samples. In 2019 this instrument will be complemented by a new state-of-the-art FESEM with a second Symmetry EBSD system, which will allow EBSD analysis at up to 3000 Hz.
- 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:
The 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.

(WAAIF) Western Australian Argon Isotope Facility:
This is located at Curtin and is equipped with A MAP215-50 mass spectrometer and an Argus VI Multi-Collector Noble Gas Mass Spectrometer with a low-blank automated extraction system coupled with a New Wave Nd-YAG dual IR (1064 nm) and UV (216 nm) lasers, electromultiplier detectors and Niers sources. 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 $^{40}Ar/^{39}Ar$ 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

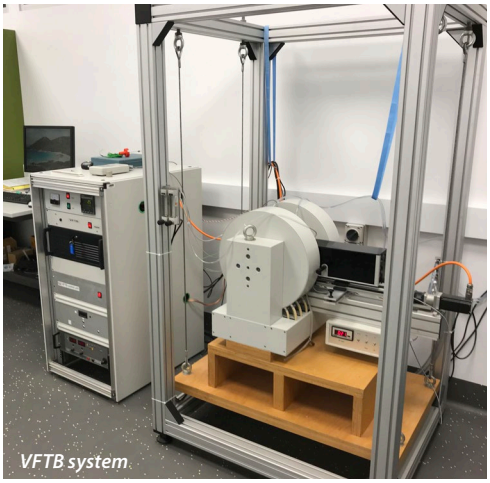
WESTERN AUSTRALIA PALEOMAGNETIC AND ROCK-MAGNETIC FACILITY

The Western Australia Paleomagnetic and Rock-magnetic Facility is a national research infrastructure supported 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 facility is now completely housed in purpose-built laboratories on Curtin University's Bentley campus.

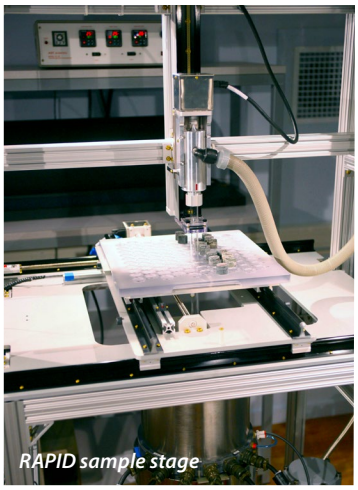
Inside the Shielded Room

A significant component of the facility is the magnetically shielded room (constructed in mid-2015 by Dr Gary Scott's team) which provides a 20m^2 laboratory space with ambient magnetic fields less than 0.5% of the local geomagnetic field. Within this shielded room are: a 2G 755 superconducting rock magnetometer with a vertical Model 855 automated sample handler (the RAPID system), an AGICO JR-6A spinner magnetometer, and ASC TD-48SC and MAGNETIC MEASUREMENTS thermal demagnetisers. An earlier model 2G 755 cryogenic magnetometer, which underwent repair and upgrade during 2017-18, was installed within the shielded room during the first half of 2019.

Other apparatus are housed in the renovated laboratory spaces surrounding the shielded room and include: a MAGNETIC MEASUREMENTS MMPM5 pulse magnetiser, an AGICO MFK-1FA Kappabridge, and the Petersen Instruments Variable Field Translation Balance (VFTB). In mid-2018 both the Kappabridge and VFTB were upgraded to bring them up to the current state-of-the-art. A temperature-susceptibility (K-T) module was added to the Kappabridge and a full electronics upgrade was performed on the VFTB system, improving the sensitivity and response time, as well as providing additional functionality (First Order Reversal Curve measurement). An additional module has also been recently installed on the RAPID system to enable acquisition, and subsequent measurement, of Isothermal Remanent Magnetisation (IRM).



VFTB system



RAPID sample stage

The recent purchases, upgrades 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, ARM and IRM modules)
- an earlier model 2G 755 cryogenic magnetometer upgraded to a 4K DC SQUID system (plus a recent upgrade carried out by 2G enterprises, including the repair of the lightning-damaged cold head)
- 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, reconstructing 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.

A national workshop on paleomagnetism, rock magnetism and their applications to tectonics, paleoclimate research, and Earth resource exploration will be conducted in February 2020. It will include a tour of the facilities along with training on the operation of all instruments for potential users of the laboratory.

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 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/who-we-are/collaboration) provides CCFS with a unique interface with a broad spectrum of mineral exploration companies and many CET activities (e.g. research projects, workshops and postgraduate short courses).

SUPPORT SOURCES

CCFS industry support includes:

- direct funding of research programs
- industry subscriptions (CET)
- '*in kind*' funding including field support (Australia and overseas), access to proprietary databases, sample collections, digital datasets and support for GIS platforms
- logistical support for fieldwork for postgraduate projects
- collaborative research programs through ARC Linkage Projects and the University External Collaborative Grants (e.g. Macquarie's Enterprise Grant Scheme) and PhD program support
- assistance in the implementation of GIS technology in postgraduate programs
- participation of industry colleagues as guest lecturers in undergraduate units
- extended visits by industry personnel for interaction and research

ACTIVITIES IN 2019

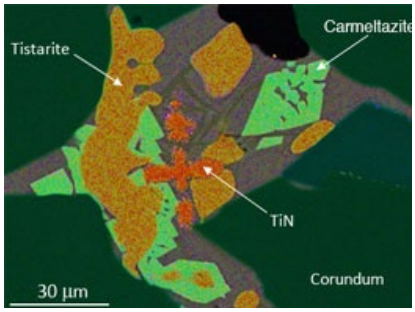
- *TerraneChron*® studies (*see p. 59* and http://www.gemoc.mq.edu.au/TerraneChron.html) have enjoyed continued uptake by a significant segment of the global mineral exploration industry. This methodology, currently unique to CCFS/GEMOC, requires the integration of data from three instruments (electron 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 32,000 zircon U-Pb and Hf-isotope analyses) in the Macquarie laboratory allows unparalleled contextual information in the interpretations and reports provided to industry. Associate Professor Elena Belousova delivered a keynote presentation at Goldschmidt 2019 titled *TerraneChron*®'s trajectory 2000-2030.
- In 2019 the Geological Survey of Western Australia commissioned Velseis Integrated Technologies to conduct

UNCOVER AUSTRALIAN EXPLORATION GEOSCIENCE RESEARCH

CCFS supports the national UNCOVER initiative: CCFS Chief and Associate Investigators, collaborating researchers and Board members have been instrumental in shaping UNCOVER Australia and 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. ***http://www.uncoverminerals.org.au/***

a 2D seismic survey along an aggregate 305 km in seven traverses in the Eastern Goldfields of Western Australia. Velseis also undertook an initial interpretation of the data, with input from GSWA geoscientists, to identify major features and structures visible in the data. The data and interpretation were released to the public in September and presented to industry at the annual '*GSWA in the Goldfields*' event in Kalgoorlie at the Joe Lord Core Library on Thursday, 28 November 2019. GSWA's 2019 High-Resolution Seismic Survey was presented to Industry, and relevant drillcore was on display *(pictured p. 39)*.

- The CCFS collaboration with Shefa Yamim (A.T.M.) Ltd. (Akko, Israel) continued in 2019. As part of the collaboration the mineral Carmeltazite was discovered in pockets of trapped melt in corundum xenocrysts from the Cretaceous Mt Carmel volcanics of northern Israel by CCFS's Bill Griffin, Sarah Gain, Luca Bindi (Università degli Studi di Firenze, Italy), Vered Toledo (Shefa Yamim Ltd., Israel), Fernando Cámara (Università degli Studi di Milano, Italy), Martin Saunders (UWA) and Sue Y. O'Reilly. In 2019, the IMA Commission on New Minerals, Nomenclature and Classification chose carmeltazite as its Mineral of the Year 2018.



- GSWA Open Day 2019: The popular annual event which showcases the latest geological information and major activities of the GSWA was held on Friday, 22 February at the Esplanade Hotel in Fremantle.
- CET held their annual "*Corporate Members Day*" on the 27th of November 2019, 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 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.
- The "*LAMP*" (Lithosphere Architecture Mapping in Phanerozoic orogens) project was originally funded 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.

  In 2019 a new project "*Archean mantle and plate tectonics: the seismic record of arc magmatism*" commenced. The multi-disciplinary project (geophysics, geochemistry and modelling) will examine the robustness of global horizontal-Vs tomographic models. The project also aims to characterise the seismic signature of subduction zones in ancient terranes. The role of subduction processes in the formation of mineral deposits (e.g. Cu, Au) in these ancient terranes, now undercover, is critical for future mineral exploration.

  Dr Begg spent significant research time at GEMOC through 2019 as part of the close collaborative working pattern for this project *(pictured below)*.

- In the project "*Developing thermochemical models of Australia's lithosphere*" funded by GA, researchers from GA and CCFS are using and further developing the LitMod inversion platfom to study the deep architecture and thermochemical structure of the Australian continent using recently acquired datasets from the AusLAMP and AusArray national initiatives. This represents one of the largest probabilistic inversions ever attempted, which required the development of efficient multi-algorithm techniques and parallel software infrastructure.
- Industry partners provided mentoring and both logistical and financial support for CCFS postgraduate research projects in 2019.

  Through a Cotutelle PhD, the Geological Survey of Brazil (CPRM) is collaborating by providing samples for Lynthener Bianca Takenaka de Oliveira's PhD project, including mineral concentrates, diamonds and thin sections. The collaboration, also allows access to internal geochemistry datasets, geophysical and geological maps, software licences and collaboration with other researchers from the company on data treatment, interpretation and scientific writing.

  A project funded by Northern Star Resources is providing funding for Dennis Sugiono's PhD project including a PhD scholarship as well as additional funding for analytical costs and travel.

  Other participating organisations include: BHP Billiton (BHP Chile Inc.), Barrick Exploration (Compania Minera Barrick Chile Ltd.)., Teck Resources Ltd, CSIRO, ANSTO and MRIWA. See *CCFS postgraduates* (*pp. 41-47*) for a full list of postgraduate projects.


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
ARC CoE CCFS & GEMOC National Key Centre
Department of Earth and Planetary Sciences
Macquarie University, NSW 2109, Australia
www.gemoc.mq.edu.au/ www.ccfs.mq.edu.au/
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

- The Linkage project "*Illuminating AusLAMP*", led by Profs Klaus Reguenauer-Lieb and J.C. Afonso, includes over 6 industry partners. The project attempts to provide a new conceptual and computational platform for interpreting data from the AusLAMP initiative using advanced physical models rooted on fundamental physics and thermodynamics. The result will be a collection of predictive tools and models to assist in the exploration of energy and minerals, as well as a more fundamental understanding of the MT signals at continental scale. As part of this project, the first 3D full probabilistic inversion software for MT and joint MT+seismic data will be developed
- In 2019, Marco Fiorentini continued to collaborate with BHP on the utilisation of detrital minerals in the exploration for porphyry systems. This project involves PhD student Gonzalo Henriquez and long-term CCFS collaborator Bob Loucks. This work has laid a robust foundation for the establishment of a new 3-year BHP-funded project that is set to start in late 2020 in collaboration with the University of Bristol, UK.
- A new multi-sponsored MRIWA project (M 530 Yilgarn 2020) has started in 2019. The project aims to constrain the multi-scale controls on the metal endowment of the Yilgarn Craton. A lot of this work is underpinned by science developed throughout CCFS.
- Ongoing engagement with IGO aims at developing predictive understanding of the genesis of chonoliths that contain magmatic nickel-sulfide mineralisation. The work is focused at the Nova-Bollinger Nickel Deposit, in the Albany-Fraser Belt of Western Australia.
- Industry visitors spent varying periods at Macquarie, Curtin and UWA (CET) in 2019 to discuss our research and technology development (see visitor list, *Appendix 5*). This face-to-face interaction has proved highly effective both for CCFS researchers and industry colleagues.
- 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 2019 (see Abstracts, *Appendix 4*).

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.

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 the granting of licence to use methodologies developed.

Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia

Linkage Project (LP160100483)
Industry Collaborators: Rio Tinto Limited; Alkane Resources Ltd; Sandfire Resources NI; 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.

Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP)	***Linkage Project (LP170100233)*** ***Industry Collaborators: CSIRO, Geological Survey of NSW, Geological Survey of South Australia, Geoscience Australia, Northern Territory Geological Survey*** ***CIs: Regenauer-Lieb, Afonso, Clark, Thiel, Czarnota, Poulet, Jones, Walsh*** ***Summary:*** This project aims to provide a newly developed science approach to the Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP). AusLAMP provides unparalleled geophysical information aimed at unravelling the tectonic history of the Australian continent and its mineral potential. The project will use thermodynamically based geodynamic simulators to jointly analyse and quantify intraplate deformation. This will illuminate the cause of driving fluid flow thorough the lithosphere, mineralisation phenomena, their datasets and geometries, and dynamic aspects of the processes driving mineral systems.
Enabling 3D stochastic geological modelling	***Linkage Project (LP170100985)*** ***Industry Collaborators: AUSCOPE, British Geological Survey, Department of Planning and Environment, Geological Survey of Canada, Geological Survey of South Australia, GSWA, Geoscience Australia, Northern Territory Geological Survey, Research for Integrative Numerical Geology, Georessources - Université de Lorraine, RWTH Aachen University of Technology, Germany*** ***CIs: Ailleres, Jessell, de Kemp, Caumon, Wellmann, Armit, Droniou, Lindsay, Cui, Betts, Cruden, Kemp, Gessner, Spampinato, Harrison, Kessler*** ***Summary:*** The project aims to develop technologies to mitigate 3D geological risk in resources management. The project is expected to create new knowledge and methods in the field of 3D geological modelling through the innovative application of mathematical methods, structural geology concepts and cutting-edge probabilistic programming. The expected outcomes are an enhanced capability to model the subsurface, characterise model uncertainty and test multiple geological scenarios. This enhanced capability is extremely important for the future of Australia's subsurface management; including urban geology and our continuously growing sustainable resources industry (including water).
Enhanced 3-D seismic structure for Southwest Australia	***Linkage Project (LP180101118)*** ***Industry Collaborators: Geological Survey of Western Australia ; Geoscience Australia; Department of Fire and Emergency Service*** ***CIs: Miller, Kennett, Yuan, Allen, Gray, Gessner*** ***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.
Archean mantle and plate tectonics: the seismic record of arc magmatism	***Industry Collaborator: Minerals Targeting International (PI G. Begg)*** ***CIs: Griffin, O'Reilly, Begg*** ***Summary:*** This multi-disciplinary project (geophysics, geochemistry and modelling) will examine the robustness of global horizontal-Vs tomographic models. The project also aims to characterise the seismic signature of subduction zones in ancient terranes. The role of subduction processes in the formation of mineral deposits (e.g. Cu, Au) in these ancient terranes, now undercover, is critical for future mineral exploration.

Multiple sulfur isotope systematics of the Kanowna Belle Gold deposit	***Industry Collaborator: Northern Star Resources Ltd*** ***CIs: LaFlamme, Thébaud, Fiorentini*** ***Summary:*** This study aims to 1) resolve the paragenetic sequence of veins in relation to the mineralisation, intrusions and structural episodes of the Kanowna Belle deposit, Western Australia, 2) apply the quadruple sulfur isotope techniques in conjunction to the vein paragenesis and structural events to understand the evolution, possible source changes of hydrothermal fluids and their relationship to the tectonic framework changes in Archean orogenic gold deposits, and 3) carry out in-depth mineral scale quadruple sulfur isotope analysis incorporated with other geochemical analyses to interpret how gold is transported and precipitated in Archean orogenic gold systems.
Genesis of the Nova Nickel Deposit	***Industry Collaborator: IGO Independence Group*** ***CIs: Barnes, Fiorentini*** ***Summary:*** This study aims to determine the multiple sulfur isotope architecture of the Nova-Bollinger deposit in the Albany-Fraser Belt of Western Australia by spatially mapping tracer S isotopes across the orebody as well as country rocks.
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 mineralisation. Then, how do we 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.
Yilgarn 2020	***Supported by MRIWA M530*** ***Industry Collaborators: Gold Road Resources, BHP Billiton Nickel West, Newmont, Northern Star Resources Limited, Saracen, Evolution Mining*** ***CI: Thebaud, Aitken, Jessell, Occhipinti, Dentith, Hagemann, Kemp, Fiorentini, Smithies, Lu, Gessner*** ***Summary:*** Yilgarn 2020 is a 3-year research-intensive program that integrates priority research and technology activities with complementary data compilation and targeted data acquisition. The research project is articulated into three modules ranging from regional- to camp- and deposit-scale studies applied to both well-mineralised, and less well-endowed areas. The combination of studies conducted on both mineralised and less mineralised areas is critical to evaluate and test the robustness of perceived mineralisation controls derived from the study of well mineralised domains.
Multiobservable thermochemical tomography of Central and South Africa	***Industry Collaborator: DeBeers*** ***CI: Afonso*** ***Summary:*** This ambitious project co-funded by DeBeers involved the creation of a 3D thermochemical model of Central and South Africa at a resolution of .5x.5 degrees via Multi-observable Thermochemical Tomography (MTT), a technique developed by CCFS researchers. The model will be used for exploration strategies as well as for understanding the complex physiochemical evolution of this part of the African continent and the interaction between plates and deep mantle dynamics.

Resistate indicator minerals for magmatic nickel sulfide ores	***Industry Collaborators: Anglo American, CSIRO, UWA*** ***CIs: Fiorentini, Barnes*** ***Summary:*** This project aims at investigating the potential of silicate and oxide phases such as olivine, pyroxene and chromite to be used as resistate indicator minerals in the exploration for magmatic nickel sulfide ores. Minerals from selected samples from a number of representative ore systems are investigated with *in situ* analytical techniques available at CSIRO and UWA.
Establishing the precise width of the Ni-Cu ore- forming window along the Halls Creek Orogen of Western Australia through CA-IDTIMS high- precision geochronology	***Industry Collaborators: Panoramic Resources and Innovation Connections*** ***CIs: Fiorentini, Denyszyn*** ***Summary:*** This project, in partnership with industry and the Commonwealth government, investigates the role of high-precision geochronology as a tool to unveil the timescales of ore forming processes in magmatic systems. The natural laboratory is the Savanna nickel sulfide ore in the Kimberley, Western Australia.
Geochemical appraisal of mafic and ultramafic rocks from a series of IGO prospects along the Albany-Fraser Belt of Western Australia	***Industry Collaborator: IGO*** ***CI: Fiorentini*** ***Summary:*** This project aims at characterising the geochemical and isotopic signature of mafic and ultramafic rocks located in the Proterozoic Albany-Fraser Belt, which is located along the south-eastern margin of the highly metallogenic endowed Yilgarn Craton, Western Australia. The focus is to build on the wealth of existing information and understand whether fertile magmas display geochemical and isotopic features that may be useful to identify them during exploration.
Tectonic evolution and amalgamation of continental, arc and arc-related terranes of Northern Thailand	***Industry Collaborator: Auldana*** ***CIs: George, Fiorentini, Parra Avila*** ***Summary:*** This project centres on the characterisation of volcanic and sedimentary records to unravel the records of convergence and amalgamation of the continental arcs and terranes of north-eastern Thailand. Furthermore, it addresses the closure of an oceanic basin (Nan Suture Zone) between the Sukothai and Indochina Terrane. Current tectonic models will be tested, and improved models will be developed. Unfolding the geologic history of this region is relevant to the development of valuable petroleum and mineral resources in Northern Thailand.

International links

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 MEMORANDUM 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

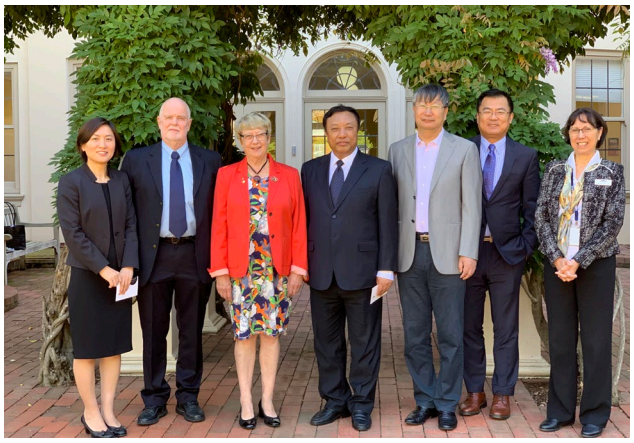
COTUTELLE MOU

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

INTERNATIONAL LINKS - 2019 SELECTED HIGHLIGHTS

- Professor Zengqian Hou, Vice President of the National Natural Science Foundation of China (NSFC) visited Australia from February 11-15 2019. Professor Hou met to discuss Australia-China Earth Science research collaboration with key government and opposition resource leaders, Geoscience Australia, ARC administrators and AuScope, accompanied by Australian Academy of Science representatives (and CCFS participants, Sue O'Reilly and Phil McFadden). The NSFC delegation also included Mr Wang Qiang, Counsellor for Science and Technology Affairs at the Chinese Embassy in Australia, Dr Fan Yingjie of the Bureau of International Cooperation and Dr Yupeng Yao, Deputy Director of the Department of Earth Science, National Natural Science Foundation of China (NSFC). (*see pictures below*)



CCFS INTERNATIONAL COLLABORATIVE NETWORK

In July, Prof Sue O'Reilly, Joanna Bunting and Hongyu Chen (Australian Embassy in China) attended a meeting in Beijing with members of the National Natural Science Foundation, the Chinese Academy of Geological Sciences and China University of Geosciences (Beijing). The meeting aimed to explore frameworks and mechanisms for collaboration in geoscience. Among the items discussed were the Sinoprobe Program, China's Deep-Earth Exploration project and possible opportunities for China to collaborate within the framework of the UNCOVER initiative. During the meeting, Professor Hou noted that the delegate visit to Australia had laid a solid foundation for bilateral cooperation.

Meeting with members of the Australian Embassy in China, the National Science Foundation China, the Research Center on Deep Exploration (CAGS) and China University of Geoscience Beijing. From left to right: Bo Xu (CCFS & CUG Beijing), Jing Chen, Yu-Peng Yao, Zeng-Qian Hou (NSFC), Bill Griffin, Sue O'Reilly (CCFS), Joanna Bunting (Counselor, Australian Embassy in China), Qing-Tian Lu (CAGS) and Hongyu Chen (Australian Embassy in China).

- A collaborative project between the Institute of Geology and Geophysics, China Academy of Science, Beijing (IGG CAS), CCFS, Geoscience Australia (GA), and ANSIR (Australian facilities for Earth sounding) resulted in a 4-year passive seismological deployment (China-Western Australia Seismic survey - CWAS) along a 900 km profile across Western Australia from Port Hedland to the southwestern border of the Kimberly Craton. 80 broadband seismic stations were established and extended beyond the continent margin in the Canning Basin using ocean-bottom seismometers (CANPASS).

  Phase 2 was completed successfully in September 2018. Colleagues and students from the GSWA, IGC CAS and CCFS "*in-filled*" the Phase 1 deployment with 38 broadband portable seismic stations which started recording late 2017. Combining stations from CANPASS, early portable deployments by ANU and permanent networks of GA and the German GEOFON program, the CWAS project provided an exciting opportunity to seismically map the crust and lithosphere architecture beneath both onshore and offshore regions of the Canning.

A major task of the seismic component was to wrap up a major field campaign in late November 2019 in which 60 broadband temporary stations were deployed for over a year in the Canning region (the Canning Seismic project). The collected data will be analysed in 2020 to develop seismic velocity models of the crust and the shallow upper mantle which will put tighter constraints to regional tectonic development and provide background (deep) knowledge for resources exploration purposes.

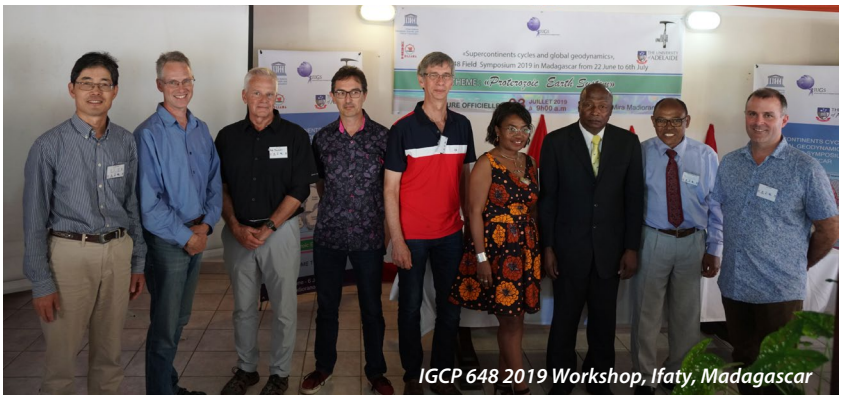
A collaboration to deploy semi-permanent real-time seismic stations along the Canning coastal area was carried out with GA to improve the national network coverage in the region, which will improve the capability in hazard assessment and structural imaging. A related Chinese NSF proposal funded in 2019, commencing in 2020, will expand the Canning project into the Archean cratonic regions. This 4-year project will also seek opportunities to put a second Ocean Bottom Seismic Array offshore of the Canning coastal region.

Second workshop and field excursion of IGCP662, Mongolia, 4-10 July 2019.

- Delegates from a range of international institutions visited CCFS in 2019 to discuss programs including the exchange of staff, joint research activities and the exchange of students (*see Visitors list, Appendix 5*).
- 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.
- 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/).

  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.
- CCFS Director, Professor Sue O'Reilly, is a group leader of UNESCO-IUGS IGCP 662 project aimed at providing insights on current global issues and supported by the International Geoscience Programme (IGCP) (https://en.unesco.org/news/new-projects-will-explore-geological-record-support-sustainable-development). IGCP 662: *"Orogenic architecture and crustal growth from accretion to collision"* aims to conduct comparative studies of several types of orogens (accretionary and collisional) to better understand the dynamics of Earth's crust, and the genesis and distribution of mineral deposits (metallogenesis). It will include a comparative study of the Central Asian Orogenic Belt (CAOB); one of the world's largest accretionary orogens spanning six nations and evolving over some 800 million years, the Tethyan orogenic belt; the world's youngest extensive collisional and metallogenic belt, and other composite orogens. The project included participants from more than 143 countries with diverse socio-economic and political contexts.

  The second IGCP 662 workshop was held successfully on the 4-10 July 2019 in Ulaanbaatar, Mongolia. Sue O'Reilly delivered an invited talk. It also included a field trip *"Gobi-Altai accretionary orogeny"*. IGCP 662 project information and upcoming events are available from http://igcp662.org.cn/.
- The UNESCO-IUGS IGCP 648 project *"Supercontinent cycles and global geodynamics"* continued in 2019. 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.
  IGCP 648 Database Workshop 2019 was held in Perth from the 24-30 March 2019.



IGCP 648 2019 Workshop, Ifaty, Madagascar

IGCP 648 2019, co-led by Zheng-Xiang Li, organised the Field Symposium *"Geological transect of Madagascar"* held from Berforona to Toliara, Madagascar *(pictured below)*.

For more information visit http://geodynamics.curtin.edu.au/igcp-648-2019-field-symposium-2/.

Prof Andy Biggin

- Zheng-Xiang Li has established new collaborative ties with researchers at the University of Liverpool studying the evolution of the Earth's magnetic field through time. A field trip to the Bangamall Basin was conducted in June-July with Prof Andy Biggin (*pictured above*).
- Steve Foley visited GUKO Sondermaschinenbau GmbH, Uslar in Germany, manufacturers of the two new piston-cylinder presses installed in Macquarie's high-pressure laboratory in 2019. The instruments are prototypes and have new features and software that is still under development.
- A collaboration with the University of Oslo via the multi-Institution ESA-funded project *"3D Earth"* continued and was completed at the end of the year. Researchers from the two centres of excellence CCFS and The Centre for Earth Evolution and Dynamics (CEED, Norway) joined forces to create a world reference lithospheric model and a high resolution thermochemical model of the North Atlantic region, including Greenland and parts of continental Europe.
- Marco Fiorentini continued international collaborations with:
  - University of Milan, Italy: Marilena Moroni and Massimo Tiepolo on the Ivrea Zone (Italy) and the role of volatiles in magmatic systems
  - Moscow State University, Russia: Alexey Ariskin on the genesis of Ni-Cu-PGE mineralisation in the Dovyren layered intrusion, Russia
  - Siberian Branch of the Russian Academy of Science, Irkutsk, Russia: work to establish the nature of the volatiles in the Siberian Traps
  - University of Bologna, Italy: ongoing work on the nature of the sulfur cycle in magmatic arcs
  - University of Leicester, UK: David Holwell on the Ivrea Zone (Italy), the role of volatiles in magmatic systems, and the Munali Ni-Cu-PGE deposit
  - ETH, Switzerland: Andrea Giuliani on metasomatism of the lithospheric mantle
  - Tokyo Institute of Techonology, Japan: Yuichiro Ueno on multiple sulfur isotope characterisation of Archean magmatism

International visitors are listed in Appendix 5.

IGCP 648 2019 Field Symposium "Geological transect of Madagascar" (photo Z.X. Li)

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.

Spectacular section of pillow lavas from the Oman ophiolite on the IGCP 649 project "Diamonds and Recycled Mantle" workshop (photo Simon Wilde).

Appendix 1: Independently funded basic research projects

Independently funded research projects now provide resources for the continuation of CCFS research and play an important role in research work plans over their duration. 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 and ARC Linkage Projects, see *Industry Interaction pp. 60-63*.

Mantle dynamics and ore deposits	A. Cruden, **M. Fiorentini**, S. Barnes, A. Bunger, C. Jackson: *Support by ARC DP (commenced 2019)* ***Summary:*** This project aims to investigate where, how and why narrow finger-like conduits form in lithosphere-scale magma plumbing systems by a novel integration of field surveys, three-dimensional reflection seismic data, laboratory experiments and rock fracture mechanics. The project expects to generate new knowledge on the formation and location of highly valuable ore deposits of nickel, copper, cobalt and platinum group elements, which are preferentially trapped in poorly understood finger-like magma conduits.
Unveiling the fine structure of the Australian continent using ocean waves	**Y. Yang**, **J.C. Afonso**, N. Rawling, M. Ritzwoller, F. Niu: *Support by ARC DP (commenced 2019)* ***Summary:*** This project aims to develop new methods to better image lithospheric and upper-mantle structures by using noise from ubiquitous ocean waves, and then use these methods to illuminate fine-scale lithospheric-asthenospheric structures in Australia, from the surface to the upper mantle. Imaging the Earth's structure using seismic tomography is one of the most fundamental tasks of geoscience. Conventional earthquake-based seismic tomography has difficulties in deciphering fine-scale lithospheric structures. The images from this project will provide a better understanding of the nature of intraplate earthquakes and volcanoes and improve the assessment of intraplate seismic and volcanic hazards in Australia.
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 (commenced 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.
Engineering planetary habitability: Earth's critical first billion years	A. Nutman, V. Bennett, **M. Van Kranendonk**: *Support by ARC DP (commenced 2017)* ***Summary:*** 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.

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.
The roles of carbon, water and nitrogen in the development of plate tectonics as drivers of mantle evolution	**S. Foley**: *Supported by ARC Laureate Fellowship (commencing 2019)* ***Summary:*** This project aims to understand the roles of carbon, water and nitrogen in the development of plate tectonics as drivers of mantle evolution. Through improved understanding of the impact of melting on the deep earth cycles of carbon, water and nitrogen, this project intends to better understand how key elements are enriched towards economically viable concentrations. This project will generate knowledge of long-term benefit for decision-making in the minerals exploration industry and key government agencies. The project will establish a new generation of Australian scientists with a deep interdisciplinary understanding of earth sciences and pave the way for eventual unification of plate tectonics with climate systems.
How the Earth works- toward building a new tectonic paradigm	**Z.X. Li**: *Supported by ARC Laureate Fellowship (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.
Measuring mantle hydrogen to map ore fluids and model plate tectonics	**K. Selway**: *Supported by ARC Future Fellowship (commenced 2016)* ***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.

Earth's origin and evolution: a sulfurous 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.
The Western Australia ThermoChronology Hub	M. Danisik, N. Evans, B. McInnes, **C. Kirkland**, **Z.X. Li**, **M. Fiorentini**, **M. Wingate**: *Support by ARC LIEF (commenced 2019)* ***Summary:*** This project aims to facilitate novel geochronological research in diverse areas of Earth and planetary science by providing a world-first triple-dating instrument facility. Combining three independent radiometric dating methods, the facility will undertake research to advance our understanding of the origin and evolution of the Earth and other planets and provide tools to enhance exploration for Earth's resources. Expected outcomes include the formation of a strong collaborative facility for academic, government and industry research and a further strengthening of Australia's position as an international research and education leader in the field of geochronology. It will lead to an improved understanding of the evolution of Earth's surface, and the formation and distribution of mineral and petroleum resources.
A novel ToF-SIMS facility for organic and inorganic analyses in WA	K. Grice, W. Rickard, G. Benedix, S.-P. Jiang, **S. Reddy**, **M. Kilburn**, P. Clode, D. Peyrot, D. Wacey, P. Lavery, P. Masque, R. Trengove, F. Xia, A. Deditius, G. Maker: *Support by ARC LIEF (commenced 2019)* ***Summary:*** Time-of-flight secondary ion mass spectrometry is a surface sensitive analytical technique that provides detailed elemental, isotopic and molecular information on surfaces, interfaces and thin layers with detection limits reaching in the parts-per-billion-range. The proposed facility is a next generation time-of-flight secondary ion mass spectrometer that allows parallel detection of organic and inorganic species in a given sample. Most importantly it will provide structural information of organic molecules intimately associated with minerals, meteorites, fossils, petroleum source-rocks to biochemical samples bolstering Western Australia's Earth and planetary sciences, energy, materials sciences, life science and metabolomics research.
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 (commenced 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.

Determining the extent and nature of the oldest crust in Antarctica	**S. Wilde**, **A. Nemchin**, M. Whitehouse, S. Harley, **M. Kusiak**, D. Dunkley: *Support by Australian Antarctic Science Grant (commenced 2019)* ***Summary:*** A large inventory of samples, collected by past Australian expeditions to Antarctica, reside with Geoscience Australia and provide a unique treasure-trove of information that can now be tapped, following major advances in knowledge and instrumentation over the past three decades. Selected samples collected from the Napier Complex in Enderby and Kemp Lands, on the western frontier of the Australian Antarctic Territory, have already provided exciting new insights into the timing and complexity of geological processes acting during the earliest stages of Earth's history. In order to further advance our understanding of this globally significant area, and to add value to a vital academic resource, this project aims to determine the extent of this most ancient terrain and to unravel the complex geological events that affected the area since its formation almost four billion years ago.
Magnetotelluric analysis for Greenland and Postglacial Isostatic Evolution (MAGPIE)	C.P. Conrad, **K. Selway**, C. Gaina, R. Karlsson, K. Nisancioglu, B. Steinberger, L. Tarasov: *Support by Norwegian Research Council FRINATEK (commenced 2019)* ***Summary:*** With this project we seek to develop new constraints on rock viscosity beneath Greenland by collecting geophysical data on the ice sheet. The magnetotelluric (MT) data image the Earth's electrical conductivity, which is sensitive to the temperature and water content of mantle rocks. Because these factors also control mantle viscosity, we can use MT data to map viscosity variations beneath Greenland. These data are also sensitive to subglacial melt, which will enable us to detect extra heat added beneath Greenland by the Iceland Plume. We will develop a new numerical modelling technique for GIA that can accommodate large viscosity variations. The code will be useful to study GIA problems worldwide, but we will use it to predict GIA uplift patterns associated with the viscosity variations beneath Greenland. We will then use these much-improved GIA models to produce more accurate estimates for modern-day ice loss in Greenland.
Using geochemical and microstructural XFM mapping to identify proximal, medial and distal vectors around magma transfer zones	**N. Daczko**, **J. Munnikhuis**: *Supported by ANSTO – Australian Synchrotron Beamline Program (commenced 2019)* ***Summary:*** The Earth is composed of a layered crust overlying a relatively homogeneous mantle. This layered nature necessitates material (in the form of melts) to be transferred from the mantle to the crust. However, the types of melt migration pathways remain unclear. We aim to assess changing the degree of chemical interaction of melt pathways from a transect near a mass transfer zone from the crust-mantle transition zone using the Maia-384 detector. This study will allow for better identification of other more cryptic mass transfer zones from surrounding rocks on the km scale.
Constraining the palaeodepth evolution of the South Tasman Rise and determining its role in development of the Antarctic Circumpolar Current (ACC)	S. Loehr, J. Wittaker, **N. Daczko**, P. Hall: *Support by ANZIC IODP Legacy Analytical Funding (AILAF) (commenced 2019)* ***Summary:*** This project aims to determine the palaeodepth evolution of the South Tasman Rise, a tectonically-thinned and submerged continental block formerly part of the Tasmanian Land Bridge which connected Australia and Antarctica until the Eocene. This will provide important constraints on the opening of the Tasmanian oceanic gateway to deep water circulation, hypothesised to be a primary control on the Eocene-Oligocene climate transition, arguably the most profound climatic re-organisation of the Cenozoic. A multiproxy sediment geochemistry approach developed and validated by the authors during recent work on the East Tasman Plateau will be employed to 1) determine the palaeodepth evolution of the South Tasman Rise during the Eocene and 2) to identify the timing of initial submergence of the continental blocks in this critical region of Eocene tectonics.

Melt-present deformation within the dynamic oceanic crust: Recognition and rheological consequences	**N. Daczko**, **R. Gardener**, S. Piazolo: *Support by ANZIC IODP Legacy Analytical Funding (AILAF) (commenced 2019)* ***Summary:*** Once the oceanic crust is formed, it is commonly assumed to remain rigid with only very limited chemical and rheological (i.e. flow property) changes other than ocean floor metamorphism occurring close to the interface with sea water. However, studies of deformed gabbroic portions of oceanic crust show that it is not "passive" but actively deforms, leading to important changes in its chemistry and rheology. These changes influence the long-term behaviour of the oceanic crust with consequences for our understanding of its flow properties, resource development and location of melt generation. Based on our pilot examination of a legacy thin section from ODP leg 176, core 735B (section 148R2, depth 952.7 mbsf), we postulate that melt migration in oceanic crust is in fact an important process that not only changes the chemistry but also substantially changes the rheology of the oceanic crust; hence this process is important in the evolution of the oceanic crust and oceanic plates in general.
3D Earth	**J.C. Afonso**, J. Ebbing: *Supported by European Space Agency and MQ University (commenced 2017)* Summary: The goal of this project is to 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.
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.
CWAS: China-Western Australia Seismic Survey	L. Zhao, **H. Yuan**, **GSWA**: *Supported by the Institute of Geology & Geophysics, Chinese Academy of Sciences, Beijing (commenced 2016)* ***Summary:*** Western Australia is an ideal natural laboratory for understanding the evolution of the Australian craton. To better understanding how and where the cratonic nuclei merged in the Precambrian requires high-resolution probing of the crustal and mantle structure beneath Western Australia. IGGCAS, CCFS and GWSA will install a 900-km-long dense (station spacing of 10 to 15 km) seismic profile across Western Australia from Port Hedland to the southwestern border of the Kimberly Craton, in order to: - image the crustal structure of the north edge of Pilbara craton, the Canning basin and south edge of the Kimberly craton with a high-resolution, and address the following issues: 1) deep geometry of the craton boundaries, 2) deep geometry of craton collisional belt; 3) differences of crustal structures between two cratons - image the mantle structure of the north edge of Pilbara craton, the Canning basin and south edge of Kimberly craton and address the following questions: 1) geometry of the convergence beneath the craton boundaries, 2) characteristic difference of the upper mantle of the two cratons.

Appendix 2: 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)
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- Professor Stephen Foley (MQ)
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- Professor Jochen Kolb (GEUS and KIT, Germany)
- Dr Yongjun Lu (GSWA at UWA)
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- Professor Steven Reddy (CU)
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- Professor Michael Brown (University of Maryland, USA)
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- Dr Uwe Kirscher (CU)
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- Dr Romain Tilhac (MQ)
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- Ms Sally-Ann Hodgekiss, Reporting & Comms. Manager (MQ)
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Dr Mike Etheridge	Dr Jon Hronsky	Dr John Vann
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Dr Richard Glen	Dr Robert Loucks	Professor Xisheng Xu
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Dr Mei-Fe Chu	Dr Ria Mukherjee	Dr Kuo-Lung Wang
Professor Massimo Coltorti	Dr Rosanna Murphy	Dr Xiao-Lei Wang
Professor Kent Condie	Dr Lev Natapov	Dr Qing Xiong
Professor Jean-Yves Cottin	Dr Oded Navon	Dr Jin-Hui Yang
Professor Manel Fernandez	Dr Ryan Portner	Professor Jin-Hai Yu
Ms Sarah Gain	Dr Yvette Poudjom Djomani	Dr Ming Zhang
Dr José María Gonzaléz-Jiménez	Dr William Powell	Professor Jianping Zheng
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Mr Anthony Lanati (MQ)	Mr Sinan Özaydin (MQ)	Mr Jonathon Michael Wasiliev (MQ)
Mr Pablo Lara (MQ)	Miss Zsanett Pintér (MQ)	Miss Anqi Zhang (MQ)

Appendix 3: 2019 Publications

A FULL LIST OF CCFS PUBLICATIONS IS UPDATED AT: http://www.ccfs.mq.edu.au/

1011. **Yao, W.** and **Li, Z.X.** 2019. Tectonostratigraphy and provenance analysis to define the edge and evolution of the eastern Wuyi-Yunkai orogen, South China. *Geological Magazine*, *156*, *83-98*.

1016. Badanina, I.Yu., **Belousova, E.A.** and Malitch, K.N. 2019. Hafnium isotope composition of zircons from the Kondyor clinopyroxenite-dunite massif (Khabarovsk Territory, Russia). *Doklady Earth Sciences*, *486*, *679-682*.

1067. **Lampinen, H.M.**, Laukamp, C., Occhipinti, S.A. and Hardy, L. 2019. Mineral footprints of the Paleoproterozoic sediment-hosted Abra Pb-Zn-Cu-Au Deposit Capricorn Orogen, Western Australia. *Ore Geology Reviews*, *104, 436-461*.

1123. **Liu, Y.**, **Li, Z.X.**, **Pisarevsky, S.**, **Kirscher, U.**, **Mitchell, R.N.** and **Stark, J.C.** 2019. Palaeomagnetism of the 1.89 Ga Boonadgin dykes of the Yilgarn Craton: Possible connection with India. *Precambrian Research*, *329*, *211-223*.

1153. **Steller, L.**, Nakamura, E., Ota, T., Sakaguchi, C., Sharma, M. and **Van Kranendonk, M.J.** 2019. Boron isotopes in the Puga geothermal system, India, and their implications for the habitat of early life. *Astrobiology*, *19*, *DOI: 10.1089/ast.2018.1966*.

1154. **Soares, G.G.**, **Van Kranendonk, M.J.**, **Belousova, E.** and Thomson, S. 2019. Phosphogenesis in the immediate aftermath of the Great Oxidation Event: Evidence from the Turee Creek Group, Western Australia. *Precambrian Research*, *320, 193-212*.

1158. Liu, S-W., Fu, J-H., **Lu, Y-J.**, Chen, X., Wang, M-J., Hu, F-Y., Gao, L., Sun, G-Z. and Hu, Y-L. 2019. Precambrian Hongqiyingzi Complex at the northern margin of the North China Craton: Its zircon U-Pb-Hf systematics, geochemistry and constraints on crustal evolution. *Precambrian Research*, *326*, *58-83*.

1168. Shirey, S.B., Smit, K., Pearson, D.G., Walter, M.J., Aulbach, S., Brenker, F.E., Bureau, H., Burnham, A. D., Cartigny, P., Chacko, T., Frost, D.J., Hauri, E.H., **Jacob, D.E.**, Jacobsen, S.D., Kohn, S.C., Luth, R.W., Mikhail, S., Navon, O., Nestola, F., Nimis, P., Palot, M., Smit, K.V., Smith, E.M., Stachel, T., Stagno, V., Steele, A., Stern, R.A., Thomassot, E., Thomson, A.R. and Weiss, Y. 2019. Diamonds and the mantle geodynamics of carbon. *In B. Orcutt, I. Daniel & R. Dasgupta (eds)*, *Deep carbon: Past to pesent*, *89-128*.

1180. Aulbach, S., Heaman, L.M., **Jacob, D.** and Viljoen, K.S. 2019. Ages and sources of mantle eclogites: ID-TIMS and *in situ* MC-ICPMS Pb-Sr isotope systematics of clinopyroxene. *Chemical Geology*, *503*, *15-28*.

1182. Gladkochub, D., Donskaya, T., Stanevich, A., **Pisarevsky**, **S.**, Zhang, S., Motova, Z., Mazukabzov, A. and Li, H. 2019. U-Pb detrital zircon geochronology and provenance of Neoproterozoic sedimentary rocks in southern Siberia: new insights into breakup of Rodinia and opening of Paleo-Asian Ocean. *Gondwana Research*, *65*, *1-16*.

1185. **Jessop, K.**, **Daczko, N.R.** and Piazolo, S. 2019. Tectonic cycles of the New England Orogen, eastern Australia: a review. *Australian Journal of Earth Sciences*, *66*, *459-496*.

1194. Mambwe, M.P., Lavoie, S., Delvaux, D. and **Batumike, J.M.** 2019. Soft sediment deformation structures in the Neoproterozoic Kansuki formation (Katanga Supergroup, Democratic Republic of the Congo): Evidence for deposition in a tectonically active carbonate platform. *Journal of African Earth Sciences*, *150*, *86-95*.

1198. **Caruso, S.**, **Fiorentini, M.L.**, Barnes, J.B., **LaFlamme, C.K.** and **Martin, L.** 2019. Microchemical and sulfur isotope constraints on the magmatic and hydrothermal evolution of the Black Swan Succession, Western Australia. *Mineralium Deposita*, *https://doi.org/10.1007/s00126-019-00891-7*.

1199. Kazemi, Z., Ghasemi, H., **Tilhac, R.**, **Griffin, W.L.**, Shafaii Moghadam, H., **O'Reilly, S.Y.** and Mousivanda, R. 2019. Late Cretaceous subduction-related magmatism on the southern edge of Sabzevar basin, NE Iran. *Journal of the Geological Society, London*, *176*, *530*.

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Appendix 4: 2019 Abstract titles

A FULL LIST OF CCFS ABSTRACTS FOR CONFERENCE PRESENTATIONS IS AVAILABLE AT: http://www.ccfs.mq.edu.au/

MELT EVOLUTION IN SPACE AND TIME SYMPOSIUM, MELBOURNE, AUSTRALIA, 14-15 FEBRUARY 2019	Impacts of relative melt ascent through deep arc crust on melt evolution: recognising and investigating melt migration pathways **N.R. Daczko** and S. Piazolo Incipient mantle melts and mantle metasomatism **S. Foley**
EGU GENERAL ASSEMBLY 2019, VIENNA, AUSTRIA, 7-12 APRIL 2019	The thermochemical structure of central and southern Africa from multi-observable probabilistic inversion **W. Ben Mansour**, **J.C. Afonso**, A. Macdonald and N. Januszczak Lead on the nanoscale in metamorphosed zircon **M.A. Kusiak**, D.J. Dunkley, R. Wirth, M.J. Whitehouse and **S.A. Wilde** Decoding Earth's rhythms: Modulation of supercontinent cycles by longer superocean cycles **Z.X. Li**, **R. Mitchell**, C. Spencer, **U. Kirscher**, **S. Pisarevsky**, R. Ernst and B. Murphy Global Paleomagnetic Database, global 2000-0 Ma paleogeographic animation and Large Igneous Provinces **S. Pisarevsky**, **Z.X. Li**, L. Wu and R. Ernst The temperature-dependent visibility of the 660-km discontinuity B. Tauzin, L. Waszek, N.C. Schmerr, M. Ballmer and **J.C. Afonso** Tectono-metamorphic record of final Nuna assembly and orogenic collapse in the Georgetown Inlier, NE Australia: Insights from multiple P–T–d–t paths **S. Volante**, W.J. Collins, **E. Blereau**, **A. Pourteau**, **Z.X. Li**, C. Spencer, **A. Nordsvan**, J. Li and M. Smit Earth's earliest chemofossils? The importance of getting the geology and geochronology right! M. Whitehouse, D. Dunkley, **M. Kusiak** and **S. Wilde** A new global full-plate reconstruction model for Phanerozoic time **L. Wu**, **Z.X. Li** and **S. Pisarevsky**
GACMAC 2019, QUEBEC, CANADA, 11-13 MAY 2019	Tracking slab sediment devolatilisation using the mass independent fractionation of sulfur signature of Proterozoic magmatic arcs **C. LaFlamme** and **M. Fiorentini** Super Wilson Cycle: The birth and destruction of superoceans during supercontinent cycles **Z.X. Li** Early Cretaceous sinistral strike-slip faulting in NW Pacific: Implications from the U-Pb dating of detrital zircon in SikhoteAlin, Russian Far East **K. Liu**, J. Zhang, **S. Wilde** and W. Xiao Laurentia during the mid-Ediacaran: Paleomagnetism and 580 Ma age of the Saint-Honoré alkali intrusion and related dykes, Québec P. McCausland, M. Higgins, **S. Pisarevsky**, A. LeCheminant, F. Jourdan, M. Hamilton and J.B. Murphy Ediacaran supercontinent: Did it exist? **S. Pisarevsky** Tracking hydrothermal fluid evolution of an Archean orogenic gold deposit through multiple sulphur isotope analysis linked to detailed structural paragenesis **D. Sugiono**, **C. LaFlamme**, **N. Thébaud**, **M. Fiorentini**, **L. Martin** and J. Rogers
JAPAN GEOSCIENCE UNION MEETING 2019, CHIBA, JAPAN, 26-30 MAY 2019	Interaction between volcanisms inland and the spreading center: Example of Galápagos archipelago **W. Ben Mansour**, G. Nolet, M. Ruiz and **J.C. Afonso**

DRT: 22ND DEFORMATION MECHANISMS, RHEOLOGY AND TECTONICS MEETING "FROM MICROTECTONICS TO PLATE TECTONICS", TUBINGEN, GERMANY, 11-14 JUNE 2019	The negative effects of coupled dissolution-precipitation on U-Pb geochronology **N.R. Daczko**
ABSCICON, SEATTLE, USA, 24-28 JUNE 2019	Investigating alien life on early Earth: Branching organic-siliceous structures from a c. 2.4 Ga microbialite reef in the Turee Creek Group, WA **G. Soares**, **M.J. Van Kranendonk** and **B.L. Teece** Looking for life: Determining biogenicity of ancient organic matter **B.L. Teece**, J.-P. Duda, **G.G. Soares**, **E.V. Barlow** and **M.J. Van Kranendonk** A pyramid of life detection for ancient life, based on deep-time earth experience **M.J. Van Kranendonk**, K.A. Campbell, **E.V. Barlow**, **R. Baumgartner**, **T. Djokic**, J.-P. Duda and **B.L. Teece**
2ND IGCP 662 WORKSHOP AND FIELD EXCURSION, ULAANBAATAR, MONGOLIA, 5 - 8 JULY 2019	Does continental crust grow significantly by collision and/or subduction **S.Y. O'Reilly** and **W.L. Griffin** **Invited**
XIII INTERNATIONAL SYMPOSIUM ON ANTARCTIC EARTH SCIENCES, INCHEON, REPUBLIC OF KOREA, 22-26 JULY 2019	Crustal evolution of the Archean Napier Complex O. Król, **M.A. Kusiak**, D.J. Dunkley, **S.A. Wilde**, K.W. Yi and S. Lee
AOGS 16TH ANNUAL MEETING, SINGAPORE, 28 JULY - 2 AUGUST 2019	Interaction between volcanisms inland and the spreading Center: Example of Galápagos Archipelago **W. Ben Mansour**, G. Nolet, M. Ruiz and **J.C. Afonso**
GOLDSCHMIDT 2019, BARCELONA, SPAIN, 18-23 AUGUST 2019	Mobility of Re and Os isotopes in platinum-group minerals during Laterization? T. Aiglsperger, J.M. González-Jiménez, J.A. Proenza, S. Galí, F. Longo, **W.L. Griffin** and **S.Y. O´Reilly** *In situ* Mantle sulfide geochemistry: A brief review and new perspectives **O. Alard** Os isotope systematics of Ru-Os Sulfides and Ru-Os-Ir alloys from the Verkh-Neivinsk and Kunar Ophiolite-Type Complexes (Russia) I. Badanina, K. Malitch, **E. Belousova**, I. Puchtel and V. Murzin Metalheads of the early Earth: Biologically mediated accumulation of transition metals and metalloids in 3.5 billion–year–old stromatolites **R. Baumgartner**, **M. Van Kranendonk**, P. Anais, D. Wacey, **M. Fiorentini** and C. Ryan *TerraneChron®*'s trajectory 2000-2030 **E. Belousova**, **W.L. Griffin** and **S.Y. O'Reilly** **Keynote** Zircon in lithosphere evolution studies: Exploring the weak link **E. Belousova**, **W.L. Griffin** and **S.Y. O'Reilly** Deciphering molecular-scale mechanisms governing scandium dynamics in the critical zone **M. Chassé**, M. Blanchard, D. Cabaret, A. Juhin, **W.L. Griffin**, **S.Y. O'Reilly** and G. Calas Geochemistry of Paleoproterozoic mafic magmatism in the South Siberian post-collision magmatic belt T. Donskaya, D. Gladkochub, A. Mazukabzov, E. Demonterova and **S. Pisarevsky** The oceanic mantle plume database and the tale of two superplumes **L. Doucet**, **Z.X. Li**, R. Ernst, **U. Kirsher** and **R. Mitchell** Focussed degassing of stored carbon T.P. Fischer, J. Muirhead, **S.F. Foley**, Y. Sano, H. Lee, N. Takahata, A. Laizer, E., Kazimoto, S. Oliva, C. Ebinger, J. Van Wijk, C. Werner, A. Aiuppa, P. Allard, T. Lopez, J. Dufek and B. Marty

GOLDSCHMIDT 2019, BARCELONA, SPAIN, 18-23 AUGUST 2019 *cont...*

Metal formation in ordinary chondrite
G. Florin, **O. Alard**, B. Luais and T. Rushmer

Experimental characterization of mantle wedge-metasomatism by sediment-peridotite reaction in subduction zones
S. Foley, **M. Förster**, Y. Bussweiler, D. Prelevic and **N. Daczko**

Reaction of subducted sediment with peridotite produces saline fluid inclusions in diamonds
M. Förster, **S. Foley**, H. Marschall, **O. Alard** and S. Buhre

Mantle-like oxygen isotopes in kimberlites determined by *in situ* SIMS analyses of zoned olivine
A. Giuliani, **L.A.J. Martin,** A. Soltys and **W.L. Griffin**

In situ Laser ablation split-stream (LASS-) MC-ICP-MS/ICP-MS for simultaneous determination of Re-Os isotopes and siderophile-chalcophile elements in sulfides: Ablating away a cornelian dilemma
Y. Gréau, **O. Alard** and **S. O'Reilly**

Magmatic and tectonic controls on kimberlite genesis and evolution beneath Slave Craton locations
S. Greene, **D.E. Jacob**, **Z. Pinter**, **S. O'Reilly** and L. Heaman

The lithosphere and metallogeny: A 40-year evolution of concepts
W. Griffin and **S. O'Reilly** **Keynote**

Abundance and distribution of volatile elements (C, H, N, S) in the sub-continental lithospheric mantle
A. Halimulati, **O. Alard** and **S.Y. O'Reilly**

The evolution of the Archean mantle from combined isotope systematics in Pilbara basalts and komatiites
E. Hasenstab, J. Tusch, C. Schnabel, V. Schmitt, C.S. Marien, **M. Van Kranendonk** and C. Münker

Deformation mechanisms related to olivine megacrysts in mantle dunite
H. Henry, **W.L. Griffin** and **S.Y. O'Reilly**

An SCLM control on the metallogenic DNA of the continental lithosphere
D. Holwell, **M. Fiorentini**, I. McDonald, **Y. Lu**, **A. Giuliani**, D. Smith, M. Keith and M. Locmelis **Invited**

The mantle mega-wedge beneath East Asia formed ~145 million years ago
Q. Ma, Y.-G. Xu, S.-L. Chung, J.-H. Yang and **W.L. Griffin**

Origin of zircon from the Talnakh Economic Ultramafic-Mafic Intrusion (Noril'sk Province, Russia): Evidence from oxygen isotope data
K.N. Malitch, **E.A. Belousova**, **W.L. Griffin**, I.Yu. Badanina, L.A.J. Martin and S.F. Sluzhenikin

Re-Os Dating of sulfide inclusions in Cr-pyropes from the Upper Muna Kimberlites
V. Malkovets, D. Rezvukhin, **W.L. Griffin**, **I. Tretiakova**, **N. Pearson**, A. Gibsher, **E. Belousova**, D. Zedgenizov and **S.Y. O'Reilly**

Are modern plate tectonic cycles inherited from Hadean mantle convection?
R. Mitchell, C. Spencer, **U. Kirscher** and W. Collins

Composition of micrometre-scale zircon grains from the Bunburra meteorite
S.D. Montalvo, **S.M. Reddy**, G.K. Benedix, D.W. Saxey, W.D.A. Rickard and **D. Fougerouse**

Multiphase multicomponent reactive transport: Disequilibrium melt-rock processes and geochemical geodynamics
B. Oliveira, **J.C. Afonso** and **R. Tilhac**

Extremely low structural hydroxyl contents in upper mantle xenoliths from the Nógrád-Gömör Volcanic Field (Northern Pannonian Basin)
L. Patkó, **N. Liptai,** I.J. Kovács, L.E. Aradi, Q.-K. Xia, J. Ingrin, J. Mihály, **S. O'Reilly**, **W.L. Griffin**, V. Wesztergom and C. Szabó

TTG formation: Water-present melting as an alternative to high-pressure melting
A. Pourteau, **E.R. Blereau**, **L.S. Doucet**, **S. Volante**, T.E. Johnson, W.J. Collins and **Z.X. Li**

Indicators of craton-edge mantle processes in phenocrystic olivines of Eastern Australian basaltic rocks
J. Shea and **S.F. Foley**

Dating of rutile in diamondiferous eclogites from the Mir Pipe, Yakutia: Evidence for Late Metasomatic origin
Z. Spetsius, **W. Griffin**, **S. O'Reilly**, **E. Belousova** and **I. Tretiakova**

GOLDSCHMIDT 2019, BARCELONA, SPAIN 18-23 AUGUST 2019 *cont...*	Lithosphere features from garnet xenocrysts of the western edge of São Francisco Craton, Brazil **L. Takenaka** and **W. Griffin** Mesozoic–Cenozoic thermal evolution of SE China in response to flat-slab subduction at the proto-Western Pacific Margin **N. Tao**, **Z.X. Li**, M. Danisik and N. Evans Metasomatic e addition overprints unradiogenic Os in sub-arc mantle **R. Tilhac**, **B.F. Schaefer**, G. Ceuleneer, **B. Oliveira**, **W.L. Griffin**, **S.Y. O'Reilly** and M. Grégoire Evidence for the composition and tectonic affinity of continental crust between 4.3 and 3.0 ga from the trace element composition of detrital zircons from Jack Hills S. Turner, **S. Wilde**, **B. Schaefer** and Y.-J. Lai Long-term preservation of W Isotope anomalies in crustal rocks from the Pilbara Craton, NW Australia J. Tusch, C. Münker, M. Jansen, E. Hasenstab, C.S. Marien, F. Kurzweil and **M. Van Kranendonk** Ediacaran magmatism in the evolution of the transform active continental margin of the Siberian Craton: Geochemistry, geochronology and geodynamics A. Vernikovskaya, V. Vernikovsky, N. Matushkin, P. Kadil'nikov, **Z.X. Li**, **S. Wilde**, I. Romanova and A. Travin Improved LA-ICP-MS analytical routine for low-concentration chalcophile and siderophile elements in olivine and orthopyroxene **M. Veter**, **S.F. Foley** and **O. Alard** Lithospheric mantle of North China Craton is instinctly rich in gold? Z. Wang, H. Cheng, K. Zong, Y. Liu, J. Yang, F. Wu and **S. Foley** Zircon provenance of Cretaceous sandstones in the Perth Basin, Australia: A cautionary tale **S. Wilde** Sulfides in ophiolitic dunite channels cause Os-isotope decoupling between oceanic crust and mantle **Q. Xiong**, J.-P. Zheng, Y. Xu, J.-G. Liu, **W.L. Griffin** and **S.Y. O'Reilly** Mantle metasomatism, oxidation and kimberlite magma genesis G. Yaxley and **S. Foley**
2019 ADA LOVELACE WORKSHOP ON MODELLING MANTLE AND LITHOSPHERE DYNAMICS, SIENA, ITALY, 25-30 AUGUST 2019	How does the interaction between mantle upwelling and lithosphere affect locally the thermochemical structure **W. Ben Mansour**, **J.C. Afonso**, G. Nolet, S. Antipolis and **B. Oliveira Bravo** Exploring the limits of *in situ* Rb-Sr dating by LA–ICP–MS/MS **L. Gorojovsky** and **O. Alard** Hadean mantle dynamics, tectono-volcanic regimes, and the role of impacts **C. O'Neill** **Keynote**
15TH BIENNIAL MEETING SGA 2019, GLASGOW, SCOTLAND, 27-30 AUGUST 2019	Cassiterite as a record of Sn mineral system processes **J.M. Bennett**, A.I.S. kemp, S.G. Hagemann, **M.L. Fiorentini** and M.P. Roberts Fluorine and PGE-Au elevated signature of alkaline magmas from the Yilgarn Cratin: Insights into mantle fertility **E. Choi**, **M. Fiorentini**, **A. Giuliani** and **S. Foley** Reactivation and enrichment of a Gondwana margin Ni-Cu-PGE - (Te-Au) mineral system during the breakup of pangea **M. Fiorentini**, **S. Denyszyn**, **G. Dering**, D. Howell, D. Blanks, R. Maas, M. Locmelis and **C. Laflamme** **Keynote** Fertilisation of porphyry magmas by Cu-Au sulfide melt mobilisation in the lower crust D. Howell, T. Knott, D. Blanks, **M. Fiorentini**, I. McDonald and **C. McCuaig** Mineral trace element chemistry in the exploration for magmatic sulfide deposits M. Locmelis, J. Obrist-Farmer, A. Eckert, **M.L. Fiorentini**, S.J. Barnes, E.J. Hanski, A.F. Kobussen, R.D. Arevalo Jr and I.S. Puchtel Naturally occurring Au nanoparticles associated with high-grade mineralization at the world-class Callie deposit, Northern Territory, Australia L. Petrella, **N. Thebaud**, **D. Fougerouse**, K. Evans, Z. Quadir, **C. LaFlamme**, S. Occhipinti and S. Turner

15TH BIENNIAL MEETING SGA 2019, GLASGOW, SCOTLAND, 27-30 AUGUST 2019 *cont...*	Tracking the Archean orogenic gold deposit evolution through multiple sulfur isotopes **D. Sugiono**, **N. Thebaud**, **M.L. Fiorentini**, **L. Martin**, **C.K. LaFlamme**, J. Rogers and G. Lorusso Tracing the S source reservoir of the Tropicana Gold Camp, Western Australia **N. Thebaud**, S. Hagemann, **L. Martin**, **S. Caruso**, S. Ulrich and D. Allan
THE SECOND AUSTRALASIAN EXPLORATION GEOSCIENCE CONFERENCE (AEGC), PERTH, AUSTRALIA, 2-5 SEPTEMBER 2019	AusArray: Toward updatable, high-resolution seismic velocity models of the Australian lithosphere A. Gorbatov, K. Czarnota, M. Haynes, R. Hassan, B. Hejrani, J. Zhao, M. Salmon, M. Sambridge, H. Tkalčić and **H. Yuan** Passive seismic studies of the Capricorn Orogen, Western Australia R.E. Murdie, **H. Yuan**, M. Dentith and X. Xu MT conductivity signatures of mineral systems: 3D MT over the Eastern Goldfields Super Terrane, Yilgarn Craton **K. Selway**, M. Dentith and **S. Özaydin** Magnetotellurics for resource exploration and monitoring the crust **K. Selway**
7TH INTERNATIONAL LARGE IGNEOUS PROVINCES CONFERENCE 2019, TOMSK, RUSSIA 28 AUGUST - 8 SEPTEMBER 2019	LIPs and supercontinent reconstructions **S.A. Pisarevsky** **Keynote**
SIMP, SGI, SOGEI JOINT CONFERENCE, PARMA, ITALY, 16-19 SEPTEMBER 2019	Exotic mineralogy in an ultra-reduced magmatic system beneath Mt Carmel, Israel **W.L. Griffin**, **S.E.M. Gain**, F. Camara, L. Bindi, V. Toledo and **S.Y. O'Reilly** Crystallographic relationships between diamond and its clinopyroxene inclusions A. Pasqualetto, F. Nestola, P. Nimis, **D.E. Jacob**, B. Oliveira, S. Perritt, I Chinn., S. Milani and J.W. Harris
SELWYN SYMPOSIUM 2019. GSA VICTORIA DIVISION: THE CO-EVOLUTION OF LIFE AND PRECAMBRIAN ENVIRONMENTS, MELBOURNE, AUSTRALIA, 30 SEPTEMBER 2019	Localised oxygen and the complexification of life during the great oxygenation event **G.G. Soares**, **M.J. Van Kranendonk** and **B.L. Teece**
SEG 2019 SOUTH AMERICAN METALLOGENY: SIERRA TO CRATON, SANTIAGO, CHILE, 7-10 OCTOBER 2019	Can zircon trace elements correlate whole-rock fertility indicators for porphyry-copper deposits? Application of a new zircon oxybarometer at El Teniente District G. Javier Henriquez, **R.R. Loucks**, **M.L. Fiorentini** and C.M. Allen Geochemical indicators of orogenic compressive stress in datable igneous rocks, with implications for porphyry copper ore genesis and exploration targeting **R. Loucks** and **M. Fiorentini** Zircon fingerprinting of magmatic hydrothermal systems in the Archean Yilgarn Craton **Y. Lu**, H. Smithies, **M.T.D. Wingate**, N.J. Evans, **T.C. McCuaig**, D. Champion and M. Outhwaite
INTERNATIONAL SYMPOSIUM ON DEEP EARTH EXPLORATION AND PRACTICES BEIJING, CHINA, 24-26 OCTOBER 2019	Government-funded deep geophysical surveys to encourage mineral exploration: Results from the Western Australian "*Exploration Incentives Scheme*" M. Dentith, **K. Gessner**, S. Johnson, R. Murdie, P. Pina-Varas, J. Spratt, I. Tyler and **H. Yuan**

GESSS NSW 2019, UNSW, SYDNEY, 31 OCTOBER - 1 NOVEMBER 2019	Mineralogy, geochemistry and genesis of ophiolites and associated economic minerals in Waziristan, north-west Pakistan - Implications for mineral exploration models **R. Jalil**, **B. Schaefer**, **O. Alard**, L. Ali and M. Sajid Texture-specific trends in stable isotope data from a microbialite reef complex in the c. 2.4 Ga Turee Creek Group, Western Australia **B. Nomchong** and **M. Van Kranendonk** Phosphogenesis during the Great Oxidation Event **G. Soares**, **M.J. Van Kranendonk**, **E. Belousova** and S. Thomson The search for life on Mars: A geological perspective from Earth **M. Van Kranendonk** Evaluating uncertainties of phase velocity measurements from cross-correlations of ambient noise **Y. Yang** and Y. Luo
5TH IGCP-649 DIAMONDS AND RECYCLED MANTLE WORKSHOP AND FIELD TRIP, OMAN, 13-22 NOVEMBER 2019	Evaluating the precise $^{39}Ar/^{40}Ar$ dating of multiple mineral phases in ultra-alkaline rocks: applications to mantle systematics **S.A. Wilde**, F. Jourdan, L. Frewer and **M.A. Kusiak**
BIENNIAL MEETING OF THE SPECIALIST GROUP FOR TECTONICS AND STRUCTURAL GEOLOGY AND THE SPECIALIST GROUP IN SOLID EARTH GEOPHYSICS, PORT LINCOLN, WA, AUSTRALIA, 18-22 NOVEMBER 2019	The lithospheric architecture of Australia from multi-observable probabilistic inversion **J.C. Afonso**, M. Haynes, A. Gorbatov and K. Czarnota Tectonic evolution of the forearc mantle reconstructed by dikes in the peridotites of the New Caledonia ophiolite V. Chatzaras, D. Gürer and **O. Alard** The necessity of a Neoproterozoic full plate reconstruction to quantify the global earth system and understand deep time plate tectonics A.S. Collins, A.S. Merdith, M.L. Blades, S.E. Williams, S. Armistead, D. Archibald, **S. Pisarevsky**, B.L. Alessio, C. Clark, T. Johnson, J. Foden and R.D. Müller Rudall Province - Witness to assembly of western and northern Australia cratons, but how did it happen? **W. Gorczyk** and F. Kohanpour Integrating isotopic signatures and geodynamic numerical models to fingerprint geodynamic settings F. Kohanpour, **C. Kirkland**, **W. Gorczyk**, S. Occhipinti and M. Lindsay Tectonic controls on nickel and gold mineral systems; Halls Creek Orogen, Western Australia F. Kohanpour, S. Occhipinti, M. Lindsay and **W. Gorczyk** New insights into the subglacial geology of interior of Wilkes Land, East Antarctica: Implications for supercontinent evolution A. Maritati, J.A. Halpin, J.M. Whittaker and **N.R. Daczko** Thermal controls on rifting regimes in earth history - Insights from 2-D geodynamic modelling B. Mi, **W. Gorczyk** and M. Jessell Multiscale structural analysis of Boulder Lefroy Shear Zone in eastern goldfields of Western Australia S. Sumail, **N. Thebaud** and R. Quentin De Gromard Experimental alteration of monazite in granitic melt: Pb mobility during melt-mediated coupled dissolution-reprecipitation J. Varga, T. Raimondo, **N. Daczko** and J. Adam
GESSS-WA 2019, PERTH, AUSTRALIA, 29 NOVEMBER 2019	Integration of multiple sulfur isotopes with structural analysis in the Kanowna Belle deposit of the Yilgarn Craton unveils the evolution of hydrothermal fluids in the Archean orogenic gold deposit **D. Sugiono**, **C. LaFlamme**, **N. Thébaud**, **M. Fiorentini**, **L. Martin** and J. Rogers

AGU FALL MEETING 2019, SAN FRANCISCO, USA, 9-13 DECEMBER 2019

Thermochemical imaging of the lithosphere and upper mantle from geophysical observations: what can we really see?
W. Ben Mansour, **J.C. Afonso**, N. Januszczak, A. Macdonald, G. Nolet, Y. Aoki and **F. Salajegheh**

Carbonate transfer from subducting slab to mantle wedge by diapirism and melting
C. Chen, **M. Förster**, **S.F. Foley** and Y. Liu

Shear wave splitting observations in the middle and western Australian cratons
A. Chen, **H. Yuan** and V.L. Levin

The tale of two cratons: Upper mantle anisotropy under the Superior and West Australian Cratons
X. Chen, Y. Li, **H. Yuan** and V. L. Levin

Relative roles of mantle plumes and orogens in causing the opening of the South Atlantic Ocean
Z. Dang, **N. Zhang**, **Z.X. Li**, C. Huang, C.J. Spencer and **Y. Liu**

Focussed degassing of stored continental deep carbon
T.P. Fischer, J.D. Muirhead, **S.F. Foley**, Y. Sano, H. Lee, N. Takahata, A. Laizer, E. Kazimoto, S.J.C. Oliva, C.J. Ebinger, J.W. Van Wijk, C.A. Werner, A. Aiuppa, P. Allard, T.M. Lopez, J. Dufek and B. Marty

Ammonium in phlogopite and its effects on the nitrogen budget of Earth's mantle
M. Forster, **S.F. Foley**, **O. Alard** and **H. Ananuer**

Global geochemical fingerprinting points to a mantle dynamics coupled with the supercontinent cycle
H.M. Gamal El Dien, **L.S. Doucet** and **Z.X. Li**

Updatable, high-resolution seismic velocity models of the Australian lithosphere
A. Gorbatov, K. Czarnota, M. Haynes, R. Hassan, B. Hejrani, J. Zhao, M. Salmon, M. Sambridge, H. Tkalcic and **H. Yuan**

Modeling the inception of supercontinent break-up: Stress state and the importance of orogenies
C. Huang, **N. Zhang**, **Z.X. Li**, M. Ding, Z. Dang, **A Pourteau** and S. Zhong

Quantitative evidence for a Neoproterozoic glacial origin of the Great Unconformity
C.B. Keller, J.M. Husson, **R. Mitchell**, W.F. Bottke Jr, T. Gernon, P. Boehnke, E.A. Bell, N. Swanson-Hysell and S.E. Peters

Long memory: Structural differences in continental upper mantle at the Grenville Front in Quebec
V.L. Levin, Y. Li and **H. Yuan**

Reconstructing Earth's supercycles for the past 2 Ga: Key constraints for global geodynamics
Z.X. Li, **S. Pisarevsky**, **Y. Liu**, **L. Wu** and R.E. Ernst

Crustal Vs model along a transect in south-eastern China: Insights into paleo-Tethys accretion and post-assembly reworking
T. Li, L. Zhao, **H. Yuan**, K. Wang and T. Bodin

Was the Tethys ocean a legacy of the Nuna and Rodinia superocean? - A new perspective from the point of supercontinent-superocean cycles **Invited**
Z.X. Li

Roles of south-dipping subduction in southern Tethys in the breakup of Australia from Antarctic
X. Liu, **N. Zhang**, Z. Dang, C. Huang, P. Yan, **Y. Liu** and **Z.X. Li**

Including 3D magnetotelluric data into joint probabilistic inversions
M.C. Manassero, **J.C. Afonso**, F. Zyserman and S. Zlotnik

Understanding variations in tectonic degassing of CO_2 during continental rifting
J.D. Muirhead, T.P. Fischer, A. Laizer, A. Zafu, H. Lee, S.J.C. Oliva, R. Pik, B. Marty, E.J. Judd, E. Kazimoto, M.W. Broadley, A. Caracausi, Y. Sano, N. Takahata, D. Ayalew, C.J. Ebinger, G. Kianji, C. Tiberi, J. van Wijk, J. Dufek, **S.F. Foley** and C.A. Currie

Lithospheric and deep mantle structure of the North Atlantic Region from joint probabilistic inversion of seismic, satellite, and geochemical datasets
F. Salajegheh, **J.C. Afonso**, A. Minakov, C. Gaina, A. El-Sharkawy, T.M. Meier and M. Kloecking

NoLiMit: Software and physics-based catalogs of seismic waveforms for analyses of the Earth's Mantle Transition Zone
B. Tauzin, L. Waszek, **J.C. Afonso**, M. Sambridge, H. Tkalcic, T. Bodin and E. Debayle

AGU FALL MEETING 2019, SAN FRANCISCO, USA, 9-13 DECEMBER 2019 *cont...*

Numerical investigation of three-dimensional sensitivity kernels of rayleigh-wave ellipticity based on the adjoint-state method
K. Wang, Q. Liu and **Y. Yang**

Seismic observations of ponding plumes beneath the mantle transition zone
L. Waszek, B. Tauzin, N.C. Schmerr, M. Ballmer, **J.C. Afonso** **Invited**

The amalgamation of Pangea: Reappraisal of paleomagnetic and geological data
L. Wu, B. Murphy, C. Quesada, **Z.X. Li**, J.W.F. Waldron, S. Williams and **S.A. Pisarevsky**

Tomographic evidence beneath the Indian Ocean for a Mesozoic south-dipping subduction system in Southern Tethys
P. Yan, **N. Zhang**, **H. Yuan**, **Z.X. Li** and X. Liu

New seismic observations in Western Australia from dense array deployments
H. Yuan, X. Xu, R. Murdie, M.C. Dentith, S. Johnson, **K. Gessner** and L. Zhao **Invited**

Crustal Vs images of the Canning Basin: Is ancient rifting analog to the Neo-Tethys Ocean opening?
H. Yuan, L. Zhao, R. Murdie, **K. Gessner**, K. Wang, T. Li and T. Bodin

Pamir lithospheric structure revealed by transdimensional inversion of ambient noise and surface wave dispersion
J. Zhang, K. Wang, **H. Yuan**, L. Zhao, W. Li, T. Li and T. Bodin

The deep lithospheric structure of the Junggar Terrane, NW China: Implications for its origin and tectonic evolution
A. Zhang, **J.C. Afonso**, S. Wu, **Y. Yang** and Y. Xu

CIFALPS seismic experiment reveals high-resolution characteristics of continental subduction channel beneath western Alps, Europe
L. Zhao, A. Paul, S. Solarino, M. Giovanni Malusa, S. Salimbeni, S. Guillot, C. Aubert, S. Pondrelli, E. Eva, **H. Yuan** and W. Sun

Appendix 5: CCFS visitors

CCFS VISITORS 2019 (Excluding participants in conferences and workshops)

VISITOR	ORGANISATION	COUNTRY
Prof Luc André	Royal Museum for Central Africa, Department of Earth Sciences, Tervuren	Belgium
Dr Paul Bedrosian	US. Geological Survey (USGS)	USA
Prof Andy Biggin	University of Liverpool	UK
Prof Kathleen Campbell	University of Auckland	New Zealand
Miss Xiaoran Chen	Rutgers University	USA
Ms Giulia Consuma	University of Bologna	Italy
Dr Yingjie Fan	International Cooperation Bureau	China
Prof Laura J. Crossey	Dept Earth & Planetary Sciences, University of New Mexico	USA
Mr Dong Fu	China University of Geosciences	China
Prof Carmen Gaina	Geophysics with the Department of Geosciences, University of Oslo	Norway
Mr Baoping Gan	State Key Laboratory of Continental Dynamics, Department of Geology, Northwest University, Xi'an	China
Mr Mingdi Gao	China University of Geosciences (Wuhan)	China
Dr Yongbao Gao	Xi'an Centre of the China Geological Survey (CGS)	China
Dr Wei Guo	Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS), Beijing	China
Prof Trinity Hamilton	University of Minnesota	USA
Ms Louise Hawkins	University of Liverpool	UK
Dr David Holwell	University of Leicester	UK
Mr Jue Hou	Institute of Geophysics, China Earthquake Administration	China
Prof Zengqian Hou	Vice-President National Science Foundation of China (NSFC)	China

VISITOR	ORGANISATION	COUNTRY
Dr Chuan Huang	Peking University	China
Mr Bo Huang	China University of Geosciences	China
Prof Karl Karlstrom	Dept Earth & Planetary Sciences, University of New Mexico	USA
Dr Monika Kusiak	Institute of Geophysics, Polish Academy of Sciences	Poland
Miss Tingzi Li	Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS), Beijing	China
Mr Zhengyang Li	Tsinghua University	China
Dr Yunshuai Li	Institute of Surface-Earth System Science, Tianjin University	China
Dr Jiqiang Liu	Key Laboratory of Submarine Geosciences	China
Ms Jing Liu	China Earthquake Administration	China
A/Prof Joe Michalski	University of Hong Kong	China
Dr Alexander (Sasha) Minakov	Centre for Earth Evolution and Dynamics, University of Oslo	Norway
Prof J. Brendan Murphy	St Francis Xavier University	Canada
Dr Cecilio Quesada-Ochoa	Complutense University of Madrid	Spain
Dr Oldga Ortega	Technical University of Spain (UPC)	Spain
Dr Taichi Sato	Geological Survey of Japan	Japan
Dr Ed Saunders	University of New England, Armadale, NSW	Australia
Dr Limei Tang	Key Laboratory of Submarine Geosciences	China
Prof Martyn Unsworth	University of Alberta	Canada
A/Prof Kuo-Lung Wang	Academia Sinica, Taipei	Taiwan
Dr Qirong Wei	China University of Geosciences (Wuhan)	China
Prof Frances Westall	CNRS, Orleans	France
Mr Jinyun Xie	China University of Geosciences (Wuhan)	China
Dr Qing Xiong	China University of Geosciences (Wuhan)	China
Dr Bo Xu	China University of Geosciences (Beijing)	China
Mr Xinran Xu	Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS), Beijing	China
A/Prof Guoling Yang	Hubei Earthquake Agency, China Earthquake administration	China
Dr Yupeng Yao	Deputy director of the Department of Earth Science, National Natural Science Foundation of China (NSFC)	China
Dr Yongqian Zhang	Chinese Academy of Geological Sciences	China
Dr Irina Zhukova	University of Tasmania	Australia

Appendix 6: Research funding

GRANTS AND OTHER INCOME FOR 2019

Investigators	2019 Funding Source	Project Title	Amount
Jacob, Eggins, Wirth	ARC Discovery Project (DP160102081)	Mechanisms of proxy uptake in biominerals	$30,000
Nutman, Bennett, Van Kranendonk	ARC Discovery Project (DP170100715)	Engineering planetary habitability: Earth's critical first billion years	$70,000
Van Kranendonk, Fiorentini, Campbell, Deamer	ARC Discovery Project (DP180103204)	A terrestrial hot spring setting for the origin of life?	$253,098
Yang, Afonso, Rawling, Ritzwoller, Niu	ARC Discovery Project (DP190102940)	Unveiling the fine structure of the Australian continent using ocean waves	$130,000
Cruden, Fiorentini, Barnes, Bunger, Jackson	ARC Discovery Project (DP190102422)	Magma dynamics and ore deposits	$100,000
Foley	ARC Australian Laureate Fellowship (FL180100134)	Understanding the roles of carbon, water and nitrogen in the development of plate tectonics as drivers of mantle evolution	$619,275
Foley	ARC Australian Laureate Fellowship (FL180100134) MQ contributions	Understanding the roles of carbon, water and nitrogen in the development of plate tectonics as drivers of mantle evolution	$251,388
Li	ARC Australian Laureate Fellowship (FL150100133)	How the Earth works - Toward building a new tectonic paradigm	$564,331
Selway	ARC Future Fellowship (FT150100541)	Measuring mantle hydrogen to map ore fluids and model plate tectonics	$76,044
Alard	ARC Future Fellowship (FT150100115)	Earth's origin and evolution: A sulphurous approach	$100,120
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
Danisik, Evans, McInnes, Kirkland; Li, Fiorentini, Wingate	ARC LIEF (LE190100079)	The Western Australia ThermoChronology Hub	$365,380
Grice, Rickard, Benedix, Jiang, Reddy, Kilburn, Clode, Peyrot, Wacey, Lavery, Masque, Trengove, Xia, Deditius, Maker	ARC LIEF (LE190100053)	A novel ToF-SIMS facility for organic and inorganic analyses in WA	$1,267,674
Meffre, Whittaker, Norman, Cracknell, Belousova, Collins, Arundell, Cooke, Maas, Huston, Musgrave, Greenfield	ARC Linkage Project (LP160100483)	Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia	$45,000
Miller, Kennett, Yuan, Allen, Greay, Gessner, Murdie	ARC Linkage Project (LP180101118)	Enhanced 3-D seismic structure for Southwest Australia	$145,000
Ailleres, Jessell, Armit, Droniou, Lindsay, Cui, Betts, Cruden, de Kemp, Caumon, Wellmann, Kemp, Gessner, Spampinato, Harrison, Kessler	ARC Linkage Project	Enabling 3D stochastic geological modelling	$237,000

Investigators	2019 Funding Source	Project Title	Amount
Regenauer-Lieb, Afonso, Clark, Thiel, Czarnota, Poulet, Jones, Walsh	ARC Linkage Project (LP170100233)	A newly developed science approach to the Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP)	$220,000
Ailleres, Jessell, de Kemp, Caumon, Florian Wellmann, Armit, Droniou, Lindsay, Cui, Betts, Cruden, Kemp, Gessner, Spampinato, Harrison, Kessler	ARC Linkage Project (LP170100985)	Mitigating 3D geological risk in resources management	$240,000
Afonso	European Space Agency	3D Earth	$130,000
Giuliani	Swiss National Foundation Ambizione Fellowship	A new understanding of kimberlite magmas from deep Earth to diamond mines	CHF 952,334
Conrad, Selway, Steinberger, Tarasov, Kellogg, Nisancioglu	Norwegian Research Council, FRINATEK	Magnetotelluric Analysis for Greenland and Postglacial Isostatic Evolution (MAGPIE)	$283,700
Sun, Lu	National Natural Science Foundation of China	Magmatic oxidation state, water content, and volatile nature: New insights into genesis of porphyry copper mineralisation at Zhunuo in the Gangdese belt, southern Tibet	$40,000
Afonso	Geoscience Australia	Developing thermochemical models of Australia's lithosphere	€83,000
Afonso	DeBeers	Multiobservable Thermochemical Tomography of Central and South Africa	$75,000
Thebaud, Aitken, Jessell, Occhipinti, Dentith, Hagemann, Kemp, Fiorentini, Smithies, Lu, Gessner	MRIWA M530, Industry	Yilgarn 2020	$663,500
LaFlamme, Thebaud, Fiorentini, Sugiono	Northern Star Resources	Multiple sulfur isotope systematics of the Kanowna Belle Gold deposit	$73,774
Barnes, Fiorentini	IGO Independence Group	Genesis of the Nova Nickel Deposit	$160,000
Loucks, Fiorentini	BHP Billiton	Improving zircon morphology and chemistry as a tool of assessing and ranking the relative prospectivity for Cu porphyry deposits in "*greenfield*" terrains	$176,000
Fiorentini, Barnes	Anglo American, CSIRO	Resistate indicator minerals for magmatic nickel sulfide ores	$203,000
Fiorentini, Denyszyn	Panoramic Resources and Innovation Connections	Establishing the precise width of the Ni-Cu ore-forming window along the Halls Creek Orogen of Western Australia through CA-IDTIMS high- precision geochronology	$52,000
Fiorentini	IGO	Geochemical appraisal of mafic and ultramafic rocks from a series of IGO prospects along the Albany-Fraser Belt of Western Australia	$60,000
George, Fiorentini, Parra Avila	Auldana	Tectonic evolution and amalgamation of continental, arc and arc-related terranes of Northern Thailand	$24,000
Huaiyu Yuan	Canning CWAS	China-Western Australia Seismic Survey (CWAS 2nd stage)	$53,330
O'Reilly	NCRIS AuScope	AuScope Project Plan 3.53 - Earth composition and evolution	$200,382
O'Reilly	NCRIS AuScope (MQ contribution)	AuScope Project Plan 3.53 - Earth composition and evolution	$50,000

Investigators	2019 Funding Source	Project Title	Amount
Selway, Goodwin	Macquarie Research Infrastructure Scheme	Geophysical infrastructure for polar measurements	$75,300
Campbell, Van Kranendonk, Guido	Marsden Grant	Some liked it hot: Searching for early life in terrestrial hot springs	$333,000
Daczko, Munnikhuis	ANSTO – Australian Synchrotron Beamline Program	Using geochemical and microstructural XFM mapping to identify proximal, medial and distal vectors around magma transfer zones	$983,352
Loehr, Whittaker, Daczko, Hall	ANZIC IODP Legacy Analytical Funding (AILAF)	Constraining the palaeodepth evolution of the South Tasman Rise and determining its role in development of the Antarctic Circumpolar Current (ACC)	$19,292
Daczko, Gardner, Piazolo	ANZIC IODP Legacy Analytical Funding (AILAF)	Melt-present deformation within the dynamic oceanic crust: recognition and rheological consequences	$9,126
Pages, Barnes, Laukamp, Van Kranendonk, Michalski, Schulte	CSIRO	From the Red Sea to the Red Planet	$120,000
Wilde, Nemchin, Whitehouse, Harley, Kusiak, Dunkley	Australian Antarctic Science Grant	Determining the extent and nature of the oldest crust in Antarctica	$30,991
O'Reilly	Commercial - ACCESS MQ	GLITTER	$44,954

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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
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
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
EES	Earth and Environmental Sciences (MQ Department, formerly EPS)
EPS	Earth and Planetary Sciences (Department, MG)
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
MG3	Geophysics and Geodynamics Group
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

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