

ANNUAL  
REPORT

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UNIVERSITY of  
TASMANIA







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*OPPOSITE PAGE: (Top left) PhD student Amery Jackson, former CRC ORE student (now working at MRT) Jake Moltzen, and Research Fellow Nathan Fox using the HyLogger at Mornington, Tasmania. (Top right) Quartzite fragment-rich layers in sandy coastal soils near Trial Harbour, western Tasmania. (Bottom) Honours student Hannah Couper with Chris Miller inspecting drill core at Newcrest Mining's Telfer core shed, Western Australia.*

*RIGHT: Quartz monzonite porphyry dyke crosscutting and crosscut by quartz-bornie stockwork in feldspar-hematite altered trachyte, North Parkes porphyry Cu-Au deposit, NSW.*

*FRONT COVER: Participants of the 2017 MEconGeol Geometallurgy short course touring the ore processing plant at Grange Resources' Savage River iron ore mine, western Tasmania.*

*BACK COVER: The CODES SEG Student Chapter annual field trip in 2017 was to western and northwestern Tasmania; here field trip participants are collecting specimens at the Mount Bischoff fossicking lease.*

# Director's report 2017

## **GENERATIONAL CHANGE AT CODES**

2017 was a time of unprecedented change at CODES. Our former Director, Professor Bruce Gemmell, retired at the end of June 2017, and Professor David Cooke was appointed as his replacement in July. Professor Leonid Danyushevsky has replaced David as the Deputy Director of CODES. Bruce's departure, coupled with the tragic and unexpected passing of Dr Garry Davidson in April 2017, meant that CODES arrived at a point of generational change in 2017.

With such a significant change in its leadership team, CODES has taken the opportunity to restructure its research programs to more accurately reflect our strengths and interests, and to provide our outstanding young scientists with opportunities to step up to leadership roles. As part of these changes, CODES has been renamed as the Centre for Ore Deposit and Earth Sciences. This name change

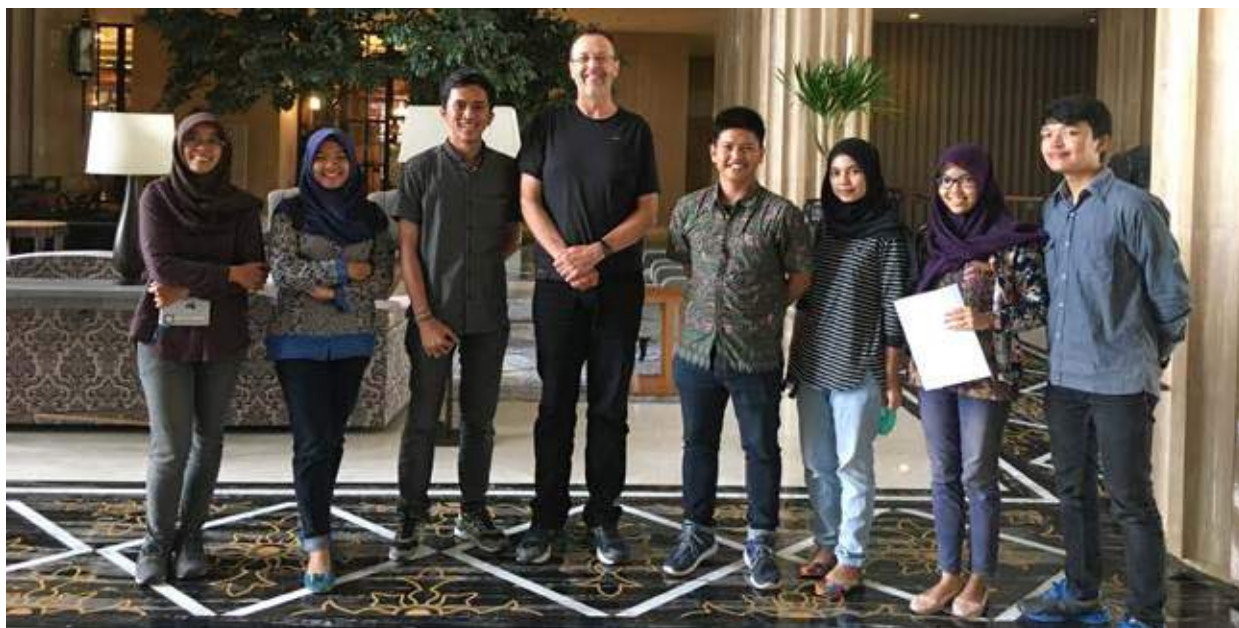
reflects the fact that we want to encompass all our research strengths under the CODES umbrella – from applied research on ore deposits to fundamental Earth Sciences research across a range of sub-disciplines. Leaders and deputy leaders have been appointed for each of the six new programs, which are outlined in detail in the 'Profile and Research Structure' section of this report.

CODES' success is underpinned by the close link between fundamental research in the broad discipline of Earth Sciences and end-user-focussed research in economic geology, geoenvironment and geometallurgy. CODES' traditional areas of strength include igneous petrology and geochemistry, volcanology, sedimentology, structural geology and geophysics.

With its new structure, CODES builds on almost 30 years of experience at developing and fostering extensive collaborations with industry and academia in the field of economic geology. Our Centre has an exceptional

education track record through its world-class PhD (research) and Master of Economic Geology (coursework) programs. The CODES team comprises world-class researchers who deliver end-user-driven solutions critical to Australia's economic prosperity and the future of the global minerals industry, facilitated by state-of-the-art analytical facilities in the CODES Analytical Laboratories. CODES' educational training and research enables companies to make new discoveries with innovative techniques, thereby increasing their productivity and competitive advantage.

CODES conducts research programs in 30 countries, has more than 50 staff, 110 postgraduate students, and a budget of approximately \$6 million per annum. In collaboration with the Discipline of Earth Sciences within the School of Natural Sciences, CODES supplies a significant proportion of graduates (Honours, Masters and PhD) in the geosciences required by the Australian and global minerals industry.



*ABOVE: CODES Director Professor David R. Cooke and the executive committee members of the Society of Economic Geologists Student Chapter at Universitas Gadjah Mada, Yogyakarta, Java, Indonesia.*





ABOVE: (Left) Professor David Green (left) receives the Royal Society's 2016 R. M. Johnston Memorial Medal from Professor Matt King, president of the Royal Society of Tasmania, in May 2017. (Right) A riverboat cruise on the Derwent formed part of the celebrations for the events to mark the 70th anniversary of Geology at the University of Tasmania in November 2017.

## AWARDS AND ACCOLADES

We are proud that several of our staff and students received significant recognition of their outstanding efforts through a series of awards and accolades in 2017. Dr Anita Parbhakar-Fox was jointly awarded the *Materials World* Medal for 2018 for an article she wrote on mining waste. Professor Anya Reading travelled to the USA for an extended stay at the University of Colorado in early 2017 as part of her Fulbright Tasmania Senior Scholarship.

The 2016 Royal Society of Tasmania's prestigious R. M. Johnston Memorial Medal, established in 1920 and awarded to a scholar of great distinction, was presented to Professor David Green FRS during the year. Professor Ross Large was announced as the winner of the Royal Society of Tasmania Medal, and will be presented with his medal during 2018. And during the year it was announced that Professor David Cooke won the Haddon Forrester King Medal for 2018. This medal is awarded by the Australian Academy of Science, sponsored by Rio Tinto, for life-long achievement and outstanding contribution to science, and is considered one of the Academy's top honours.

## CONFERENCES

CODES staff and students actively participated in numerous conferences throughout 2017, with 84 conference abstracts, papers and presentations, including seven invited keynote and plenary presentations helping to showcase some of our major research outcomes to the global scientific community.

A major highlight in early 2017 was CODES staff organising and hosting the Chapman Conference on 'Submarine Volcanology: New Approaches and Research Frontiers' in Hobart, Tasmania. This international conference, which was organised by Rebecca Carey, Karin Orth, Jocelyn McPhie, Ray Cas, Martin Jutzeler and Mike Coffin (IMAS), brought together researchers and students from all over the world to discuss the past decade's advances in understanding various types, mechanisms, consequences and tectonic environments of submarine volcanic eruptions.

In November 2017, 70 years of Geology at the University of Tasmania were celebrated with a two-day event that included a one-day symposium highlighting major research initiatives of CODES and the Discipline of Earth Sciences, and a riverboat cruise and reunion dinner. Past and present alumni of CODES and the Discipline of Earth Sciences enjoyed a stimulating series of presentations that highlighted major innovations from our research team past and present. Ross Large organised the event, which was ably coordinated by Irina Zhukova.

## PUBLICATIONS

2017 was an exceptional year for CODES in terms of publications. Our team published 83 refereed journal articles; we also published 41 book chapters. We regained our status as the leading academic group to publish in *Economic Geology*, passing the USGS once again in 2017. This is a remarkable achievement, especially when considering our consistently high output in terms of reports to industry. We sustained a very high level of industry reporting, with 126 reports in 2017 slightly down on our output of 134 in 2016, but still well above our ARC Performance Indicator of 80.

## CODES ANNUAL REVIEW MEETING

CODES initiated a new event in November 2017 – the CODES Annual Review Meeting. This meeting provides our staff and students with a vehicle to showcase our major research highlights for the calendar year, both to our academic collaborators and industry stakeholders. Anya Reading did a superb job in coordinating an excellent series of presentations and poster displays that were greatly appreciated by all who attended. Going forward, this annual event will be held in conjunction with a CODES Advisory Board Meeting, and with other major meetings such as AMIRA Sponsor Review Meetings, so as to maximise opportunities for engagement and participation of our industry partners.



## VALE GARRY, KATIE AND PAT

As highlighted in the 2016 annual report, our staff and students were profoundly affected by the passing of Garry Davidson and Katie McGoldrick in 2017. Garry and Katie were both integral parts of the CODES family, and all who worked at CODES and in the Discipline of Earth Sciences in 2017 were strongly influenced by these tragic losses. Both are deeply missed, and our thoughts remain with Garry and Katie's families. Garry and Katie may be gone, but they are not forgotten.

Sadly, as the 2017 Annual Report goes to press, another beloved member of our Earth Sciences community at the University of Tasmania has passed away. Honorary Research Professor Pat Quilty lost his long battle with cancer in late August 2018 at the age of 79. Pat gained his PhD from the University of Tasmania in 1969. Pat was globally renowned as a pioneer of Antarctic scientific research, working for many years in the Australian Antarctic Division, where he was a former chief scientist. Pat won many awards during his illustrious career, including the United States Antarctic Services Medal in 1974, the Royal Society of Tasmania Medal in 1996 and the Phillip Law Medal in 2016. He was made a member of the Order of Australia in 1997.

## THE YEAR AHEAD: 2018

Our team is looking forward with optimism to 2018. The TMVC's major research project, AMIRA P1153, is scheduled to finish in mid-2018, and we are optimistic that the success of

## STATISTICS AT A GLANCE 2017

Academic Research Staff	58
Postgraduate Students	115
Major Research Projects	73
Countries Involved	30
Publications in Refereed Journals	83
Research Reports to Industry	126

### WORKSHOPS AND SHORT COURSES

Number	22
Countries	8
Attendees	760

### FUNDING

Industry	\$1.26 million
UTAS	\$1.84 million
TMVC	\$2.12 million

### WORLDWIDE COLLABORATIONS

Industry	63
Institutes and Universities	114

that project will lead to a new phase of AMIRA-funded research in the porphyry-epithermal footprints space.

We have new industry-funded research initiatives commencing in collaboration with new industry research partners Goldcorp and Evolution. We also look forward to reinvigorating our research efforts in sediment-hosted base metal and IOCG deposits through a new collaborative research initiative being funded by the Queensland Government and coordinated by the Queensland Geological Survey and the University of Queensland.

Our team working on the CRC ORE program should reach full capacity in 2018, and our team of researchers working on the TMVC-related projects will be starting to bring the

many threads of that major research program together in its penultimate year of funding. We continue to have an excellent crop of students at the PhD, Masters and Honours level, and will be actively promoting our research successes through presentations at major conferences globally.

New collaborations will be established with new mineral characterisation service providers (including Orexplore and Minerals Insight) to explore how predictive geometallurgical and geoenvironmental data can be extracted and used to predict processing attributes and forecast waste characteristics.



ABOVE: (Left) Professor Pat Quilty AM, a stalwart of Earth Sciences at UTAS, passed away in August 2018, and will be greatly missed by his colleagues and friends here at CODES. (Right) The 2017 FUTORES II conference in Townsville, Queensland, was attended by several researchers from CODES. L-R: Tristan Wells, Wei Hong, Christopher Leslie, David Cooke, Angela Escolme, Josh Phillips and Noel White. OPPOSITE PAGE: (Top left) The highly successful Chapman Conference on Submarine Volcanology organised by CODES researchers in early 2017 was well attended, and an important achievement for the Program 4 team. (Top right) CODES staff and students presented at many conferences throughout 2017; here Dr Anita Parbhakar-Fox addresses the 8th World Conference on Sampling and Blending in Perth. (Bottom) Dr Mike Roach presents details about the AusGeol Virtual Library of Australia's Geology at the inaugural CODES Annual Review Meeting in December 2017.







# Profile and research structure



ABOVE: 2017 SEG Beijing post-conference field trip participants at Batu Hijau copper-gold mine, Indonesia.

## AN OVERVIEW

CODES was formed in 1989, and was known as the Australian Research Council (ARC) Centre of Excellence in Ore Deposits between 2005 and 2016. It is now known as CODES, the Centre for Ore Deposit and Earth Sciences. Based at the University of Tasmania, the Centre has grown substantially over the years and is now widely regarded as a global leader in ore deposit research and postgraduate training. It is home to 58 highly qualified research staff and 115 postgraduate students, further cementing its position as the largest university-based team of ore deposit researchers in the world.

Highly productive worldwide collaborations have been developed with over 63 industry companies, plus a host of joint research initiatives with 114 institutions and universities – 24 in Australia and 90 overseas. It currently has 73 major research projects spanning 30 countries, and all seven continents. It is also the leading academic group to publish

in *Economic Geology*. In the past year, it maintained its reputation for delivering excellence in technology transfer by producing 126 reports to industry and conducting 22 short courses, workshops, conferences and field trips in eight countries, spread around the world.

## INDUSTRY-FOCUSED RESEARCH AND TRAINING

In 2017 CODES made significant changes to the structure of its research programs, transitioning from the previous four-program model to the current six-program model. This new structure more accurately reflects the breadth of CODES' present research activities. It provides a logical framework for CODES' role in developing exploration techniques for metal discovery, new practices for sustainable mining and a steady supply of world-class geoscience graduates, as well as creating a platform to meet the training and upskilling needs of the minerals industry.

## RESEARCH STRUCTURE: THE PROGRAMS

**Program 1: Ore deposits and mineral exploration** encompasses all of our research into the characteristics and genesis of ore deposits. It also includes our applied research that is strategically aligned with the mineral exploration industry's major challenges across all scales of exploration. It fosters the training of the next generation of ore deposit and exploration specialists, by enabling students' and HDR candidates' projects to be undertaken in close collaboration with our industry partners.

**Program 2: Geometallurgy, geoenvironment and mining** aims to facilitate sustainable mining, mineral processing and waste management practices in the minerals industry. As a result of our research, transformations made to each phase of resource extraction and processing are achieved in collaboration with our industry partners. Our goals are to minimise the impacts and maximise the



benefits of metallic mining in diverse environments, and to assist with remediation of legacy issues.

### Program 3: Sedimentation, tectonics and Earth evolution

activities aim to understand the formation and evolution of sedimentary basins, together with their histories of deformation and metamorphism. Basin development is placed within the broader context of geodynamic processes and Earth evolution through time. We aim to develop new and refined genetic and exploration models for sediment-hosted mineral systems.

### Program 4: Magmatic and volcanic processes

researches magma genesis and evolution, volcanology and the architecture of magmatic plumbing systems. Investigations of volcanic phenomena

in subaerial and submarine settings provide the geological framework for understanding alteration and mineralisation in volcanic terrains. Geochemical insights into magma fertility and the roles of mantle and crustal processes provide an improved understanding of magmatic, volcanic-hosted and magmatic-hydrothermal mineral systems.

### Program 5: Analytical research

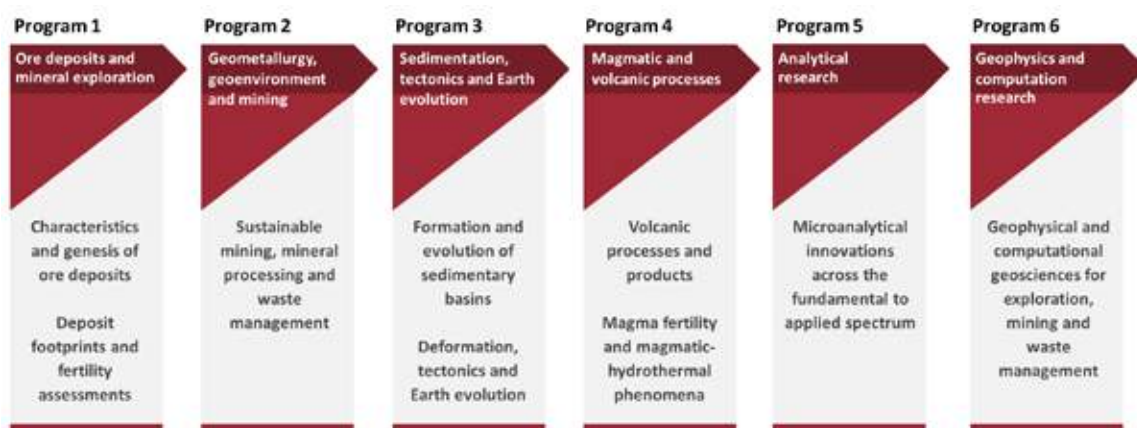
underpins much of our most innovative research across the fundamental-to-applied spectrum. New developments in analytical research provided by CODES' Analytical Laboratories provide the basis for CODES' global leadership in microanalytical techniques specifically applied to mineral exploration, mineral processing,

ore genesis and waste management. This program also provides analytical services to government, academia and industry.

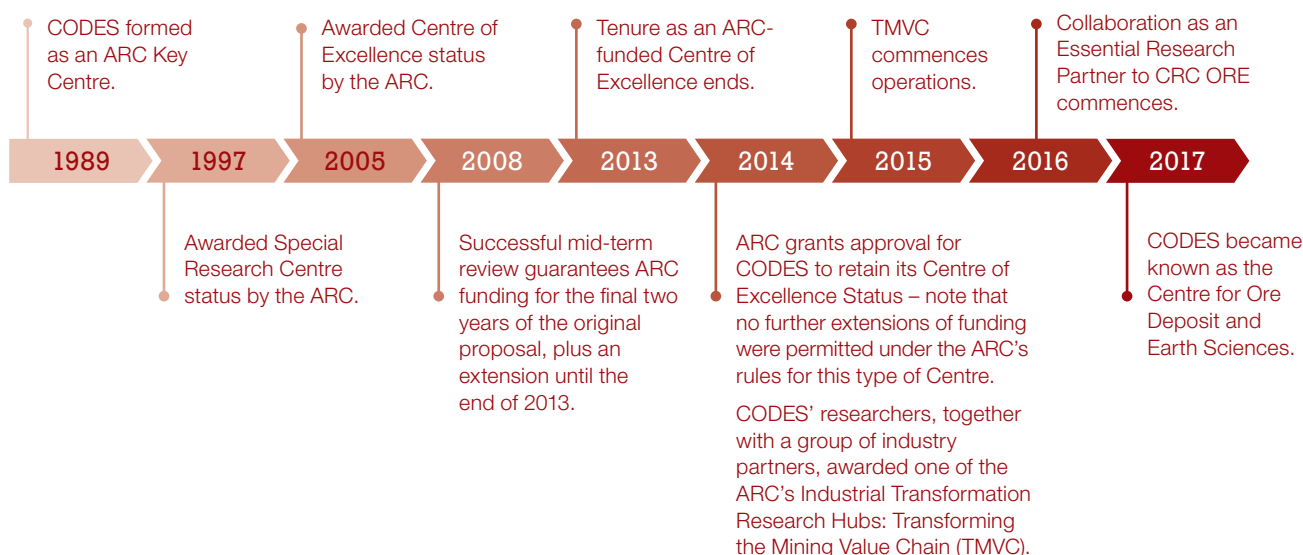
### Program 6: Geophysics and computational geosciences

addresses challenges with handling, processing, visualising and interpreting Big Data in the minerals industry, from exploration, mining and mineral processing to waste management. Geophysical data acquisition, processing and interpretation are a core component of CODES' research and training activities. Computational geosciences are becoming increasingly important as technological advances drive a step-change in automated data acquisition and imaging methods across the geosciences.

## CODES' NEW PROGRAM STRUCTURE



## TIMELINE





## TRAINING AND EDUCATION

Training and education at CODES provides an ongoing supply of world-class geoscience graduates, and delivers a range of professional development short courses and workshops tailored to meet the needs of the minerals industry in terms of upskilling its workforce. The schedule for upskilling courses varies in line with demand. Typical courses include Geophysics for Geologists and Engineers, and Advances in Geo-logging. Postgraduate courses are offered at the following levels:

### HONOURS

A one-year degree that will significantly increase employment options, or can be used as a stepping-stone to a PhD. Courses are available in Economic Geology, Geophysics and Geochemistry.

### MASTER OF ECONOMIC GEOLOGY

A series of intensive, two-week courses aimed at the working geologist. Available in coursework only and coursework/thesis (25%) options. The degree is part of the national Minerals Geoscience Masters program.

### PHD AND MSC

These higher degree by research programs enable students to complete their theses in an environment that provides access to state-of-the-art technology, exceptional links with industry, and supervisors who are international leaders in their respective fields.

## RESEARCH FACILITIES

CODES' state-of-the-art analytical facilities cover a wide range of applications, encompassing the routine multi-element analysis of sulfide and oxide minerals, including the full range of platinum group elements; U/Pb dating of zircon and monazite; and multi-element analysis of silicates. These facilities include five laser ablation ICP-MS laboratories specialising in ore deposit applications, an XRF laboratory, solution ICP-MS and clean room, fluid/melt inclusion laboratory, a lapidary department and sample preparation facilities.

In addition, portable analytical techniques are provided, including shortwave infrared (SWIR) and portable XRF.

CODES has reciprocal access arrangements with the UTAS Central Science Laboratory, which has an extensive suite of complementary equipment, particularly in the areas of electron microscopy and mineral liberation analysis (MLA), X-ray microanalysis, laser Raman and FTIR spectroscopy, and ICP-MS.

CODES' leading edge is based on the development of a number of unique analytical techniques and calibration standards, combined with employing staff with extensive expertise in analytical protocols and the interpretation of results.

## TRANSFORMING THE MINING VALUE CHAIN

### AN ARC INDUSTRIAL TRANSFORMATION RESEARCH HUB

CODES is home to an Australian Research Council Industrial Transformation Research Hub, entitled Transforming the Mining Value Chain (TMVC). The Hub encompasses a wide array of activities from exploration, discovery, ore deposit characterisation, and environmental assessment, through to mining, ore processing and waste rock disposal. The main objective is to improve efficiencies within the mining value chain, focussing on areas that will have a marked impact on the value of mineral resources. In addition to CODES, the industry partners involved in the research hub include BHP, Corescan, Newcrest Mining, and a consortium of global companies co-ordinated by AMIRA International. Other organisations affiliated with the initiative include Laurin Technic, UTAS Engineering, and RWTH Aachen University in Germany.

TMVC activities are covered later in this annual report.

*TOP LEFT: Setting up equipment for a seismic survey on Sørsdal Glacier as part of the research carried out by Honours student Thomas Schaap in Program 6 during 2017. These surveys give information on the thickness of the ice beneath. It takes a 15-minute flight by helicopter to get to the glacier from Davis Research Station. BOTTOM LEFT: Students at CODES performing static geochemical testing as part of a unit on environmental geology.*



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# Staff and management

## **CENTRE DIRECTOR**

Professor David Cooke was appointed as the Centre Director in mid-2017; he is responsible for the scientific leadership and operational management of the Centre, and is assisted in this role by Professor Leonid Danyushevsky, who is acting as Deputy Director of the Centre. Assisting them in these roles are the Advisory Board and the Executive Committee.

## **ARC TMVC RESEARCH HUB DIRECTOR**

Professor David Cooke is Director of the ARC Research Hub for Transforming the Mining Value Chain. He is supported in these duties by Deputy Director Professor Leonid Danyushevsky.

## **ADVISORY BOARD**

The Advisory Board meets at least once a year to review the progress of the Centre and to advise on future directions. The Board is composed of representatives from major industry partners, University of Tasmania senior management and key national geoscience organisations. It is chaired by Dr Paul

Heithersay from the Department of State Development, South Australia, who has extensive experience in the minerals industry and the public service. Paul Agnew from Rio Tinto is Deputy Chair.

## **ANNUAL REVIEW**

The Annual Review (formerly the Science Planning Panel) is an annual one-day forum of presentations relating to the Centre's research. The membership is wider than that of the Advisory Board and includes a representative from all partner companies. The Annual Review is designed to provide industry with an opportunity to see the breadth of the research conducted at CODES and to influence future research directions.

## **EXECUTIVE COMMITTEE**

The Executive Committee consists of the Centre Director, Deputy Director, the Program Leaders, the TMVC Research Hub Manager, and the leaders of the training program. It meets approximately six times a year, working closely with the Director to develop the Centre's goals, strategies and research directions.

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## STAFF MOVEMENTS 2017

### **APPOINTMENTS**

#### **ACADEMIC STAFF**

Dr Angela Escolme, who completed her PhD at CODES during 2017, was appointed as a Postdoctoral Research Fellow in Geometallurgy for the ARC TMVC Research Hub.

Dr Nathan Fox was reappointed in 2017 as a Postdoctoral Research Fellow and leader of the CRC ORE program at CODES responsible for managing research activities including postgraduate student projects.

Dr Martin Gal completed his PhD during the year, and was appointed as a Postdoctoral Research Fellow in Computational Geophysics for CODES, working in Program 6 on seismic array investigations of ocean storms.

*BELOW: Staff and students at CODES make the acquaintance of a large newly acquired model T-Rex, which is used to promote geology-related outreach and teaching activities.*





## PROFESSIONAL STAFF

Troy Finearty took up the role of the Maintenance, Field Equipment & WHS Officer for CODES and Earth Sciences.

Karen Huizing returned to CODES as an Administrative Support Officer, on secondment from the Finance area.

Caroline Mordaunt returned to CODES in a part-time administrative role.

## DEPARTURES

### ACADEMIC STAFF

As recorded in the 2016 CODES annual report, Dr Garry Davidson, Senior Lecturer and Honours Coordinator, sadly succumbed to cancer in April 2017. This has left an enormous hole to fill at CODES in terms of both his teaching and research roles.

Professor Bruce Gemmell stepped down as Director of the Centre during 2017 to enjoy the benefits of retirement. He has a role as honorary researcher at CODES and will take an active part in his research interests.

Dr Sean Johnson relinquished his role as a Postdoctoral Research Fellow in LA-ICP-MS and took up an appointment at the Irish Centre for Research in Applied Geosciences as a Postdoctoral Research Fellow in the Raw Materials area.

### PROFESSIONAL STAFF

Steve Calladine left the role of Communications Manager during 2017.

Ian Little vacated his position as Maintenance, Field Equipment & WHS Officer at CODES to pursue a career elsewhere.

Katie McGoldrick, a Laboratory Assistant and stalwart of the professional staff for many years at CODES, sadly passed away in April 2017, as recorded in the 2016 annual report.

## SENIOR MANAGEMENT

NAME		%*	TMVC†
Director, Professor David Cooke, BSc Hons (Latrobe), PhD (Monash)	Porphyry Cu-Au, fluid-rock geochemistry	50	✓
Deputy Director, Professor Leonid Danyushevsky, PhD (Vernadsky Inst.)	Petrology, geochemistry, LA-ICP-MS analysis	50	✓

## ACADEMIC/RESEARCH STAFF AT UTAS

NAME		%*	TMVC†
Dr Sharon Allen, BSc (Massey), MSc (Auckland), PhD (Monash)	Volcanic facies analysis	Hon	
Dr Mike Baker, BSc Hons (Sydney), PhD (UTAS)	Igneous petrology, mineral chemistry	100	✓
Associate Professor Ron Berry, BSc, PhD (Flinders)	Structure of mineralised provinces, CHIME dating, geometallurgy	Hon	✓
Dr Stuart Bull, BSc Hons, PhD (Monash)	Clastic and carbonate sedimentology and volcanology	Hon	
Dr Rebecca Carey, BSc Hons (UTAS), PhD (U Hawaii)	Volcanology	100	
Dr Matthew Cracknell, BSc Hons, PhD (UTAS)	Geophysics, machine learning and data mining	100	✓
Professor Tony Crawford, BSc Hons, PhD (Melbourne)	Petrology, geochemistry and tectonics of volcanic arcs	Hon	
Dr Paul Davidson, BSc Hons, PhD (UTAS)	Melt and fluid inclusions	Hon	
Dr Angela Escolme, MEarthSci Hons (Manchester), PhD (UTAS)	Geometallurgy, geochemistry, mineralogy	100	✓
Dr Trevor Falloon, BSc Hons (Canterbury), BTeaching, PhD (UTAS)	Marine geoscience, petrology	Hon	
Dr Nathan Fox, MSc Hons (Imperial), PhD (UTAS)	Ore deposit geology, environmental mineralogy and geometallurgy	100	
Dr Martin Gal, MSc (TUWien), PhD (UTAS)	Geophysics, seismology, computational methods	100	
Professor J Bruce Gemmell, BSc (UBC), MA, PhD (Dartmouth)	VHMS deposits and epithermal Au-Ag	Hon	✓
Professor David Green, BSc Hons, MSc, DSc, DLitt Hon (UTAS), PhD (Cambridge)	Experimental petrology	Hon	
Dr Jacqui Halpin, BSc Hons (Melbourne), PhD (Sydney)	Metamorphic petrology, geochronology	Hon	

\*Research percentage † TMVC affiliated





ABOVE: CODES staff and students taking part in the Geological Society of Australia Earth Science Student Symposium, which was held at IMAS in Hobart in November 2017.

## ACADEMIC/RESEARCH STAFF AT UTAS

NAME		%*	TMVC†
Dr Martin Jutzeler, MSc (ULausanne), PhD (UTAS)	Volcanology and clastic sedimentology	50	
Dr Maya Kamenetsky, PhD (UTAS)	MLA-SEM, geometallurgy, petrology	100	
Professor Vadim Kamenetsky, BSc Hons (Moscow), PhD (Vernadsky Inst.)	Petrology and geochemistry of melt inclusions	100	
Professor Khin Zaw, BSc (Rangoon), MSc (Queen's U), PhD (UTAS)	Fluid inclusions, SE Asian metallogenesis	10	
Professor Ross Large, BSc Hons (UTAS), PhD (UNE)	Volcanic-hosted and sediment-hosted base metal and gold ores	Hon	✓
Dr Peter McGoldrick, BSc Hons, PhD (Melbourne)	Ore deposits and their halos	Hon	
Professor Jocelyn McPhie, BA Hons (Macquarie), PhD (UNE)	Volcanic facies architecture and volcanic textures	Hon	
Associate Professor Sebastien Meffre, BSc Hons, PhD (Sydney)	Petrology and tectonics of the SW Pacific	100	✓
Dr Evan Orovan, BSc Hons (Carleton), PhD (UTAS)	Porphyry environment, mineral chemistry and hydrothermal geochemistry	100	✓
Dr Karin Orth, BSc Hons (Monash), PhD (UTAS)	Volcanology	40	
Dr Anita Parbhakar-Fox, MSc Hons (Imperial), PhD (UTAS)	Environmental geology, mineralogy, geochemistry	100	✓
Professor Pat Quilty AM, PhD (UTAS)	Palaeontology, Antarctic research	Hon	
Professor Anya Reading, BSc Hons (Edinburgh), PhD (Leeds)	Geophysics, seismology, computational methods	50	✓
Dr Michael Roach, BSc Hons (Newcastle), PhD (UTAS)	Geophysical responses of ore deposits	20	
Dr Robert Scott, BSc Hons, PhD (Monash)	Structural geology, gold deposits / MTEC Senior Lecturer and Masters Program Coordinator	70	
Dr David Selley, BSc Hons (Adelaide), PhD (UTAS)	Structural geology, basin analysis, ore deposit modelling	Hon	
Dr Jeff Steadman, BSc (Central Missouri), MSc (Iowa), PhD (UTAS)	Ore and sedimentary pyrite geochemistry; seawater composition through geologic time	100	
Dr Aleksandr (Sasha) Stepanov, MSc (Novosibirsk), PhD (ANU)	Geochemistry of rare metals	100	
Dr Tony Webster, BSc Hons (Latrobe), BA (UNE), BAVE, BEd Hons (UTAS), GDipMinEng (UNSW), MSc (JCU), PhD (UTAS)	Mining structural geology, complexly deformed deposits	Hon	
Dr Lejun Zhang, BSc, PhD (HFUT)	Porphyry Cu-Au and HS epithermal	100	✓

\*Research percentage † TMVC affiliated

## ACADEMIC/RESEARCH STAFF BASED AT COLLABORATIVE INSTITUTIONS/INDUSTRY

NAME		TMVC
Dr John Bishop	Consultant	Hon
Dr Tony Brown	Consultant	Hon
Professor Ray Cas	Monash University	Hon
Dr Kathy Ehrig	BHP	Hon ✓
Professor Andrea Gerson	Blue Minerals Consultancy	Hon
Neil Goodey	CoreScan	✓
Professor Mark Hannington	University of Ottawa	Hon
Dr Anthony Harris	Newcrest Mining	Hon ✓
Professor Peter Hollings	Lakehead University	Hon
Mr Terry Hoschke	Consultant	Hon
Dr Julie Hunt	Mineral Deposit Research Unit (MDRU)	Hon
Dr David Huston	Geoscience Australia	Hon
Dr Tim Ireland	First Quantum Minerals	Hon
Professor Bernd Lottermoser	RWTH Aachen University	Hon ✓
Mr Adi Maryono	J Resources	Hon
Dr Andrew McNeill	Mineral Resources Tasmania	Hon
Adele Seymon	AMIRA International	✓
Michael Shelley	Laurin Technic	✓
Professor Roger Smart	Blue Minerals Consultancy	Hon
Professor Noel White	Consultant	Hon
Professor Jamie Wilkinson	Natural History Museum / Imperial College London	Hon

## TECHNICAL/ADMINISTRATIVE STAFF

NAME		%*	TMVC†
Dr Ivan Belousov, BSc, MSc (Moscow), PhD (Vernadsky)	Research Associate – ARC TMVC Research Hub	100	✓
Mrs Michele Chapple-Smith	Lapidary Technician	40	
Mr Alex Cuison	Lapidary Manager	80	
Mr Troy Finearty	Maintenance, Field Equipment, and Safety Officer	50	
Dr Jane Higgins, BIS, BAntSt Hons, PhD (UTAS)	Personal Assistant to the Director	100	
Ms Karen Huizing	Administrative Assistant	100	
Ms Elena Lounejeva	Laboratory Analyst	100	
Mrs Michelle Makoundi	Laboratory Assistant	40	
Ms Caroline Mordaunt, BA Hons (King's College London)	Administrative Assistant	10	
Dr Paul Olin, BA (SOU), MSc, PhD (WSU)	Laser Ablation Technician – ARC TMVC Research Hub	100	✓
Mrs Claire Rutherford	Administrative Assistant – ARC TMVC Research Hub	60	✓
Ms Helen Scott, BSc Hons (UTAS), BEd (QUT)	Hub Manager – ARC TMVC Research Hub	100	✓
Mr Jay Thompson, BSc Hons, MSc (U Iowa)	Laboratory Analyst	100	
Ms Isabella von Lichten, BSc Hons (UTAS)	Curator	25	
Dr Irina Zhukova, MSc (Novosibirsk), PhD (ANU)	Research Assistant	20	

\*Research percentage † TMVC affiliated



## ADVISORY BOARD

Chair: Paul Heithersay	Department of State Development, South Australia
Deputy Chair: Paul Agnew	Rio Tinto
David Cooke	Director, CODES, UTAS
Leonid Danyushevsky	Deputy Director, CODES, UTAS
John Dickey	Head of School of Physical Sciences, UTAS

Kathy Ehrig	BHP
Anthony Harris	Newcrest Mining Limited
Neil Macalalad	Anglo American
Adele Seymon	AMIRA International
Brett Stewart	MRT
Noel White	Consultant
Brian Yates	Dean, Faculty of Science, Engineering and Technology, UTAS

## EXECUTIVE COMMITTEE

FOR MEETING HELD ON 16 FEBRUARY 2017

Chair: Bruce Gemmell	Director, CODES
Steve Calladine	Communications Manager
David Cooke	Deputy Director CODES/ARC TMVC Research Hub Director
Leonid Danyushevsky	Enabling Technologies Module Leader/Head of the Discipline of Earth Sciences

Garry Davidson	Ore Deposits: Characterisation and Context Module Leader
Jane Higgins	PA to the Director and Minute Taker
Anita Parbhakar-Fox	Acting Geometallurgy Module Leader
Robert Scott	Training Module Co-leader
Helen Scott	ARC TMVC Research Hub Manager

## SCIENCE PLANNING PANEL

ALSO INCLUDES THE EXECUTIVE COMMITTEE AND ALL CODES RESEARCH STAFF AND STUDENTS

Chair: David Cooke	Director, CODES, UTAS
Ben Adair	CRC ORE
Paul Agnew	Rio Tinto
Debora Araujo	Rio Tinto
John Bishop	Mitre Geophysics
Tim Chalke	Mira Geoscience
Karol Czarnota	Geoscience Australia
Mark Duffett	Mineral Resources Tasmania
Kathy Ehrig	BHP
Andrea Gerson	ANU
David Green	Mineral Resources Tasmania
Anthony Harris	Newcrest Mining
Paul Heithersay	Department of State Development, South Australia

Robert Hough	CSIRO
Tim Ireland	First Quantum Minerals
Neil Macalalad	Anglo American
Andrew McNeill	Mineral Resources Tasmania
Paul Revell	CRC ORE
Adele Seymon	AMIRA International
Trevor Shaw	Mt Isa Mines
Penny Sinclair	CAMECO
Roger Smart	University of South Australia
Andrew Somers	SciAps Australia
Stephanie Sykora	First Quantum Minerals
Steve Turner	Newmont
Steve Walters	CRC ORE
Noel White	Consultant



ABOVE: CODES students and collaborators undertaking fieldwork at Rocky Cape, northwest Tasmania.



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## OBJECTIVE

This program aims to use newly developed geological, geochemical, mineral chemical and geophysical features of ore forming systems and terrains in order to devise better means of discovering mineral resources at surface and under cover.

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# INTRODUCTION

**Program 1: Ore Deposits and Mineral Exploration** provides industry-focussed process-based models for the formation of base and precious metal ore deposits. It also seeks to develop innovative new tools for determining the most prospective regions for minerals exploration (fertility), and for targeting of buried ore deposits (vectoring).

The program was formed in 2017 as a revision to the Ore Deposits: Characterisation and Context Module that had been in operation since 2014. This revised program retains CODES' core research strengths, while providing a platform that allows projects to be developed that meet the evolving needs of the minerals industry. Program 1: Ore Deposits and Mineral Exploration consists of nine key sub-projects (as well as other smaller projects), which reflect the range of expertise and level of diversity in the field of hard-rock geology at CODES.

## HIGHLIGHTS

Since inception, Program 1: Ore Deposits and Mineral Exploration and its prior iterations have consistently retained a critical mass of projects, spread across a diverse range of geological fields and locations. That trend continued into 2017 with the major projects that have carried over from the former Ore Deposits Characterisation and Context Module.

The current list of projects and research continued to have an impact around the world, as the following highlights illustrate:

### SW PACIFIC

Five manuscripts from the Newcrest-sponsored 'Exploring the porphyry environment' project that concluded in 2016 were submitted to, or published in, *Economic Geology* over the course of 2017, including a paper by Nic Jansen and co-authors on SWIR analyses of degraded drill core from Lihir gold mine, and results from the PhD studies of Marc Rinne (Wafi-Golpu), Evan Orován (Namosi) and Stephanie Sykora (Lihir). Each paper has made a significant

contribution to our understanding of the complexities of porphyry and epithermal-related mineralisation and metal deportment in the region.

### SE ASIA

During 2017, a new project focussing on the tectonic and mineral resources of Sumatra and Myanmar terranes has been under development by Khin Zaw and the SE Asia research team at CODES. This new project will be linked with the recently awarded IGCP668 Project: 'Equatorial Gondwanan History and Early Palaeozoic Evolutionary Dynamics of Sibumasu Terrane' for which Khin Zaw will play a key role.

### NORTH AMERICA

In May, PhD student Brian McNulty gave a presentation on the application of systematic portable X-ray fluorescence analysis of drill core to identify the lithology of altered volcanic rocks at the annual CODES Science Planning Meeting in Hobart. He submitted a research grant annual report to the SEG Canada Foundation in mid-2017 on his findings, which used a combination of LA-ICP-MS and CA-ID-TIMS zircon U-Pb geochronology to constrain the timing of volcanic host rock stratigraphy at Myra Falls. Additionally, Brian presented the key results of this work at the 14th SGA Biennial International Meeting in Québec City, Canada, in August. His research will be published in the *Journal of Exploration Geochemistry* in 2018.

### SOUTH AMERICA

Juan Diego Rojas Lopez is continuing his Master of Economic Geology project on the Ollachea deposit, situated in north Region Puno, southeast Peru. In 2017 Juan made considerable progress towards characterisation of the deposit and determining a paragenetic sequence of vein formation. This has led to an initial assessment that the deposit contains three main mineralising vein stages, of which the earliest ('stage 1') contains economic gold mineralisation.

### AUSTRALIA

David Douch has continued his PhD study on the geology and genesis of the Invincible Au deposit in the St Ives Goldfield, Kambalda, WA. During 2017 David documented an abrupt and major change in palaeo-environmental setting, from volcanically-derived submarine-fan-dominated sedimentation for the Black Flag Group, to subaerial delta and braid plain for the Merougil Group. Despite this major change, available geochronological data, and similarity of bedding orientations, suggest the two sequences are conformable. David has interpreted the first appearance of granite clasts in basal conglomerates of the Merougil Group to suggest the change in palaeo-environmental setting may have been due to uplift associated with the local emplacement and unroofing of granite batholiths, rather than regional deformation.

Key conclusions of the pyrite, magnetite, and hematite fingerprint database sub-project within the 'Power of pyrite' project, which concluded in 2017, included the recognition of areas for increased greenfields exploration prospectivity in South Australia as a result of trace element analyses of pyrite, along with a better understanding of trace element deportment in magnetite and hematite, which will complement existing pyrite trace element data.

*OPPOSITE PAGE: (Bottom) PhD student Rob Davidson examining outcrop in the open pit of the intermediate sulfidation epithermal Middle Vein, San Sebastian mine, Durango, Mexico. (Top) Hematite-pyrite ore from the Intercept Hill IOCG prospect, Olympic Dam domain, South Australia (IHAD5-1063m). This sample was collected as part of the Program 1 project, 'The power of pyrite', which tested the viability of pyrite as a geochemical vector towards hydrothermal ore deposits. A LA-ICP-MS trace element image of pyrite and hematite in this sample is shown on page 21.*



## The program team

**LEADER** MIKE BAKER

**DEPUTY LEADER** LEJUN ZHANG

### TEAM MEMBERS:

Ron Berry, David Cooke, Matthew Cracknell, Leonid Danyushevsky, Garry Davidson, Angela Escolme, Nathan Fox, Ross Large, Charles Makoundi, Adi Maryono, Sebastien Meffre, Evan Orován, Robert Scott, David Selley, Jeff Steadman, Jay Thompson, Khin Zaw

### PHD STUDENTS:

Ayesha Ahmed, Heidi Berkenbosch, Jing Chen, Rob Davidson, David Douth, Peter Duerden, Angela Escolme, Amos Garay, Rachel Harrison, Margy Hawke, Wei Hong, Carlos Andres Jimenez Torres, Sean Johnson, Joseph Knight, Erin Lawlis, Christopher Leslie, Claire McMahon, Brian McNulty, Indrani Mukherjee, Jacob Mulder, Joshua Phillips, Subira Sharma Steadman, Nathan Steeves, Yi Sun, Stephanie Sykora, Francisco Testa, Jennifer Thompson, Tristan Wells

### MASTERS STUDENTS:

Sebastien Benavides, Arga Firmansyah, Kyle Hughes, Corey Jago, Juan Diego Rojas Lopez, Perrapong Sritangsirikul, Leo Subang

### HONOURS STUDENTS:

Colin Jones, Sigmund Lloyd, Ben Ridgers, Riquan Ropli

### COLLABORATORS:

**AKITA UNIVERSITY JAPAN**  
Akira Imai

**ARGENT METALS**  
David Busch, Todd McGilvray

**BRITISH GEOLOGICAL SURVEY, UK**  
Mike Crow

**CHIANG MAI UNIVERSITY, THAILAND**  
Phisit Limtrakun, Sampan Singharajwarapan

**CHINA UNIVERSITY OF GEOSCIENCES, BEIJING, CHINA**  
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**CHINA UNIVERSITY OF GEOSCIENCES, WUHAN, CHINA**  
Jian Ma

**CHINESE ACADEMY OF SCIENCES, GUIYANG, CHINA**  
Feng Xiong

**CHULALAKORN UNIVERSITY, THAILAND**  
Abhisit Salam

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Ye Myint Swe

**EAST YANGON UNIVERSITY, MYANMAR**  
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Frank Doedens, Dermot Ryan

**FEDERAL INSTITUTE FOR GEOSCIENCES AND NATURAL RESOURCES, GERMANY**  
Sabastien Henning

**GEOLOGICAL SURVEY OF SOUTH AUSTRALIA**  
Adrian Fabris, Steve Hill

**GEOSCIENCE AUSTRALIA**  
David Huston

**GUANGZHOU INSTITUTE OF GEOCHEMISTRY, CHINESE ACADEMY OF SCIENCES, CHINA**  
Chao Wu

**HANOI UNIVERSITY OF MINING AND GEOLOGY, VIETNAM**  
Hai Thanh Tran

**HECLA MINING**  
Kurt Allen, Stephen Redak

**INTREPID MINES**  
Tom Woolrych

**LAKEHEAD UNIVERSITY, CANADA**  
Peter Hollings

**MACQUARIE UNIVERSITY**  
Nathan Daczko

**MANDALAY UNIVERSITY, MYANMAR**  
Tin Aung Myint



**MANITOBA GEOLOGICAL  
SURVEY, CANADA**

Marc Rinne

**MINERAL RESOURCES TASMANIA**

Clive Calver, Grace Cumming,  
John Everard

**MONASH UNIVERSITY**

Ray Cas

**NANYANG TECHNOLOGY  
UNIVERSITY, SINGAPORE**

Grahame Oliver

**NEW BOLIDEN**

Rodney Allen, Georgian Manuc,  
Roger Nordin

**NEWCREST MINING**

Karyn Gardner, Anthony Harris

**NYRSTAR**

Rick Sawyer, Armond Stansell

**PIONEER RESOURCES**

David Crook

**QPX**

Nic Jansen

**ROYAL HOLLOWAY UNIVERSITY  
OF LONDON, UK**

Tony Barber, Ian Watkinson

**SANDFIRE RESOURCES**

Bruce Hooper

**TINTINA RESOURCES**

Jerry Zieg

**UNIVERSITAS PADJADJARAN,  
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BRUNSWICK, CANADA**

David Lentz

**UNIVERSITY OF NEW MEXICO,  
USA**

Karl Karlstrom

**UNIVERSITY OF SYDNEY**

Dietmar Müller, Sabin Zahirovic

**UNIVERSITY OF TASMANIA**

Clive Burrett

*BELOW: Participants of the inaugural Myanmar Applied Sciences Association (MAESA) Conference field trip, led by Khin Zaw, examining the limestone unit and in the background, the Upper Paleozoic carbonate sequence hosting MVT Pb-Zn deposits, Myanmar.*





## Projects

### Exploring the porphyry environment

Geology and genesis of the Invincible gold deposit, St Ives

Geology and genesis of the mineral deposits of the Myra Falls VHMS district, Canada

Origin, characteristics and age of mineralisation of the Ollachea orogenic gold deposit, Region Puno, southeastern Peru: Implications for exploration

The power of pyrite

Tectonic and mineral resources of Sumatra and Myanmar terranes

Epithermal research

Porphyry research

Tasmanian tin granites

## PROJECT SUMMARIES

### EXPLORING THE PORPHYRY ENVIRONMENT

**Leaders:** David Cooke, David Selley

**Team member:** Evan Orovan

**Student:** Erin Lawlis

**Collaborators:** Karyn Gardner, Anthony Harris, Nic Jansen, Marc Rinne

The team has closely collaborated with Newcrest Mining to obtain new knowledge and maximise opportunities for the discovery of porphyry and epithermal-related gold resources in the South West Pacific region. The research has advanced the conceptual models and exploration techniques at the relevant deposits and districts.

This new knowledge was passed directly to Newcrest geologists through onsite training during 2017. A close working relationship with Newcrest throughout the life of this project was facilitated by the company's strong leadership in research, both logistically and financially.

Erin Lawlis continued working on her PhD study of the Kapit NE zone in 2017. Nic Jansen and co-authors published an *Economic Geology* paper on SWIR analyses of degraded drill core from Lihir gold mine in 2017. Research results from the PhD studies by Marc Rinne (Wafi-Golpu), Evan Orovan (Namosi) and Stephanie Sykora (Lihir) were written up in a series of manuscripts that will be published by *Economic Geology* in early 2018. All other research activities on this project are now complete.

*LEFT: PhD student Brian McNulty collecting samples of the Price Formation andesite for zircon U-Pb geochronology at Myra Falls, Canada, August 2017.*





*ABOVE: Looking westwards from the slopes of Yanaloma towards the Ollachea deposit in north Region Puno, southeastern Peru; PhD student Juan Diego Rojas Lopez is documenting the characteristics of the deposit.*

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## GEOLOGY AND GENESIS OF THE INVINCIBLE GOLD DEPOSIT, ST IVES

**Leader:** Robert Scott

**Student:** David Douch

**Collaborator:** Ray Cas

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David Douch's PhD study, funded by Gold Fields, is investigating the geology and genesis of the >1 Moz Au Invincible deposit in the St Ives Goldfield, Kambalda, WA. This deposit differs from most in the >12 Moz Au St Ives Goldfield, as it is hosted by sedimentary rocks at the top of the Black Flag Group (2680–2665 Ma), rather than by mafic rocks of the older mafic Kambalda Sequence (2720–2680 Ma), which host the vast majority of the known deposits. This project seeks to better understand stratigraphic and structural controls on gold mineralisation at Invincible, unravel the deposit paragenesis, characterise the geochemical footprint of the deposit, and develop criteria to guide future exploration.

In the Kambalda area, the Black Flag Group consists of felsic to intermediate volcano-sedimentary rocks, locally capped by thick black shale, which is the primary host to ore at Invincible.

These rocks are overlain by arkosic/lithic sandstone, polymict conglomerate and conglomeratic sandstone of the >2665 Ma Merougil Group, which forms the immediate hanging wall to the Invincible deposit. A key aspect of David's study has been to better define, and interpret, stratigraphic subdivisions in these rocks using a combination of lithofacies analysis, geochemistry, and detrital zircon U/Pb geochronology.

Since his research commenced in 2015, David has documented an abrupt and major change in palaeo-environmental setting, from volcanically-derived submarine-fan-dominated sedimentation for the Black Flag Group, to subaerial delta and braid plain for the Merougil Group.

Despite this major change, available geochronological data, and similarity of bedding orientations, suggest the two sequences are conformable. David has interpreted the first appearance of granite clasts in basal conglomerates of the Merougil Group to suggest the change in palaeoenvironmental setting may have been due to uplift associated with the local emplacement and unroofing of granite batholiths, rather than regional deformation.

During 2017, David worked on resolving the vein paragenesis and structural controls on vein development at Invincible. By investigating the cross-cutting relations between vein sets, as well as between the veins, associated wall rock alteration mineral assemblages and structural fabrics developed in the host rocks, David was able to establish the sequence of vein formation and relative timing of gold mineralisation at the deposit. An exciting outcome of this work has been the recognition of two distinct stages of gold mineralisation, characterised by differences in vein geometry, kinematics and geochemical signature.

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## GEOLOGY AND GENESIS OF THE MINERAL DEPOSITS OF THE MYRA FALLS VHMS DISTRICT, CANADA

**Leaders:** Garry Davidson, Nathan Fox, Bruce Gemmell,

**Student:** Brian McNulty

**Collaborators:** Rick Sawyer, Armond Stansell

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Brian McNulty continued his PhD research on the lithological setting and geochronology of the West Block area at the Myra Falls VHMS district on Vancouver Island, Canada. His research aims to propose a model for the genesis of the VHMS deposits in the West Block, which can be compared to the other deposits in the area, with the aim of developing useful criteria for exploration in the Myra Falls District.

In May, Brian gave a presentation on the application of systematic portable X-ray fluorescence analysis of drill core to identify the lithology of altered volcanic rocks at the annual CODES Science Planning Meeting in Hobart. He submitted a research grant annual report for his findings using a combination of LA-ICP-MS and CA-ID-TIMS zircon U-Pb geochronology to constrain the timing of volcanic host rock stratigraphy at Myra Falls to the SEG Canada Foundation in mid-2017. Additionally, he presented these results at the 14th SGA Biennial International Meeting in Québec City, Canada, in August.

Research in 2017 focussed on three themes: geochronology, hydrothermal alteration characterisation, and ore mineralogy. A combination of whole rock lithogeochemistry, electron microprobe analysis and shortwave infrared spectroscopy are being utilised to assess possible mineral exploration vectors in the variably altered footwall volcanic stratigraphy in the West Block. Detailed ore microscopy using Mineral Liberation Analysis and electron microprobe analyses are being used to characterise the mineralisation styles in the West Block area, which will be compared to other mineralised zones at Myra Falls. Thesis compilation has been ongoing, and the candidate is expected to complete in mid-2018.

*LEFT: PhD student Rob Davidson logging and sampling drill core from Francine vein, an intermediate sulfidation epithermal deposit, San Sebastian mine, Durango, Mexico.*

## ORIGIN, CHARACTERISTICS AND AGE OF MINERALISATION OF THE OLLACHEA OROGENIC GOLD DEPOSIT, REGION PUNO, SOUTHEASTERN PERU: IMPLICATIONS FOR EXPLORATION

**Student:** Juan Diego Rojas Lopez

### Team members:

Angela Escolme, Robert Scott

The Ollachea deposit, situated in north Region Puno, southeastern Peru, contains >2.4 Moz Au with an average grade of 3.5 g/t Au. Mineralisation is hosted within slates belonging to the Silurian-Devonian Ananea Formation, and locally within metamorphosed igneous dykes and sills. At a regional scale, the ore deposit is located in the western margin of an orogenic belt that extends along the northwest trending Eastern Cordillera of the Andes. The goal of this Master of Economic Geology project, funded by a PRONABEC Scholarship, is to document the characteristics of the Ollachea deposit, determine its genesis, and constrain the age of ore emplacement.

Major activities in 2017 were:

- completion of first-stage fieldwork in early January, which involved detailed mapping and sampling in the deposit area and extensions
- progress made on deposit characterisation and in determining a paragenetic sequence of vein formation. This led to an initial finding that suggests the deposit contains three main veining stages of which the 'stage 1' (the earliest) contains the economic gold grades.

Second-stage fieldwork is planned for January 2018, which will be followed up by petrology, geochronology and mineral chemistry studies.



## THE POWER OF PYRITE

**Leaders:** Ross Large, Jeff Steadman

**Team members:** Matthew Cracknell, Leonid Danyushevsky, Charles Makoundi, Sebastien Meffre

**Students:** Sean Johnson, Indrani Mukherjee

**Collaborators:** Rodney Allen, David Busch, David Crook, Frank Doedens, Adrian Fabris, Dan Gregory, Steve Hill, Bruce Hooper, Georgian Manuc, Todd McGilvray, Roger Nordin, Dermot Ryan, Tom Woolrych, Jerry Zieg

The research in 'The power of pyrite' project is split into the following sub-projects:

- Pyrite and pyrrhotite as ore vectors and stratigraphic markers for orogenic gold, Carlin gold, VHMS, IOCG, sediment-hosted copper, and stratiform zinc targets.

- South Australia pyrite, hematite, and magnetite fingerprint database.
- McArthur River Basin pyrite research (this area of research is expected to form part of a Linkage Grant proposal in 2018).
- DeGrussa VHMS vectoring (this sub-project is currently on hold).

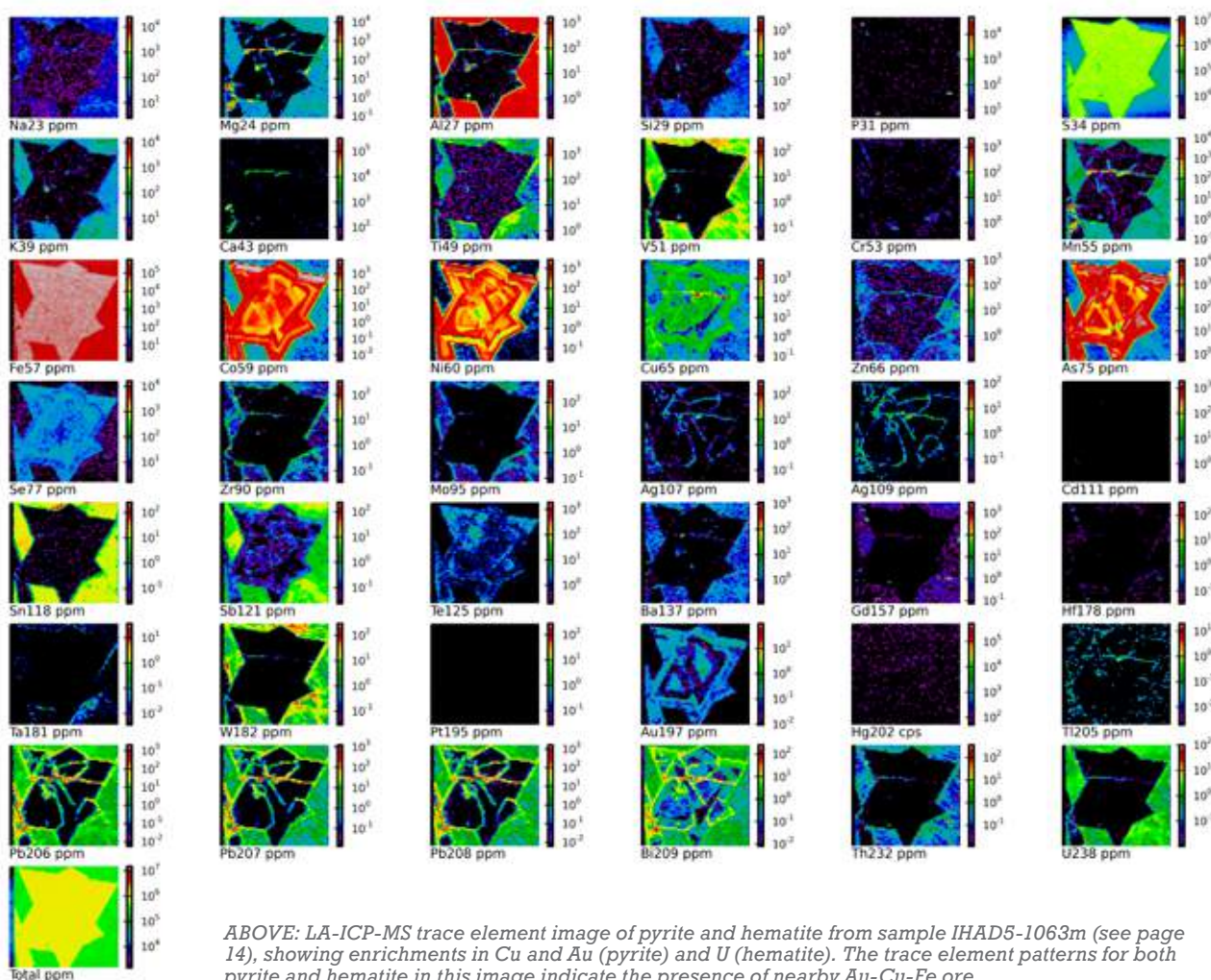
The industry-funded sub-project 'Pyrite and pyrrhotite as ore vectors and stratigraphic markers for orogenic gold, Carlin gold, VHMS, IOCG, sediment-hosted copper, and stratiform zinc targets', led by Jeff Steadman, came to an end in 2017 after delivering 12 technical reports to the six industry sponsors (two reports per sponsor). Some of the major results from this work include:

- a better understanding of pyrite paragenesis in all deposits studied
- refined exploration plans for several of the study areas, including Black Butte (Montana) and Kalpini South (Western Australia)

- new  $^{207}\text{Pb}$ - $^{206}\text{Pb}$  model ages for ore horizons in the Black Butte area and the Doolgunna district (Western Australia).

The South Australian State Government-funded research initiative 'South Australia pyrite, hematite and magnetite fingerprint database' also concluded at the end of 2017. Some of the highlights of this project include:

- a new database for trace element mineral chemistry, including pyrite, hematite and magnetite, analyses, which can be added to in the future
- increased and decreased prospectivity for greenfields exploration areas in South Australia as a result of trace element analyses of pyrite
- a better understanding of trace element deportment in magnetite and hematite, which will complement existing pyrite trace element data.



ABOVE: LA-ICP-MS trace element image of pyrite and hematite from sample IHAD5-1063m (see page 14), showing enrichments in Cu and Au (pyrite) and U (hematite). The trace element patterns for both pyrite and hematite in this image indicate the presence of nearby Au-Cu-Fe ore.

## TECTONIC AND MINERAL RESOURCES OF SUMATRA AND MYANMAR TERRANES

**Leader:** Khin Zaw

**Team members:** Ross Large, Charles Makoundi, Sebastien Meffre, Jay Thompson

**Collaborators:** Mike Crow, Cho Cho Aye, Tony Barber, Mohd Basril Iswadi Bin Basori, Clive Burrett, Pol Chaodumrong, Azman Ghandi, Sabastien Henning, Akira Imai, Somboon Khositanont, Kit Chun Lai, Mohd Shafeea Leman, David Lentz, Phisit Limtrakun, Robert Moritz, Dietmar Müller, Tin Aung Myint, Grahame Oliver, Mega Rosana, Abhisit Salam, Sampan Singharajwarapan, Holly Stein, Ye Myint Swe, Hai Thanh Tran, Ian Watkinson, Sabin Zahirovic

This research builds on previous 'Ore deposits of SE Asia' projects (2008–2017) and the recently published Geological Society of London (GSL) publication called *Myanmar: Geology, Resources and Tectonics* edited by A.J. Barber, Khin Zaw and M. Crow. This publication draws on the project leader's extensive geological experience in Myanmar, dating back to 1968. The SE Asia projects focussed on the geochronology, metallogenesis and deposit styles of mainland areas of the region.

This new initiative looks mainly at the tectonic, zircon geochronology, pyrite chemistry, mineralisation and metallogeny of the Western Myanmar-Sumatra and Sibumasu Terranes including Borneo (Sarawak and Sabah in Malaysia, Kalimantan in Indonesia) in 2018–2020. This project will be linked with the recently awarded IGCP668 Project: 'Equatorial Gondwanan History and Early Palaeozoic Evolutionary Dynamics of Sibumasu Terrane' for which the project leader plays a key role.

## EPITHERMAL RESEARCH

**Student:** Rob Davidson

**Team members:** David Cooke, Bruce Gemmell

**Collaborators:** Kurt Allen, Stephen Redak

Rob Davidson has begun his PhD research on the San Sebastian intermediate sulfidation epithermal vein system in Durango, Mexico. His research aims are to: determine the relationship between the vein systems and occurrences within the San Sebastian district, characterise the host rock sequence lithologies and controls on vein development, understand the structural controls on vein formation, characterise whole rock and trace element geochemistry of veins, vein stages, host rock,

volcanic rocks, and alteration in order to develop potential vectors toward mineralisation, and date, using a range of geochronological methods, veins, vein stages, host rock, volcanic rocks and alteration.

This research is supported by Hecla Mining over a three-and-a-half-year period. Rob undertook fieldwork between October and December; he will start to carry out analysis of his findings in 2018, followed by further fieldwork.

## PORPHYRY RESEARCH

**Leader:** David Cooke

**Team members:** Michael Baker, Adi Maryono, Evan Orovan, Lejun Zhang

**Students:** Sebastien Benavides, Leo Subang

**Collaborators:** Xue Gao, Peter Hollings, Bin Lin, Jian Ma, Chao Wu, Feng Xiong

Porphyry copper and gold deposits are a major focus of research activity at CODES. In addition to our major collaborative research, there were several one-on-one industry-related PhD and Master of Economic Geology studies and visiting academic research activities that continued throughout 2017.

Two Master of Economic Geology theses were completed in 2017

*BELOW: PhD student Wei Hong sampling tourmaline orbicules at Trial Harbour, Heemskirk Granite, on the west coast of Tasmania, for his research on Tasmanian tin granites.*





that were conducted as part of the general porphyry-related research activities at CODES. Sebastian Benavides' thesis on the Taca Taca Bajo porphyry Cu deposit investigated grade-additive and grade-destructive styles of phyllic alteration at this major new porphyry discovery in Argentina. Leo Subang investigated the geology and geochemistry of the quartz – pyrite – gold high sulfidation epithermal Au + Ag ± Cu veins from the Mankayan mineral district, Philippines. Both theses achieved first-class results, and Leo's research stimulated a new PhD study in the TMVC of the QPG veins by PhD candidate Yi Sun, which was initiated in late 2017.

Several team members were involved in finalising a special issue of *Economic Geology* that showcases major research outcomes from several PhD studies conducted at CODES on SW Pacific porphyry and related epithermal deposits. New CODES adjunct Adi Maryono wrote a synthesis of the porphyry Cu-Au deposits of the Sunda-Banda Arc in Indonesia, which will be the lead article in an *Economic Geology* special issue in 2018.

## TASMANIAN TIN GRANITES

**Leader:** David Cooke

**Team members:** Nathan Fox, Sebastien Meffre, Jay Thompson, Lejun Zhang

**Student:** Wei Hong

**Collaborators:** Mostafa Fayek, David Huston, Roland Maas

Wei Hong's PhD thesis on the origins and significance of magmatic-hydrothermal features in Tasmanian Sn granites was completed in 2017. This study provided new insights into the geodynamic setting, timing and origins of tin granites in the eastern and western Tasmanian terranes. A systematic evolution of magmatic-hydrothermal features, from diffuse tourmaline patches to tourmaline-quartz filled miarolitic cavities and tourmaline orbicules, and quartz-K-feldspar-tourmaline-bearing unidirectional solidification textures

formed in the roof of the white phase of the Heemskirk Granite.

These features were the precursor to mineralised veins that formed during release of magmatic-hydrothermal fluids when the sill carapace was breached. Tourmaline and quartz trace element and isotopic compositions varied systematically with progressive fluid exsolution and in response to phase separation and fluid mixing during granite emplacement. Comparison of the chemistry of tourmaline from the strongly mineralised Heemskirk granite and the unmineralised Pieman Heads granite highlighted the potential of mineral chemistry for fertility assessments in tin granite systems, with high tin contents characteristic of tourmaline collected from mineralised tin granites.

Two journal articles were published from this study in 2017.

Key findings of the geochronological, geochemical and isotopic analyses of Tasmanian tin granites were published in *Gondwana Research*. Key aspects of the magmatic-hydrothermal features of the tin granites, including their characteristics, origins and implications for tin mineralisation, were published in *American Mineralogist*. Draft manuscripts on the isotopic compositions of magmatic-hydrothermal features in the tin granites, quartz chemistry and cathodoluminescence, and the results of detailed fluid inclusion analyses were initiated in 2017 and are scheduled to be submitted in 2018.

## LOOKING FORWARD

As mentioned in the Highlights section, a number of sub-projects within Program 1 came to an end during the current reporting cycle, but those losses will be balanced by the commencement and continuation of other projects during 2018.

At the St Ives Goldfield, the spatial variations in mineral chemistry and paragenesis will be investigated as a potential source of new, longer range, or more definitive vectors to ore. This work will complement work that has characterised the geological evolution of the district, as well as the interpretation of whole rock geochemical data, by providing additional paragenetic (i.e. relative temporal) constraints on observed patterns.

Khin Zaw and the SE Asia research team will be commencing a new multi-year project investigating the mineral chemistry, mineralisation and metallogeny of the Western Myanmar-Sumatra and Sibumasu Terranes.

In Peru, a second stage of fieldwork will be undertaken at the Ollachea deposit which will complement initial fieldwork completed on the deposit and provide further insights into paragenesis and mineralisation through the use of mineral chemistry studies.

It also promises to be another excellent year for scientific reporting to the wider academic community, with a number of journal publications and theses completions expected over the coming year.

## OBJECTIVES

- Create an integrated, cross-disciplinary geometallurgical research platform that delivers fundamental knowledge, tools and methods to the global mining industry for optimising sustainable and profitable mineral extraction.
- Develop more effective approaches to the definition of mineralogy, element deportment and texture using new technologies that can be linked to mineral processing performance and waste management, at a range of scales.
- Provide improved attributes or indices of processing performance that can be embedded into block models to define processing domains, which can be exploited in mine planning and optimisation.
- Deliver new cross-discipline geometallurgical education, training and awareness.





## INTRODUCTION

Geometallurgy is the integration and utilisation of geological, metallurgical, environmental and economic information to maximise the value of an ore body, while minimising technical and operational risk. Through a holistic approach, it identifies attributes that contribute to the realised value of a resource, and enables ore variability to be factored into the flowsheet, infrastructure design, and the production and quality forecasts over the life-of-mine. This includes traditional attributes, such as grade, as well as less traditional factors, such as hardness (crushability, grindability), mineral species and abundance, mineral liberation, metallurgical recovery, concentration of deleterious elements, acid generating potential, neutralising potential and smelter enabling characteristics.

The discipline of geometallurgy seeks to efficiently integrate and use mineralogical and geochemical characterisation tools to undertake deposit-wide characterisation in order to maximise ore body knowledge. The output data and models are used to assist with mine planning, mineral processing and geoenvironmental forecasting.

Over the past 15 years, CODES has established itself as a national centre for geometallurgical research, spurred mainly by an increased interest in the discipline by the minerals industry. This increase in industry involvement led to the large AMIRA P843 and P843A (GeM<sup>III</sup>) collaborative projects that ran from 2005 to 2013. In these projects, an array of geometallurgical methods and protocols were developed in the areas of mineralogy, comminution, heap leaching and flotation – and were tested on case study sites culminating in the publication of a series of technical reports released to the AMIRA sponsors.

The outcomes of the GeM<sup>III</sup> project provided a solid foundation for further research, particularly in relation to understanding mineralogical and textural controls over a range of scales, which dictate Grade Engineering® and mineral

processing responses. This research is largely being conducted as part of CRC ORE's (Cooperative Research Centre for Optimising Resource Extraction) remit, of which CODES is an Essential Research Participant.

CRC ORE aims to support mining sector growth through implementation of technological innovations in minerals characterisation, extraction and processing. Fundamental to CRC ORE's research is the concept of Grade Engineering®, which provides the ability to improve mill feed quality by implementing specific technological levers at critical points in the extraction and processing circuit. CRC ORE's research is organised into five programs: Define, Separate, Extract, Control and Operate. Project P1:006, which operates at CODES, sits within Program 1 – Define.

This project aims to evaluate the geological controls that influence the preferential partitioning of ore phases between different size fractions during early comminution stages (blasting, crushing). The tendency for some ores to naturally fractionate ore minerals into finer-size fractions, termed natural deportment, is fundamental to effective Grade Engineering® levers that upgrade ores by size-based screening. Using a range of deposit and mineralisation styles, P1:006 will evaluate the geometallurgical drivers that influence natural grade-by-size deportment. The workflow will integrate existing geological, geochemical, mineralogical and metallurgical datasets with innovative new technologies for mapping mineralogy and geochemistry in drill cores to provide predictive geometallurgical indices relating to the amenability of ore domains to Grade Engineering® levers.

Additional geometallurgical research is being carried out in the Optimising Geometallurgical Prediction and Minimising Geoenvironmental Risks themes within the ARC Industrial Transformation Research Hub – Transforming the Mining Value Chain (TMVC), which is covered elsewhere in this report.

## HIGHLIGHTS

- Commencement of Dr Nathan Fox and Dr Angela Escolme as Postdoctoral Research Fellows in the discipline of geometallurgy.
- Dr Nathan Fox and PhD candidate Amery Jackson attended the CRC ORE Annual Assembly and participated in several researcher forum activities presenting their research objectives.
- Dr Anita Parbhakar-Fox gave an invited keynote presentation at the AusIMM 8th World Sampling and Blending Conference in Perth, Western Australia.
- Dr Anita Parbhakar-Fox and Dr Angela Escolme gave presentations on geoenvironmental prediction and geometallurgical characterisation using calculated from mineralogy assay data at the AusIMM 10th Mining Geology Conference in Hobart.
- Successful running of the revised MEconGeol Geometallurgy course in October/November with invited lecturers from CSIRO, CRC ORE, ALS Global and Mineral Resources Tasmania (MRT).

## TECHNOLOGY TRANSFER

Because many projects are in their early stages, few new tools were delivered to industry in 2017 with the exception of Angela Escolme's PhD, which delivered a revised calculating mineralogy from assay platform. Staff members actively participated in collaborative research forums with one-on-one industry collaborator meetings held to discuss new research ideas building on the successes of the GeM<sup>III</sup> project, CRC ORE and Angela Escolme's PhD study.

*OPPOSITE PAGE: (Bottom) PhD student Laura Jackson examines waste rock at Grange Resources Savage River mining operation, western Tasmania. (Top) Acid drainage associated with abandoned mine waste in the Mount Dundas area, western Tasmania.*



ABOVE: Participants of the MEconGeol Geometallurgy course visiting the Savage River iron ore processing plant.

Building on CRC ORE outcomes using Specim, Anita Parbhakar-Fox and Nathan Fox visited the Swedish Geological Survey to discuss hyperspectral technology applications for mineral characterisation. Nathan Fox participated in a Mining3 forum in November hosted by CSIRO where participants explored the development of new platforms to handle big data to support CRC ORE projects. Anita Parbhakar-Fox also gave an invited seminar at the University of Cape Town following the Process Mineralogy conference; she discussed geoenvironmental characterisation in Tasmania and how a similar approach could be adopted in a South African context.

### SHORT COURSES

Nathan Fox organised a three-day X-ray diffractometry course for UTAS and MRT staff taught by CSIRO expert Dr Ian Madsen in July. All Program 2 staff members taught in the ten-day geometallurgy MEconGeol short course at CODES (organised by Anita Parbhakar-Fox) in October/November. The course

was redesigned to include several new topics. Lecturers from CSIRO (Dr Angus MacFarlane and Dr Naomi Boxall) gave presentations on heap- and bio-leaching, whilst Drs Michael Scott, Luke Keeney and Steve Walters gave lectures on Grade Engineering® and comminution. Burnie-based ALS Global manager John Glen provided new lectures on flotation, and opened his laboratory to the students to visit as part of the associated field course, while Dr David Green from MRT gave lectures on hyperspectral mineralogy.

### CONFERENCES

Anita Parbhakar-Fox and Nathan Fox presented research outcomes from the CRC ORE project at the Process Mineralogy Conference in Cape Town in March with the publication of associated conference papers. Throughout the year, Angela Escolme delivered presentations on research outcomes from her PhD research to stakeholders and at national and international conferences. CODES had a strong presence at the AusIMM 10th Mining Geology Conference, held in Hobart on 20–22 September,

including an exhibition booth and three presentations from CODES/TMVC team members. Former CODES geometallurgy program leader Dr Steve Walters also gave a presentation on Grade Engineering®. The CODES/TMVC Theme 3 team had a strong presence at the 9th Australian Acid and Metalliferous Drainage Workshop in Burnie, Tasmania (November) with five oral presentations (and peer-reviewed papers) and two posters given (with one poster receiving the best poster award). Anita Parbhakar-Fox gave a presentation on her cobalt bioleaching research, chaired the geoenvironmental research session, and was involved in leading the workshop field trip.





# The program team

**LEADER** ANITA PARBHAKAR-FOX

**DEPUTY LEADER** ANGELA ESCOLME

## TEAM MEMBERS:

Ron Berry,  
Leonid Danyushevsky,  
Nathan Fox, Bruce Gemmell,  
Sebastien Meffre, Jay  
Thompson

## PHD STUDENTS:

Cassady Harraden, Amery  
Jackson, Laura Jackson,  
Sibele Cristina do Nascimento

## MASTERS STUDENT:

Joanne Morrison

## HONOURS STUDENTS:

Rebekah Cornelius, Hannah  
Couper, Sarah Gilmour,  
Robert McLaine

## COLLABORATORS:

### ALS GLOBAL

John Glen, Donna Kemp,  
Bonita Raimondo

### ANGLOGOLD ASHANTI

Alvaro Barros, Vaughan  
Chamberlain, Nick Clarke

### BLUESTONE MINES LIMITED

Aslam Chapri

### BRUKER AXS

Jens Bergman, Gertruida Gloy

### CRC ORE

Ben Adair, Paul Revell,  
Greg Wilkie

### CSIRO

Louise Fisher, Ian Madsen,  
Mark Pearce

### CURTIN UNIVERSITY

Louisa O'Connor

### GOLD MINES OF WALES, UK

Simon Dominy

### GRANGE RESOURCES

Tony Ferguson, Roger Hill,  
Ben Maynard

### JULIUS KRUTTSCHNITT MINERAL RESEARCH CENTRE/UNIVERSITY OF QUEENSLAND

Khoi Nguyen

### MINERAL RESOURCES TASMANIA

David Green, Jake Moltzen,  
Jennifer Parnell

### MININGS

Craig Lindsey,  
Charlotte Sennersten

### OLYMPUS

Dane Burkett, Sam Habib

### PETROLAB, UK

Christopher Brough, James  
Strongman

### SCIAPS, USA

Andrew Somers

### SPECIM

Rainer Bärts, Kati Laakso

### DEPT OF PRIMARY INDUSTRIES, PARKS, WATER AND ENVIRONMENT, TASMANIA

Alison Hughes

### TERRACORE

Phil Harris

### UNIVERSITY OF CAPE TOWN, SOUTH AFRICA

Megan Becker, Dee Bradshaw,  
Sue Harrison

### UNIVERSITY OF LIEGE, BELGIUM

Julie Hunt

### UNIVERSITY OF TASMANIA, CENTRAL SCIENCE LABORATORY

Sandrin Feig, Karsten  
Goemann, Thomas Rodemann

## Projects

Extracting cobalt from legacy mine tailings

Evaluating mineralogical fractionation at the Renison Sn mine

Controls on mineralogical fractionation at the Gramalote Au deposit, Colombia

Geometallurgical applications for sorting by surface analysis: review of status

Micro-XRF analysis of drill core for geometallurgical characterisation and application to grade-by-size fractionation

## PROJECT SUMMARIES

### EXTRACTING COBALT FROM LEGACY MINE TAILINGS

**Leader:** Anita Parbhakar-Fox

**Collaborators:** Tony Ferguson, John Glen, Alison Hughes

At the Old Tailings Dam (OTD), Savage River, Western Tasmania, 38 million tonnes of pyritic tailings were deposited (1967 to 1982), and have since been generating acid and metalliferous drainage (AMD). Long-term management options considered for this site have included the establishment of either a water, hard-engineered or vegetation cover. However, due to geotechnical challenges and the lack of success demonstrated by previous pilot studies, these strategies have not been implemented. A detailed mineral chemistry study indicated elevated

cobalt in pyrite (up to 3 wt. %), however, as this is refractory, recovery via biohydrometallurgical processing was tested in this project, commissioned by the Tasmanian State Government and Grange Resources (through the Savage River Rehabilitation Program).

Bulk tailings samples were collected across the OTD targeting three sulfide-bearing facies. A bulk composite of these materials was subjected to bacterial oxidation using BIOX® bacteria to determine if Co could effectively be leached under standard operating conditions. This research focussed on producing a sulfide concentrate and optimising the recommended procedure for undertaking BIOX® experiments, with pH, temperature and iron concentration in the nutrient medium varied. Cobalt recovery was high (> 80 %) suggesting reprocessing of these tailings might be a viable option for managing this historic waste as part of an integrated tailings management strategy.

*LEFT: Classified mineral map (GXMAP) of drill core sample obtained using the MLA650 at the UTAS Central Science Laboratory. Coarse-grained pyrite (yellow) is intergrown with quartz (grey) and chlorite (apple green) which dominates the sample. Calcite (pink) and Fe-oxide (red) veinlets cross-cut the sample. Image width is 30 mm.*





ABOVE: Laura Jackson, Thomas Ostersen and Matthew Cracknell with a Grange Resources staff member at the Savage River mining operation, western Tasmania.

## EVALUATING MINERALOGICAL FRACTIONATION AT THE RENISON SN MINE

**Leader:** Nathan Fox

**Team member:** Ron Berry

**Collaborators:** Aslam Chapri, Greg Wilkie

The Renison tin mine, operated by Bluestone Mines Limited, is the largest operating tin mine in Australia. This project is assessing the degree of fractionation of ore phases (cassiterite, sphalerite, galena, chalcopyrite) during breakage to evaluate the upgrade potential of specific ore domains in a Grade Engineering® context. This study builds on a low-cost geometallurgical screening test developed by CRC ORE to identify upgrade potential in drill core by utilising multi-element assay, calculated mineralogy, XRD and MLA techniques for full mineralogical characterisation. Mineralogical relationships between ore and

gangue phases were defined to evaluate the specific mineralogical drivers controlling ore fractionation in these samples.

The project has assessed the amenability of specific ore types for upgrading mill feed using size-based screening and other separation technologies. The project will be completed during 2018 with a confidential report provided to CRC ORE and Bluestone Mines Limited.

## CONTROLS ON MINERALOGICAL FRACTIONATION AT THE GRAMALOTE AU DEPOSIT, COLOMBIA

**Leader:** Nathan Fox

**Student:** Amery Jackson

**Collaborators:** Alvaro Barros, Vaughan Chamberlain, Nick Clarke, Phil Harris

Amery Jackson began his PhD project in November working on evaluating geological factors that drive natural fractionation of gold

during early stages of comminution (e.g., blasting, crushing). Drill core and bulk sample material was collected in late 2017 by AngloGold Ashanti's site-based metallurgical group for delivery to CODES in early 2018. Prior to commencing the research program, Amery conducted a desk-study using existing metadata from drill cores (hyperspectral data, multi-element assay data and logging information) and metallurgical test work information from bulk samples to design a research program to commence in early 2018. The research outputs from the project will be to identify the site-specific geological features that control grade-by-size fractionation, and to generate geometallurgical indices for predicting upgrade response in other parts of the ore system.







## GEOMETALLURGICAL APPLICATIONS FOR SORTING BY SURFACE ANALYSIS: REVIEW OF STATUS

**Leader:** Ron Berry

This CRC ORE project (P1:007) led by Ron Berry, investigated the application of surface analytical techniques for measuring bulk and particle sorting applications in a Grade Engineering® context. Upgrading mill feed by selectively sorting high-grade material at the bulk scale or on the particle scale requires application of different technological methods. Outcomes of the report identified surface analytical techniques suited to being used for sorting both blasted material (e.g., in shovels) and crushed material on conveyors to improve mill feed grade in low-grade, high-tonnage bulk mining operations. Outputs include a confidential report to CRC ORE sponsors.

## MICRO-XRF ANALYSIS OF DRILL CORE FOR GEOMETALLURGICAL CHARACTERISATION AND APPLICATION TO GRADE-BY-SIZE FRACTIONATION

**Leader:** Nathan Fox

**Team members:** Karsten Goemann, Anita Parbhakar-Fox

**Collaborator:** Gertruida Gloy

Working with Bruker AXS (Brisbane) this project evaluated the use of rapid micro-XRF analysis of drill core samples for applications related to geometallurgical characterisation and development of predictive grade-by-size indices. Sample material from porphyry copper systems was analysed using a Bruker M4 Tornado with AMICS for mineralogical mapping and textural assessment of ore and gangue phases to evaluate pre-breakage geological/geometallurgical controls on grade-by-size fractionation.

Development work has been completed with validation using MLA and whole-rock mineralogical techniques. Final reporting and research outputs will be delivered in 2018.

## LOOKING FORWARD

The new project initiatives within CODES and CRC ORE will continue into 2018 with new laboratory protocols and workflows being developed to examine ore fractionation as part of determining which materials are suitable for Grade Engineering®. One new PhD candidate will also be appointed to work within the CRC ORE collaboration examining textural and mineralogical controls on grade-by-size responses for different gold deposit types. An additional PhD student will join the program, continuing the group's research into hyperspectral mineralogy applications for ore deposit characterisation. Further growth in capacity is expected if the ARC Industrial Transformation Training Centre for Waste Handling Advancements in Mining (WHAM) bid is successful in 2018.

Anita Parbhakar-Fox has been appointed as co-editor of a Geometallurgy Special Issue of *Minerals* whilst Ron Berry is co-editor of an *Economic Geology* special issue on the same topic. Both are expected to be published in 2018 and will include contributions from Program 2 researchers. Anita Parbhakar-Fox has also been appointed the deputy-chair of the next AusIMM Geometallurgy Conference, which will be held in 2019. Locally, a 'Metallurgy for Geologists' course will be organised by the CODES Society of Economic Geologists (SEG) Student Chapter with Diana Drinkwater and Peter Munro of Mineralis teaching this one-day course.

Collaborations with the Tasmanian Government will continue through their Mining Sector Innovation Program, with potential new projects including metal recovery from acid mine drainage at historical sites, and building on the success of the tailings bioleaching project, other Tasmanian sites will be nominated for similar geometallurgical characterisation.

Angela Escolme will chair the Geochemistry of Mineral Deposits Gordon Research Seminar (GRS) in August to be held in New Hampshire, USA. Several researchers in Program 2 also plan to attend Process Mineralogy '18 and the 11th International Conference for Acid Rock Drainage (both of which will be held in South Africa).

New collaborations will be established with new mineral characterisation service providers (including Orexplore and Minerals Insight) to explore how predictive geometallurgical and geoenvironmental data can be extracted and used to predict processing attributes and forecast waste characteristics.

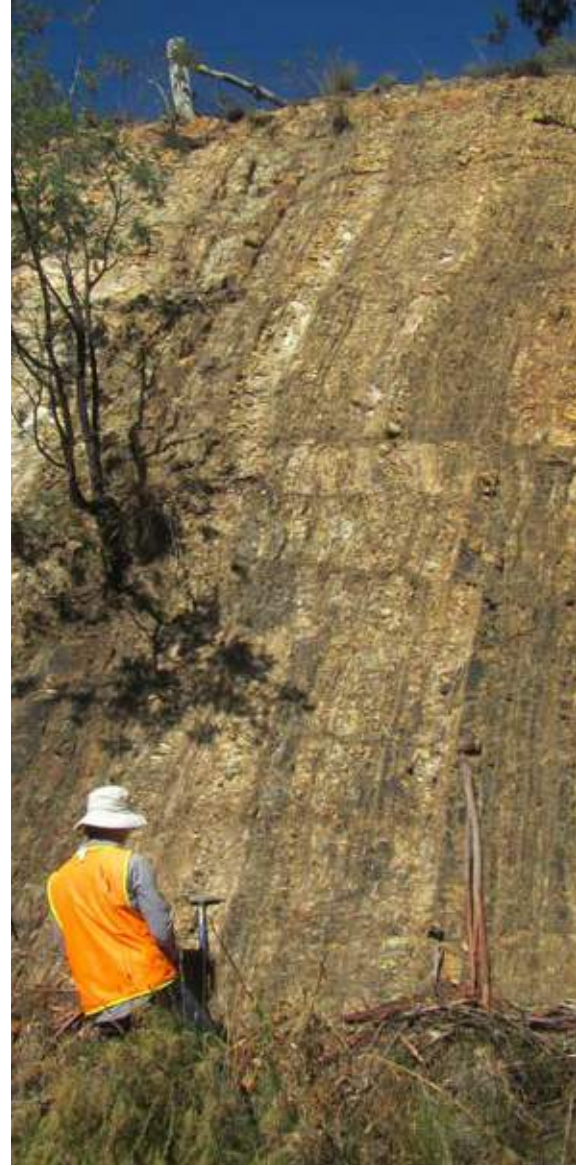
*OPPOSITE PAGE: (Bottom) Masters Geometallurgy students visiting John Glen (centre, holding sample) at the ALS Global laboratory in Burnie, Tasmania. (Top) PhD student Amery Jackson and Nathan Fox inspecting drill core from the Gramalote Au prospect, Colombia.*

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## OBJECTIVE

This program aims to understand the formation and evolution of sedimentary basins, including their metamorphic and deformation histories, within the broader context of geodynamic processes and Earth evolution through time. Our goal is ultimately to develop new and refined genetic and exploration models for diverse sediment-hosted mineral systems across all time periods of Earth history.

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ABOVE: Cowal core yard, central New South Wales. This core yard is located at the exploration office near the Cowal gold mine. Here, hundreds of kilometres of drill core from throughout the Cowal district are stored.

## INTRODUCTION

### Program 3: Sedimentation, tectonics and Earth evolution

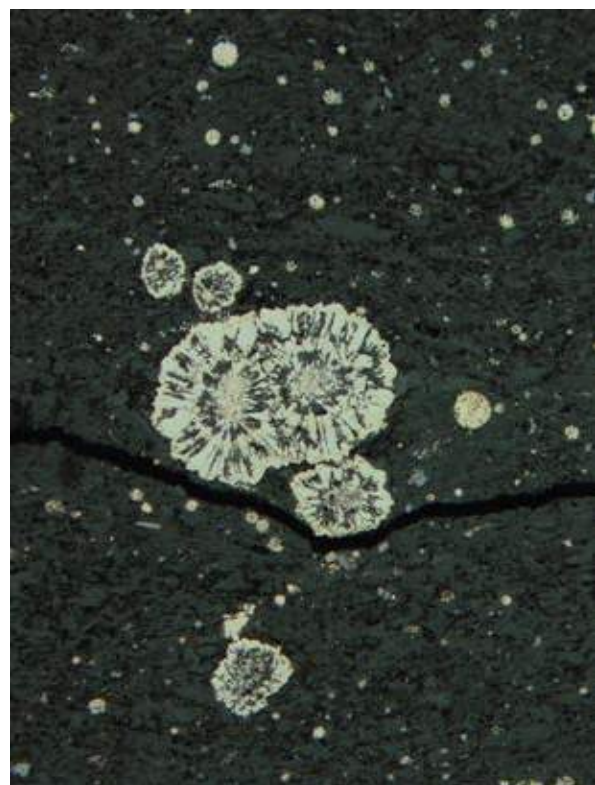
encompasses all aspects of sedimentary basin geologic history and the development of life on Earth, including how cycles of marine geochemistry profiles and craton amalgamation may influence the location and timing of sediment-hosted mineral systems. This has a direct impact on the search for, and understanding of, a vast array of ore types, including sedimentary exhalative (SEDEX) Zn-Pb-Ag, Broken Hill-type Ag-Pb-Zn, sediment-hosted orogenic Au, and Zambian-style Cu-Co-Au.

## HIGHLIGHTS

In 2017, several research endeavours led by personnel now in Program 3 but previously in Module 1 came to a close, including the highly successful ARC Discovery project 'Trace elements in ancient oceans' (winner of the 2016 Eureka Prize in the Excellence in Interdisciplinary Research category).

Ongoing projects within Program 3 include the Kansanshi gold project, funded by Kansanshi Mining, and the ARC Linkage project entitled 'Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia'. Several new students have been brought in to work on the Lachlan Orogen project and during 2017 work on this major initiative began in earnest.

The initiation of a major new collaborative research initiative into Paleoproterozoic sediment-hosted base metal and IOCG deposits of northern Queensland is providing CODES researchers with the opportunity to work with scientists from the Queensland Geological Survey, University of Queensland, CSIRO and James Cook University to stimulate mineral exploration and discovery in one of Australia's premier mineral provinces.



ABOVE: Pyrite atolls in black shales of the Tapley Hill Formation possibly formed due to recrystallisation and crystal growth centred on pyrite framboids formed during early diagenesis of the host sediments. This research has been carried out by Indrani Mukherjee.

OPPOSITE PAGE: (Bottom) PhD student Jacob Mulder takes in the views at the Grand Canyon, Arizona, USA, which he visited when documenting the stratigraphic, depositional, sedimentological provenance and geochronological links between Tasmania and northwestern America. (Top) Fine-grained Ordovician volcanoclastic rocks from the Triangle Formation, Oberon, New South Wales, with Masters student Peerapong Sritangsirikul working in the foreground.



## The program team

**ACTING LEADER** JEFF STEADMAN

### TEAM MEMBERS:

Ron Berry, Stuart Bull, David Cooke, Leonid Danyushevsky, Garry Davidson, Jacqueline Halpin, Sean Johnson, Ross Large, Peter McGoldrick, Sebastien Meffre, Indrani Mukherjee, Karin Orth, Michael Roach, Robert Scott, David Selley, Sasha Stepanov, Irina Zhukova

### PHD STUDENTS:

Richelle Awid-Pascual, David Douth, Peter Duerden, Jacob Heathcote, Sean Johnson, Christopher Leslie, Elena Lounejeva, Indrani Mukherjee, Jacob Mulder, Thomas Schaap, Tristan Wells

### MASTERS STUDENTS:

Chloe Cavill, Brendan Hardwick, Kyle Hughes, Corey Jago, Peerapong Sritangsirikul, Sitthinon Kultaksayos

### HONOURS STUDENTS:

Jonathon Donaghy, Kathryn Job, Sigmund Lloyd, Ben Ridgers, Riquan Ropli, Mark Sinfield

### COLLABORATORS:

#### AUSTRALIAN NATIONAL UNIVERSITY

Janaina Avila, Marc Norman

#### CAMECO RESOURCES

Penny Sinclair, Ben Walsh

#### CSIRO

James Austin

#### CURTIN UNIVERSITY

William Collins

#### EMMERSON RESOURCES

Grant Osborne

#### FIRST QUANTUM MINERALS

Tim Ireland, Louis van Heerden

#### FLINDERS UNIVERSITY

John Long

#### GEOFORSCHUNGSZENTRUM POTSDAM, GERMANY

Rainer Thomas

#### GEOLOGICAL SURVEY OF NSW

John Greenfield,  
Robert Musgrave

#### GEOLOGICAL SURVEY OF QUEENSLAND (DEPARTMENT OF NATURAL RESOURCES AND MINES)

Vladimir Lisitsin

#### GEOSCIENCE AUSTRALIA

David Huston

#### IMAS

Joanne Whittaker

#### IMEX CONSULTING

Mark Arundell

#### MACQUARIE UNIVERSITY

Elena Belousova,  
Nathan Daczko

#### MINERAL RESOURCES TASMANIA

Clive Calver, Grace Cumming,  
John Everard

#### RUSSIAN ACADEMY OF SCIENCE, RUSSIA

Valeriy Maslennikov

#### TASMANIAN INSTITUTE OF AGRICULTURE

Ross Corkrey

#### UNIVERSITY OF CALIFORNIA RIVERSIDE, USA

Dan Gregory

#### UNIVERSITY OF DELHI, INDIA

Mihir Deb

#### UNIVERSITY OF MELBOURNE

Roland Maas

#### UNIVERSITY OF MISSOURI, USA

Ray Coveney

#### UNIVERSITY OF NEW MEXICO, USA

Karl Karlstrom

#### UNIVERSITY OF QUEENSLAND

Rick Valenta

#### UNIVERSITY OF TASMANIA

Ross Corkrey, Sandrin Feig

#### US GEOLOGICAL SURVEY, USA

Karen Kelley, John Slack

#### YUKON GEOLOGICAL SURVEY, CANADA

Patrick Sack



# Projects

## Trace elements in ancient oceans

### Kansanshi gold

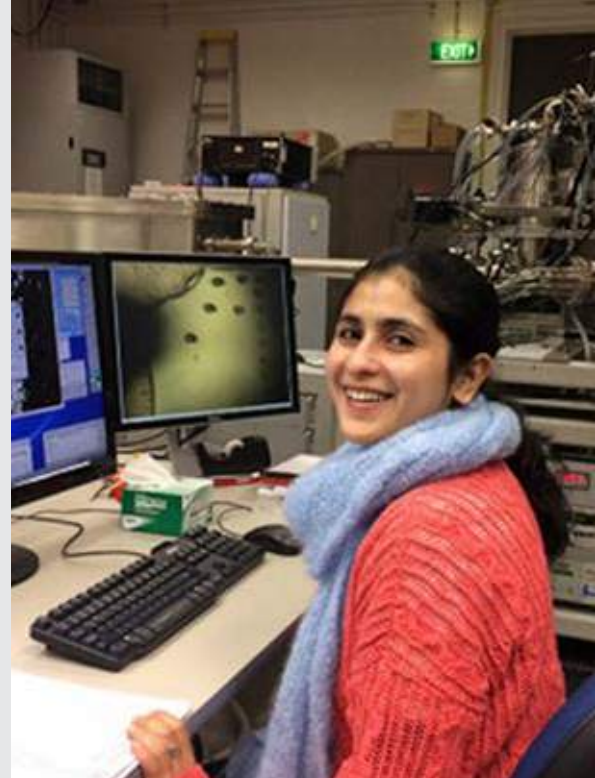
### Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia

### Building Tasmania: The Cambrian and beyond

### Uranium concentrations in basins

### Ore deposit cycles and ocean/atmosphere conditions

### Mineral chemistry vectoring: uncovering Northwest Queensland's hidden potential



ABOVE: PhD student Indrani Mukherjee on the SHRIMP-SI at the Australian National University, Canberra, July 2017. Indrani used this equipment in her research on the importance of nutrient availability in the Proterozoic oceans in the 'Boring Billion' period.

## PROJECT SUMMARIES

### TRACE ELEMENTS IN ANCIENT OCEANS

**Leader:** Ross Large

**Team members:** Leonid Danyushevsky, Indrani Mukherjee, Jeff Steadman, Sasha Stepanov, Irina Zhukova

**Collaborators:** John Long, Valeriy Maslennikov

In 2017 this project focused on determining temporal REE patterns measured by LA-ICP-MS on the matrix of black shales. The results demonstrate that the oceans during the Boring Billion or Middle Proterozoic were enriched in REE, U, Th and Tl, but depleted in most bio-essential elements. This anomalous situation resulted from a change in the uppermost continental crust around 1800 Ma from a mixed mafic-felsic composition to one dominated by felsic intrusives, particularly

K-Th-U-anorogenic granites, and had a major influence on biological evolution during the period. The results were published in *Earth and Planetary Science Letters*.

### KANSANSHI GOLD

**Leader:** Robert Scott

**Team member:** Garry Davidson

**Student:** Jacob Heathcote

**Collaborators:** Tim Ireland, Louis van Heerden

This research project commenced in early 2014 and is funded by Kansanshi Mining Plc (KMP), a subsidiary of First Quantum Minerals. PhD student Jacob Heathcote has been researching the origins, distribution, mineral associations and paragenesis of gold at the Kansanshi Cu-Au deposit in NW Zambia.

The Kansanshi mine, which is a globally significant copper producer, also produces around 100,000 oz Au per year, from sheeted arrays of quartz – carbonate – sulfide veins up to 10 m wide.

The primary objectives of the project are to:

- (1) improve deposit-scale understanding of gold distribution, mineral associations and paragenesis, in both primary (sulfide zone) and secondary (oxide zone) ores, and
- (2) identify field-based geological criteria (e.g. alteration assemblages, vein composition and/or texture, structural features, etc) that both help identify and predict the distribution and extent of gold mineralised zones.

Through a combination of pit mapping, core logging, and detailed petrographic analysis (optical microscopy, SEM, LA-ICP-MS) of over 230 samples Jacob has developed robust paragenesis for gold, sulfides and gangue minerals at the deposit. His study has revealed the importance of (i) exsolution (i.e. chemical unmixing of minerals precipitated at higher temperatures) and recrystallisation, and (ii) variations in host rock composition, in determining certain aspects of metal and element distribution at the deposit.

## ORE DEPOSITS AND TECTONIC EVOLUTION OF THE LACHLAN OROGEN, SE AUSTRALIA

**Leaders:** Ron Berry, David Cooke, Matthew Cracknell, Sebastien Meffre, Joanne Whittaker

**Team members:** Michael Roach, Jeff Steadman, Irina Zhukova

**Students:** Peter Duerden, Kyle Hughes, Corey Jago, Kathryn Job, Sitthinon Kultaksayos, Christopher Leslie, Sigmund Lloyd, Ben Ridgers, Riquan Ropli, Chris Rutherford (Curtin), Peerapong Sritangirikul, Thomas Schaap, Tristan Wells

**Collaborators:** Mark Arundell, Elena Belousova, William Collins, John Greenfield, David Huston, Roland Maas, Robert Musgrave, Marc Norman

This ARC Linkage project aims to improve economic mineral discoveries through an increased understanding of the geology and tectonic evolution of the Lachlan Orogen in southeastern Australia, and to integrate that knowledge with

existing geological information to subsequently develop predictive and explanatory models.

The project commenced in mid-December 2016 when the legal agreement was signed by all the collaborating organisations, which include five universities, four geological surveys and ten mining industry partners. This was followed by a planning meeting held at Macquarie University in March 2017 where a detailed research plan was formulated, and a research meeting in September 2017 where the first research results were presented to the collaborators.

A successful recruitment campaign has resulted in eight students being brought into the team – one PhD, four Masters and three Honours. The services of CODES' Postdoctoral Research Fellow Jeff Steadman and project manager Irina Zhukova were secured on a part-time basis.

Fieldwork and the acquisition of new geochemical, geochronological and geophysical data compilation activities will continue in 2018. Initial results have been submitted for publication as conference abstracts.

## BUILDING TASMANIA: THE CAMBRIAN AND BEYOND

**Leaders:** Sebastien Meffre, Robert Scott

**Team members:** Ron Berry, Jacqueline Halpin

**Student:** Jacob Mulder

**Collaborators:** Clive Calver, Grace Cumming, Nathan Daczko, John Everard, Karl Karlstrom

Much of the activity in this project has been led by Jacob Mulder who finished his PhD research in June 2017 drawing together many aspects of the Precambrian–Cambrian geological evolution of Tasmania.

Jacob focused on refining the depositional age and better understanding the stratigraphic relationships of Mesoproterozoic sedimentary rocks. Major breakthroughs in his PhD have been as follows:

- documenting the stratigraphic, depositional, sedimentological provenance and geochronological links between Tasmania and north western America

*BELOW: PhD student Jacob Mulder teaching CODES SEG Student field trip participants at Rocky Cape, northwest Tasmania, December 2017.*







ABOVE: Cowal mine site, central New South Wales. The Cowal gold mine is owned and operated by Evolution Mining Pty, who are also key sponsors of the multidisciplinary ARC Linkage Lachlan Orogen project.

- defining Tasmania's place within the Nuna Supercontinent
- providing new insights into the Cambrian tectonic setting of the Gondwana Pacific margin
- refining the depositional age of turbidites comprising the Oonah Formation and their correlation with Mesoproterozoic turbidites exposed on King Island.

In the second half of 2017 Jacob, together with the project leaders, members and collaborators, worked on refining the stratigraphy, magmatic and tectonic history of Tasmania between 700–550 Ma.

## URANIUM CONCENTRATIONS IN BASINS

**Leader:** Garry Davidson/Karin Orth

**Team member:** Sebastien Meffre

**Collaborators:** Sandrin Feig, Grant Osborne, Penny Sinclair, Ben Walsh

This project is focussed on researching the nature and causes of uranium concentration in sedimentary basins. In 2017, the project focussed on the East Alligator Rivers Province, Northern Territory, at the Angularli U unconformity-style mineralisation with joint venture partners Cameco (managing) and Rio Tinto Exploration.

Working in close collaboration with Cameco geologists Ben Walsh and Penny Sinclair the project used MLA-SEM-based detailed petrology, LA-ICP-MS analysis, and element mapping of pyrite to target LA-ICP-MS geochronology. A report on these findings was delivered to the joint venture partners in 2017.

## ORE DEPOSIT CYCLES AND OCEAN/ATMOSPHERE CONDITIONS

**Leader:** Ross Large

**Team members:** Sean Johnson, Sebastien Meffre, Indrani Mukherjee, Jeff Steadman

**Collaborators:** Janaina Avila, Ross Corkrey, Ray Coveney, Mihir Deb, Daniel Gregory, Karen Kelley, Valeriy Maslennikov, Patrick Sack, John Slack

This project is investigating the relationship between variation of oxygen in the atmosphere and the cycles of basin-hosted ore deposits. Oxygen cycles have been estimated using the chemistry of sedimentary pyrite through time. Redox sensitive trace elements in pyrite, particularly Se, Mo, Co, Sb and Tl, have proved to be the best indicators of oxygen variation. In a 2017 paper published in *Economic Geology*, the research

team discussed the controls of atmosphere oxygen on the genesis of uranium, copper, gold and lead-zinc in sedimentary basins in the Proterozoic.

Sean Johnson led a study of metalliferous black shales containing enrichments of Se, Zn and Mo, in addition to Ni, Co, Cu and Ag. The results, published in 2017 in *Mineralium Deposita*, demonstrate how highly metalliferous black shales coincide with periods of elevated oxygen in the atmosphere throughout the Phanerozoic.

Indrani Mukherjee's PhD thesis, 'Pyrite trace element geochemistry of Proterozoic organic matter-rich shales of the Boring Billion period (1800–800 Ma)', was submitted in 2017. It investigated the importance of nutrient availability in the Proterozoic oceans in the 'Boring Billion' period. The thesis focussed on analysing bio-essential trace element concentrations and sulphur isotopic compositions of sedimentary pyrite in Proterozoic black shales using Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS) and Sensitive High Resolution Ion Microprobe-Stable Isotope (SHRIMP-SI) respectively, to further our understanding of the 'Boring Billion'.

The thesis provided insights on trace element availability and paleo-redox structure of the Proterozoic oceans and atmosphere, including its effect on biologic evolution and results were published in *Precambrian Research and Nature's Scientific Reports*. In addition, the thesis also explored the possibility of using trace element concentrations in pyrite as mineralisation vectors such as in the Barney Creek Formation hosting the McArthur River deposit. Application of pyrite chemistry for exploration of SEDEX Zn-Pb deposits in the McArthur Basin was discussed in a publication in *Ore Geology Reviews*.

### MINERAL GEOCHEMISTRY VECTORING: UNCOVERING NORTHWEST QUEENSLAND'S HIDDEN POTENTIAL

**Acting leader:** Jeff Steadman

**Team members:** David Cooke, Peter McGoldrick, Robert Scott

**Collaborators:** James Austin, Vladimire Lisitsin, Rick Valenta

The Paleo- to Mesoproterozoic Mount Isa district, Northwest Queensland, anchors the Northwest Queensland Mineral Province, one of the preeminent mining districts of the world. Unfortunately, many of the mines of the Mount Isa district are approaching end-of-life scenarios, which could have a significant negative socio-economic impact on the region. Finding new resources and revitalising the Northwest Queensland Mineral Province is therefore of paramount importance.

In 2017, CODES was invited to participate in a new research initiative, the Strategic Resources Exploration Program, which is being led by the Geological Survey of Queensland (Department of Natural Resources and Mines) and the University of Queensland. This research program involves a consortium of researchers from several organisations, including CSIRO and James Cook University, and aims to stimulate exploration and discovery of new resources in the Northwest Queensland Mineral Province. CODES will be a key participant in this collaboration,

generating a wealth of new pre-competitive mineral chemistry data as we assess whether low-level trace element dispersion halos are encapsulated in distal regions around major sediment-hosted base metal and IOCG deposits in NW Queensland.

Jeff Steadman was appointed as a postdoctoral researcher to this project in mid-2017. A pilot study of pyrite chemistry from the Lady Loretta deposit was initiated as a proof-of-concept study while contract negotiations were

finalised. The project is scheduled to get fully underway in 2018, with the appointment of a second postdoctoral researcher, and with Shaun Barker to take on a leadership role for the project once his appointment is finalised in 2018.

## LOOKING FORWARD

2018 is shaping up to be a year full of new initiatives and achievements for Program 3, starting with the continuation of our flagship project, 'Mineral geochemistry vectoring: Uncovering Northwest Queensland's hidden potential', funded by the State of Queensland through the Department of Natural Resources, Mines, and Energy. This project is part of the Strategic Resources Exploration Program, a wider Queensland Government-funded research initiative. It is a three-year, multi-stage project which will investigate the trace element characteristics of key sulfide, silicate, carbonate and oxide alteration minerals associated with various ore deposits located in the Proterozoic Mount Isa Inlier.

The Mount Isa Cu-Pb-Zn mine, along with several others (e.g., Ernest Henry), is nearing the end of its life, and the closure of this world-class operation would deal a significant blow to the socio-economic structure of northwest Queensland. Finding new resources and revitalising the Northwest Queensland Mineral Province is therefore of paramount importance.

Our objectives will be to provide the Department and industry stakeholders with new geochemical information on known systems in the Mount Isa district, which can then be applied on greenfields targets elsewhere in the region, ideally leading to the discovery of new base- and/or precious-metal resources to reinvigorate the Mount Isa-Cloncurry area.

Crucial to the success of this venture, and of CODES post-2017, is the appointment of Dr Shaun Barker to the role of Program 3 Leader. Shaun will join CODES in 2018 from the University of Waikato as an Associate Professor, and his expertise and leadership will be of great benefit to all of us.







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## OBJECTIVE

This program aims to investigate volcanic processes and products, magma fertility, and the roles of mantle and crustal processes in magmatic-hydrothermal mineral systems to enable efficiencies in the discovery of mineral resources.

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# INTRODUCTION

**Program 4: Magmatic and volcanic processes** provides end-users with a magmatic and volcanic framework to determine the most prospective regions for exploration and for targeting buried ore deposits.

The Program was created in 2017 by bringing together projects that for the past few years were included in the former Ore Deposits Module and the Discipline of Earth Sciences area. This new classification of all the volcanic- and magma-related projects into one program ensures that researchers working across this area have the best opportunities for collaboration and exchange of knowledge. There are some crossovers with other programs, notably Program 1.

We have an international profile in magmatic and volcanic processes research, which is reflected in the collaborative network of industry, research institutions, volcano observatories, oceanographic institutes and other universities that we work with. In the past three years we have participated in six ship voyages; the science and collaborative work stemming from these activities is only now being reflected in our publications output.

## HIGHLIGHTS

### INTERNATIONAL PROFILE

One of the most significant highlights of the year was hosting an American Geophysical Union Chapman Conference on submarine volcanism in Hobart in late January. This conference was organised by Drs Karin Orth and Rebecca Carey. Over 100 scientists came together

*OPPOSITE PAGE: (Bottom) Intensive deformation and mingling texture between obsidian and pumice in the obsidian lava of Glass Mountain in Medicine Lake volcano, California, USA, visited by CODES and UTAS researchers during a pre-IAVCEI conference trip on Holocene silicic lavas on the West Coast of the USA. (Top) Paul Olin (left), pictured with Ray Cas from Monash University at the Panglo core farm, looking at drill core from the Enterprise Dolerite, which is currently being mined for dolerite-hosted orogenic gold. Paul and Ray worked with Ryan McMann on his Honours project.*



*ABOVE: Jocelyn McPhie pictured during a field workshop on Cenozoic basaltic volcanism at Cape Grim, northwest Tasmania.*

to overview the current understanding of submarine volcanism and plan the next decade of research both in modern and ancient environments, and to find the technology to do this research. Professor Jocelyn McPhie, Dr Carey and Dr Martin Jutzeler all gave invited presentations. Postgraduate students Rhiannan Mundana, Fumihiko Ikegami and Sally Watson also presented posters, and Rhiannan received a best poster award. The outcomes of this conference were reported in *Nature Geoscience*'s 'News and Views' (<https://www.nature.com/articles/ngeo2929>).

### INTERNATIONAL WORKSHOPS/ PRESENTATIONS

The volcanology team was successful in gaining internal funding success through the Environment, Resources and Sustainability theme for two workshops to foster collaboration and ARC funding opportunities in submarine volcanism. Six scientists from GNS Science (New Zealand) and the New Zealand National Institute of Water and Atmospheric Research (NIWA) participated in these workshops.

Internationally renowned volcanologist and geochemist Professor Ken Rubin from the

University of Hawaii visited CODES and Earth Sciences in January, funded with a special award by the then UTAS Vice Chancellor, Professor Peter Rathjen. During the visit, Professor Rubin gave a public lecture and a presentation to staff in CODES/Earth Sciences on submarine boninite volcanism in the Lau Basin, Tonga. Boninite magmatism and volcanism form the focus for PhD student Evan Draayers' research.

### PUBLICATIONS IN 2017

During 2017, 36 papers were published in international peer-reviewed journals by researchers within Program 4, with 29 papers from the magmatic processes group alone. Highlights include a paper published in *Nature Geoscience* by Professors Vadim Kamenetsky and Leonid Danyushevsky ('Seawater cycled throughout Earth's mantle in partially serpentinized lithosphere') and the acceptance of a paper for publication in the January 2018 edition of *Science Advances* (lead author: Dr Rebecca Carey).

Professor Kamenetsky and his research group had a total of 20 papers published across the year (see 2017 Publications in this report and individual project summaries below).



## The program team

**LEADER** REBECCA CAREY

**DEPUTY LEADER** VADIM KAMENETSKY

### TEAM MEMBERS:

Sharon Allen, Stuart Bull,  
Leonid Danyushevsky,  
Garry Davidson, Paul Davidson,  
Trevor Falloon, Bruce Gemmell,  
David Green, Martin Jutzeler,  
Maya Kamenetsky, Ross Large,  
Jocelyn McPhie, Sebastien  
Meffre, Paul Olin, Karin Orth,  
Robert Scott, David Selley,  
Jay Thompson, Khin Zaw

### PHD STUDENTS:

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Chapman, Alex Cherry, Evan  
Draayers, Matt Ferguson, Jodi  
Fox, Sam Holt, Qiuyue Huang,  
Fumihiko Ikegami, Naomi  
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### MASTERS STUDENT:

Eyob Andemeskel

### HONOURS STUDENTS:

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Sue DeBari

**WOODS HOLE OCEANOGRAPHIC  
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## Projects

### Volcanology research related to ore deposits

Subaerial and submarine volcanology

Sedimentary volcanology

Pegmatites and pegmatite-related ores

Kimberlites and flood basalts: Linking primary melts with mantle and crustal sources

A melt inclusions pursuit into identity of carbonatite magmas and their economic potential

Melt-fluid evolution, magmatic immiscibility and budget of chalcophile and noble metals in basaltic magmas

Olympic Dam

Boninite petrogenesis: Hunter Ridge, SW Pacific

Magma petrogenesis

VHMS research – modern

VHMS research – ancient

## PROJECT SUMMARIES

### VOLCANOLOGY RESEARCH RELATED TO ORE DEPOSITS

**Leader:** Rebecca Carey

**Team members:** Bruce Gemmell, Ross Large, Jocelyn McPhie, Sebastien Meffre, Paul Olin, Karin Orth, Robert Scott, David Selley

**Students:** Eyob Andemeskel, David Douch, Ryan McMann, Riquan Ropli

**Collaborators:** Ray Cas, Matthew Crawford, Kim Denwar, Leon Grimbeek, Andrew McNeill, Gary Sparks

Modern volcanic arcs provide constraints on the physio-chemical factors for seafloor ore deposits and the paleoenvironment setting

of ancient volcanic-hosted sulfide deposits. We are applying new knowledge of modern volcanic architectures to ancient mineralised volcanic successions with industry partners and collaborators.

In 2017, Masters student Eyob Andemeskel submitted his thesis on the Rosebery Group on the Mount Read Volcanics for assessment. Eyob used lithofacies, lithogeochemical and structural analysis to establish local and regional correlations of strata prospective for VHMS mineralisation in the Mount Read Volcanics.

David Douch's PhD project on the controls on gold mineralisation at the Invincible gold deposit has provided a wealth of new

*LEFT: Jocelyn McPhie (front) logging drill core from the volcanic island of Surtsey, Iceland, in September 2017.*





ABOVE: In 2017, CODES and UTAS staff and students took part in pre- and post-IAVCEI conference field trips: pictured is the Newberry volcano in Oregon, USA, with the obsidian lava of the Big Obsidian Flow in the foreground and a caldera lake in the background.

understanding on the volcano-sedimentary Neoarchaeic Black Flag and Merougil Groups, and concluded that the conglomerates found therein are the product of diapiric uplift related to the intrusion of large granite batholiths rather than conventional tectonic models of regional deformation. David is in the final stages of his project.

Honours student Ryan McMann, together with Paul Olin and Ray Cas, are collaborating with the Geologic Survey of Western Australia (GSWA) on the Golden Mile Dolerite, which is also funding the project. Materials for this project are provided by the GSWA and Kalgoorlie Consolidated Gold Mines Pty Ltd. (KCGM). Ryan's thesis is entitled 'A syn-depositional sill intrusive model for the Golden Mile Dolerite, Kalgoorlie, WA'.

Riquan's Ropli's Honours project examined the volcanology of Cambrian geological units in central Victoria in collaboration with the Geological Survey of Victoria. He then incorporated the volcanology into an ore genesis model for the deposit.

## SUBAERIAL AND SUBMARINE VOLCANOLOGY

**Leader:** Rebecca Carey

**Team members:** Sharon Allen, Trevor Falloon, Martin Jutzeler, Jocelyn McPhie, Paul Olin, Karin Orth

**Students:** Jodi Fox, Sam Holt, Fumihiko Ikegami, Naomi Potter, Caleb Sang, Daniele Vergani

**Collaborators:** Daniele Andronico, Costanza Bonadonna, Fabio Caratori-Tontini, Ray Cas, Maya Coussens, Grace Cumming, Nathan Daczko, Cornel de Ronde, Andrea DiMuro, Robert Duncan, John Everard, Richard Fiske, Daniel Fornari, Yoshi Goto, Julie Hollis, Bruce Houghton, Maria Janebo, Sean Johnson, Michael Manga, Tim Orr, Matthew Patrick, Christopher Phillips, Ryan Portner, Michael Rosenberg, Jack Simmons, Adam Soule, Kenichiro Tani, Rex Taylor, James White, Joanne Whittaker, Richard Wysoczanski

The submarine volcanology research theme is focused on developing an understanding of volcanic eruption and transport processes, volcanic architectures and hydrothermal systems in modern and ancient environments. Research in subaerial volcanology covers a wide range of topics. Current research includes projects in various global locations where active hotspot volcanism is taking place: Hawaii, Reunion Island, Kerguelen Plateau and the Etna and Stromboli volcanoes in Italy.

There were many highlights to report in 2017 on this project, including the hosting of a Chapman Conference on submarine volcanism in Hobart and the team's success in obtaining funding to foster collaboration in submarine volcanism with other globally recognised oceanographic institutes. We are on track to deliver at least 10 publications, most led by PhD students.

In August 2017, Rebecca Carey, Martin Jutzeler, Karin Orth, Jodi Fox and Fumi Ikegami went to the IAVCEI conference in Portland,



USA. Rebecca was invited to give a presentation of research at CODES/ Earth Sciences on submarine volcanology. UTAS staff and students participated in pre- and post-workshop field trips in Oregon, Northern California and Washington.

PhD and Honours students have been outstandingly productive. Jodi Fox has completed research on the volcanic architecture and setting of Cenozoic volcanism in northwest Tasmania. Jodi hosted a workshop at Cape Grim associated with the AGU Chapman Conference on Submarine Volcanism, which included past Alumni Kate Bull and other high-profile academics from Japan, Australia and the USA. Naomi Potter has been working with Rebecca Carey to prepare and translate her Honours research into a manuscript for an international peer-reviewed journal. She is making excellent progress.

The sub-projects within 'Subaerial and submarine volcanology' also achieved excellent progress:

#### **SUBMARINE SILICIC VOLCANISM: HAVRE 2012 ERUPTION, KERMADEC ARC, NEW ZEALAND**

This year the volcanology group have had an article accepted in the highly prestigious journal *Science Advances* (to be published in January 2018) providing the first quantitative eruption data for a large-scale silicic submarine eruption. Rebecca Carey is the lead scientist for this project which is currently composed of 27 UTAS and international participants, including nine PhD, Honours and undergraduate students. PhD student Fumihiko Ikegami has used a high-resolution 1 m-scale seafloor topographic map of the volcano summit to identify 15 individual domes and lavas that erupted in 2012 on faults. Together these two studies provide a stratigraphic

framework and quantitative constraints on eruption dynamics critical to understanding the role of the ocean in modulating submarine seafloor eruptions.

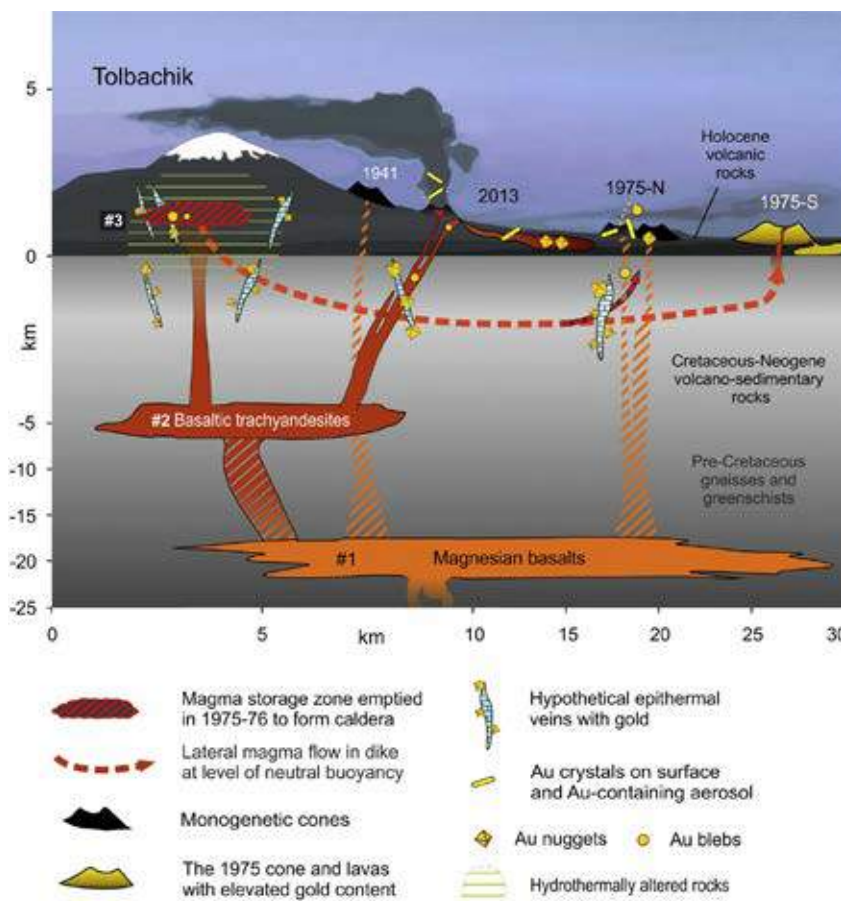
#### **LARGE IGNEOUS PROVINCE VOLCANISM: KERGUELEN PLATEAU**

Big Ben volcano on Heard Island is one of three hotspot volcanoes globally. Rebecca Carey is the geoscience lead for a multidisciplinary research project designed to understand volcanism of the Kerguelen Plateau and its role in physical and chemical oceanography in this region. PhD student Jodi Fox is leading the study of the geological history of Heard and McDonald Islands on the Kerguelen Plateau, and relating this to submarine volcanos on the wider plateau together with Professor Jocelyn McPhie, Dr Trevor Falloon and IMAS collaborators. Jodi is due to finish her PhD in mid-2018.

*BELOW: Cathedral Rock in the John Day Fossil Beds National Monument, Oregon, USA, visited by CODES and UTAS researchers during a post-IAVCEI conference trip to the Columbia River in August. Here gorge ignimbrite sits on top of Miocene tuffaceous lacustrine sediments.*







LEFT: The magmatic system under Tolbachik volcano and possible mechanisms of gold recycling, as illustrated in Vadim Kamenetsky's 2017 article 'Gold recycling and enrichment beneath volcanoes: A case study of Tolbachik, Kamchatka' in *Earth and Planetary Science Letters*.

Hokkaido, Japan. Kutcharo is the largest Quaternary silicic caldera in Japan, and formed in response to nine large-volume explosive eruptions, the most recent of which was at ~34 ka. Of major importance in this research is the recognition that Kutcharo has a resurgent dome and that the caldera structure is coupled with regional faults related to the wider convergent margin setting. This setting and signs of unrest (fumarolic activity and hot springs, a series of large earthquakes, ground deformation) indicate that Kutcharo must be considered active and highly hazardous. The results have been accepted for publication in the *Geological Society of America Bulletin*.

### SURTSEY INTERNATIONAL CONTINENTAL SCIENTIFIC DRILLING PROGRAM

In September 2017, Jocelyn McPhie and collaborator James White logged drill core from Surtsey, Iceland, as part of an International Continental Scientific Drilling Program project. Surtsey was formed by submarine and later subaerial eruptions over a four-year period beginning in 1963. Much of the activity was explosive, involving interaction between basalt and seawater, and this style of explosive eruption is now known as 'Surtseyan'. The drill core will provide data on the character of the products of the explosive eruptions, and also on the mineralogical and textural changes accompanying hydrothermal, diagenetic and microbial alteration.

### CASCADE SEAMOUNT AND THE BALLENY MANTLE PLUME

Honours student Rhiannan Mundana, together with Jo Whittaker and Rebecca Carey, are using R/V *Investigator* data to understand the geological history of the Cascade Seamount on the East Tasman Plateau. Rhiannan's research has demonstrated that the Cascade

### HOTSPOT VOLCANISM: 1983–1986 ERUPTION OF KILAUEA VOLCANO

Lava lakes are mesmerising, and a fascination for volcanologists and the public alike. It is rare to have the opportunity to study these lakes in combination with high-frequency multidisciplinary monitoring data in order to understand mass and heat transfer from the deep Earth to the atmosphere. PhD student Sam Holt, Rebecca Carey and Jocelyn McPhie are collaborating with staff from the Hawaiian Volcano Observatory and University of Oregon, using high-speed camera footage of the summit lava lake on Kilauea volcano to understand shallow conduit and lake convection dynamics. Video observations of the lake surface reveal a consistent bubble rise pattern that is hypothesised to be related to the deep conduit geometry. Work is still in progress, but initial data is exciting and Sam will be writing up this research as his final PhD project component. He is on track for submission in mid-2018.

### HOTSPOT VOLCANISM: 2007 ERUPTION OF PITON DE LA FOURNAISE VOLCANO, REUNION ISLAND

Piton de la Fournaise volcano on Reunion Island in the Indian Ocean is a hotspot volcano, with magma fed from a mantle plume and erupting at the surface. The 2007 eruption of Piton de la Fournaise is one of the larger eruptions of this volcano in human history. Daniele Vergani's PhD thesis is focussed on understanding the dynamics of eruptions during this phase. The eruptions were diverse, encompassing lava–water interaction explosions, lava fountaining and the eruption and collapse of the summit caldera. Daniele has pieced together all of the observation data to aid in the understanding of this eruption, and how the magma plumbing system is connected at depth. His PhD study will conclude in mid-2018.

### KUTCHARO CALDERA, HOKKAIDO, JAPAN

Jocelyn McPhie and long-term CODES collaborator Dr Yoshi Goto have produced a new map and interpretation of Kutcharo caldera,

Seamount was at, or very close to, sea level at ~35 Ma, before subsiding to its current depth of 1,400 mbsl as the Balleny plume moved southwards with time. The subsidence rate is important – as subsidence was essential to the opening of the Tasman Gateway between Tasmania and Antarctica and the initiation of the Antarctic Circumpolar Current.

## SEDIMENTARY VOLCANOLOGY

**Leader:** Martin Jutzeler

**Team members:** Stuart Bull, Rebecca Carey, Jocelyn McPhie, Karin Orth

**Collaborators:** Abigail Barker, Cathy Busby, Ray Cas, Maya Coussens, Sue DeBari, James Gill, Paul Hammond, Kaj Hoernle, James Hunt, Steffen Kutterolf, Michael Manga, Robert Marsh, Ed Pope, James Shreeve, Adam Soule, Peter Talling, Yoshihiko Tamura, Christian Timm, Erik Van Seville, Reinhard Werner, James White, Richard Wysoczanski

Sub-projects in the ‘Sedimentary volcanology’ theme are focussed on volcano sediment aprons and volcanic architectures, to better understand ancient analogues.

## LACUSTRINE SEDIMENTATION OF MASS FLOWS: OLIGOCENE ANCESTRAL CASCADES VOLCANO ARC

This sub-project aims to characterise the sedimentation mechanisms acting in lakes adjacent to subaerial arc volcanoes. The Oligocene Wildcat Creek beds in Washington State, USA, record volcanoclastic deposition in a lacustrine basin in the Ancestral Cascades arc. The succession is well exposed over 300 km<sup>2</sup> of remote forested area, and is made up of hundreds of laterally extensive beds interpreted to record below wave-base deposition of explosive subaerial volcanism in a lacustrine setting.

In 2016 and 2017, Martin Jutzeler carried out detailed stratigraphic logging and extensive fieldwork in wilderness areas that allowed the reconstruction of the architecture

of the basin. Facies analysis identified deposits from eruption-fed pyroclastic density currents, subaqueous debris flows, airfall onto water, reworking by rivers, and local peperitic intrusions. Preliminary results from 2016 fieldwork were published as a United States Geological Survey field guide in 2017. This project is part of a broader research focus on subaqueous volcanoclastic density currents encompassing marine core data collected by Martin during International Ocean Discover Program expeditions 340 and 350 in island arcs.

## ORIGIN OF GIANT SEDIMENT WAVES ON SUBMARINE VOLCANOES

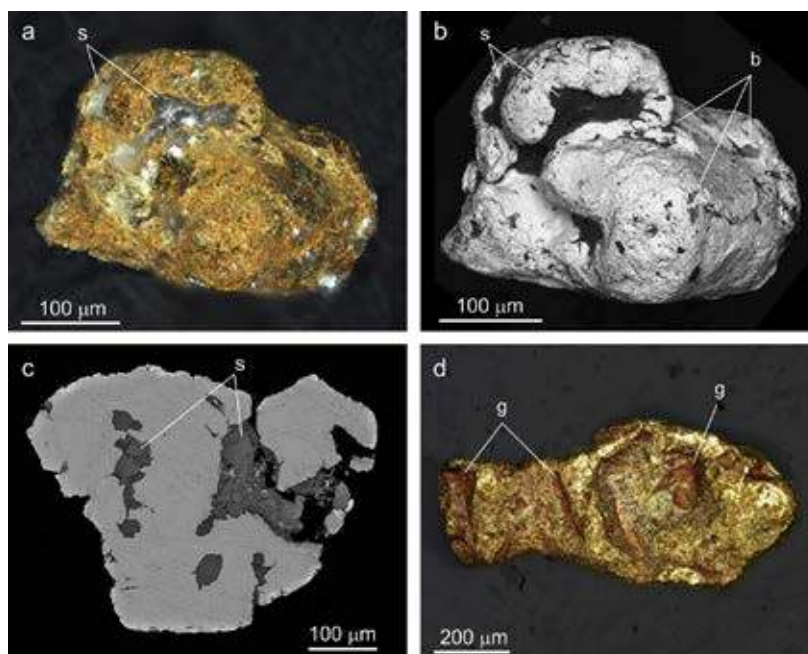
Based on marine geophysical data, this sub-project identifies the origins of widespread seafloor waveforms surrounding submarine silicic caldera arc volcanoes. The eruption-fed waveforms identified at several submarine volcanoes worldwide consist of fanning out, upward-migrating cyclic steps and anti-dune deposits, resulting from voluminous deposition from Froude supercritical density currents. These deposits indicate high-flux sedimentation regimes that were reached at the climactic phase of silicic caldera-forming submarine explosive eruptions.

Further, this project identifies key characteristics that distinguish these bedforms from submarine landslide deposits, and compares them with subaerial analogues. This study has strong links with ore exploration, through reconstruction of volcanic architecture and identification of a new type of proximal volcanoclastic deposits. Martin Jutzeler has co-edited the study and is author of a manuscript to be published in *Earth and Planetary Science Letters* in early 2018.

## REGIONAL DISPERSAL OF VOLCANIC PRODUCTS IN THE KERMADEC ARC, NEW ZEALAND

Knowledge about the dispersal of pyroclasts in island arc and back-arc settings remains very poor. In 2017, Martin Jutzeler participated as sedimentologist/volcanologist on a six-week voyage aboard the new R/V *Sonne*, flagship of the German research fleet; the voyage (expedition SO255) was led by Professor Kaj Hoernle (GEOMAR Germany). Through dredging at 179 stations over 200,000 km<sup>2</sup>, Martin collected numerous samples of volcanoclastic sediment and hemipelagic mud rich in volcanic particles. This extensive collection will allow us to chemically characterise the dispersal of pyroclasts in the context of an island arc, and compare it with

*BELOW: Nuggets of electrum (Au:Ag ~50:50 by wt.), recovered from the 2012 basaltic andesite lava flow of the Tolbachik volcano, taken from Vadim Kamenetsky's 2017 article 'Gold recycling and enrichment beneath volcanoes: A case study of Tolbachik, Kamchatka' in Earth and Planetary Science Letters.*







ABOVE: Pumice is brought aboard the R/V Sonne during Martin Jutzeler's research voyage to the Kermadec arc, March 2017.

compositions of known edifices. This will allow reconstruction of sedimentation patterns by ocean and atmospheric dispersal. Further, multiple samples include rafted pumice clasts from the 2012 deep submarine eruption of Havre volcano. Mapping of these deposits will constrain dispersal of pumice clasts by surface oceanic currents and improve existing models of oceanographic current modelling.

## PEGMATITES AND PEGMATITE-RELATED ORES

**Leader:** Paul Davidson

**Collaborators:** Walter L. Pohl, Adolf Rericha, Rainer Thomas

This initiative examines melt-melt immiscibility in felsic silicate melts, in the formation of pegmatites and pegmatite-related ore deposits. Pegmatites are noted for the presence of giant crystals, sometimes including rare minerals and gems, and are prime sources of several rare elements, even though

their major element chemistry differs little from the standard haplogranitic melts, which are generally accepted to be their parental magmas. Therefore, it can be inferred that something in their origin favours extremely efficient partitioning, which would explain the high rare element concentrations (up to ore grade). Moreover, such processes need not be restricted to pegmatites, or even terrestrial processes.

During the year, a paper was published in *Mineralogy and Petrology* entitled 'Hingganite-(Y) from a small aplite vein in granodiorite from Oppach, Lusatian Mts., E-Germany' by Rainer Thomas and Paul Davidson. Two more papers – 'Genetic significance of the 867 cm<sup>-1</sup> out-of-plane Raman mode in graphite associated with V-bearing green grossular' by Rainer Thomas, Adolf Rericha, Walter L. Pohl and Paul Davidson, and 'Shaw meteorite: water-poor and water-rich melt inclusions in olivine and enstatite' by Rainer Thomas and Paul Davidson – have been accepted for publication in *Mineralogy and Petrology*.

## KIMBERLITES AND FLOOD BASALTS: LINKING PRIMARY MELTS WITH MANTLE AND CRUSTAL SOURCES

**Leader:** Vadim Kamenetsky

**Team members:** Maya Kamenetsky, Sebastien Meffre, Jay Thompson

**Student:** Adam Abersteiner

**Collaborators:** Ilya Bindeman, Elena Demonerova, Kathy Ehrig, Andrea Giuliani, Karsten Goemann, Alexei Ivanov, Alexei Kargin, Ekaterina Kiseeva, Dmitry Kuzmin, Roland Maas, Alexander Sobolev, Greg Yaxley, Georg Zellmer

This project is aimed at understanding the relationship between kimberlites and diamonds, flood basalts and magmatic sulfides, and chromitites and related PGE mineralisation, by linking mantle structure, phase and chemical composition, isotope evolution and temperature to the melting processes.

Outcomes in 2017 included genetic constraints for a number of continental magmatic provinces (Tasmania, South Africa, Arctic Siberia, SW China, NW Canada and eastern Finland).

These outcomes, published in several high-profile publications (Ivanov et al. and Kamenetsky et al. in *Chemical Geology*), focused on the understanding of the origin and evolution of Large Igneous Provinces in time and space, and in particular their relationships to the so-called mantle plumes and widespread subduction.

A particular emphasis was on the Karoo-Ferrar igneous province, which is one of the largest igneous provinces on Earth. Our new isotope dilution thermal ionization mass spectrometry (ID-TIMS) single grain U-Pb ages for zircon and baddeleyite from Tasmanian dolerites combined with ID-TIMS literature single grain U-Pb ages from the Ferrar and Karoo suites are consistent with the major pulse of synchronous magmatism throughout the province lasting about 1 Ma or less for the major pulse of magmatism at the time of the Toarcian mass extinction event.

We argue that the mechanism of synchronisation of magmatism over such a short period of time along such a long distance is the major question to be answered in search of the correct model for the origin of the Karoo-Ferrar large igneous province. It cannot be reconciled with the lower mantle plume head model with the plume impingement beneath the Karoo. Plume material could not spread beneath the lithosphere at a rate of ~ 5–10 m/yr (5000 km per 0.5–1 Myr), at least based on the current knowledge of the mantle physical properties. Our preferred model for the origin of the Karoo-Ferrar large igneous province is associated with subduction of the Phoenix plate beneath the southern Gondwana.

Large datasets on kimberlites, melt inclusions in kimberlite minerals and kimberlite-hosted lithospheric peridotite and eclogite xenoliths were presented in four papers published in *Chemical Geology* (Abersteiner et al., Giuliani et al. and Kiseeva et al.) and *Lithos* (Kargin et al.).

## A MELT INCLUSIONS PURSUIT INTO IDENTITY OF CARBONATITE MAGMAS AND THEIR ECONOMIC POTENTIAL

**Leader:** Vadim Kamenetsky

**Team member:**

Maya Kamenetsky

**Student:** Naomi Potter

**Collaborators:** Marc Campeny, Anton Chakhmouradian, Karsten Goemann, Roland Maas, Juan Carlos Melgarejo, Anthony Simonetti, Victor Sharygin

This project aims to understand primary compositions of mantle-derived carbonatite magmas and carbonate-rich components in association with alkali silicate magmas. The study is based on a set of fresh samples representing worldwide occurrences of carbonatites.

In 2017, our research on liquid-liquid immiscibility in the Oldoinyo Lengai 1993 lava was published in *Chemical Geology* (Potter et al.). This paper presents petrographic evidence of liquid immiscibility between silicate, carbonate, chloride, and fluoride melt phases. Several textural features preserved in the silicate spheroids, melt inclusions, and carbonatite groundmass have been identified, which exhibit evidence of silicate-carbonate, carbonate-carbonate and carbonate-halide immiscibility. Rapid quenching of the lava facilitated fortuitous preservation of the end products of these multi-stage liquid immiscibility processes within the groundmass.

We continue to resolve the origin of intraplate carbonatitic to alkaline volcanism using examples from western Africa. The first radiometric and isotopic results for the Catanda complex, which hosts the only extrusive carbonatites in Angola, are reported by Giuliani et al. in *Geology*. Apatite (U-Th-Sm)/He and phlogopite  $^{40}\text{Ar}/^{39}\text{Ar}$  ages of Catanda aillikite lavas indicate eruption at ca. 500–800 ka, more than 100 m.y. after emplacement of abundant kimberlites and carbonatites in this region.

The lavas share similar high- $\mu$  (HIMU)-like Sr-Nd-Pb-Hf isotope compositions with other young mantle-derived volcanics from Africa (e.g., Northern Kenya Rift; Cameroon Line). The position of the Catanda complex in the Lucapa corridor, a long-lived extensional structure, suggests a possible tectonic control for the volcanism. The complex is also located on the Bié Dome, a broad region of fast Pleistocene uplift attributed to mantle upwelling. Seismic tomography models indicate convection of deep hot material beneath regions of active volcanism in Africa, including a large area encompassing Angola and northern Namibia.

## MELT-FLUID EVOLUTION, MAGMATIC IMMISCIBILITY AND BUDGET OF CHALCOPHILE AND NOBLE METALS IN BASALTIC MAGMAS

**Leader:** Vadim Kamenetsky

**Team members:**

Leonid Danyushevsky,  
Maya Kamenetsky

**Collaborators:** Kathy Ehrig, Sandrin Feig, Andrey Gurenko, Mark Kendrick, Roland Maas, John Mavrogenes, Jung-Woo Park, Vsevolod Prokofiev, Thomas Rodemann, Sergei Smirnov, Michael Zelenski

This research aims to establish the initial metal abundances in common primitive magmas, and the mechanisms of separation of immiscible liquids and fluids from the silicate melt, through studies of melt and fluid inclusions in minerals.

Compositions of sulfide melt inclusions entrapped in primitive olivine phenocrysts can be used to understand the compositions of early sulfide melts that may ultimately contribute to magmatic sulfide ore deposits. In 2017 our publication in *Lithos* (Zelenski et al.) characterised sulfide globules hosted in olivine (86–92 mol% Fo) from the Tolbachik basalt (the 1941 eruption) in terms of their major and trace element abundances.



Trace elements (platinum-group elements – PGE, Ag, Te, Au, Pb and Bi) are present in solid solution in sulfide phases and as micron-sized particles ('nuggets'). Such nuggets of dominantly Au, Pt, Au–Pd and Pd–Te compositions are contained randomly within sulfide matrices or, more commonly, at phase boundaries. The highest measured noble metal concentrations in the analysed globules (436 ppm Au + PGE) are 13.3 ppm Au, 115 ppm Pt and 299 ppm Pd, whereas 40% of globules have < 15 ppm of noble metals. Although the individual Tolbachik sulfide globules have variable PGE abundances, their mean composition resembles those of major PGE-sulfide ore deposits (e.g., Norilsk, Sudbury, Platreef and Merensky Reef).

Our publication in *Geochimica et Cosmochimica Acta* (Park et al.) aimed at understanding the factors controlling the enrichment of Rh and IPGEs in Cr-spinels in magmas in different geodynamic environments.

We estimated partition coefficients between Cr-spinel and silicate melts, and investigated the role of Cr-spinel fractional crystallisation on the PGE geochemistry of primitive magmas during the early stages of fractional crystallisation.

The extent to which water and halogens in Earth's mantle have primordial origins, or are dominated by seawater-derived components introduced by subduction was explored in our study, published in *Nature Geoscience* (Kendrick et al.).

In the study published in *Geology* (Prokofiev et al.) we report for the first time fortuitously preserved, large-sized fluid inclusions in chalcedony in the basalts belonging to the Siberian large igneous province. We propose that the colloidal nature of fluids forming chalcedony lends strong support to the natural existence of experimentally predicted 'silicothermal fluids'.

## OLYMPIC DAM

**Leader:** Vadim Kamenetsky

### Team members:

Maya Kamenetsky, Jocelyn McPhie, Sebastien Meffre, Jay Thompson

### Students:

Alex Cherry, Matt Ferguson, Qiuyue Huang

### Collaborators:

Andrea Agangi, Cristiana Ciobanu, Nigel Cook, Ken Cross, Kathy Ehrig, Karsten Goemann, Roland Maas

This project is building on existing knowledge related to economic geology at Olympic Dam through a combination of petrological, geochemical and geochronological research initiatives.

One of the main outputs in 2017 was the publication of an article in *Precambrian Research* (Cherry et al.). The study of a quartz sandstone facies in the Olympic Dam Breccia Complex

BELOW: PhD student Jodi Fox (left) leads a post-Chapman Conference field trip to Cape Grim in northwest Tasmania in early 2017.





demonstrated significant differences to the other bedded clastic facies that have been described in our previous publications (e.g. different mineralogy, detrital zircon age populations). Similarity of the quartz sandstone facies in Olympic Dam with those from the Cariewerloo Basin demonstrate that the latter once overlay the Olympic Dam Breccia Complex. We also discussed potential implications of tectonic longevity and modification (or even upgrading) of the orebody at Olympic Dam.

Another publication in *Precambrian Research* by our group (Huang et al.) demonstrates effects of multiple hydrothermal events on mafic lithologies at the Olympic Dam deposit. Two groups of such lithologies, namely olivine-phyric lava and dykes belonging to the ca. 1590 Ma Gawler Range Volcanics and dolerite dykes affiliated with the ca. 820 Ma Gairdner Dyke Swarm, occur within and adjacent to the Olympic Dam Breccia Complex, the immediate host to the deposit.

Our discovery of the earliest magnetite-fluorapatite mineralisation in the deepest diamond drill hole to date (RD2773, end at ~2,329 m) at the Olympic Dam deposit was published in *Economic Geology* (Apukhtina et al.). U-Pb ages for hydrothermal uraninite ( $1593.5 \pm 5.1$  Ma), fluorapatite ( $1583.3 \pm 6.5$  Ma), and hematite ( $1592 \pm 15$  Ma) indicate that deposition of the U-REE-rich hydrothermal magnetite-fluorapatite-pyrite-quartz assemblage and replacement of magnetite by hematite occurred soon after emplacement of the granitic host rocks. The deep ~1.59 Ga magnetite-fluorapatite-pyrite-quartz assemblage at Olympic Dam resembles those characteristic of iron oxide-apatite deposits and many other sensu stricto IOCG deposits.

## BONINITE PETROGENESIS: HUNTER RIDGE, SW PACIFIC

**Leader:** Leonid Danyushevsky

**Team member:** Trevor Falloon

**Student:** Evan Draayers

**Collaborators:** Karsten Goemann, Roland Maas

Evan Draayers continued work on his PhD research project, aimed primarily at providing new insights into the petrogenesis of high-Ca boninite and related lavas from the Hunter Ridge, SW Pacific, largely through detailed investigation of phenocryst mineralogy and host-rock 'groundmass' geochemistry.

Evan was able to calibrate and use a relatively novel method for derivation of bulk compositional data for entire phenocryst populations (namely olivine and orthopyroxene) by combining BSE-mosaic imagery with EPMA and LA-ICP-MS data. Late 2017 saw the return of radiogenic isotope data for 12 samples (submitted for analysis in 2016), an invaluable tool for modelling of mantle components involved in magma genesis. Throughout 2017, Evan achieved comprehensive characterisation of geochemistry and mineralogy for most of his 24 chosen representative samples, allowing him to begin working on the various geochemical modelling techniques required to build an internally consistent petrogenetic model for the Hunter Ridge boninites and related rocks in early 2018.

## MAGMA PETROGENESIS

**Leaders:** Trevor Falloon, David Green

**Team members:** Leonid Danyushevsky, Paul Davidson, Vadim Kamenetsky

**Collaborators:** Sandrin Feig, Roland Maas

Trevor Falloon and David Green continued the application of experimental high pressure, high temperature studies of lherzolite compositions to two fundamental questions:

- The thin plate behaviour ('Plate Tectonics') of the Earth's lithosphere as a consequence of the intersection of local geotherm and the appropriate lherzolite solidus (sensitively dependent on content of H and C and oxidation state, i.e., lherzolite + C, H, O).
- Demonstration that a lherzolitic composition for the upper mantle is able to provide an extraordinary range of parental magmas from high-SiO<sub>2</sub> boninites through olivine-rich picrites to alkali-rich, low SiO<sub>2</sub> ankaramites, olivine melilitites and sodic-dolomitic carbonatites. By controlled experiments (P, T, compositional variation of C, H, S, O) on parental magmas, they can be assigned to specific locations in the 'Plate Tectonic' cycle. Results from this strategic research underpin interpretations of specific magmatism in the geological record.

## VHMS RESEARCH – MODERN

**Leader:** Bruce Gemmell

**Team members:** Rebecca Carey, Martin Jutzeler, Sebastien Meffre

**Student:** Heidi Berkenbosch

**Collaborators:** Fabio Caratori-Tontini, Cornel de Ronde, Mark Hannington, Andrew McNeill, Adam Soule

Submarine volcanic arcs provide at least 10% of volatile gas discharge globally, and coupled with physiochemical factors produce a huge diversity in mineral type. Arcs therefore provide many modern analogues to ancient volcanogenic sulfide deposits.

Heidi Berkenbosch's PhD project at Brothers volcano, in the Tonga Kermadec arc, was accepted and she graduated in 2017. This collaborative project with GNS Science, New Zealand (Cornel de Ronde), is investigating the ore and gangue mineralogy, textures, paragenesis, mineral chemistry and copper isotopes of the sulfide-sulfate chimneys. A paper detailing the trace element mapping, using synchrotron radiation XRF and LA-ICP-MS of Cu- and Zn-rich black smoker chimneys from the volcano, has been accepted and will be published in *Economic Geology*.



## VHMS RESEARCH – ANCIENT

**Leader:** Bruce Gemmell

**Team members:** Ron Berry, Rebecca Carey, Garry Davidson, Ross Large, Jocelyn McPhie, Sebastien Meffre, Martin Jutzeler, Khin Zaw

**Students:** Brian McNulty, Nathan Steeves

**Collaborators:** Mohd Basril Iswadi Bin Basori, Mark Hannington, Andrew McNeill, Jim Mortensen, Fardin Mousivand, Mike Vicary

The genesis of volcanic-hosted CuPb-Zn-Ag-Au massive sulfide deposits is being investigated across the spectrum of massive sulfide deposit types, from typical seafloor VHMS (ZnPb-Cu-Ag-Au) deposits, through sub-seafloor shallow-water, replacement gold-rich epithermal styles, to deep sub-volcanic intrusion-related Cu-Au-rich styles.

In 2017, research was undertaken on deposits in the Mount Read Volcanic Belt (Tasmania), DeGrussa (Western Australia), Greens Creek (Alaska), Myra Falls (Canada), Tasik Chini (Malaysia), Nuddeh (Iran) and Macquarie Island.

In collaboration with Mark Hannington from the University of Ottawa, Nathan Steeves continued his PhD investigation of the mineralogy, metal distribution and geometallurgical characteristics of the complex ore bodies at the Greens Creek VHMS deposit in Southeast Alaska. Based in new age dates, a revised interpretation of the chronostratigraphy places Late Triassic volcanic rocks at a similar stratigraphic horizon to massive sulfide. A new genetic model has been proposed that will significantly aid in the exploration for more deposits in the Greens Creek district.

Brian McNulty continued his PhD research on the geologic and structural setting of the West Block area at the Myra Falls VHMS deposit on Vancouver Island, Canada. He has obtained new age dates on the host rocks at Myra Falls that have determined the timing of host rock emplacement and mineralisation and compared these ages to other

VHMS deposits across Vancouver Island. He has written a paper on the lithological discrimination of altered volcanic rocks based on systematic portable X-ray fluorescence analysis of drill core at the Myra Falls; this paper has been accepted and will be published in the *Journal of Exploration Geochemistry* in 2018 (see also Program 1).

Margy Hawke completed her thesis on the DeGrussa VHMS deposit and graduated in 2017. Her research covered the geological evolution of the DeGrussa volcanic-hosted massive sulfide deposit and the Eastern Capricorn Orogen, Western Australia. Her results have significantly assisted in constraining stratigraphy and mineralising events of the Paleoproterozoic Yerrida, Bryah and Padbury Groups and their associations with regional orogenic events. Identification of prospective time periods and stratigraphy associated with major mineralising events will assist in exploration for significant gold and base metal mineralisation in the Capricorn Orogen.

VHMS research in SE Asia, particularly in Myanmar, continued in 2017. Ongoing studies demonstrate that the formation and location of the Myanmar deposits were related to rifting on the northern margin of Gondwana during the Cambro-Ordovician. Results have been published in *Geological Society London Memoirs*, *Island Arc Journal* and *Turkish Journal of Earth Sciences* (see also Program 1).

A project aimed at improving the age and geochronological constraints on the development of the Mount Read Volcanic Belt (MRV) continued during the year, in collaboration with Jim Mortensen (UBC), and Andrew McNeill and Mike Vicary (both from MRT). Outcomes to date include the U-Pb dating of zircons, which produced many new dates that have helped to constrain the timing of the development of the MRV and associated VHMS mineralisation. A second phase of age dating throughout the MRV has been completed and results are being compiled for inclusion in a paper to be submitted to *Economic Geology*.

## LOOKING FORWARD

In 2018 we are looking forward to the submission of nine PhD student theses in Program 4: Jodi Fox, Daniele Vergani, Sam Holt, Nathan Steeves, David Douth, Alex Cherry, Naomi Potter, Matt Ferguson and Bryan McNulty. We wish them the best as they wrap up their PhD studies.

In tandem with so many PhD submissions are student first-author publications to international peer-reviewed journals. A quick count reveals at least 13 papers to be published in 2018 – an amazing success within Program 4. Rebecca Carey will also publish a paper in *Science Advances* in January 2018, together with colleagues Jocelyn McPhie, Martin Jutzeler and PhD student Fumihiko Ikegami.

Dr Adam Soule, Chief Scientist of Deep Submergence for the National Deep Submergence Facility at Woods Hole Oceanographic Institution, will visit Rebecca Carey and IMAS colleagues for three weeks to prepare ARC Linkage and US National Science Foundation proposals.

Jocelyn will be the guest of the Universidad Nacional del Sur in Bahia Blanca, Argentina, for a course and field trip in December. She is also leading a field trip in the Gawler Range Volcanics for the Australian Geoscience Council Convention in Adelaide in October.

## OBJECTIVES

Analytical research underpins much of our most innovative research across the fundamental to applied spectrum.

New developments in analytical research generated by CODES Analytical Laboratories provide the basis for CODES' global leadership in micro-analytical techniques specifically applied to mineral exploration, U/Pb geochronology, mineral processing, ore genesis, igneous geochemistry and volcanology, and waste management.

CODES Analytical Laboratories also provide analytical services to government, academia and industry.





## INTRODUCTION

### Program 5: Analytical research

explores and develops novel analytical and data interpretation techniques based on the latest technological and algorithmic developments, such as a number of high spatial resolution microprobes and advanced data-reduction algorithms. This helps in the understanding, exploration and exploitation of deep Earth resources.

Current research projects focus predominantly on expanding the capabilities of laser ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS) for geological applications, analytical data reduction, and the development of new, user-friendly software packages. In 2017, a significant proportion of research activities were focussed on projects that underpin the research occurring within the ARC TMVC Research Hub.

The analytical projects using LA-ICP-MS include in-situ multi-element analysis and imaging of element distribution within minerals; in-situ isotope analysis, focussing on a range of U-Pb dating applications and Pb isotope measurements;

development of calibration standards; and technological developments aimed at improving the capabilities of the laser microprobes.

Many of the projects involve close collaborations with national and international research groups and equipment manufacturers.

## HIGHLIGHTS

### RESEARCH

- Research into understanding the impact of non-robust plasma condition has led to a new approach for assessing the internal consistency between published values for reference materials.
- CODES Analytical Laboratories played a key role in developing a new olivine reference material. A publication describing the new reference material has been submitted.

### EQUIPMENT

New developments in the fast-response LA-ICP-MS set-up led to building the first prototype of a low-dispersion ablation cell, aimed at increasing spatial resolution of LA-ICP-MS.

### SOFTWARE

Software initiatives included new data reduction software for LA-ICP-MS, developed in collaboration with Norris Software, which has been installed for use by CODES staff and students.

### STAFF

The team was sad to see the departure of Sean Johnson. Sean completed his PhD at UTAS in 2016, and worked as a Research Fellow in LA-ICP-MS.

### CONFERENCES

Team members were involved in a number of major conferences and workshops in 2017, including AGU Fall Meeting (USA), Goldschmidt (France), North American Workshop on Laser Ablation (USA), and the Exploration'17 Conference (Canada). In total, team members produced over 20 conference abstracts.

An invited presentation at the Laser Ablation Workshop has described the latest development in the geological application of the laser-ablation Time-of-Flight mass-spectrometry.

*OPPOSITE PAGE: Lapidary technician Michele Chapple-Smith preparing thin sections in the Lapidary Lab.*

*BELOW: Program 5 team members pictured at the start of a regular weekly lab meeting; L-R: Jay Thompson, Ivan Belousov, Sasha Stepanov, Leonid Danyushevsky (seated), Paul Olin (standing), Elena Lounejeva and Claire Rutherford.*





## The program team

**LEADER** LEONID DANYUSHEVSKY

**DEPUTY LEADER** SEBASTIEN MEFFRE

### TEAM MEMBERS:

Ivan Belousov, Sean Johnson, Elena Lounejeva, Paul Olin, Sasha Stepanov, Jay Thompson

### PHD STUDENTS:

Nathan Chapman, Jay Thompson

### COLLABORATORS:

#### AGILENT TECHNOLOGIES

Fred Fryer

#### IOWA STATE UNIVERSITY, USA

Sam Houk

#### LAURIN TECHNIC

Michael Shelley

#### MOSCOW STATE UNIVERSITY

Pavel Plechov

#### NORRIS SOFTWARE

Ashley Norris

#### TOFWERK

Olga Borovinskaya, Michael Cubison, Martin Tanner

#### UNIVERSITÉ GRENOBLE ALPES, FRANCE

Valentina Batanova, Alexander Sobolev

#### UNIVERSITY OF BRISTOL, UK

Jon Blundy

#### UNIVERSITY OF MELBOURNE

Roland Maas

#### UNIVERSITY OF TASMANIA

Karsten Goemann





# Projects

## Fundamentals of ICP-MS

## Fundamentals of laser ablation

## Calibration standards for LA-ICP-MS

## LA-ICP-MS instrumentation development

## U-Pb dating

## LA-ICP-MS data reduction software

## PROJECT SUMMARIES

### FUNDAMENTALS OF ICP-MS

**Leaders:** Leonid Danyushevsky, Jay Thompson

**Team members:** Ivan Belousov, Paul Olin

**Collaborators:** Olga Borovinskaya, Fred Fryer, Sam Houk, Martin Tanner

This project is aimed at better understanding the physical processes that occur in ICP-MS, in order to improve its performance and the range of applications for laser ablation.

The main focus in 2017 was on understanding robust plasma conditions and developing applications for assessing the internal consistency between the accepted compositions of international standard reference materials. Development of applications for the new Time-of-Flight (TOF) ICP-MS continued in collaboration with the manufacturer,

TOFWERK, to improve on the data acquisition and processing protocols for routine analysis for geological samples.

A manuscript covering an investigation on ion energies in the ICP with different sample introduction systems at the final stages of preparation and is in the final stages. The results highlight the fundamental differences between aerosol characteristics between laser ablation and solution sample introduction.

### FUNDAMENTALS OF LASER ABLATION

**Leader:** Leonid Danyushevsky

**Team members:** Sean Johnson, Sebastien Meffre, Paul Olin, Jay Thompson

**Collaborator:** Michael Shelley

This project aims to gain a better understanding of laser ablation processes, leading to improved analysis of geological materials, especially sulfide.

In 2017, research continued within the project jointly funded with Laurin Technic, focussed on

the characterisation of ablation processes in silicate minerals. Key research activities focussed on:

- Obtaining a detailed understanding of the importance of the optical design of laser microprobes on the ablation processes of a range of sulfide minerals. A manuscript covering the results is in preparation.
- Developing detailed characterisation of ablation depth as a function of laser beam energy and pulse width.

### CALIBRATION STANDARDS FOR LA-ICP-MS

**Leaders:** Ivan Belousov, Leonid Danyushevsky

**Team members:** Paul Olin, Jay Thompson

**Collaborators:** Valentina Batanova, Jon Blundy, Karsten Goemann, Pavel Plechov, Alex Sobolev

This project is aimed at the development and characterisation of new calibration reference materials for LA-ICP-MS analysis of various geological materials.

Calibration standard STDGL3 for sulfide analysis has been distributed to several analytical laboratories, including facilities located in Asia, Europe and the USA. A manuscript describing this new reference material is in preparation.

The compositions of an olivine reference material have been finalised as part of an international collaboration involving six laboratories in Australia, the USA, Europe and Japan. A manuscript will be submitted for publication in 2018.

A collaboration continues with the University of Bristol and Moscow State University on the characterisation of plagioclase reference material.

## LA-ICP-MS INSTRUMENTATION DEVELOPMENT

**Leader:** Leonid Danyushevsky

**Team members:** Paul Olin, Jay Thompson

**Collaborators:** Olga Borovinskaya, Michael Cubison, Michael Shelley, Martin Tanner

This project tests, designs and develops new instrumentation to ensure continuing advances in geological LA-ICP-MS applications. Example developments include ablation cells, the interface between the laser and the mass-spectrometer, and testing new types of laser microprobes and mass-spectrometers.

In 2017, activities formed part of the technological developments within the TMVC Research Hub. The main focus was on developing operating conditions for ICP-TOFMS and modifications to the ablation cell designs.

## U-PB DATING

**Leader:** Jay Thompson

**Team members:** Leonid Danyushevsky, Sebastien Meffre

**Collaborator:** Roland Maas

This project investigates the causes of limitations to U-PB dating of minerals by LA-ICP-MS, with the aim of enhancing laboratory practices and instrumentation parameters to lower systematic errors and improve precision. Zircon is the primary mineral investigated; however, ongoing investigations for apatite, uraninite and monazite are currently underway.

This year the main focus was on understanding the effects of various analytical parameters on the accuracy and precision of U-PB dating of zircon. A paper summarising the outcomes will be published in the *Journal of Analytical Atomic Spectrometry* early in 2018.

## LA-ICP-MS DATA REDUCTION SOFTWARE

**Leader:** Leonid Danyushevsky

**Team members:** Sebastien Meffre, Sasha Stepanov, Jay Thompson

**Collaborator:** Ashley Norris

This project aims to develop comprehensive, user-friendly LA-ICP-MS data processing software, capable of:

- Quantification of data acquired using multiple calibration standards and a range of internal standard elements.
- Quantification of images depicting distribution of major and trace element concentrations in fine-grained multi-mineral aggregates of sulfides, silicates, phosphates and carbonates.
- Identification of mineral phases in, and sizes of, micro inclusions in minerals.

Activities in 2017 were directed towards developing the first public release of the software, which will include U-Pb dating calculations, analysis of isotopic compositions and interference corrections.

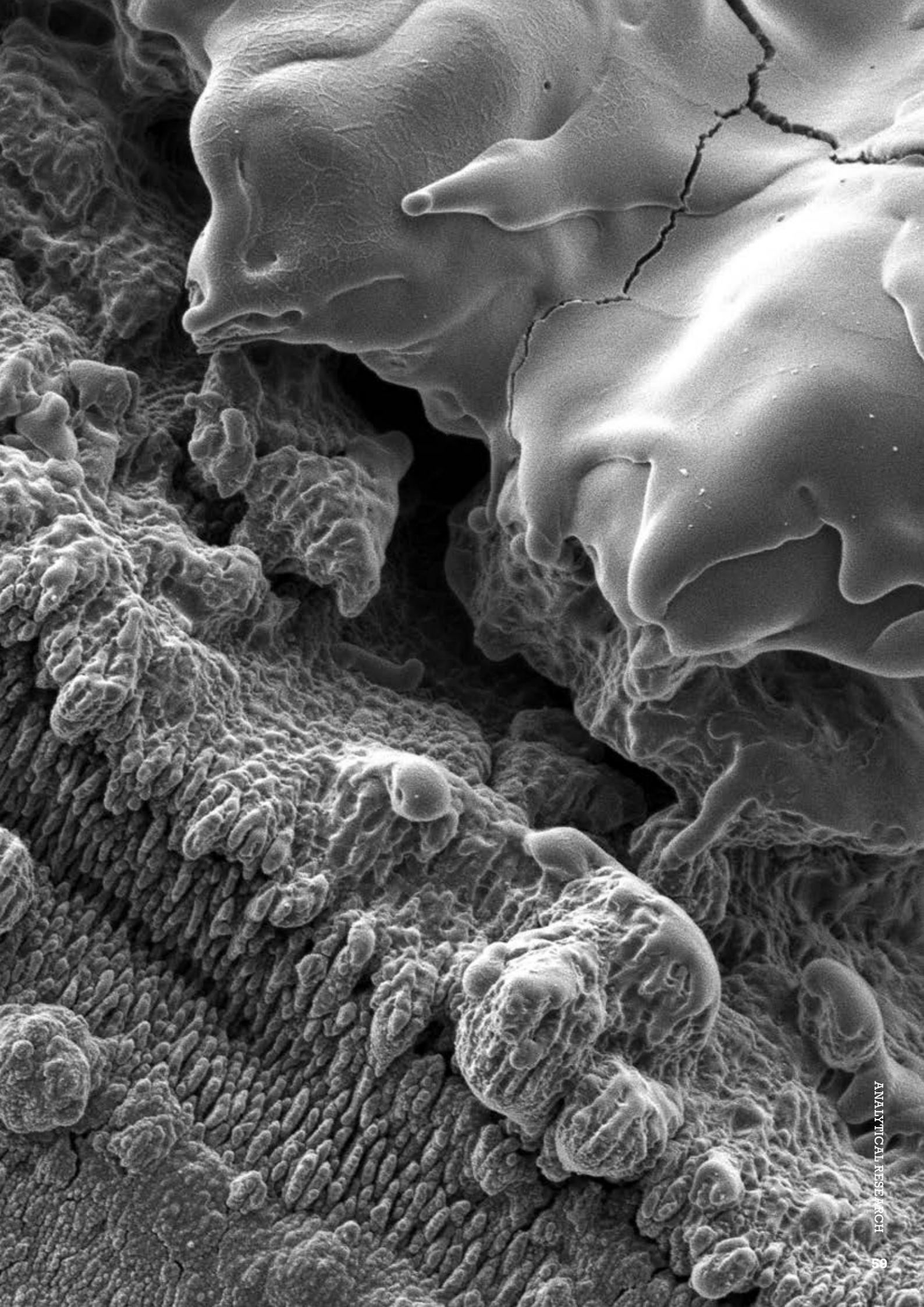
## LOOKING FORWARD

The team will further develop its analytical research in 2018, working in close collaboration with the TMVC Research Hub. Developments are expected to include:

- Researchers building on their early work using the new ICP-TOFMS instrument, which enables advance quantification of micro-inclusions in minerals.
- Collaboration with the University of Bristol and Moscow State University on the characterisation of plagioclase reference material continuing as part of a new PhD project.
- Continuation of work into establishing correction factors for pressed pellets of finely ground sulfide mixes in Collaboration with the Canadian Geological Survey and the University of Kiel.

OPPOSITE PAGE: Ejecta on sample surface of chalcopyrite around the ablation crater, seen at x6,000 magnification.





## OBJECTIVE

This program establishes geophysical and geological data acquisition, processing and interpretation as core components of CODES' research and training activities. Program 6 aims to meet the challenges associated with technological advances in automated data acquisition and imaging methods across the geosciences. It addresses issues associated with managing, processing, visualising and interpreting Big Data in the minerals industry at all stages from exploration to mining and mineral processing to waste management.







## INTRODUCTION

### **Program 6 Geophysics and computational geosciences**

focusses on the applications of new methods for data analysis, data integration, data-driven decision making, and novel visualisation techniques. It includes a diverse range of projects that focus on three-dimensional geophysical interpretation, seismic array studies, geodata analytics, data visualisation, exploration targeting and geoscience education.

Modern minerals industry activities are increasingly undertaken in highly data-rich environments characterised by a wide range of quantitative and qualitative information. There have been significant recent advances in areas such as geophysical data acquisition, geophysical data processing and inversion, multi-element geochemical analyses, and a range of new optical and infrared imaging techniques. The challenge is to be able to effectively integrate all of these diverse data streams using new methods and workflows that can effectively transform data into information and knowledge. The ultimate aim of this data synthesis process is to facilitate more informed decision making at all stages in the mineral exploration, extraction and processing sequence.

*OPPOSITE PAGE: (Top) Honours student Thomas Schaap dragging a Ground-Penetrating Radar (GPR) unit across the surface of Sørsdal Glacier, attempting to detect pools of liquid water trapped in the ice beneath, which might provide insight into the glacier's response to temperature. (Bottom) PhD student Thomas Ostensen braves the cold while deploying a magnetotelluric instrument at Strathgordon, western Tasmania. BELOW: The calving front of Sørsdal Glacier, East Antarctica, where the East Antarctic Ice Sheet meets the Southern Ocean. Honours student Thomas Schaap carried out research on the glacier during 2017.*

## HIGHLIGHTS

From a geophysical perspective, 2017 highlights for Program 6 include:

- the development of innovative new methods for analysis of passive seismic array data developed by Martin Gal in his studies of the ambient seismic wavefield
- generation of new geologically-constrained geophysical models for western and northwestern Tasmania by Esmaeil Eshaghi in his PhD study
- collection of new palaeomagnetic data by Kathryn Job that may provide support for the proposed oroclinal model for Palaeozoic tectonics in Tasmania.

In the field of computational science and data visualisation, the major achievements of 2107 were:

- the development of the AusGeol Virtual Library of Australia's Geology with associated software and educational resources
- testing of novel methods for handling geoscience data with contrasting scales and spatial supports (geometries)
- successful application of unsupervised machine learning algorithms for regional- and local-scale mapping and prospectivity modelling.





## The program team

**LEADER** MICHAEL ROACH

**DEPUTY LEADER** MATTHEW CRACKNELL

### TEAM MEMBERS:

Martin Gal, Anya Reading

### PHD STUDENTS:

Esmail Eshaghi, Martin Gal, Shawn Hood, Stephen Kuhn, Stephen Meyer, Peter Morse, Thomas Ostensen, Tobias Staal (IMAS)

### HONOURS STUDENTS:

Matt Bodini, Jonathon Donaghy, Stewart Jackson, Kathryn Job, Thomas Schaap

### COLLABORATORS:

**AUSTRALIAN NATIONAL UNIVERSITY**  
Stephen Cox

**CSIRO OCEANS AND ATMOSPHERE FLAGSHIP**  
Mark Hemer

**FIRST QUANTUM MINERALS**  
Tim Ireland, Chris Wijns

**GEOLOGICAL SURVEY OF NEW SOUTH WALES**  
Bob Musgrave

**GEOLOGICAL SURVEY OF SOUTH AUSTRALIA**  
Kate Robertson, Stephan Thiel

**GEOSCIENCE AUSTRALIA**  
Patrice de Caritat

**GHD**  
Hugh Tassell

**INSTITUTE OF MINE SEISMOLOGY**  
Gerrit Olivier, Brian Salmon

**MINERAL RESOURCES TASMANIA**  
Mark Duffett

**UNIVERSITY OF BRITISH COLUMBIA, CANADA**  
Christian Schoof

**UNIVERSITY OF CANBERRA**  
Alie Cowood, Leah Moore

**UNIVERSITY OF MELBOURNE**  
Sandra McLaren

**UNIVERSITY OF QUEENSLAND**  
Charles Verdel, Kevin Welsh

**UNIVERSITY OF SWANSEA, WALES**  
Brend Kulesa

**UNIVERSITY OF TASMANIA**  
Sue Cook, Ben Galton Fenzi, Christopher Lueg, Leo Peters

**UNIVERSITY OF UTAH, USA**  
Keith Koper

**UNIVERSITY OF WESTERN AUSTRALIA**  
Annette George



# Projects

Geophysical investigations of Tasmania at multiple scales

Integrating geology and geophysics for resources targeting

Geodata analytics, visualisation and decisions

Seismic array investigations of ocean storms

AusGeol Virtual Library of Australia's Geology

Magnetotelluric imagery of the Earth's crust and mantle

Geophysical investigations on the Sorsdal Glacier, Antarctica

Generation of geological logs from 3D virtual models

Elastic modelling of seismic wave propagation in mine environments

Palaeomagnetic analysis of the Palaeozoic orocline model for Tasmania

Assessment of rock strength from petrophysical and mineralogical data

of Applied Ecology, this project has developed methods for the meaningful integration of geoscience data for regional resource targeting and management. The focus of this project has been the investigation of approaches for appropriate handling of geoscience data with different scales and spatial supports (geometries). This has ultimately contributed to the development of novel pre-processing methods that facilitate bringing data together, and unique visualisation and analysis methods that aid the interpretation of resulting models.

In 2017, unsupervised clustering algorithms were combined with robust geochemical data processing and extraction of multi-scale textural indices from geophysical imagery to highlight similarities between catchments in northern Australia. The geochemical and geophysical characteristics of the resulting catchment clusters were analysed in conjunction with gold deposit occurrence data and geological and geographic information. These results highlighted the importance of considering river system networks and sediment provenance when assessing regional-scale prospectivity models. The outcomes of this research culminated in the identification of several catchments highly prospective for gold mineralisation that will feed into pre-competitive geoscience data products delivered by Geoscience Australia.

In conjunction with researchers from the University of Canberra this project has investigated the use of unsupervised clustering for local- and regional-scale mapping applications. The automated construction of landscape 'units' based on a range of data representing geographical, geological and biological features was evaluated in conjunction with expert interpretations of landscape characteristics using the Hydrogeological Landscape (HGL) Framework. The successful outcomes of this research have led to the planned roll-out of automated

## PROJECT SUMMARIES

### GEOPHYSICAL INVESTIGATIONS OF TASMANIA AT MULTIPLE SCALES

**Leader:** Anya Reading

**Team member:** Michael Roach

**Student:** Esmaeil Eshaghi

**Collaborator:** Mark Duffett

2017 saw the graduation of PhD candidate Esmaeil Eshaghi, who carried out a project – 'Geophysical investigations of Tasmania at multiple scales' – that used petrophysical measurements to improve our understanding of the upper crustal architecture of north and northwest Tasmania.

Esmaeil was supervised by Anya Reading and Michael Roach with Mark Duffett, from Mineral Resources Tasmania, as research advisor. The better constrained rock properties, such as density and magnetic susceptibility, enabled the 3D geometry of granite bodies, potentially associated with mineralisation, to be investigated and refined.

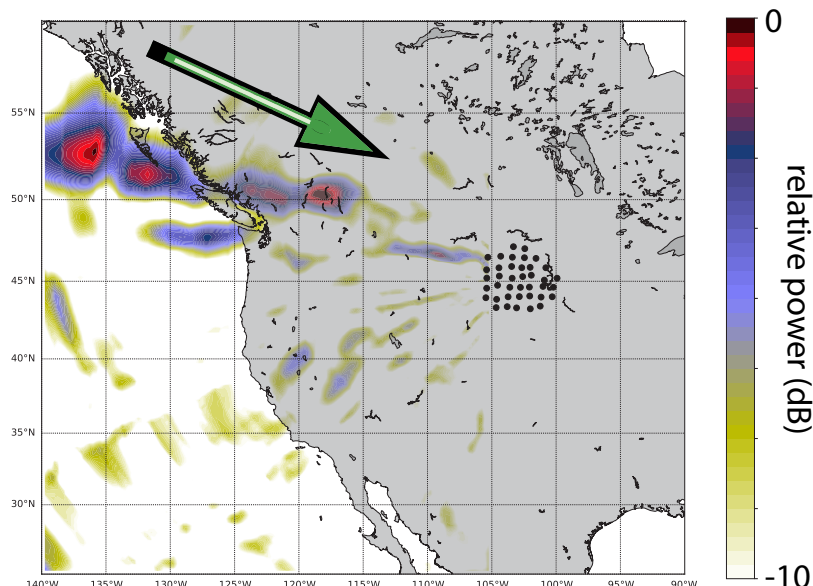
### INTEGRATING GEOLOGY AND GEOPHYSICS FOR RESOURCES TARGETING

**Leader:** Matthew Cracknell

**Team member:** Anya Reading

**Collaborators:** Patrice de Caritat, Alie Cowood, Leah Moore

In collaboration with Geoscience Australia's Minerals Division and the University of Canberra's Institute



*ABOVE: PhD student Martin Gal has been developing innovative new methods for the analysis of passive seismic array data. Shown is an example snapshot (2010) of ocean-generated seismic energy by a part of the Transportable USArray in the USA. The black dots are seismic stations used for the array analysis and the green arrow displays the propagation direction of the seismic energy towards the array. The contour map displays the normalised strength of the incoming ocean-generated seismic energy and displays the underlying pulse structure. The pulse structure emerges due to the superposition principle given that microseisms are excited in an extended area in the oceanic environment.*

HGL mapping in several regions across New South Wales. While these computer-assisted mapping methods were specifically developed for defining land management zones the learnings gained from this project have implications for geologically focussed mapping projects.

### GEODATA ANALYTICS, VISUALISATION AND DECISIONS

**Leader:** Anya Reading

**Student:** Peter Morse

**Collaborator:** Christopher Lueg

This project expands the scope of research undertaken within CODES and the Discipline of Earth Sciences into geodata analytics and innovative visualisation strategies. During 2017, PhD student Peter Morse continued computational work making progress on an app for interactive volumetric visualisation of 3D contoured datasets in geoscience.

The flexible nature of the computer application allows colours to be selected with insight into the confidence limits of the data being visualised. This results in a reduction in the number of distracting artefacts in the image seen on the screen and

a better capacity to see features that were previously not visible in plan or cross-section slices.

### SEISMIC ARRAY INVESTIGATIONS OF OCEAN STORMS

**Leader:** Anya Reading

**Student:** Martin Gal

**Collaborators:** Mark Hemer, Keith Koper

Ocean storms have long been known to generate seismic signals (microseisms) that are present even in areas where earthquakes rarely occur. When observed on a seismogram, the ocean storm signal is visible as a continuous oscillation of the solid Earth, and techniques that average over time are usually applied to extract information about the nature of the signals. We have developed a seismic array technique that does not require averaging over time and hence allows us to view the seismic wavefield as an instantaneous snapshot similar to a photograph.

When applied to the seismic wavefield, our method allows us to study the underlying nature of the ocean-generated seismic wavefield

in unprecedented detail, and we find that seismic energy reaches the array in pulses rather than a continuous stream. We found that this was a direct result of the spatial extended generation region of microseisms, where the resulting wavefield forms pulses due to the superposition principle. The pulse-like nature can be used to retrieve relative travel times which yield information on the Earth's structure. Computational work for this research was done in 2017 under ARC DP150101005. This grant was used specifically to assess the changes in wave climate and risk management to coastal communities, and will terminate in 2018.

### AUSGEOL VIRTUAL LIBRARY OF AUSTRALIA'S GEOLOGY

**Leader:** Michael Roach

**Collaborators:** Stephen Cox, Annette George, Sandra McLaren, Charles Verdel, Kevin Welsh

The AusGeol Virtual Library of Australia's Geology is the product of a two-year project (2015–2017) funded by the Australian Government Office for Learning and Teaching (which is no longer in operation) and a consortium of universities and government geoscience agencies. This virtual library provides free online access to visualisations from over 3,500 sites across the continent and to accompanying educational resources. Its well-documented examples of important geological features are designed to assist in the development of student geological field skills. The project has largely been driven by Dr Michael Roach from Earth Sciences, together with a team of collaborators from the Australian National University, University of Melbourne, University of Queensland and University of Western Australia.

Although fieldwork is a cornerstone of geological education and nothing can fully replace the experience of holding and manipulating an object or the insight gained by exploring, touching and documenting a field site, it is not possible to expose



students to a fully comprehensive range of field experiences.

AusGeol delivers a range of visualisations including:

- photo-realistic 3D models derived from both terrestrial and UAV photography
- full-spherical panoramas and
- 'deep zoom' imagery.

Visualisations – which include photographs and descriptions – of significant localities are integrated to generate virtual tours of each particular geological feature. All visualisations are accompanied by comprehensive metadata that facilitate display and retrieval of features that meet specific keyword, stratigraphic or lithological queries. These visualisations are delivered by the AusGeol web portal ([www.AusGeol.org](http://www.AusGeol.org)) through an interactive map interface (Atlas tab) or by tabular selection and display (Sites tab).

Map and GIS data from external web map services can be displayed in the Atlas tab to provide context for the visualisations. 3D and full spherical

panorama data can be visualised within the AusGeol site and all data are available for free download for local viewing or incorporation into other applications. AusGeol provides student activities to accompany the new visualisations and software tools, and activities are available to accredited educators via a secure login.

An important outcome of the AusGeol project has been the development of a new open-access software called GeoVis3D. GeoVis3D allows users to interact with 3D virtual models to undertake annotation, analysis and measurement of virtual outcrops. Facilities are available within GeoVis3D to measure and plot structural data, to annotate models in 3D, and to measure stratigraphic or sedimentological logs.

Funding for the AusGeol initiative finished in April 2017 and an application for additional funding through the Australian Government Citizen Science Grant scheme was unsuccessful. We are keen to continue the development of the

AusGeol resource and are now seeking partner organisations and funding to continue development of the virtual library. We are seeking funding for a three-year project (2018–2021) that will:

- Improve the spatial and thematic coverage of the AusGeol database to include visualisations in large areas of the continent that currently have no data.
- Capture geological visualisations directly relevant to the exploration, minerals and energy industries. The AusGeol library currently has few objects that reflect these activities.
- Establish new mobile facilities suitable for 3D digitisation of samples from geological collections and use these to generate open-access virtual models of significant geological objects that are currently 'hidden' in the archives of museums, universities and government organisations. This would include mineralogical and palaeontological specimens and also selected drill core.

*BELOW: Web portal screenshot from the AusGeol Virtual Library of Australia's Geology, which has been developed by Michael Roach from Earth Sciences/CODES in collaboration with other Australian universities.*



- Develop educational objects, tours and activities that utilise existing and new visualisations. The generation of public outreach, minerals- and energy-related content will be particular objectives.
- Continue development of the GeoVis3D software to increase its functionality and ease of use.

## MAGNETOTELLURIC IMAGERY OF THE EARTH'S CRUST AND MANTLE

**Leader:** Anya Reading

**Student:** Thomas Ostensen

**Team members:** Matthew Cracknell, Michael Roach

**Collaborators:** Mark Duffett, Kate Robertson, Stephan Thiel

The Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) is a national initiative charged with mapping the electrical resistivity structure of the Australian lithosphere. AusLAMP data acquisition took place across

Tasmania in 2016 and was a collaborative effort involving staff and students from UTAS, Geoscience Australia, Mineral Resources Tasmania and the University of Adelaide.

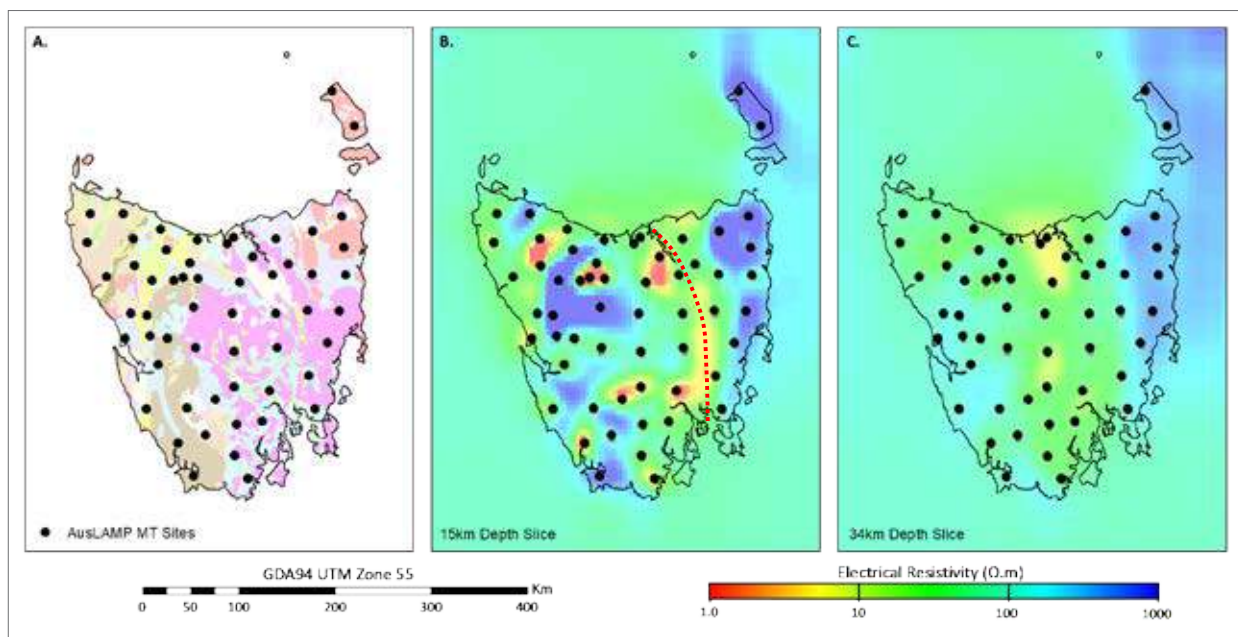
In 2017 the AusLAMP dataset was used to generate Tasmania-wide 3D electrical resistivity models of the subsurface. This extremely computationally intensive process required the use of high-performance computing infrastructure at the University of Adelaide as well as the Tasmanian Partnership for Advanced Computing (TPAC). Modelling is now complete and current efforts are focussed on integrated geophysical interpretations of Tasmania's deep electrical structure.

AusLAMP resistivity models yield insights into the regional-scale resistivity structure for the Tasmanian crust and uppermost lithospheric mantle. The models confirm the presence of the Tamar Conductivity Anomaly as a shallow- to mid-crustal arcuate structure between the Tamar

and Coal River valleys, coincident with the inferred boundary between the uniformly resistive East Tasmania Terrane and the more electrically complex West Tasmania Terrane. In the mid- to upper-crust, highly resistive zones of the model are spatially correlated with areas of voluminous Devonian granite intrusion (Eastern Tasmania, South West Cape and the central west). Areas of anomalously low resistivity at this depth are spatially correlated with outcropping Cambrian metamorphic complexes bounding the Dundas-Fossey Trough.

At uppermost mantle depths Tasmania's electrical resistivity structure splits into two distinct regions; a low resistivity region in the west and a high resistivity region in the east. As electrical resistivity is largely controlled by volatile content at this depth, where greater volatile content reduces resistivity, the relative difference in electrical resistivity is potential evidence for higher degrees of mantle depletion in the East Tasmania Terrane.

*BELOW: Thomas Ostensen's PhD involved work on the Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP). This figure shows Tasmanian AusLAMP dataset and model results in UTM projection. Figure A depicts Tasmanian 1:5M scale surface geology with the distribution of AusLAMP magnetotelluric instrument sites. Figure B presents a 15-km depth slice through 3D resistivity models generated by geophysical inversion AusLAMP data. At this mid-crustal depth, where resistivity is mainly controlled by the presence of pore-space fluids, the base of the upper-crustal Tamar Conductivity Anomaly is evident as an arcuate conductor parallel to the inferred boundary between the East and West Tasmania Terranes (highlighted). High resistivity zones (blue) at this depth are spatially correlated with areas of voluminous Devonian granitoid emplacement. Very low resistivity zones (red) in western Tasmania are spatially correlated with Cambrian upper-greenschist to amphibolite facies metamorphic complexes in Proterozoic rocks of the Rocky Cape and Tyennan regions. At uppermost mantle depths presented in Figure C, resistivity is largely controlled by the presence of hydrogen in nominally anhydrous minerals. Here Tasmania is split into two electrically distinct regions: a low resistivity region in the west and a high resistivity region in the east. This is evidence for a relatively depleted mantle in eastern Tasmania.*







ABOVE: PhD student Matthew Ferguson deploying an MT instrument on Ben Lomond plateau, northeast Tasmania. Matthew was assisting PhD student Tom Ostensen, who is using the data to learn more about Tasmania's crustal structure as part of CODES' Program 6 research.

## GEOPHYSICAL INVESTIGATIONS ON THE SORSDAL GLACIER, ANTARCTICA

**Leader:** Michael Roach

**Student:** Thomas Schaap

**Collaborators:** Sue Cook, Ben Galton Fenzi, Brend Kulesa, Leo Peters, Christian Schoof

This Honours project involved seismic and ground penetrating radar (GPR) investigations on the surface of the Sorsdal Glacier, Antarctica, to investigate ice thickness, the thickness of the underlying ocean water and potential englacial drainage networks. The seismic measurements successfully imaged the base of the floating ice sheet and the underlying water column through up to 1 km of glacial ice and confirmed the position of the glacier grounding line. GPR measurements detected reflective features in the upper 20 m of the glacier that were modelled as either water-filled or air-filled englacial drainage channels. The results of this GPR part of this project are currently being prepared for publication in the *Journal of Glaciology*.

## GENERATION OF GEOLOGICAL LOGS FROM 3D VIRTUAL MODELS

**Leader:** Michael Roach

**Student:** Jonathon Donaghy

In this Honours project Jonathon developed new code to create stratigraphic and sedimentological logs from 3D photo-realistic virtual models derived from terrestrial or UAV photogrammetry. This functionality was incorporated into the GeoVIs3D software that was initially developed as part of the AusGeol Virtual Library of Australia's Geology project. Jonathon's new code utilises a user-defined reference plane in a dipping sequence of rocks to then easily record true thickness estimates for geological intervals by simply clicking on the 3D model. Graphic logs are produced to accompany the model and the position of the mouse cursor on the model is linked to the position on the log. The new software was successfully tested for 3D models of both volcanic and clastic sedimentary strata that were created from UAV data.

## ELASTIC MODELLING OF SEISMIC WAVE PROPAGATION IN MINE ENVIRONMENTS

**Leader:** Martin Gal

**Student:** Stewart Jackson

**Collaborators:** Gerrit Olivier, Brian Salmon

Stewart Jackson's Honours project involved the development and testing of new code to numerically model 3D elastic wave propagation in mine environments. The project was undertaken in collaboration with the Institute of Mine Seismology to facilitate full-waveform inversion of seismic arrivals from mining-induced seismic events. Stewart's code implemented a 4th order implicit finite difference approximation of the elastic wave equation. The code was tested using a detailed 3D physical property model of the Renison Tin Mine in western Tasmania, and successfully simulated the recorded seismograms from local seismic events. A novel and significant aspect of Stewart's new code is the ability to model wavefields resulting from distributed non-point sources that more accurately represent movements on small faults than solutions provided by pre-existing software.

## PALAEOMAGNETIC ANALYSIS OF THE PALAEOZOIC OROCLINE MODEL FOR TASMANIA

**Leader:** Michael Roach

**Student:** Kathryn Job

**Collaborator:** Bob Musgrave

Recent models for the tectonic development of the Tasman Fold Belt postulate oroclinal bending as the mechanism for formation of arcuate geological features in eastern Australia. In Tasmania, rocks of the mid Palaeozoic Dundas-Fossey Trough appear to 'wrap around' the Neoproterozoic Tyennan block and this feature has been interpreted as a possible orocline.

Kathryn's Honours project involved palaeomagnetic analysis of samples collected from Ordovician and Silurian sedimentary strata from around the proposed Dundas-Fossey orocline to test the validity of this model. Palaeomagnetic measurements were supervised by Dr Bob Musgrave (GSNSW) and were conducted in the palaeomagnetic laboratory at the University of Newcastle. Approximately 60% of sites gave credible estimates of the original primary magnetisation direction. Magnetisation vectors are aligned in an approximately north-south orientation in western Tasmania and approximately east-west near Mole Creek in northern Tasmania. Statistical analysis of these data potentially supports the oroclinal bending model but unfortunately samples in critical locations such as the hinge of the proposed fold and on the eastern limb did not provide primary magnetisation estimates. A paper outlining the results of this investigation has been submitted to the *Australian Journal of Earth Sciences*. Additional palaeomagnetic sampling will be undertaken in 2018 to infill Kathryn's sample distribution and hopefully assess the validity of the proposed oroclinal model for Tasmania.

## ASSESSMENT OF ROCK STRENGTH FROM PETROPHYSICAL AND MINERALOGICAL DATA

**Leader:** Michael Roach

**Student:** Matt Bodini

**Collaborator:** Hugh Tassell

This project investigated relationships between rock strength, mineralogical variations and petrophysical data. The aim of this project was to provide better assessment of material properties for engineering investigations and data collection was undertaken in conjunction with engineering consultancy GHD. Petrophysical parameters (density, sonic velocity, magnetic susceptibility, porosity and resistivity) were collected

from drill core using a GeoTek logging system and bench-scale petrophysical equipment. Mineralogy was estimated from hylogger short wave and thermal infrared imaging prior to destructive testing of the drill core using point-load and UCS techniques. Data were acquired for sandstone and dolerite drill core from the Hobart region. Initial analysis suggested that interpreted mineralogy potentially provided good proxies for rock strength but unfortunately this project was not completed as the student withdrew from the Honours program due to illness.

*OPPOSITE PAGE: A magnetotelluric instrument being deployed during the winter at Lake Pedder, western Tasmania, as part of PhD student Thomas Ostensen's research.*

## LOOKING FORWARD

The computational and data science research undertaken in Program 6 in 2017 has laid the groundwork for more widespread application of techniques for turning data into knowledge and useful information. Matthew Cracknell will continue to lead CODES' efforts in the field of data analytics with particular emphasis on unsupervised methods for aggregation, clustering and classification of datasets at a wide range of scales. Matthew's skills and expertise in these fields will be applied in a wide range of projects within Program 6 and in other CODES projects including the ARC TMVC Research Hub. Developments in geological visualisation methods and spatial data analyses, that were pioneered through the AusGeol program, will be further refined with new software for geological virtual reality visualisation in development and the focus of data collection will move from field localities to archival collections, including digitisation of important mineralised specimens.

From a geophysical perspective, there are several potential highlights and new approaches that will be pursued. Tom Ostensen's MT inversions for Tasmania will be finalised in 2018. These 3D electrical models will provide a new view of the intermediate and deep structure of Tasmania that will complement information provided by previous seismic, gravity and magnetic studies. The application of new palaeomagnetic methods that can provide reliable primary magnetisation data by more effective removal of low temperature overprints promises to greatly assist tectonic studies in mineralised terranes in eastern Australia. Both passive and active seismic methods have considerable potential for mining-related applications, and Program 6 will progress the use of these techniques through targeted student projects that investigate the potential for improved tomographic imaging of a range of features from mining stopes to mine tailings dams.







## OBJECTIVES

The Australian Research Council Research Hub for Transforming the Mining Value Chain (TMVC) aims to resolve some of the greatest challenges currently facing the minerals industry, by improving efficiencies along the entire mining value chain. Its principal objectives are to:

- Achieve real-time automated acquisition and interpretation of detailed mineralogical, textural and geochemical data in mine site core sheds that can be used immediately for 3D-modelling of geometallurgical and geoenvironmental parameters and ore zone footprints.
- Move the mining industry from the data-rich, but comparatively knowledge-poor, environment it currently works in, to a data-rich, knowledge-rich environment that allows for rapid decision making during the exploration and development phases of mining operations.
- Develop tools and protocols that allow near-instantaneous identification of proximity to ore zones, together with geometallurgical and geoenvironmental characterisation of ores and waste through automated core logging and spectral analyses of drill core. This will enable 3D exploration, mining and geometallurgy models to be developed that are continually updated as the exploration or resource drilling program continues.



Australian Government  
Australian Research Council





## INTRODUCTION

**The ARC Research Hub for Transforming the Mining Value Chain (TMVC)** encompasses a wide array of activities from exploration, discovery, ore deposit characterisation, and environmental assessment, through to mining, ore processing and waste rock disposal. It sets out to improve efficiencies within this value chain, focussing on areas that will have a marked impact on the value of Australia's mineral resources. By helping to develop more efficient and environmentally sustainable practices throughout the mining value chain, it is anticipated that the TMVC's research outcomes will extend the lives of mines and create employment opportunities across Australia's regional mining centres.

The TMVC provides substantial benefits for the minerals industry through advanced mineral characterisation methods, and innovative technologies for their implementation, which can be applied much earlier in the mining value chain. This enhances decision making and maximises productivity and profitability at Australian mine sites.

The TMVC is housed within CODES at the University of Tasmania (UTAS) – the Administering Organisation. In addition to CODES, the industry partners involved in the research hub include BHP, Corescan, Newcrest Mining, and a consortium of global companies co-ordinated by AMIRA International. Other organisations affiliated with the initiative include Laurin Technic, and RWTH Aachen University in Germany.

## HIGHLIGHTS

With the TMVC now in full swing, the team has focussed on progressing the major sub-projects of the TMVC, as well as developing new initiatives with existing and new industry partners. Activities during the year included the commencement of two PhD students, one each in Theme 2 and 3, and a further two Honours students, again researching in Themes 2 and 3.

Notable achievements during the year included the Best Speaker Award for the Geological Society of Australia's Earth Sciences Student Symposium won by Cassady Harraden, and several keynote and invited presentations and workshops at various conferences around the world across all the Hub themes. The Haddon Forrester King Medal, a career award for life-long achievement presented by the Australian Academy of Science, was awarded to TMVC Director Professor David Cooke.

In Theme 1, the AMIRA P1153 project continued field campaigns at sites in Canada, Chile, Peru and the USA. A highlight of the year was the development of new screening methods for distinguishing porphyry-related alteration minerals from background metamorphic and calc-sodic alteration. Technology transfer continued via meetings at field sites and company head offices with the various stakeholders. 2017 also saw the commencement of a new project in China looking at the genesis of porphyry systems in Inner Mongolia.

Rachel Harrison completed a comprehensive PhD study of the Tumpangpitu porphyry Cu-Au deposit and related high and intermediate sulfidation epithermal mineralisation in SE Java, Indonesia.

This study demonstrated the genetic links between porphyry and epithermal mineralisation and alteration. Rachel's PhD is the first detailed documentation of this newly discovered giant porphyry deposit. As a key member of the discovery team, Rachel provides a first-hand insight into the key aspects that led to the discovery of Tumpangpitu, and highlights how this discovery revealed the exceptional exploration potential of the Sunda-Banda arc, with three giant porphyry Cu-Au deposits (Tumpangpitu, Batu Hijau and Elang) now discovered in this emerging porphyry province.

Angela Escolme dived straight into Theme 2 research initiating a project supported by CSIRO and Mineral Resources Tasmania to investigate hyperspectral signatures of supergene copper minerals, with the goal of linking these to hydrometallurgical response. She is also supervising two new student projects in the Philippines (PhD) and Western Australia (Honours).

In November, the Theme 3 team presented several talks and posters at the 9th Australian Acid and Metalliferous Drainage Workshop in Burnie, as well as contributing to the post-workshop field trip to Western Tasmania. Sarah Gilmour and Anita Parbhakar-Fox also both won external research grants from the AusIMM and ATSE respectively.

It was another productive year for student projects, with the submission of two theses, one PhD and one Honours, with a further two Honours theses to be submitted in early 2018. There was also a healthy output of various other publications, including 11 refereed journal articles, 52 conference presentations and 53 reports to industry.

*OPPOSITE PAGE: (Top) Quartz-tourmaline veins in a granodiorite from the Hadamaio prospect, Inner Mongolia, China; this was photographed during field sampling in 2017. (Bottom) Anita Parbhakar-Fox examining and sampling mine tailings at Aberfoyle, northeast Tasmania.*

*RIGHT: PhD student Cassady Harraden (centre), who won Best Speaker Award for the 2017 Geological Society of Australia's Earth Sciences Student Symposium, flanked by PhD student Matt Ferguson and Sebastien Meffre.*





## The TMVC team

**DIRECTOR** DAVID COOKE

**DEPUTY DIRECTOR** LEONID DANYUSHEVSKY

### TEAM MEMBERS:

#### **CODES**

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Ron Berry, Matthew Cracknell,  
Angela Escolme, Nathan Fox,  
Bruce Gemmell, Wei Hong,  
Ross Large, Sebastien Meffre,  
Paul Olin, Evan Orovan, Anita  
Parbhakar-Fox, Anya Reading,  
Michael Roach, David Selley,  
Sasha Stepanov, Lejun Zhang

#### **ENGINEERING, UTAS**

Danchi Jiang

#### **AMIRA INTERNATIONAL**

Adele Seymon

#### **BHP**

Kathy Ehrig

#### **CORESCAN**

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#### **LAURIN TECHNIC**

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#### **NEWCREST MINING**

Anthony Harris

#### **RWTH AACHEN UNIVERSITY**

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## Projects

The TMVC is focussed on the country's highest earning precious metal, gold; the base metal, copper; and the main energy metal, uranium. Each of these commodities has its own scientific challenges, which the TMVC is tackling through three principal research themes. In addition, Underpinning Technologies, Knowledge Transfer and Training are essential parts of the TMVC, encompassing all research themes. The full scope of research activities gain considerably from the expertise, state-of-the-art facilities and technological developments within the TMVC, and benefits to end-users are assured through extensive, hands-on technology transfer and training programs.

### THEME 1: DETECTING PROXIMITY TO ORE (FOOTPRINTS)

- Applying the explorers' toolbox to discover porphyry and epithermal Cu, Au and Mo deposits (AMIRA P1153)
- Pyrite footprints
- Geochemical and mineralogical vectors to ore, Bilihe-Hadamiao district, Inner Mongolia, China
- The magmatic-hydrothermal transition at Bluestone Bay, eastern Tasmania
- The Tumpangpitu porphyry and high sulfidation epithermal deposit, Indonesia.

### THEME 2: OPTIMISING GEOMETALLURGICAL PREDICTION

- General geometallurgy studies
- Geotechnical and geometallurgical assessment of the Cadia East deposit using Corescan automated core logging technology
- Geological and geometallurgical characterisation of QPG veins, Mankayan District, Philippines

- Geology and geometallurgical characterisation of the high Au, low Cu material at West Dome, Telfer
- Characterising supergene copper mineralogy using hyperspectral techniques

### THEME 3: MINIMISING GEOENVIRONMENTAL RISKS

- Integrated waste classification for best practice AMD prediction
- Development of effective short-term leach tests for water quality prediction
- Mineralogical domaining of low grade and no grade zones using automated drill core logging at Cadia
- Utilising industrial waste materials for AMD control
- Geometallurgy of historic mine waste: Evaluating options for reprocessing
- Determining bioaccessibility risks at the historic Aberfoyle tailings site, North East Tasmania
- Mineralogical and geochemical characterisation of historical slag: Evaluating environmental impacts and economic significance

### UNDERPINNING TECHNOLOGIES

- Development of the fast-throughput sample cell for laser ablation applications
- Corescan data feature extraction and classification for mineralogical and textural information analysis
- Linescan technologies for drill core
- Integrating chemical and mineralogical data layers for element deportment
- Interpreting structural and geochemical patterns using machine learning
- Geological feature discovery from quantitative data integration (algorithm development)

## PROJECT SUMMARIES

### THEME 1 - DETECTING PROXIMITY TO ORE (FOOTPRINTS)

#### APPLYING THE EXPLORERS' TOOLBOX TO DISCOVER PORPHYRY AND EPITHERMAL CU, AU AND MO DEPOSITS (AMIRA P1153)

**Leaders:** David Cooke, Bruce Gemmell

**Team members:** Mike Baker, Ivan Belousov, Matthew Cracknell, Evan Orovan, Lejun Zhang

**Students:** Ayesha Ahmed, Jing Chen, Nic Derome, Liam Fay, Amos Garay, Emily Gorner, Rachel Harrison, Carlos Jimenez, Josh Phillips, Francisco Testa, Jennifer Thompson, Joseph Vrzovski

**Collaborators:** Huayong Chen, Jinsheng Han, Peter Hollings, Shiwei Wang, Noel White, Jamie Wilkinson, Fan Yu, Taofa Zhou

AMIRA P1153 is being conducted in collaboration with researchers from Lakehead University, the Natural History Museum, Guangzhou Institute of Geochemistry, and Hefei University of Technology. It is developing new methods for discovering porphyry and/or epithermal deposits through improved geochemical detection of ore deposit footprints. Analysis of the geochemical signals recorded in hydrothermal alteration halos will provide explorers with methods for assessing district fertility (how large?) and vectoring information (how far, and in what direction?), allowing the presence, location and significance of porphyry and/or epithermal copper, gold and molybdenum deposits in an exploration tenement to be determined during the early stages of exploration. This approach has particular relevance to exploration involving drilling under post-mineralisation cover, or in areas where outcrop is limited or difficult to access.

The main outcomes will be tools for testing the fertility of mineral districts, and for vectoring to mineralised centres. These will involve the use

of key alteration minerals from green rock, white rock and lithocap environments. Cost-effective field-based methods will also be developed that can be applied by explorers who do not have access to suitable laboratory facilities for LA-ICP-MS analyses.

In 2017, the research team continued field campaigns at sites in Canada, Chile, Peru, and the USA, following on from initial fieldwork conducted in 2016. A number of these field sites involved postgraduate students (Honours, MSc and PhD). Ayesha Ahmed, Amos Garay, Josh Phillips and Jennifer Thompson have continued their PhD studies of the Yerington district (USA), Las Bambas (Peru), Resolution (USA), and carbonate mineral chemistry, respectively. Emily Gorner, Joseph Vrzovski and Nic Derome have also continued their MSc studies of the Hemlo and Red Lake gold deposits (Canada), while Liam Fay completed his honours study of Heron Bay (Canada). New screening methods for distinguishing porphyry-related alteration minerals from background metamorphic and calc-sodic alteration were developed through detailed studies of selected sites, and reanalysis of sample suites from previous analyses. New techniques for detecting proximity to mineralisation in lithocaps were refined through an extensive analytical campaign. Technology transfer was facilitated through on-site meetings with industry representatives at head offices and field sites.

José Piquer and Luke Neal published manuscripts, reporting on the outcomes of their postgraduate studies on the structural architecture of the Abanico Basin, central Chile, (Lithos) and spectral characteristics of propylitic alteration minerals (*Journal of Geochemical Exploration*), respectively. David Cooke also published an invited paper on porphyry indicator minerals, vectoring and fertility tools as part of the Exploration 17 Conference. David Cooke gave a keynote presentation at the SEG conference in Beijing, China, in September, and Mike Baker gave an invited presentation at the SGA conference in Quebec City, Canada, in August.

## PYRITE FOOTPRINTS

**Leader:** David Cooke

**Team members:** Leonid Danyushevsky, Anthony Harris, Sebastien Meffre, David Selley, Sasha Stepanov, Lejun Zhang

**Students:** Xue Gao, Bin Lin, Jian Ma, Stephanie Sykora, Xin Xiao, Chao Wu

**Collaborators:** Karyn Gardner, Fiona Karaut, Zhanke Li, Paul Napier

Stephanie Sykora's PhD study of the origin, evolution and significance of anhydrite-bearing vein arrays and breccias, Lienetz orebody, Lihir gold deposit, Papua New Guinea, was completed in 2017. Two manuscripts that summarise key findings of the PhD study were finalised for publication in the *Economic Geology* special issue in early 2018.

Stephanie's research findings provide significant modifications for the genetic model for Lihir, and for our understanding of mechanisms for telescoping epithermal mineralisation onto early-formed porphyry alteration. In previous models, sector collapse was inferred to have led instantaneously to catastrophic explosive brecciation and accompanying epithermal gold mineralisation at Lihir. Through detailed field mapping and a comprehensive structural and paragenetic analysis, Stephanie showed that the porphyry and epithermal systems at Lihir were in fact separated by a period of widespread anhydrite dissolution caused by infiltration of cool groundwaters, facilitating reactivation of low angle faults and contributing to mass wasting of the volcanic edifice, which all occurred prior to the formation of the giant epithermal resource. The identification of anhydrite dissolution, rather than explosive brecciation, as a key process associated with sector collapse is a major revision of the genetic model for Lihir and has profound implications for models of telescoping of porphyry and epithermal systems in similar volcanic terrains.

Stephanie applied the learnings from her detailed structural analysis at the open pit scale to unravel the complex paragenetic relationships of pyrite



at the microscopic scale through a combination of petrographic and LA-ICP-MS techniques. This work provides compelling evidence that porphyry-stage alteration and veins at Lihir produced low-grade gold mineralisation, in the form of refractory gold in early pyrite (up to 0.5 ppm Au in the pyrite cores and in early porphyry-stage veins). This weak porphyry gold mineralisation was followed by, and contrasts markedly with, the formation of epithermal pyrite, which typically contains in excess of 10 ppm refractory Au, and which constitutes the bulk of Lihir's gold resource. Stephanie has demonstrated a complicated history of pyrite dissolution and overgrowths in the evolution from porphyry to epithermal conditions. The resultant composite pyrite grains have only weak porphyry-stage gold mineralisation in their cores, with most of the gold in thin epithermal rinds, somewhat akin to Carlin-style refractory gold. This finding has profound metallurgical implications for mineral processing at Lihir.

Stephanie Sykora graduated during the year.

Additional case studies were conducted during the year with visiting Chinese PhD students Xue Gao (Yidan), Bin Lin (Tiegelongnan), Chao Wu (Halasu), Xin Xiao (Dongguashan) and Jian Ma (Fengtai). Results from several of these studies are expected to be published in 2018.

### **GEOCHEMICAL AND MINERALOGICAL VECTORS TO ORE, BILIHE-HADAMIAO DISTRICT, INNER MONGOLIA, CHINA**

**Leader:** Lejun Zhang

**Team members:** Mike Baker, Wei Hong

**Collaborators:** Wenbo Li, Xueyuan Qiao, Dapeng Ren, Bei Xu, Zhongfei Yao, Fanghua Zhang

This project aims to investigate the genesis of porphyry systems in the Bilihe-Hadamiao district of Inner Mongolia through a study of the geology, hydrothermal alteration and mineral chemistry of the Hadamiao Au-Cu prospect.

2017 activities included field sampling by Lejun Zhang and Mike Baker in May and September. The project will continue in 2018 as an Honours project.



*ABOVE: Evan Orovan looking out over the Yerington porphyry Cu district, Nevada, USA. He carried out fieldwork here as part of the TMVC's Theme 1 research.*

### **THE MAGMATIC-HYDROTHERMAL TRANSITION AT BLUESTONE BAY, EASTERN TASMANIA**

**Leader:** Evan Orovan

**Team member:** David Cooke

**Student:** Colin Jones

This Honours project aimed to describe the granitic rocks of Bluestone Bay, Tasmania, including the documentation of the magmatic-hydrothermal paragenesis, the determination of absolute ages of magmatism, the determination of magmatic provenance and intrinsic parameters, and to construct a genetic and exploration model for the region. Several trips to the field area were conducted during the year in order to conduct outcrop mapping, collect samples and observe rock relationships. Drill core logging was conducted on a 1,000 m drill hole stored at Mineral Resources Tasmania, from which additional sampling was conducted and rock relationships were observed. Samples were subject to a variety of analytical techniques, including whole rock geochemistry, U-Pb geochronology, and other mineral chemistry techniques (e.g., XRD, LA-ICP-MS, SEM).

The study found that the oldest intrusions at Bluestone Bay were 400 million-year-old granodiorites that had been crosscut by magmatic-hydrothermal transition texture-bearing alkali-feldspar

granite at 388 Ma. The alkali-feldspar granite generated hydrothermal alteration, weak mineralisation and a variety of aplite/pegmatite dikes. The project involved the calculation of temperature and depth of emplacement constraints of the granitic intrusions as well as fingerprinting the productive intrusions within the region.

### **THE TUMPANGPITU PORPHYRY AND HIGH SULFIDATION EPITHERMAL DEPOSIT, INDONESIA**

**Leader:** David Cooke

**Team members:** Adi Maryono, Jay Thompson, Lejun Zhang

**Student:** Rachel Harrison

Rachel Harrison completed her PhD study of the Tumpangpitu porphyry and high sulfidation Cu-Au deposit in 2017. Tumpangpitu is the largest deposit within the Tujuh Bukit district of SE Java, Indonesia. It is a classic example of high and intermediate sulfidation state mineralisation overprinting a giant porphyry Cu-Au deposit.

Rachel has provided the first detailed documentation of the geology, alteration, geochemistry and geochronology of this giant porphyry system. A manuscript documenting the geology of the deposit and highlighting the origins of two diatreme complexes, one that predated mineralisation and one with a late-mineralisation, has been accepted for publication in *Economic Geology* in 2018.

## THEME 2 – OPTIMISING GEOMETALLURGICAL PREDICTION

### GENERAL GEOMETALLURGY STUDIES

**Leaders:** Ron Berry, Angela Escolme

Activities in 2017 were focussed on developing new research initiatives with several industry partners as well as preparing papers for publication. Ron Berry contributed to one paper and six book chapters published in 2017, and was also invited to be guest editor for an *Economic Geology* Special Issue on Geometallurgy. A five-day course in Topas software (used for interpretation of XRD spectra), run by Ian Madsen, was 50% funded as support of geometallurgy in the TMVC Hub.

Contributions were made to the CODES Master of Economic Geology short course in geometallurgy held during October 2017. Continued distribution of methods and software for calculating mineralogy from assay, as well as preparation of papers on the method and a case study – to be submitted in 2018. Eighteen copies of STORC software have been distributed up to December 2017.

### GEOTECHNICAL AND GEOMETALLURGICAL ASSESSMENT OF THE CADIA EAST DEPOSIT USING CORESCAN AUTOMATED CORE LOGGING TECHNOLOGY

**Leaders:** Sebastien Meffre, Ron Berry

**Team members:** Matthew Cracknell, Neil Goodey, Anthony Harris

**Student:** Cassady Harraden

**Collaborators:** James Lett, Ronell Carey

The goal of this PhD project by Cassady Harraden is to use Corescan™ data to extract geotechnical parameters from drill core, as well as determine which microanalytical techniques would be best used in conjunction with the Corescan™ system to assess gold and copper grain size. The grain size assessment work is, in part, a continuation of the 2016 project 'T2b: Line scan technologies for drillcore'.

Protocols to extract morphological and mineralogical geotechnical parameters have been developed. These parameters can then be modelled in 3D and integrated with the Cadia Mine's current structural,

geotechnical and geometallurgical models. Research in 2017 has focussed on determining which microanalytical techniques could be used in conjunction with the Corescan™ system to adequately and rapidly assess gold and copper grain size. The current technologies being evaluated are: portable-XRF, micro-XRF, laser-induced breakdown spectroscopy (LIBS), and LA-ICP-MS.

In June, Cassady presented a paper on the methods for extracting fracture mineralogy from Corescan™ data at the AIG Drilling for Geology II conference in Brisbane, Queensland. She also presented a paper on assessing grain size using LA-ICP-MS line scan analysis at the 14th SGA Biennial Meeting in Quebec City, Canada. Cassady is expected to submit her thesis in mid-2018.

### GEOLOGICAL AND GEOMETALLURGICAL CHARACTERISATION OF OPG VEINS, MANKAYAN DISTRICT, PHILIPPINES

**Leaders:** Angela Escolme, Lejun Zhang

**Team member:** David Cooke

**Student:** Yi Sun

**Collaborators:** Mervin Delos Santos, Leo Subang

BELOW: Mike Baker gathering data in the Bilhe-Hadamiao district of Inner Mongolia, China, as part of his research in Theme 1 for the TMVC.







ABOVE: Honours student Hannah Couper (left) with Angela Escolme at the Telfer West Dome open pit gold-copper mine in Western Australia.

This PhD project was initiated late in 2017 with the first fieldwork scheduled for February 2018. The project is focussed on a quartz-pyrite-gold (QPG) vein and breccia system, Mankayan District, Philippines. The aims of the project are: 1) Understanding the geology, alteration patterns, mineral textures, chemistry and the genesis of the QPG system; 2) Test and develop geological and geochemical vectors to high-grade gold mineralisation zones; and 3) Investigate alteration patterns, ore texture and mineral assemblages that may impact on metallurgical processes. Special focus will be given to understanding the deportment of gold and other valuable and deleterious trace elements in the complex mineralogy.

### **GEOLOGY AND GEOMETALLURGICAL CHARACTERISATION OF THE HIGH AU, LOW CU MATERIAL AT WEST DOME, TELFER**

**Leaders:** David Cooke, Angela Escolme

**Team members:** Ron Berry, Sebastien Meffre

**Student:** Hannah Couper

**Collaborators:** James Biggam, Karyn Gardner, Anthony Harris

The focus of this Honours project is to determine the gold deportment in low copper, high gold material from the Telfer's West Dome ore body in order to recognise value-add opportunities in current processing protocols.

The project was initiated in July 2017 with two weeks of fieldwork completed in September. An analytical program consisting of petrographic characterisation, mineral liberation analysis and LA-ICP-MS will commence in January 2018.

### **CHARACTERISING SUPERGENE COPPER MINERALOGY USING HYPERSPECTRAL TECHNIQUES**

**Leader:** Angela Escolme

**Team members:** Ron Berry, Sebastien Meffre

**Collaborators:** David Green, Carsten Laukamp, Angus McFarlane, Jake Moltzen

This is a new project established in late 2017. The major goals are to develop a spectral library for supergene copper minerals which can be used to develop mineralogical models of supergene ore zones using automated hyperspectral techniques. It is anticipated that these models will

inform predictive hydrometallurgical performance models for heap and dump leach operations. A suite of type mineral specimens has been provided by CSIRO. In 2018, these samples will be fully characterised before the spectral response is defined in order to begin building the library.

### **THEME 3: MINIMISING GEOENVIRONMENTAL RISKS**

#### **INTEGRATED WASTE CLASSIFICATION FOR BEST PRACTICE AMD PREDICTION**

**Leader:** Anita Parbhakar-Fox

**Team members:** Nathan Fox, Bernd Lottermoser

**Student:** Rebekah Cornelius

**Collaborators:** Christopher Brough, Dane Burkett, Simon Dominy, Susan Harrison, Gregory Joslin, Seth Mueller

Defining the acid forming potential during the exploration stages of a mining project is critical for financial modelling and waste management planning. However, at such early stages, there are limited resources for evaluating the geoenvironmental characteristics of future waste materials. Considering this, a new



ABOVE: PhD student Laura Jackson with Andrew Somers from SciAps testing a portable laser-induced breakdown spectroscopy (PLIBS) device for rapid chemical analysis of waste rock samples.

geoenvironmental logging code was developed and trialled using drill cores from the low-grade Lill-Laverberget (Laver) porphyry copper prospect in Northern Sweden. Four drill holes were targeted with a focus on zones which were marginal or below economic grade. The logging code developed required that for each metre interval, a visual estimate of each sulfide present was recorded. As a conservative approach was adopted, the area (8.5 cm by 5.5 cm, i.e., grain size card dimensions) recognised to contain the most sulfides, was assessed using the acid rock drainage index. A geoenvironmental risk factor was calculated based on acid rock drainage index values scaled to the sulfide mineral abundance over the interval. To enhance the classification, results were screened against sulfur assay values. As corresponding drill core pulps (< 75 µm) were available in this study, they were analysed using the ASTM D492-01(2007) paste pH method.

Collectively, these cost-effective, low-technology methods enabled the identification of high- and low-risk waste zones and will allow the mine planners to start developing robust waste management strategies

rightly guided by the deposit's mineralogy and texture with these results presented at the 9th AMD Workshop, Burnie, Tasmania, in November 2017. In addition, the microtextural controls on oxidation were examined per waste lithology sampled, and free draining column leach kinetic cells for several of these waste lithologies established in mid-2017. Collectively, these results will help the company understand the geoenvironmental characteristics of their waste materials therefore helping them to develop a waste management plan.

#### DEVELOPMENT OF EFFECTIVE SHORT-TERM LEACH TESTS FOR WATER QUALITY PREDICTION

**Leader:** Anita Parbhakar-Fox

**Team member:** Nathan Fox

**Student:** Laura Jackson

**Collaborators:** Tony Ferguson, Roger Hill, Ben Maynard

Short-term leach tests used to assess water quality of mine wastes are typically modifications of paste pH or USGS field leach tests, using deionised water as the extractant fluid. Whilst they provide an indication of the current acid forming potential, they do not predict the

future acid forming characteristics, nor do they provide an indication of metal/metalloid leaching issues. Considering this, more effective predictive short-term leach tests have been developed including the blended leach test (details published in *Minerals Engineering*) and a revised multi-addition net-acid generation test. Both tests allow for improved waste forecasting at the earliest life-of-mine stages. Ongoing research in this project will focus on developing new methods integrating microwave and chemical oxidation techniques.

#### MINERALOGICAL DOMAINING OF LOW GRADE AND NO GRADE ZONES USING AUTOMATED DRILLCORE LOGGING AT CADIA

**Leader:** Anita Parbhakar-Fox

**Team members:** David Cooke, Matthew Cracknell, Anthony Harris

**Student:** Laura Jackson

**Collaborators:** Ronell Carey, Ekaterina Savinova, Rob Taube

Geoenvironmental characterisation at the earliest life-of-mine stages is critical for designing the most appropriate environmentally conscientious waste management strategies and storage facilities. However, geochemical tests typically used for predicting waste characteristics are texturally destructive, and therefore do not appropriately describe the geoenvironmental characteristics of the waste materials, and indeed how they might evolve with regards to the role of secondary minerals in metal cycling within the surficial environment. This research has been developing new protocols by which different mineralogical techniques (e.g., hyperspectral mineralogy) and mineral chemistry analyses (e.g., laser-ablation ICP-MS) can be effectively integrated to allow for mineralogical, chemical and textural information pertinent to environmental characterisation to be obtained from intact-waste materials (i.e., drill core).

To date, the geoenvironmental domaining index (GDI) algorithm has been developed using Corescan



data and allows for domaining of inherent neutralisation zones as presented at the 9th AMD Workshop, Burnie, Tasmania, in November 2017. In 2018, research will continue on improving geoenvironmental forecasting through automation of the acid rock drainage index using high-resolution drill core imagery.

### UTILISING INDUSTRIAL WASTE MATERIALS FOR AMD CONTROL

**Leader:** Anita Parbhakar-Fox

**Team member:** Nathan Fox

**Student:** Rebecca Clifton

Cost-effective waste management of materials producing acid and metalliferous drainage (AMD) is essential for successful remediation. Considering this, using alkaline waste materials generated by other industrial processes represents a potential option for managing acid-forming mine wastes. In this project, two boiler ash materials have been collected from an industrial source. Following their initial characterisation they are being added as a potential AMD ameliorant in static testing

and kinetic testing experiments. The acid forming materials which were capped by these ash included pyritic tailings materials and sulfidic waste rock samples obtained from historic mine sites across Tasmania. This project discovered that the most efficient use of the boiler ash materials was to blend it with commercial lime (50:50) to cover low-sulfide, low As tailings where it would form a cement-like caliche layer effective at retarding oxygen ingress. These findings were reported at the 9th AMD Workshop, Burnie, Tasmania, in November 2017.

### GEOMETALLURGY OF HISTORIC MINE WASTE: EVALUATING OPTIONS FOR REPROCESSING

**Leader:** Anita Parbhakar-Fox

**Team members:** Matthew Cracknell, David Cooke

**Student:** Sibele Nascimento

Strategic mine waste planning has only been actively pursued in the past decades, with historic mining operations having used inappropriate disposal methods by today's environmental standards. This can result in environmental degradation

to downstream catchments. One such example is the King River delta/Macquarie Harbour, western Tasmania, and is the focus of this project. Approximately 100 Mt of mine tailings and slag materials have been discharged into the Queen and King rivers from the Mount Lyell copper mine, Queenstown, since the 1890s. Furthermore, the 2.5 km<sup>2</sup> King River delta contains approximately 10 Mt of mine tailings, with a further 10 Mt of fine tailings deposited beyond it. Whilst the tailings properties and the geochemistry of Macquarie Harbour have been documented, the sulfide chemistry of individual minerals (i.e., pyrite) has yet to be detailed at the micro-scale. This research project aims to mineralogically and geochemically characterise tailings and slag materials in the riverine and deltaic systems, and establish if reprocessing of these materials is an environmentally and economically viable rehabilitation option.

PhD student Sibele Nascimento commenced in October, with her first fieldwork being conducted in December. Geophysical surveying as well as water and sediment sampling were performed.

*BELOW: PhD student Sibele Nascimento carrying out a hydrogeological and geochemical survey on sulphidic tailings at Macquarie Harbour in western Tasmania.*



## DETERMINING BIOACCESSIBILITY RISKS AT THE HISTORIC ABERFOYLE TAILINGS SITE, NORTH EAST TASMANIA

**Leader:** Anita Parbhakar-Fox

**Team members:** Nathan Fox, Michael Roach

**Student:** Robert McLaine

**Collaborators:** Lachlan Brown, Andrew McNeill, Jen Parnell, Michael Reid

The historic Aberfoyle Mine at Rossarden, in northeastern Tasmania, operated from 1931 to 1982 producing 11,000 tonnes of tin and 3,500 tonnes of wolfram. Ore from the Aberfoyle Mine and the nearby Storey's Creek Mine was processed on site and pyritic tailings were pumped into nine tailings dams, also located at the site. Metal sulfides within the tailings dams are a known contaminant and a source of acid and metalliferous drainage (AMD), with metal levels, including cadmium, measured above national guideline values. Rehabilitation works previously undertaken have included the emplacement of an earth capping over the tailings dams and vegetation trials. The vegetation trials have, however, shown limited success, with grass species growing with a patchy coverage to approximately 20 cm high. In this study, tailings samples (n = 75) were collected to a depth of 1.9 at the site. Tailings were logged and then subjected to a rigorous mineralogical and geochemical characterisation program. In addition, a new bioaccessibility test method developed by van Veen et al. (2016) was performed to determine the quantity of potentially harmful elements readily available for uptake by plants.

The findings from our study revealed that where the established soil cover is 300 mm thick, it is sufficiently retarding oxidation of sulfidic tailings, which are in general sparse at the site except in localised hotspots at depth (0.5–1 m). However, bioaccessibility experiments confirm that Cd, Cu and Zn are present at concentrations above national guidelines, and therefore pose a risk to larger vegetation (i.e., acacia

and wattle) which have attempted to naturally colonise the site. To chemically and physically stabilise the site, our study recommends that a clay cap is introduced in parts of the site where the soil cap is < 300 mm or tailings are exposed. Following this, a soil cap should be emplaced. Native grasses and rushes should be seeded but this time care should be taken to ensure regular irrigation.

## MINERALOGICAL AND GEOCHEMICAL CHARACTERISATION OF HISTORICAL SLAG: EVALUATING ENVIRONMENTAL IMPACTS AND ECONOMIC SIGNIFICANCE

**Leader:** Anita Parbhakar-Fox

**Team members:** Nathan Fox, Paul Olin

**Student:** Sarah Gilmour

**Collaborators:** Andrew McNeill, Jen Parnell, Rebecca Ritchie

Metallurgical slags are highly heterogeneous and mineralogically diverse materials as dictated by the composition of the ore processed and fluxes used. In general, historic slags are characterised by elevated base metal and metalloid content because of inefficient metal recovery technologies. Understanding the deportment of potentially deleterious elements within such complex minerals is critical for defining the environmental risks posed by this metallurgical waste. However, contaminant pathways are not just aqueous (i.e., percolation of rain water through a waste landform to surface and ground waters) but also airborne (i.e., through weathering and dust generation). As an alternative, micro-analytical characterisation of slag may forecast rehandling or reprocessing options to recover precious or critical elements. Therefore, slag materials present environmental management challenges but also may harbour vast economic potential. This project focusses on characterising slag materials collected from two sites (Zeehan and Copper Mines Tasmania) located in western Tasmania, with support from MRT and CMT.

## UNDERPINNING TECHNOLOGIES

### DEVELOPMENT OF THE FAST-THROUGHPUT SAMPLE CELL FOR LASER ABLATION APPLICATIONS

**Leaders:** Leonid Danyushevsky, Michael Shelley

**Team members:** Ivan Belousov, Paul Olin

**Collaborator:** Ashley Norris

This project aims to develop a new sample cell capable of high-throughput applications using laser ablation instruments, which may involve LA-ICP-MS and/or LIBS. The instrumentation developed would be used for the scanning of large sections of drill half-core. Stages within this project include prototype development and performance testing.

During the year, a range of tests were carried out in order to understand the influence of ablation of uneven, unpolished and tilted surfaces on the determined compositions. Several designs of a fast response, small volume funnel were tested in order to develop a new design with an improved response, as a major step in developing the fast-throughput cell.

The newly developed design of the fast response funnel was tested by coupling it to the Time-of-Flight (TOF) mass-spectrometer. Applications involved zircon dating and determination of the size of inclusions based on fixed-spot and line-scan data.

### CORESCAN DATA FEATURE EXTRACTION AND CLASSIFICATION FOR MINERALOGICAL AND TEXTURAL INFORMATION ANALYSIS

**Leader:** Matthew Cracknell

**Team members:** Ron Berry, Leonid Danyushevsky, Neil Goodey, Anthony Harris, Anya Reading

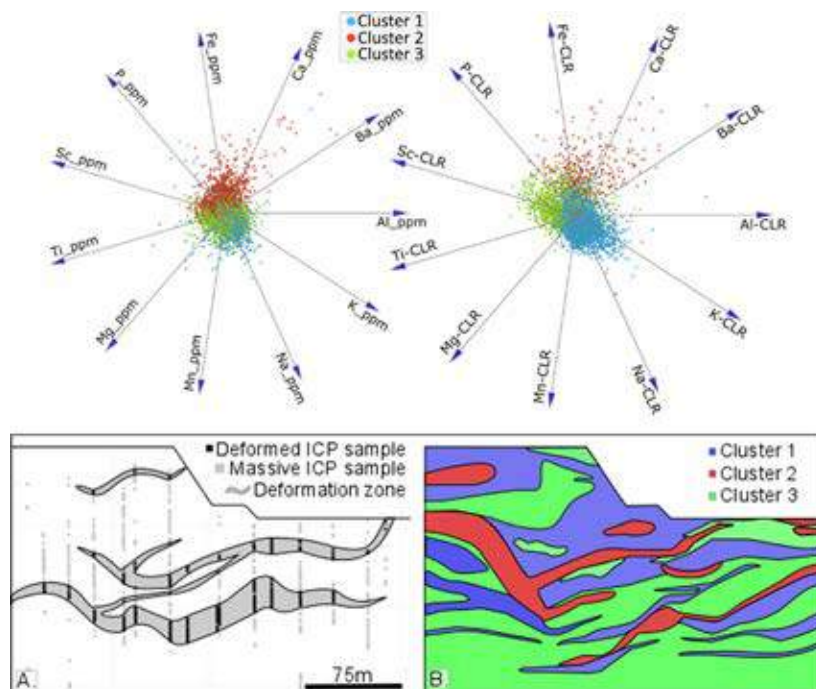
CoreScan™ generates a range of drill core image products including Digital Surface Models (DSM), Red-Green-Blue (RGB) colour photographs and Visible-Near Infrared–Short Wave-Infrared (VNIR–SWIR)-derived



mineral interpretations. Despite the rich geological information implicitly contained within these data, they are primarily used to provide percentages of identified minerals down hole to Corescan™ customers. The aim of this project is to classify and extract mineralogical and textural features from Corescan™ imagery that add value to their data products. For example, the 2-dimensional imagery generated by Corescan™ contains information on the geometric characteristics and spatial arrangement of interpreted minerals, while there are key economic mineral species, such as sulfides, that do not have characteristic absorption features in VNIR–SWIR spectra and are therefore not identified accurately in available data products.

In 2017, outputs included a presentation at the International Association for Mathematical Geosciences (IAMG) 2017 conference titled 'Image texture quantification from Corescan™ mineral classifications' which outlined research into quantifying mineral textures. This research forms the basis for developing meaningful indices characterising geological textures, such as disseminated versus massive and degree of veining. Dr Cracknell was also invited to chair two sessions on 'Machine Learning, Pattern Recognition, Data Mining, Big Data' at IAMG2017. These presentations were well received by both the public and expert geoscientists alike.

In September, recent progress on research into robust classification of sulfides from Corescan™ imagery and subsequent analysis of sulfide textural characteristics was presented to Corescan™ staff. Applications of this work for the automated classification of Acid Rock Drainage risk are being developed in collaboration with Corescan™ staff and Theme 3 researchers. Relevant algorithms are in an advanced testing phase and relevant manuscripts will be ready for submission in early 2018.



ABOVE: Lithology cluster characteristics in ppm (top left) and transformed (top right) multi-element geochemical data space. Ore deposit cross-sections showing original lithology interpretation based on drill hole information (bottom left) and updated interpretation based on lithology clusters (bottom right). This research forms part of Shawn Hood's PhD, 'Interpreting structural and geochemical patterns using machine learning'.

## LINE SCAN TECHNOLOGIES FOR DRILLCORE

**Leader:** Ron Berry

**Team member:** Sebastien Meffre

**Student:** Cassady Harraden

**Collaborators:** Richard Hark, Thomas Rodemann

The aim of this project is to assess the suitability of various line scan capable technologies for use on drill core. Factors being assessed include achievable pixel size, acquisition speed, suitability to produce a grain size proxy for base metal sulfides, and accuracy.

Data processing of Laser Raman, micro-XRF, LA-ICP-MS and LIBS technologies were completed on representative samples of drill core with the following outcomes:

- The laser Raman technology was deemed to be unsuitable for analysis of sulfides in drill core.
- LIBS and micro-XRF data suggest that currently available technology will be suitable for line scan analysis of sulfides.
- LA-ICP-MS data suggests that while currently not appropriate for rapid analysis by line scan, it may be viable for offline, non-continuous sample analysis.

Results of testing will be presented to Corescan in mid-2018 with an aim to discuss an upscale trial of micro-XRF.

## INTEGRATING CHEMICAL AND MINERALOGICAL DATA LAYERS FOR ELEMENT DEPARTMENT

**Leaders:** Ron Berry, Matthew Cracknell, Leonid Danyushevsky, Sebastien Meffre

**Team members:** Ivan Belousov, Nathan Fox, Paul Olin, Sasha Stepanov

**Students:** Cassady Harraden, Laura Jackson

This project aims to integrate mineralogical and chemical data from various spectral and analytical techniques in order to extract information on element department, mineral chemistry, mineral association and other mineral-based information, such as the ability to automatically recognise gold in solid solution, and gold in particles. Digital cameras, short wave infrared spectrometry and laser Raman spectroscopy will be used to acquire mineralogical data, with chemical information being garnered from laser ICP-MS, pXRF and/or laser-induced breakdown spectroscopy (LIBS).

Work was ongoing during the year, with scanning of unpolished drill core samples from porphyry deposits. The results were presented at Goldschmidt in August. Cassidy Harraden used LA-ICP-MS to estimate Cu sulfides and Au grains in drill core, the results of which form part of her thesis.

### INTERPRETING STRUCTURAL AND GEOCHEMICAL PATTERNS USING MACHINE LEARNING

**Leaders:** Matthew Cracknell, Anya Reading

**Student:** Shawn Hood

**Collaborators:** Michael Gazley

This PhD project aims to develop novel approaches for interpreting large datasets of metalliferous-ore exploration and mining data. To achieve this, computational methods are being used to represent and interpret geological patterns in three dimensions. More specifically, Machine Learning methods are being developed and tested for the statistical inference of structural and geochemical patterns around hydrothermal ore deposits. This research encompasses three main aims:

- Investigating metasomatic alteration using clustering and classification of geochemical data to construct models of element migration
- Creating models of permeability networks in complex structural environments using automated statistical inference of structural geology data
- Creation of 3D ore deposit prospectivity models by combining statistical geochemical and structural models.

These research thrusts involve automated workflows developed using open source software, and aim to rapidly generate repeatable and objective three-dimensional models of geologically relevant features with input from geoscientists. A chief goal is to produce practical workflows that fit seamlessly into existing industry methodology for defining ore bodies, especially in brownfields environments. During 2017, preliminary results of these efforts were given as oral presentations at conferences in New Zealand and China, and supported by peer-reviewed extended abstracts.

An initial manuscript is currently under review by the *Journal of Geochemical Exploration*.

### GEOLOGICAL FEATURE DISCOVERY FROM QUANTITATIVE DATA INTEGRATION (ALGORITHM DEVELOPMENT)

**Leader:** Anya Reading

**Team member:** Matthew Cracknell

**Students:** Stephen Kuhn, Peter Morse

**Collaborators:** Mike Christie, Tim Ireland, Christopher Lueg, Chris Wijins

This project aims to test and refine supervised and unsupervised learning methods for the automated classification of lithology and alteration zonation from geological, geophysical and geochemical data. By exploring unique characteristics of individual ore deposit styles (e.g., orogenic gold, sedimentary copper, etc.), this project will identify appropriate scales of investigation, and optimal input data, given a resource project's development stage (e.g. area selection, target prediction, resource evaluation, and resource development). Resulting models will be used to independently validate existing geological maps, while also identifying mineralisation targets, especially in areas concealed by cover.

Development activities focussed on geological feature discovery included the publication of a computer application by PhD student Peter Morse that enables a first pass reconnaissance of large datasets using an animated desktop computer user interface. The application is flexible for use on datasets held locally, but also compatible with cloud computing architecture which enables an interface with large, national databases. The project leader, Professor Anya Reading, gave a keynote presentation 'Machine Learning using high-D spatial data' at the Colorado School of Mines Symposium on Machine Learning in Geophysics, and contributed as co-Director to the institute-wide UTAS Research Theme on Data, Knowledge, Decisions.

Research achievements in the project area centred on the PhD research of Stephen Kuhn have progressed very significantly in 2017.

Highlights include the completion of a project that uses only airborne geophysics and remote sensing data to refine a geological map in the reconnaissance stage of exploration, and substantial progress on a project which used a case study approach to optimise strategies for Machine Learning at early to late stages of project maturity. Notable achievements also include the geologically referenced use of metrics to quantify the uncertainty associated with prediction of lithology. Based on the ongoing success of Earth Informatics being undertaken through the TMVC Hub, Stephen Kuhn and co-supervisor Dr Matthew Cracknell were invited to contribute to a training workshop at the Australian Exploration Geoscience Conference to be held in Sydney in early 2018.

### KNOWLEDGE TRANSFER AND TRAINING

Knowledge transfer and training are an integral part of the TMVC, encompassing all research themes and impacting all parts of the mining value chain.

During the year TMVC staff and students produced 11 refereed journal articles, provided 53 reports and 14 on-site presentations to industry, delivered 53 conference presentations, and 6 workshops (both local and international). Several staff and students delivered a dedicated session on research highlights and the forward program at the annual CODES Annual Review Meeting (oral and poster presentations).

Team members also participated in public outreach opportunities including the University of Tasmania's Open Day, Beaker Street roving scientists, and 'Science in the Pub'. A highlight of the TMVC's public outreach was a waste + waste exhibition and live experiment run at the MOMA Sunday Market in February that focussed on educating the public about the circular economy and how one industry's waste (i.e., oyster food waste) could be used to ameliorate that from another (i.e., acid and metalliferous drainage, AMD). As part of this, a film of mine waste features across the Tasmanian state was produced in collaboration with a local filmmaker, and a write-up of the exhibition is to be published in the MONA book 'Eat the Problem' in 2018.



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## LOOKING FORWARD

In 2018 the TMVC will have passed its half-way point and its projects will be running at full stretch marked by the completion of AMIRA project P1153 in Theme 1 – ‘Detecting proximity to ore (footprints)’. This is the TMVC’s largest sub-project. New tools for the detection of low-level hypogene geochemical footprints developed during this project will be finalised and presented at the final sponsors’ meeting to be held in late June.

AMIRA project P1202, ‘Far-field and near-mine footprints –finding and defining the next generation of Tier 1 ore deposits’, aims to continue the research initiated in P1153, and will commence as P1153 winds up. The project will also integrate the research developments from the TMVC’s geometallurgy, geoenvironmental and underpinning technologies research, as the culmination of the TMVC’s research activities, providing sponsors with the transformative technologies, workflows and methodologies required to achieve the three major aims of the TMVC. Fieldwork is planned to commence in July 2018 and the first sponsors’ review meeting will be held in November 2018.

Theme 1 will also see the return of former CODES PhD student Francisco Testa as a short-term postdoctoral researcher working on the Cerro Negro district in Argentina. He will use SWIR, multi-element whole rock analyses and LA-ICP-MS analyses to assess the geological and geochemical footprints of low sulfidation epithermal veins, with a view to developing new vectoring tools that aid exploration.

In Theme 2, the geometallurgy theme, Hannah Couper will complete her Honours study of West Dome, Telfer, while Angela Escolme will commence a pilot study on the pyrite trace element geochemistry of samples from the Lihir gold mine in Papua New Guinea.

Theme 3 will see the completion of Laura Jackson’s PhD project on early geoenvironmental characterisation of intact materials. 2018 will also involve fieldwork and analytical programs for Sibebe Nascimento’s PhD on the tailings of the King–Queen River system and Macquarie Harbour in western Tasmania.

Underpinning Technologies will continue to play a key role throughout all TMVC activities, with hopes of upscale trials being implemented by partner organisations.

Several other PhD projects are expected to conclude during the year including Cassady Harraden’s study of the geometallurgy of Cadia, and research by Josh Phillips, Steve Kuhn and Jing Chen.

New research by commencing PhD students will continue to expand the work of the TMVC in 2018. Emily Smyk will assess the chemistry of zircon and other magmatic minerals as a tool to assess the fertility of igneous complexes for porphyry-style mineralisation. Yi Sun will investigate the geology and genesis of the QPG system in the Mankayan District in the Philippines. And new PhD student Nanda Mrabawani will work on method development for laser-ablation ICP-MS applied to complex matrices.

It promises to be another busy year for conference-related activities, with staff and students chairing both the Gordon Research Conference (GRC) and Gordon Research Seminar (GRS) on the Geochemistry of Mineral Deposits in August. David Cooke is to chair the GRC, with Ayesha Ahmed and Angela Escolme chairing the GRS. Other TMVC representation will be at the RFG 2018, European Workshop on Laser Ablation (EWLA), Goldschmidt and ICARD conferences.

A large number of publications are planned for 2018 reflecting the high-quality output generated by TMVC projects. Staff and students will contribute to special issues of *Economic Geology*: Ron Berry will edit a complete issue on geometallurgy studies; Stephanie Sykora will publish on pyrite footprints; and the preparation of manuscripts will continue from the AMIRA P1153 project for another special issue of *Economic Geology* scheduled for publication in 2019/2020.

## OBJECTIVES

- Provide an ongoing supply of world-class PhD, Masters and Honours geoscience graduates.
- Deliver a range of professional development short courses and workshops tailored to meet the needs of the minerals industry in terms of re- and up-skilling its workforce.







**LEADERS** ROBERT SCOTT AND ANYA READING

## INTRODUCTION

The Centre has an international reputation for delivering excellence in postgraduate education, which includes providing students with a comprehensive grounding in the Earth sciences. Students come from all over the world to study at CODES, with many progressing to senior roles in the minerals industry, state and federal governments, and academia.

Training and education activities also play a vital role in the Centre's research program via a wide array of student theses, which are integral to research activities across our six Programs.

Areas covered under Training and education include the Higher Degree by Research (HDR), Master of Economic Geology and Honours programs. CODES also runs a variety of one-off short courses and workshops, most of which are aimed at re- and up-skilling of professionals in the minerals industry (see the Technology transfer section in this report for details about these short courses and workshops).

*OPPOSITE PAGE: (Top) Layered orthopyroxenite and harzburgite of the Serpentine Hill Complex in western Tasmania, taken on the CODES SEG Student Chapter 2017 field trip. (Bottom) CODES SEG Student Chapter visit to the Mount Bischoff mine site, western Tasmania, during the Chapter's field trip to western Tasmania in December 2017.*

## HIGHLIGHTS

It was another good year for the Training and education program, which was marked by healthy enrolments for the HDR and Master of Economic Geology programs, and increased enrolments in the Honours program and its associated coursework components.

There were eight new enrolments for the HDR program, which included five Australian students. Although there has been an increase in Australian students in the PhD program in recent years, over two-thirds of the current cohort emanate from overseas, from a total of 17 countries. A major highlight for 2017 was the largest number of graduations (11) from the PhD program in a single year in CODES' history, with a further three PhD students and one MSc student also submitting their theses for examination late in the year.

Strong enrolments in all three short courses delivered in 2017 (45% increase on 2016 enrolments), seven new students and five graduations were highlights of another successful year for the Master of Economic Geology program. The long-running and highly regarded short course Ore Deposits of South America had a facelift in 2017. Under the new name of Ores in Magmatic Arcs this short course was run in Indonesia for the first time in March, and was very well received by all participants.

Enrolments in the Honours Program were up compared to 2016, with an unexpectedly high 2017 mid-year intake of eight.

The CODES SEG Student Chapter field trip for 2017 was a highlight: it was a week-long tour consisting of a combination of visits to geological features and to operating and legacy mine sites across western Tasmania. Fourteen postgraduate and undergraduate students participated and the consensus was that the trip had provided a valuable all-round education about the state's important economic geology and its mining industries.

In addition, postgraduate students had 15 refereed journal articles published, and produced 27 presentations for major international conferences.

## POSTGRADUATE PROGRAMS

CODES has a range of postgraduate programs aimed at providing the next generation of world-class geoscientists. The main programs are the Higher Degree by Research (HDR), Master of Economic Geology and Honours.

### HDR PROGRAM

Students enrolled in the UTAS HDR Program make a major contribution to CODES' research activities. 66% of the HDR projects involve collaborations with the minerals industry.

CODES' success in attracting international HDR students is underpinned by its reputation for excellence as a research training centre. This success continued in 2017 with over two-thirds of the students enrolled in the program coming from overseas, representing a total of 17 nationalities. Notwithstanding the high ratio of international students, the trend of relatively healthy enrolment numbers for Australian students was maintained, with five of the eight new starters in 2017 being domestic candidates. This is considered to be partly due to the challenging employment conditions that continue within Australia's minerals



*ABOVE: CODES SEG Student Chapter members inspect the final tin concentrate product from the Renison Tin Mine and processing plant, western Tasmania.*

industry, plus the greater scholarship opportunities for local applicants.

There were 58 students enrolled in the HDR program during 2017 (56 PhD and 2 MSc), including eight new arrivals. The new enrolments were Australian students Peter Duerden, Tristan Wells, Stephen Meyer, Amery Jackson and Thomas Schaap, and international students Robert Davidson (USA), Yi Sun (China) and Sibebe Nascimento (Brazil). Eleven PhD students graduated – namely, Angela Escolme, Sean Johnson, Wei Hong, Martin Gal, Margy Hawke, Heidi Berkenbosch, Jacob Mulder, Richelle Pascual, Stephanie Sykora, Esmaeil Eshaghi and Carlos Andres Jimenez Torres – and a further three PhD, plus one MSc student, had theses under examination. One PhD candidate withdrew, and several students had periods of suspension.

The HDR program depends on UTAS funding in the form of highly competitive living allowance scholarships and tuition fee waivers, as well as industry funding of scholarships and research costs.

## MASTER OF ECONOMIC GEOLOGY PROGRAM

The coursework-based Master of Economic Geology degree at CODES forms part of the national Minerals Geoscience Masters (MGM) program – a collaboration between UWA, JCU, UTAS and Curtin University. The MGM remains the course of choice for industry-based geoscientists, attracted by the opportunity of studying for an internationally recognised degree, while still being able to pursue their careers in the minerals industry.

It was another successful year for the Master of Economic Geology (MEconGeol) Program, with strong enrolments in all three short courses, seven new students, and six students completing their Masters degrees. Joanna Morrison, Wayne Carter, Anna Kutkiewicz, Alexei Nicholls and Sebastian Benavides all completed the MEconGeol and graduated in 2017. Chris Shanley also completed his degree and will graduate in 2018.

While the MEconGeol program at UTAS remains strong, late in the year James Cook University announced the closure of their equivalent degree program, and that 2018 would be their final year in the MGM program.

Three short courses were held during the year, in accordance with the usual biennial scheduling model:

### ORES IN MAGMATIC ARCS

For those fortunate enough to attend it, Ore Deposits of South America has long been one of CODES' most highly regarded short courses. On that short course participants visit and learn about an array of important geological sites, and some of the largest ore deposits of their type (porphyry, epithermal) in the world. All within the spectacular setting of the Peruvian and Chilean Andes. However, that short course is undeniably very costly to attend, and is complex and time-consuming to organise. In an effort to reduce costs and boost student numbers on our field-based short courses, in 2016 CODES' decided to change the name of Ore Deposits of South America to Ores in Magmatic Arcs.



With the name change came the option of running the short course in either South America or closer to home – in Indonesia, which is also host to a number of world-class porphyry and epithermal deposits.

Ores in Magmatic Arcs – Indonesia ran for the first time in March 2017. The course was led by Lejun Zhang and David Cooke, ably assisted by Indonesia-based colleagues Rachel Harrison (a former MEconGeol graduate, and CODES PhD student) and Iryanto Rompo. The short course was attended by 17 Masters students, three PhD students and one industry participant.

Apart from a series of new lectures on regional geology and tectonic setting, the technical content of Ores in Magmatic Arcs was similar to that previously presented during Ore Deposits of South America. However, the total cost to participants was about half that of previous courses in South America. This fact doubtless contributed to the largest ever student enrolment for this unit. The inaugural running of Ores in Magmatic Arcs was extremely well received by all participants, with highlights including visits to the Tuhuh Bukit and Batu Hijau deposits, and a midnight hike up Mount Ijen volcano to watch the sunrise over Crater Lake.

## ORE DEPOSIT GEOCHEMISTRY, HYDROLOGY AND GEOCHRONOLOGY

In June a large group, comprising 22 Masters students, five industry participants and 15 other students (CODES PhD, MSc and visiting students) attended the Ore Deposit Geochemistry, Hydrology and Geochronology short course, led by David Cooke. The short course is designed to introduce participants to a wide range of geochemical, isotopic, hydrological, and geochronological techniques used to understand ore genesis and aid in the exploration for mineral deposits.

During the short course participants are introduced to pioneering work on mineral chemistry vectoring and discrimination techniques for ore deposits developed by CODES researchers over the past decade. As usual, the unit was delivered by a mixture of CODES staff (David Cooke, Mike Baker, Ron Berry, Leonid Danyushevsky, Sebastien Meffre, Robert Scott, Jeff Steadman and Lejun Zhang) and guest presenters with wide-ranging expertise. The guest presenters were Shaun Barker (Waikato University), Phil Blevin (GSNSW), Stephen Cox (ANU), Tony Crawford (UTAS, Consultant), Scott Halley (Consultant), Nick Oliver (Consultant) and Leslie Wyborn (ANU).

## GEOMETALLURGY

In 2017, Anita Parbhakar-Fox took over leadership of the Geometallurgy short course. The course structure was similar to that originally devised by Julie Hunt and Ron Berry, but included an expanded range of topics and expert guest speakers: Steve Walters (BHP), Luke Keeney and Michael Scott (CRC ORE), Angus McFarlane and Naomi Boxall (CSIRO), John Glen (ALS Global) and David Green (MRT). This short course strives to cover key aspects of the highly specialised field of geometallurgy, including rock properties, sample selection, mineralogy, comminution, mineral processing, grade engineering, statistical analysis and modelling, environmental issues, and financial aspects. The short course includes a three-day field trip to northwest and western Tasmania, visiting the ALS Global Laboratory in Burnie, Grange Resources' Savage River iron ore mine, Bluestone Mines Tasmania's Renison tin mine and Copper Mines of Tasmania in Queenstown. We extend our gratitude to the staff at each of these facilities for facilitating very enjoyable and informative visits. The 2017 course was attended by 17 Masters students, five other students (PhD, Honours) and five industry participants.

### THE PROGRAM FOR 2018

- 4–19 March: Volcanology and Mineralisation in Volcanic Terrains (KEA703/KEA708)
- 11–22 June: Exploration in Brownfield Terrains (KEA705/KEA710)
- 22 October–2 November: Ore Deposit Models and Exploration Strategies (KEA701/KEA712), beginning with a three-day symposium dedicated to the research and career contributions of Dr Garry Davidson.

## HONOURS PROGRAM

In 2017, sixteen students were enrolled in the Honours program, which was coordinated by Martin Jutzeler, Garry Davidson and David Selley. Of these students, two were mid-year starters from 2016, while eight students commenced Honours in mid-2017. Student projects were in five of the six research programs,

*BELOW: PhD student Cassidy Harraden examines how crushing rods wear in a milling circuit at the Renison Bell Mine during the CODES SEG field trip of western Tasmania, December 2017.*



with two in each of Programs 3 and 4, and four in each of Programs 1, 2 and 6.

Four projects were computer- or lab-based, five were related to Tasmania, five to mainland Australia, and two had an international focus.

Sponsoring companies and organisations in the Honours Program included the Australian Antarctic Division, the Australian Research Council, the AusIMM, Boliden, Copper Mines of Tasmania, CSIRO, the Geological Survey of Western Australia, Heron Resources, the Institute of Mine Seismology, MMG, Mineral Resources Tasmania, Newcrest Mining, Perilya, the TMVC Research Hub and the UTAS Foundation (CockerTwo Scholarship). In addition, a proportion of the project work was supported by internal, university-based funding. CODES thanks the sponsors for their valued support. These sponsorships continue to be vital to the success of the projects, and the development of the students during a crucial phase of their studies.

## HONOURS COURSEWORK PROGRAM – VIEPS

In 2017, CODES offered four short courses as part of the Victorian Institute of Earth and Planetary Sciences (VIEPS) Honours coursework program, in addition to another Honours course for the exceptionally large number of mid-year students.

## EXPLORATION FIELD SKILLS MAPPING CAMP

**Course leaders:** Robert Scott and Martin Jutzeler

For most students, the Honours year begins with the Exploration Field Skills (EFS) mapping camp, which gives students the opportunity to develop or enhance skills in geological mapping, core logging and structural analysis, all within a mineral exploration context. Thirteen students attended the camp in 2017.

The eight-day camp, held in February, began with a day at the Mineral Resources Tasmania core library in Hobart, where the students logged three diamond drill holes from the mapping area, 20 km

northwest of Queenstown.

The following day, the students were driven to Queenstown to begin four days of mapping in the Cambrian Mount Read Volcanics. The 4–5 km<sup>2</sup> mapping area, centred on the Hall Rivulet Canal, is located 10 km along strike to the south of the world-class Rosebery VHMS, and only ~5 km south of the Hercules deposit.

The students used data collected during the mapping and core logging exercises to unravel the stratigraphy and structure of the area, and interpret the nature and likely extent of any hydrothermal alteration or mineralisation. Before returning to Hobart, each student produced their own fact and interpretation geological maps, a set of cross-sections showing the predicted subsurface extent of the prospective stratigraphy, and a report on the structure, stratigraphy and future exploration potential of the area.

## ORE DEPOSIT MODELS

**Course leader:** David Selley

**Course presenters:** Mike Baker, Sean Johnson, Chris Large, Ross Large, Brian McNulty, Evan Orován, Robert Scott, David Selley, Jeff Steadman, Lejun Zhang

In May, 17 students attended the five-day Ore Deposit Models short course, which provides an introduction to the key features of several major classes of economically important mineral deposits. Each deposit style was discussed in terms of geological and tectonic framework, mineralisation, alteration, genetic models and exploration criteria.

The deposits covered were:

- volcanic-hosted massive sulfide
- magmatic-hydrothermal: epithermal, porphyry and skarn
- sediment-hosted uranium, copper and lead-zinc
- Carlin-type and orogenic gold.

Each day of the short course involved a mixture of lectures and practical exercises. Lectures covered the general characteristics and setting of the abovementioned deposit types, as well as the various genetic models that have been proposed to explain their formation. In the practical exercises, students

examined and interpreted samples from many of the premier mineral deposits and mineralised districts throughout the world.

## PRACTICAL IGNEOUS PETROLOGY

**Course leader:**

Leonid Danyushevsky

In May, eight students attended the Practical Igneous Petrology course presented by Leonid Danyushevsky. The five-day program is a mixture of lectures and practical exercises, aimed at postgraduate students at Honours level and above with an interest in the formation and evolution of basic and ultrabasic magmas and their relationship to magmatic ore deposits.

Topics covered included:

- Key theoretical aspects of petrology, including units of concentration, solid solution and mineral formulas, activities and equilibrium, the phase rule, mass balance, phase diagrams, and equilibrium/fractional crystallisation.
- Examination of a large layered intrusion (the Dovyren Magmatic Complex in Siberia), the effect of pressure and H<sub>2</sub>O on melting and crystallisation, and the causes of melting and crystallisation.
- An introduction to the concept of distribution coefficients for trace elements.
- Trace elements in the main rock-forming minerals.
- Modelling of crystallisation and studies of melt inclusions.
- Examples from MORB, subduction-related lavas and komatiites.

## ENVIRONMENTAL GEOLOGY FIELD TECHNIQUES

**Course leader:**

Anita Parbhakar-Fox

**Course presenters:** Matthew Cracknell, Angela Escolme, Nathan Fox, Laura Jackson

The Environmental Geology Field Techniques (EGF) course ran in September and provided participants with the opportunity to develop skills in geoenvironmental sampling and in-field analyses, geophysical surveying with an





*ABOVE: Evan Orovan teaching Honours short course participants at Bluestone Bay, eastern Tasmania.*

environmental focus, and laboratory analysis (including mineralogical and static chemical methods).

The course ran for five days, starting with a day-and-a-half of lectures at CODES, followed by field site studies conducted in eastern Tasmania.

The ten participants joined KEA348 (Environmental Geology) students to learn about how coal mine waste is managed in the Fingal Valley with a visit to the Cornwall Coal mine. Students were then given the opportunity to examine historic mine waste associated with historic gold mining at Mathinna where, working in teams, they performed a general site assessment, dug trenches to profile the tailings, collected samples for laboratory analysis and performed geophysical surveys. Students were also introduced to portable XRD and XRF technologies.

Next, students visited the rehabilitated Royal George tin tailings site where they were asked to map the site and assess if the rehabilitation strategies are effective in stabilising the tailings, with water samples collected to

examine the drainage chemistry. This site was contrasted against the passively managed Aberfoyle tin tailings site where geophysical surveys were also performed. In-field chemical measurements, water and tailings samples were taken by the students at the mine tailings sites. Collectively, these data allowed them to geoenvironmentally assess these legacy sites.

This year, the final day of the course was dedicated to the students examining their collected tailings from Mathinna in the CODES geochemical laboratory where they undertook net acid generation and paste pH tests (with resulting leachates collected and analysed by ICP-MS) and assessed the bulk chemistry using the handheld portable XRF instrument. Students were also asked to analyse the mineralogy of their samples using the X-ray diffractometry facility at the Central Science Laboratory. All collected data were shared between teams and enabled the students to complete their site assessment.

At the end of the course, the students were assessed based on group assignments related to the three mine visits, with a minor assessment set on the Cornwall Coal visit. The most significant of these assessments was the Mathinna tailings report, which required the students to be able to both interpret and integrate the data in order to understand the site's geochemistry, identify potential geoenvironmental risks and recommend potential future management options.

## **OTHER HONOURS COURSEWORK**

### **ADVANCES IN GEOLOGGING**

**Course leader:** Robert Scott

**Course presenters:** Ron Berry, Martin Jutzeler, Evan Orovan, Robert Scott

In September, five Honours students who had commenced their degrees mid-year, attended a five-day short course on Advances in Geologging, and the application of mineral mapping techniques in drill core. The short course involved a mix of lectures presented on campus, and



practical sessions held at Mineral Resources Tasmania's (MRT) Mornington core storage facility. Also, to help the students bridge the gap between the relatively one-dimensional geological perspective obtained from drill core, and an understanding of geological features in three-dimensions, the third day of the course involved a one-day mapping exercise at Bluestone Bay on the Freycinet Peninsula.

The first day of the course introduced graphic logging techniques and their application to logging volcanic and volcanoclastic rocks, as well as approaches to logging altered and metamorphic rocks. The second day covered structural and geotechnical logging of drill core, and core imaging techniques. On the field trip, the students were introduced to the Anaconda mapping technique and its application to the mapping and interpretation of magmatic-hydrothermal textures, and associated hydrothermal alteration, in granites at Bluestone Bay.

Day four involved further practical sessions and assessment exercises at MRT. On the final day of the course, the students undertook further analysis of data collected during the practical exercises, and finalised their remaining submissions for assessment.

## HONOURS SKILLS WORKSHOPS

### Workshops leader:

Anita Parbhakar-Fox

**Course presenters:** Mike Baker, Matthew Cracknell, Nathan Fox, Cassady Harraden, Evan Orovan, Anita Parbhakar-Fox, Lejun Zhang

From July to September, Honours and postgraduate students were invited to attend seven day-long skills workshops, consisting of both lectures and practical sessions, where students were encouraged to bring their own project data in order to get expert advice on how the data should be interrogated and presented. The workshops were organised by Anita Parbhakar-Fox, and led by various in-house presenters.

Skills and software covered during the sessions included:

- **Introduction to ioGAS** (Mike Baker) covered importing data, constructing and using diagrams, and interrogating geochemical data. These topics were followed by an interactive practical session.
- **The basics of Leapfrog** (Evan Orovan) provided students with an introduction to importing geochemical data from ioGAS and plotting this in a 3D context with case study examples given. Students were encouraged to bring their own data to work through a range of practical exercises.
- **ArcGIS for Geoscientists** (Cassady Harraden) covered a number of GIS-related topics including ArcGIS software basics, data querying, and data analysis and interrogation in the Earth sciences. Students were able to work with existing GIS datasets, as well as creating their own from freely available raster and tabular data.

*BELOW: Matthew Cracknell teaching during the 2017 Machine Learning with Orange course, which familiarised students with the Orange data mining package.*





- **Machine Learning with Orange**

(Matthew Cracknell) provided an introduction to the application of machine learning algorithms to data analysis and data inference. It covered the basic principles of supervised classification and unsupervised clustering, using the Orange data mining package.

This software is open source and allows the user to build data mining and machine learning workflows. The course focused heavily on the development of practical skills for classification and clustering, including the calculation and analysis of model uncertainty.

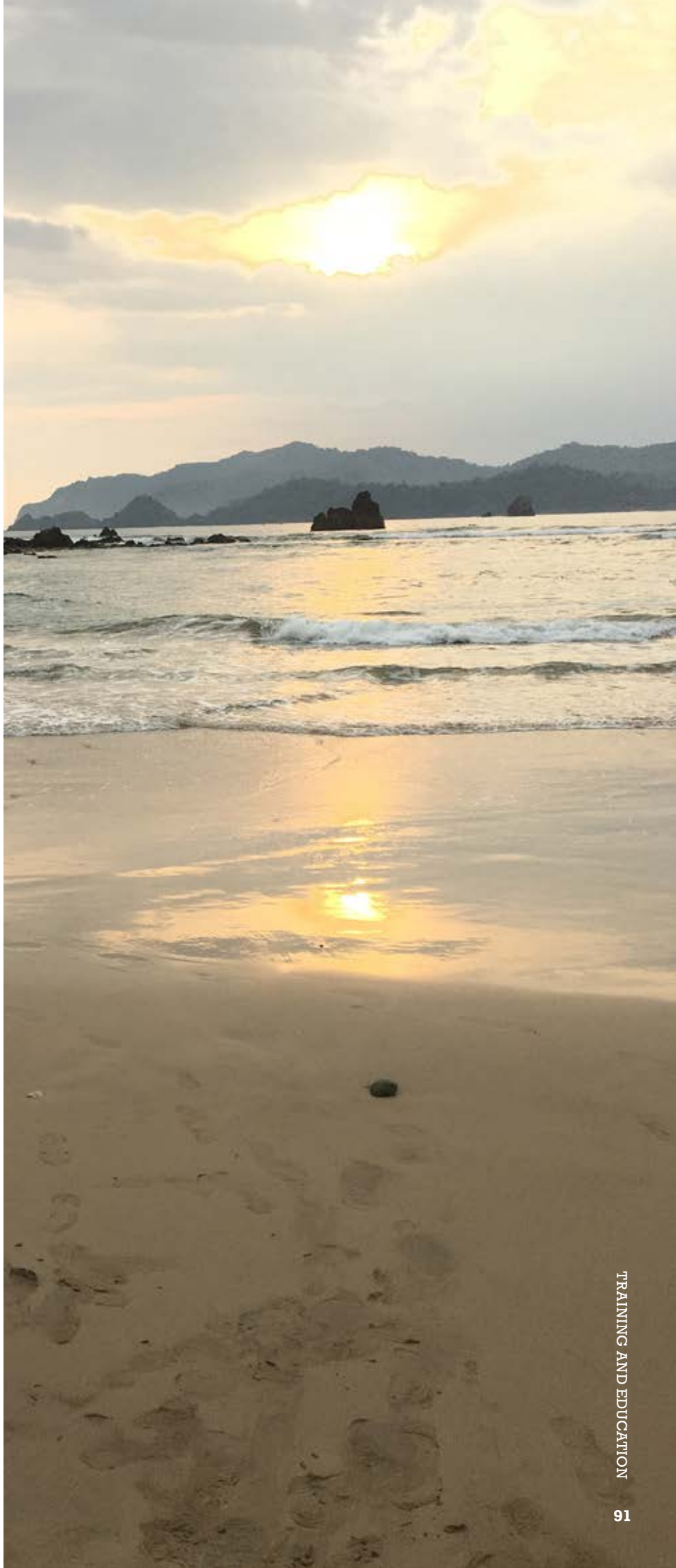
- **The Spectral Geologist**

(Lejun Zhang). This interactive workshop covered the theory of shortwave infrared analyses in Earth sciences, assembly and basic operation of the TerraSpec instrumentation, collecting spectra, and processing and identifying minerals using The Spectral Geologist (TSG) software package.

- **Adobe Creative Suite** (Nathan Fox) included an introduction to Adobe platforms, figure drawing and drafting, and an introduction to InDesign for professional thesis design.

- **Presentation Skills** (Anita Parbhakar-Fox). In the final workshop of the series, the student group was given several exercises to help with their public speaking skills, in an environment where self-analysis and group feedback were encouraged. This was followed by a detailed session showing the students how they can use PowerPoint effectively to get the most out of their newfound skills.

*RIGHT: Downtime: Participants on the MEconGeol course 'Ores in Magmatic Arcs – Indonesia' managed to have some good relaxation time too.*



## STUDENT PROJECTS

### IN AUSTRALIA

Project locations are shown in capitals. Unless marked otherwise, student projects shown here are PhDs. Projects related to the ARC TMVC Research Hub are marked with an asterisk.

#### 1. ANDEMESKEL, EYOB. TAS (MASTERS)

Litho- and chemo-stratigraphic, structural and mineral prospectivity aspects of the Rosebery Group, an enigmatic Cambrian volcano-sedimentary succession on Tasmania's west coast.

#### 2. AWID-PASCUAL, RICHELLE. TAS

The evolution of Zn-Pb-Fe-bearing minerals in the Grieves Siding peat, western Tasmania.

#### 3. CAVILL, CHLOE. VIC (MASTERS)

Geochemical classification of ore fluids, Costerfield Sb-Au deposit, Victoria.

#### 4. CHAPMAN, NATHAN. SA

Pb-isotopic insights into the crustal evolution and metallogenesis of the Gawler Craton.

#### 5. CHERRY, ALEXANDER. SA

Petrology, provenance and composition of bedded sedimentary facies in the Olympic Dam deposit.

#### 6. COUPER, HANNAH. WA (HONOURS)\*

Geology and geometallurgical characterisation of the high Au, low Cu material at West Dome, Telfer Cu-Au mine, WA.

#### 7. DOUTCH, DAVID. WA

The geology and geological controls on gold mineralisation at the Invincible deposit, St Ives Gold Mine, Kambalda, WA.

#### 8. DUERDEN, PETER. NSW

Geological framework and metallogenesis of the Northern Molong Volcanic Belt, Lachlan Orogen, New South Wales.

#### 9. ESHAGHI, ESMAEIL. TAS

Geophysical investigations of Tasmania at multiple scales.

#### 10. FERGUSON, MATT. SA

Late-stage magmatic-hydrothermal evolution of A-type Hiltaba event rocks in the Gawler Craton.

#### 11. FOX, JODI. TAS

Submarine intraplate basaltic volcanism.

#### 12. GILMOUR, SARAH. TAS (HONOURS)\*

Mineralogical and geochemical characterisation of historical slag: evaluating environmental impacts and economic significance.

#### 13. HARDWICK, BRENDAN. WA (MASTERS)

Ore mineral textures and their implication for gold genesis and deportment at the Tropicana Gold Mine, Western Australia.

#### 14. HARRADEN, CASSADY. NSW\*

Geotechnical and geometallurgical assessment by Corescan and complementary microanalytical techniques.

#### 15. HAWKE, MARGY. WA

Geological evolution of the DeGrussa Cu-Au VHMS deposit, Western Australia.

#### 16. HONG, WEI. TAS

Magmatic-hydrothermal volatile exsolution and mineralisation in Tasmanian Sn granites.

#### 17. HUGHES, KYLE. NSW (MASTERS)

Paragenesis of the Dobroyde Deposit, central NSW.

#### 18. JACKSON, AMERY. WA

Geometallurgical controls on grade-by-size fractionation in gold systems with applications to Grade Engineering®.

#### 19. JACKSON, LAURA. NSW\*

Mineralogical domaining of low grade and no grade zones using automated drill core logging.

#### 20. JAGO, COREY. NSW (MASTERS)

Toward an understanding of the temporal, spatial and mineralogical characteristics of the Northparkes Alkaline Porphyry Deposits, New South Wales.

#### 21. JONES, COLIN. TAS (HONOURS)\*

The magmatic hydrothermal transition at Bluestone Bay, Freycinet Peninsula, Tasmania.

#### 22. KULTAKSAYOS, SITTHINON (GUN). TAS (MASTERS)

Provenance of Early to Mid-Paleozoic sediments in western Tasmania.

#### 23. LESLIE, CHRISTOPHER. NSW

Porphyry and epithermal deposits of Cowal District, New South Wales.

#### 24. LLOYD, RICHARD (SIGMUN). NSW (HONOURS)

Comparison of the mineralogy and geochemistry of altered rocks in the Woodlawn and Oberon areas, NSW.

#### 25. MCLAINE, ROBERT. TAS (HONOURS)\*

Determining bioaccessibility risks at the historic Aberfoyle tailings site, North East Tasmania: Opportunities for effective rehabilitation.

#### 26. McMAHON, CLAIRE. TAS

Distribution of, and controls upon, pyrite trace element content of hydrothermal alteration zones at Hercules VHMS ore deposit, Tasmania and NICO IOCG ore deposit, Northwest Territories, Canada.

#### 27. MCMANN, RYAN. WA (HONOURS)

A syn-depositional sill intrusive model for the Golden Mile Dolerite, Kalgoorlie, WA.

#### 28. MORRISON, JOANNE. NSW (MASTERS)\*

Cadia East multi-element lithogeochemistry: Evaluation of trace element deportment important to processing.

#### 29. MUKHERJEE, INDRANI. NT

Pyrite trace element chemistry of black shales of the "boring billion" period.

#### 30. MULDER, JACOB. TAS

From Nuna to Gondwana: An evaluation of the early tectonic history of Tasmania.

#### 31. MUNDANA, RHIANNAN. TAS (HONOURS)

The geological evolution of the Cascade Seamount: implications for understanding the opening of the Tasman Gateway.





**32. NASCIMENTO, SIBELE CRISTINA DO. TAS\***

Geoenvironmental characterisation of historic mine tailings: Evaluating opportunities for reprocessing.

**33. OSTERSEN, THOMAS. TAS**

Geoelectric structure of the Tasmanian lithosphere.

**34. RIDGERS, BEN. TAS (HONOURS)**

Pb isotopic characterisation of ore deposits and prospects from NE Tasmania.

**35. ROPLI, RIQUAN. VIC (HONOURS)**

Age and paragenesis of the Hill 800 prospect, Victoria.

**36. SCHAAP, THOMAS. TAS**

Plate tectonic modelling of the Early Palaeozoic evolution of South Eastern Australia.

**37. SHARMA, SUBIRA. QLD**

Evaluation of the links between Merlin-style Mo-Re mineralisation and magmatism in the Cloncurry fold belt, Queensland: Implications for exploration.

**38. SINFIELD, BEN. NSW (HONOURS)**

Litho-structural control and origin of mineralisation at Carbonate Ridge – Broken Hill, NSW.

**39. SRITANGSIRIKUL, PEERAPONG. NSW (MASTERS)**

Tectonic evolution and ore deposit prospectivity of the Rockley Volcanics, NSW Australia.

**40. WELLS, TRISTAN. NSW**

Geochemistry and cathodoluminescence of magmatic apatite and zircon as vectors to mineralised centres within the Lachlan Fold Belt.

## OUTSIDE AUSTRALIA

Project locations are shown in capitals.

Unless marked otherwise, student projects shown here are PhDs. Projects related to the ARC TMVC Research Hub are marked with an asterisk.

### 1. ABERSTEINER, ADAM. CANADA, FINLAND, RUSSIA, SOUTH AFRICA

Kimberlites and diamonds: Understanding their petrogenesis and uncovering the identity of their source composition.

### 2. AHMED, AYESHA. USA\*

The effect of pressure/depth on propylitic alteration mineral chemistry in the porphyry environment.

### 3. BENAVIDES, SEBASTIAN. ARGENTINA (MASTERS)

Characterisation of sericitic alteration at the Taca Taca Bajo porphyry deposit, Argentina.

### 4. BERKENBOSCH, HEIDI. NEW ZEALAND

Geochemistry of hydrothermal mineral chimneys from Brothers volcano, Kermadec Arc.

### 5. CHEN, JING. CHINA\*

The geology, mineralisation, alteration and structural evolution of Zijinshan ore field, Fujian Province, China.

### 6. CORNELIUS, REBEKAH. SWEDEN (HONOURS)\*

Geoenvironmental characterisation of the Lill-Laverberget Cu-Au porphyry deposit in Laver, Sweden.

### 7. DAVIDSON, ROB. MEXICO

Geology and genesis of the San Sebastian vein system, Durango, Mexico.

### 8. DRAAYERS, EVAN. SW PACIFIC

The boninite magma genesis debate: Assessing the role of mantle sources associated with intra-plate magmatism in the generation of boninitic magmas above subduction zones.

### 9. ESCOLME, ANGELA. CHILE\*

The geology, geochemistry and geomettallurgy of Productora Cu-Au-Mo deposit, Chile.

### 10. FIRMANSYAH, ARGHA. INDONESIA (MASTERS)

Geology and mineralisation of the Trenggalek district, East Java, Indonesia.

### 11. GARAY, AMOS. PERU\*

Magnetite and epidote chemistry and textures at Las Bambas Cu-Au-Fe skarn, Peru: Assessing district and deposit-scale fertility – implications for ore genesis and exploration.

### 12. HARRISON, RACHEL. INDONESIA \*

The Tumpangpitu porphyry gold-copper-molybdenum and high-sulfidation epithermal gold-silver deposit, Tujuh Bukit, southeast Java, Indonesia.

### 13. HEATHCOTE, JACOB. ZAMBIA

Gold distribution and association at the Kansanshi copper-gold deposit, Zambia: Processes responsible for gold precipitation and implications for ore zone delineation and recovery.

### 14. HOLT, SAM. USA

Understanding of basaltic eruption dynamics and mechanisms: Effusive and explosive eruptions in Hawaii.

### 15. IKEGAMI, FUMIHIKO. NEW ZEALAND

2012 submarine silicic eruption of Havre volcano and implications for ancient submarine successions in Australia.

### 16. JACKSON, AMERY. COLOMBIA

Geometallurgical controls on grade by size fractionation in gold systems with applications to Grade Engineering®.

### 17. JIMENEZ TORRES, CARLOS ANDRES. PHILIPPINES

Bantug lithocap, Negros Island, Philippines: Mineralogy, textures, and chemistry.

### 18. JOHNSON, SEAN. FINLAND, ESTONIA, SWEDEN, RUSSIA

The geochemistry of metalliferous black shales: Understanding primary enrichments, metamorphic processes and the role of metal-rich black shales in archiving Earth evolution.

### 19. KNIGHT, JOSEPH. MYANMAR

The geodynamic and metallogenic setting of base- and precious-metal mineralisation in Myanmar: Implications for Cu and Au exploration.

### 20. LAWLIS, ERIN. PNG

Au-bearing pyritic ore of Lihir, Papua New Guinea: Its physiochemical character and nature of the causative fluids.

### 21. McMAHON, CLAIRE. CANADA

Distribution of, and controls upon, pyrite trace element content of hydrothermal alteration zones at Hercules VHMS ore deposit, Tasmania and NICO IOCG ore deposit, Northwest Territories, Canada.

### 22. McNULTY, BRIAN. CANADA

Geology and genesis of the mineral deposits of the Myra Falls VHMS District, Canada.







● CODES Projects  
● ARC TMVC Research Hub

**23. MUKHERJEE, INDRANI.**  
INDIA

Pyrite trace element chemistry of black shales of the “boring billion” period.

**24. PHILLIPS, JOSHUA.** USA\*  
Geologic and geochemical vectors to mineralisation at the Resolution porphyry Cu-Mo deposit, Arizona.

**25. POTTER, NAOMI.** TANZANIA, RUSSIA  
An investigation into the genesis of intrusive and extrusive carbonatitic melts.

**26. ROJAS LOPEZ, JUAN DIEGO.** PERU (MASTERS)  
Origin, characteristics and age of mineralisation of the Ollachea orogenic gold deposit, Region Puno, southeastern Peru: Implications for exploration.

**27. SCHAAP, THOMAS**  
ANTARCTICA (HONOURS)  
Geophysical investigation into Sørsdal Glacier, East Antarctica.

**28. STAAL, TOBIAS.** ANTARCTICA  
Seismic and geological constraints on the lithospheric structure of Antarctica.

**29. STEEVES, NATHAN.** USA  
Ore genesis of the Greens Creek VHMS Deposit, Alaska: Implications for mining, milling and exploration.

**30. SUN, YI.** PHILIPPINES\*  
Mineralogical, textural, geochemical characterisation and geometallurgical models of Lepanto Quartz–Pyrite–Gold vein and breccia system, Philippines.

**31. SYKORA, STEPHANIE.** PNG\*  
Origin, evolution and significance of anhydrite-bearing vein arrays and breccias, Lienetz orebody, Lihir gold deposit, Papua New Guinea.

**32. TESTA, FRANCISCO.** ARGENTINA, CHILE  
Tourmaline breccia pipes: San Francisco de los Andes, Argentina and Rio Blanco-Los Bronces, Chile.

**33. THOMPSON, JENNIFER.** INDONESIA, PHILIPPINES\*  
Carbonate mineral chemistry in epithermal and porphyry hydrothermal systems.

**34. VERGANI, DANIELE.** REUNION  
The 2007 explosive activity at Piton de la Fournaise volcano (Reunion): Constraints on the eruptive processes by the volcanological study of the erupted deposits.

## LAB-BASED PROJECTS

Unless marked otherwise, student projects shown here are PhDs. Projects related to the ART TMVC Research Hub are marked with an asterisk.

### DONAGHY, JONATHON. (HONOURS)

Creating sedimentological logs from 3D models of outcrop.

### GAL, MARTIN.

Seismic array analysis of ocean induced microseisms.

### HOOD, SHAWN.\*

Machine learning and automated geoscientific analyses for the spatial characterisation of metalliferous ore deposits.

### JACKSON, STEWART. (HONOURS)

Finite difference wavefield modelling for mining scale seismology.

### JOB, KATHRYN. (HONOURS)

A palaeomagnetic analysis of the Palaeozoic orocline model for Tasmania.

### KUHN, STEPHEN.\*

Lithological mapping for mineral exploration using machine learning.

### LOUNEJEVA, ELENA.

Geochemical signature of syngenetic and diagenetic pyrite from marine sediments as a paleo-environmental tool.

### MEYER, STEPHEN.

A model-based approach to the interpretation of seismicity associated with mass mining.

### MORSE, PETER.

Interactive visualisation for data inference in the geosciences.

### THOMPSON, JAY.

Understanding the specifics of H<sub>2</sub>O-free aerosol behaviour in the inductively-coupled plasma in geochemical LA-ICP-MS applications involving U/Pb dating and accurate trace element analysis in silicate minerals and glasses.

*BELOW: Four CODES students were awarded their PhDs in December 2017. Bruce Gemmell and David Cooke flank newly-minted PhDs Margy Hawke, Stephanie Sykora, Richelle Awid-Pacsual and Jacob Mulder (standing behind Richelle).*





# SOCIETY OF ECONOMIC GEOLOGISTS (SEG) STUDENT CHAPTER

The CODES SEG Student Chapter at the University of Tasmania is a student branch of the Society of Economic Geologists, dedicated to pursuing and disseminating geological knowledge among its members by organising academic and social activities. The Society plays an important role at CODES, making significant contributions to the social and professional lives of students from a diverse range of backgrounds and cultures. Towards the end of each year, the students vote for a committee that plans and oversees a comprehensive social and professional development program that caters for everyone at the Centre, including students, researchers and professional staff.

## LECTURES AND MEETINGS

The SEG Student Chapter maintained its tradition of holding informal seminars, regular 20-minute technical talks, and short courses. Eleven invited speakers from academia and industry gave talks in 2017–2018, ranging from the use of data analytics in exploration projects, to deposit characterisation studies, to reports on PhD field programs. A highlight included the 2017 SEG Thayer-Lindsley lecturer, Dan Wood, who gave a three-part seminar on mineral deposit discovery case studies. Another especially well-attended event was Greg Corbett's one-day short course on porphyry-epithermal models and practical exploration strategies.

The Student Chapter assisted in promoting and organising a portable XRF workshop in conjunction with the AusIMM and CSIRO as part of the Tenth International Mining Geology Conference 2017, held in Hobart during September. In return for organising the logistics, SEG members were offered a significantly discounted course rate, making the workshop more accessible to

students. Workshop leader Michael Gazley (CSIRO) used case studies to highlight best-practice pXRF data collection and post-collection processing methods. The course was well attended by undergraduate and graduate students, as well as industry participants from Canada, the USA and Chile.

The Solomon Lecture Series is an annual event which has been held at CODES/UTAS since 2011. Invited speakers are former students of Dr Mike Solomon, who present their research and experience in memory of Dr Solomon who passed away in 2009. The 2017 Michael Solomon Memorial Lecture was delivered by Dr John Walshe, who has researched and published numerous papers on mineral systems and geochemistry for over 40 years. Dr Walshe is currently the Chief Research Scientist with the CSIRO. John provided insight into his understanding of Mike's philosophy and knowledge of ore deposits.

Another highlight from 2017 was the Chapter's hosting of the Tasmanian Minister for Mines and Resources, the Honourable Guy Barnett, in August. Minister Barnett attended the department for several hours as a guest of the CODES SEG. Staff and students received an update on the state of mineral resources in Tasmania, along with the Minister's thoughts on potential future employment for UTAS graduates in the sector. Afterwards, during a lengthy question-and-answer session, a range of related discussions took place.

UTAS, AusIMM and WIMNet student chapter groups were active in 2017. In early June, we hosted an informal 'postgraduate-undergraduate social'. Its purpose was to introduce undergraduates to what postgraduate work can offer, the different paths that have led students to take on a PhD, and the jobs they plan to pursue after graduation. The event was a total success with over 40 people in attendance, and a good mix of both undergraduate and postgraduate students. The PhD students were put to the test when they were asked to present for only five minutes each! Sincere thanks

to Jing Chen, Josh Phillips, Jacob Mulder and Laura Jackson for their efforts.

In August, we hosted a presentation by Rio Tinto's Debora Araujo. Debora works with the Rio Tinto Growth and Innovation team at Bundoora outside Melbourne. She gave an overview of her life from undergraduate studies through to the present, highlighting the decisions she made both personally and professionally to get her to where she is today. The discussion following her talk was highly engaging tackling issues ranging from mineral chemistry to gender equality and equal opportunity in the workforce. Sincere thanks to AusIMM, WIMNet Tasmania, CODES (University of Tasmania) and the Society of Economic Geologists Student Chapter for funding both events. We look forward to hosting many similar events in the months to come.

## CONFERENCES, EXHIBITIONS AND PUBLICATIONS

One of the key areas in which the students contribute to enhancing CODES' profile is by attending and presenting papers at domestic and international conferences. A number of the CODES SEG Chapter members presented at conferences across the world during the year. These include Student Chapter members presenting topics of their research at the SGA conference in Quebec City, Canada; Goldschmidt conference in Paris, France; FUTORES II conference in Townsville, Australia; Mining Geology conference in Hobart, Tasmania; and Drilling for Geology II conference in Brisbane, Australia. Three Student Chapter members attended the 2017 SEG Conference in Beijing. These three students received support from the SEG to attend the conference and presented four oral presentations related to their PhD research.

It was also another highly productive period for student outputs in terms of publications, with several refereed journal articles being produced throughout the year.



*ABOVE: Participants of the 2017 CODES SEG Student Chapter field trip to western Tasmania take a well-earned break.*

## ANNUAL FIELD TRIP

In mid-December, the CODES SEG Student Chapter arranged a field trip to northwest and western Tasmania. The trip presented 14 postgraduate and undergraduate students with an opportunity to learn about the geological evolution and mineral deposits of Tasmania. The first three days were dedicated to regional-scale geology and geological history, with the group visiting key outcrops across the northwest coast guided by postdoctoral researcher Jacob Mulder. The next four days had an economic geology focus where the group toured a series of operating and legacy mine sites across western Tasmania with expert guides from Mineral Resources Tasmania, including Ralph Bottrill and Carl Jackman.

The trip began with a transect along the exposed boundary between Proterozoic rocks of the Ulverstone metamorphic complex, and unmetamorphosed rocks of the Proterozoic Burnie Formation, followed by vertical cross-sections through Ordovician limestone and sandstone. Placer gold deposits hosted in Permo-Carboniferous tillite were a special highlight.

After touring Proterozoic Tasmania, with a focus on tectonic history and reconstructions, the group moved on to several famous ore deposits. Chief among these was Mount Bischoff, the first major mine in

Tasmania, and one of the richest tin mines in the world. Mount Bischoff is currently being progressed through mine closure, with rehabilitation requirements largely related to legacy issues from historical mining. We were lucky to have a full morning in the inactive open pit. Renison Bell, currently the only operational tin mine in Tasmania, was next. The mine visit consisted of two themes:

- economic geology, with a comprehensive overview of the deposit at the core shed; and
- geometallurgy, with a tour through the mill and complex processing circuit.

Towards the end of the trip we visited the historic mining school at Zeehan (now an excellent museum) and a variety of crocoite mineral specimen mines. A number of shorter geological stops rounded out the excursion, and attendees completed the trek with an excellent overview of Tasmanian geology.

## SOCIAL EVENTS

Social events are another important activity organised by the CODES SEG Student Chapter: they provide a chance for postgraduate students to get to know the undergraduate cohort, and for the greater student body to get exposure to researchers and industrial sponsors in a relaxed, social environment.

Two speaking events involving Chapter members dealt specifically with providing practical information to undergraduates. The aim of these was to share details of Chapter members' early-career successes. Four postgraduate presentations were given under the banner 'My Experience in Industry'. CODES postgraduates gave excellent overviews on their career paths thus far, and reflections on which choices and experiences had been most valuable. Most interesting was the diversity of paths between the speakers, differing nationalities, and relative experiences in academia or industry. The function was attended by more than 30 undergraduates. During a half-time break and afterwards these students networked with postgraduates.

The locus of CODES and the SEG Student Chapter is the communal lunch room. The 'Winter Warmers' trend continued, where affordable homemade soup and bread were provided to the department, both as a social exercise and to fundraise. The most intense event in 2017 involved a cook-off challenge of Russian-made vs. Australian-made borscht. Both nationals made their country proud that day, but the Russian soup was a clear winner: the serving bowl was clean. Continuing the social event theme, the Student Chapter organised multiple social barbeques and icebreakers for new



Honours and Master of Economic Geology students, numerous pub evenings and movie nights, and assisted with Earth Science/CODES 70th anniversary events and holiday get-togethers.

## FUNDRAISING

In 2017, the SEG Student Chapter received \$2,165 of Stewart R. Wallace Funding from the Society of Economic Geologists. This funding is being used to promote the Society's objective of advancing the study of mineral deposits by supporting the field trips organised by the Student Chapter. Our Chapter provides a small tea and coffee station for staff and postgraduates, with weekly milk delivery to the Chapter fridge. Payment for this is via an 'honesty box' which essentially covers costs of the service and generates a nominal amount of income for the Chapter. Additionally, the Chapter coordinates a geological equipment store, including mineral ID kits for undergraduates, hammers, hand lenses of every description, notebooks, and more. Pricing is designed so that key equipment for fieldwork is provided nearly at cost; this service keeps students in possession of key equipment and is an irreplaceable means of first-engagement by undergraduate members with the Chapter. Approximately \$1,119 was raised through the preceding events, earmarked for an upcoming field trip.

## AWARDS AND GRANTS

Again CODES SEG Student Chapter members were successful in gaining awards and grants from a number of sources including:

- Amos Garay, Jing Chen and Shawn Hood received SEG travel grants to attend the 2017 Beijing SEG conference.
- Ayesha Ahmed received a UTAS Travel Grant to attend Exploration 17, the Sixth Decennial International Conference on Mineral Exploration in Toronto, Canada. Ayesha also won an AusIMM Education Endowment Scholarship.
- Cassady Haraden won an award for the best speaker at the GSA Earth Sciences Student Symposium held in Hobart in November.

## LOOKING FORWARD

The healthy level of HDR enrolments should be maintained in 2018, with the number of graduations being balanced by a strong intake of new students, from both Australia and overseas.

The Master of Economic Geology Program will again present a full offering of three short courses in 2018, beginning with the field-based short course Volcanology and Mineralization in Volcanic Terrains in March, which will be led for the first time by the new team of Rebecca Carey, Martin Jutzeler and David Cooke. Next up is the Exploration in Brownfield Terrains short course in June, which introduces participants to a range of cutting-edge techniques in machine learning, geophysics, geochemistry, hyperspectral mineral analysis and 3D visualisation, and their application to exploration in the typically data-rich environments close to existing mines. This short course is presented by a mix of expert staff from CODES and the minerals industry.

A very special event is planned for the final Master of Economic Geology short course for the year, Ore Deposit Models and Exploration Strategies, in late October 2018. This short course will begin with a three-day symposium dedicated to the career contribution of Dr Garry Davidson. The symposium will address current ideas on genesis and exploration for iron oxide Cu-Au (IOCG), uranium, sediment-hosted base metal, volcanic-hosted massive sulfide (VHMS) and orogenic and intrusion-related gold deposits; the deposits types that Garry worked on most extensively throughout his career. The more than 30 invited speakers for the Symposium include many of Garry's past students, colleagues and collaborators. Following the symposium, the remainder of the short course will cover skarns, granite-related Sn-W, porphyry-Cu, Au, and Mo deposits, high, low- and intermediate epithermal deposits, Carlin-type gold deposits and the ore deposits of Tasmania.

Based on the large number of enquiries from prospective students, and increasing optimism in the Australian minerals industry, CODES expects to see an increase in student numbers in the Master of Economic Geology program in 2018. In contrast, Honours enrolments are likely to remain at a low level in the coming year, reflecting the decrease in undergraduate student numbers in the years following the mining boom. However, if career opportunities in the minerals industry continue to improve as they have over the past couple of years, undergraduate student numbers should improve in future years. The series of Honours workshops introduced in 2016 will continue, as will the successful courses run in conjunction with the Victorian Institute of Earth and Planetary Sciences (VIEPS).

Following the highly successful inaugural Geological Society of Australia Earth Sciences Student Symposium at the UTAS Institute of Marine and Antarctic Studies (IMAS) in 2017, CODES and the Discipline of Earth Sciences will host the second GESS Symposium on 16 November 2018. This event provides an important platform for students to showcase the results of their research to an audience of their peers, government and minerals industry representatives, and academics. The SEG Student Chapter is also planning to have another full schedule of social and professional development events throughout the year.







Each year, CODES works with the Discipline of Earth Sciences to engage in a program of activities aimed at promoting the value of the geosciences to the broader community, and encouraging young people to consider a career in this field. The past year was another busy period for this program, which saw a further expansion of the range and breadth of outreach activities, both on campus and in the local community, as this selection of activities shows:

### SCIENCE EXPERIENCE

CODES and Earth Sciences hosted 39 Year 9/10 students as part of the Science Experience program on 25 January. Hands-on demonstrations included seismology, determining the ages of rocks (using both palaeontology and a laser ablation mass spectrometer), and a look at a variety of Tasmanian rocks with the aid of petrological microscopes.

### SCIENCE IN THE PUB

In February, Matthew Cracknell was part of a Science in the Pub panel discussing big data – the session was entitled 'It's not the size of the data – it's what you do with it'.

### HEAVY METALS PROJECT SHOWCASE AT MONA MARKET

Also in February, researchers from the ARC Transforming the Mining Value Chain (TMVC) research hub and IMAS (led by Associate Professor Catriona Macleod) exhibited their research outcomes at the Mona Market (MOMA): this research was the culmination of work carried out in 2016 under the Heavy Metals Project, several strands of which focussed on pacific oysters.

*OPPOSITE PAGE: (Top left) PhD student Tristan Wells was among CODES/Earth Sciences personnel promoting the study of geology with a booth at the Festival of Bright Ideas, held on Hobart's waterfront on 11 and 12 August. (Top right) Dr Robert Scott is interviewed by Hilary Burden for ABC Radio's The Country Hour about the MEconGeol Geometallurgy field trip to Tasmania's West Coast. (Bottom) The Earth Sciences' newly acquired T-rex dinosaur was used to promote research and teaching at the 2017 Open Day in Hobart in July.*



*ABOVE: The TMVC Geoenvironmental team: (L-R) Sarah Gilmour, Rebekah Cornelius, Anita Parbhakar-Fox, Laura Jackson and Rob McLaine at the Mona Market, presenting their research which formed part of the Heavy Metals Project.*

The Heavy Metals Project was founded in 2014 by Mona's Kirsha Kaechele, who was motivated to improve the water quality of the heavily contaminated Derwent River. This project nurtures collaborations between artists and scientists hoping that their shared skills will develop innovative and stimulating solutions to protect and fix the Derwent.

Dr Anita Parbhakar-Fox and her geoenvironmental team from the TMVC led a 'live' experiment supported with a visual installation (produced by Keith Deverell, RMIT) to explain how two waste streams could be blended to improve the health of a mine-affected river system.

Anita explained: 'Approximately 4 million tonnes of oyster shell waste is generated annually. In many cases, this is sent to landfill. We collected shell waste from two local oyster sheds, mineralogical analysis confirming them as pure calcium carbonate – a potent neutraliser. The live experiment took acid mine drainage water (produced when iron sulfide minerals contained in the solid mine waste oxidise) and added oyster shells and then tracked the pH response. Within 15 minutes, we saw the pH increase from 2.7 to 5.5. Therefore, instead of landfilling, we could recover the shell waste and use it to build flow-through reactors

to neutralise acid mine drainage. There are already examples in New Zealand using mussel shell waste to neutralise acidic drainage from coal mines. Conceptually, this cost-effective technology could work too in Tasmania, particularly when treating waters from abandoned mine sites'.

Researchers in the TMVC Hub aim to develop a lab-scale flow-through reactor prototype using this material as part of their research.

### GEOLOGIC TIME SCALE

In July, approximately 90 primary students accompanied by their teachers, parents and/or guardians participated in a 'Geologic Time Scale' activity organised by PhD candidates Cassady Harraden and Brian McNulty. Marine and terrestrial fossils throughout Earth's history were examined by the students while Cassady and Brian provided an introduction to: How old is the Earth; what is a palaeontologist and when did the dinosaurs rule? As well as the Geologic Time Scale activity, students made pH measurements on rock samples and looked at rocks under the microscope. Laura Jackson, Naomi Potter, Rebekah Cornelius, Karin Orth and Sean Johnson assisted.

## UTAS OPEN DAY

At the Hobart campus Open Day on 31 July, the Earth Sciences' newly acquired large T-Rex interactive dinosaur costume was used to promote our research and teaching program, the Royal Society of Tasmania's 175th anniversary and a dinosaur exhibition scheduled for TMAG in 2018.

Once again CODES and Earth Sciences staff participated in a range of hands-on activities designed to engage young and old in the study of geology and Earth science. Activities included panning for gold and sapphires, demonstrations of bicarb volcanic eruptions, lab tours and slinky seismic waves.

CODES staff also travelled to the Launceston campus to participate in Open Day activities: Karin Orth gave a presentation about dinosaurs and mass extinctions. Anita Parbhakar-Fox and Laura Jackson manned (or womanned) a stall for the day.

## PUBLIC LECTURE: DINOSAUR OR DELIVERER?

In August CODES facilitated a public forum at the RACV/RAC Apartment Hotel in central Hobart aimed at raising community awareness and understanding of the current issues around the future of mining in Tasmania – is the mining industry a 'dinosaur' or a 'deliverer' of a sustainable source of economic prosperity for the State?

Moderator Louise Saunders from ABC Radio in Hobart introduced a panel of guest speakers including CODES' own Anita Parbhakar-Fox; Saul Eslake, an independent economist; and Phil Vickers, the Mayor of the East Coast Council. They ranged across issues from the role of technology and innovation in sustainable mining to alternatives to mining as a means of obtaining the resources the world needs.

## FESTIVAL OF BRIGHT IDEAS

Earth Sciences/CODES staff and students promoted the study of geology with a booth at the Festival of Bright Ideas held at PW1 on Hobart's waterfront on 11 and 12 August. The festival is part of National Science Week each year and was a free, family-friendly event to inspire young and old with fun and interactive science activities.

Dr Mike Roach was there to explain the AusGeol Virtual Library of Australia's Geology, which he has been instrumental in setting up, and PhD student Tristan Wells assisted visitors to find out the type of rock on which their homes were built. Overall it was a successful two-day outreach event with around 2,000 school children visiting on the first day and around 5,000 on the second day.

*BELOW: PhD student Nathan Chapman (left) is interviewed by ABC Radio Northern Tasmania about his work on the Gawler Craton; he is pictured with Zach Brown, a UTAS biology PhD student.*





## THE ROCK LIBRARY

Our Rock Library is a continual source of inspiration and wonder – and not just for the staff and students here at CODES. Our rock library curator Isabella (Izzy) von Lichtan again used her knowledge and skills to produce items for display to the public or to collaborate with other institutions. Highlights for 2017 included:

- Providing samples for the interactive/hands-on parts of the exhibition 'One Hell of an Inferno: The 1967 Tasmanian Bushfires', which opened in February at the Tasmanian Museum and Art Gallery.
- Providing samples and geological background/context for the exhibition 'Imagining food: Art, aesthetic and design' held at the Academy Gallery as part of the Ten Days on the Island arts festival during March and April.
- Assisting with samples, including unusual crystalline minerals, and context for the 'Treasures from the University of Tasmania Collections' exhibition at the Academy Gallery in April/May to raise awareness about the diversity of research material held by UTAS.
- Restoring a wooden cabinet – built by Professor Max Banks and displaying within it a selection of fossils that he used during his research – for the Max Banks Memorial Talk 2017 in November.

## SCHOOL VISITS AND TRIPS

Once again CODES and Earth Sciences worked together to host a large number of visits from both primary and secondary schools.

Fahan School students visited the Earth Sciences department in June to view geological demonstrations involving microscopes and lasers. The Bigger Things Project, a joint UTAS/State Government initiative, aims to improve retention and transition among Huon Valley students; Huonville High School students visited the campus in June. And students from Ogilvie High School's Learning Centre visited the Earth Sciences department in August, hosted by Dr Rebecca Carey.



*ABOVE: Children who attended Open Day in Hobart were keen to pan for gold and sapphires.*

Younger children didn't miss out: Lady Gowrie Child Care Centre visited the Earth Sciences department in August, hosted by Dr Anita Parbhakar-Fox, Dr Nathan Fox and Dr Angela Escolme. Waimea Heights Primary students from Grade 1 visited Earth Sciences/ CODES in September.

Off-campus activities included Dr Michael Roach visiting Hutchins School to promote geology to classes in September – three classes on two consecutive days.

## MEDIA

Media coverage of things geological continued apace with several staff members from CODES and Earth Sciences being asked for their input on a variety of issues across all media platforms. These included:

- Professor Leonid Danyushevsky interviewed by ABC Radio (Hobart) on 28 February about his collaborative research relating to how the Earth's atmosphere and oceans formed.

- Dr Rebecca Carey interviewed by ABC Radio (Hobart) on 21 March about Earth and Marine Sciences' achievement of being placed in the top 50 in the QS World University Rankings.
- Emeritus Professor Ross Large giving several ABC interviews related to Earth evolution and ore deposit cycles.
- Dr Robert Scott interviewed in November by ABC Radio's The Country Hour while in western Tasmania on the CODES Geometallurgy MEconGeol field trip.
- Dr Anita Parbhakar-Fox was asked to do a promotional video for Olympus with the KEA 348 class (watch the video at: <https://www.youtube.com/watch?v=qlgsJzwDNNU>).

## SOCIAL MEDIA AT CODES

CODES/Earth Sciences has an active presence on social media:



Earth Sciences Facebook page:  
<https://www.facebook.com/EarthSciUTAS/>



TMVC Facebook page:  
<https://www.facebook.com/tmvc.utas>



TMVC Twitter:  
[https://twitter.com/tmvc\\_utas](https://twitter.com/tmvc_utas)

## OBJECTIVES

- To be a research focus for the national and international minerals industry.
- Strategically collaborate with other top-level national and international research groups in the field of ore deposits, mineral exploration technologies and mineral processing.





CODES is recognised as a world leader in industry-linked, collaborative ore deposit research. Strong relationships have been developed with a range of industry partners and researchers who invest in, support, and contribute to, research projects. Fostering and growing these national and international collaborations is a key strategic focus.

## INDUSTRY LINKS AND SYNERGIES

CODES has strong, enduring and mutually beneficial links with a group of major Australian and international mining companies. These links have been critical for funding CODES' research, and for technology transfer to the mining and mineral exploration community.

In 2017, the group of CODES' industry partners comprised of nine Australian and international mining companies: Anglo American, AngloGold Ashanti, Barrick, Buenaventura, First Quantum Minerals, Mount Isa Mines (Glencore), Newcrest Mining, Rio Tinto and Teck.

Partner companies have been providing support of up to \$60,000 in cash per year to the core research budget of the Centre. Representatives of these companies are invited to the CODES Annual Review, along with other government and university researchers. The Annual Review showcases the breadth of research undertaken at the Centre through a day of oral and poster presentations for

our stakeholders, and offers the opportunity to influence future research directions. Gold and Platinum Partners are also offered a seat on the CODES Advisory Board, which meets annually to discuss the strategic direction of the Centre.

## INDUSTRY PARTNERSHIP OPPORTUNITIES

CODES offers partnership opportunities aligned to the evolving needs of mining companies. The minerals industry is cyclical by nature, and operating conditions can vary greatly from one year to the next, often through unforeseen circumstances. For this reason, our partnership opportunities are offered on an annual basis, giving partners the flexibility to adjust their involvement in line with their current operating conditions and research requirements.

Funding levels are tailored to suit all levels of operation, from junior explorers through to the large multinationals. Companies may sign up at either the Silver (\$20K), Gold (\$40K) or Platinum (\$60K) level, depending on their planned level of involvement with the Centre.

Benefits of a partnership agreement vary depending on the level of investment, but include enhanced prospects of discoveries, optimisation of existing reserves, first call on geoscience graduates, and access to a world-class research team and state-of-the-art facilities. Further details can be found at: <http://www.utas.edu.au/codes/about-us/industry-partnership-program>

## ROLE OF AMIRA INTERNATIONAL

AMIRA plays a vital role in facilitating the funding of collaborative research involving university research groups and the minerals industry. AMIRA has agreed to fund projects within the Centre, which will run over a period of three to four years. In 2017 it funded AMIRA P1153 Applying the explorers' toolbox to discover porphyry and epithermal Cu, Au and Mo deposits, which is being conducted within the ARC TMVC Research Hub.

## RESEARCH COLLABORATIONS

In 2017, CODES further cemented its reputation for cultivating research collaborations with other Australian and international research organisations. Throughout the year, collaborative research was conducted with 90 international and 24 national organisations.

*OPPOSITE PAGE (Bottom): AMIRA P1153 team members and sponsors pictured at the 7th sponsors' meeting, Hobart, November 2017. David Cooke, the Director of CODES, is fifth from right. (Top) Ross Large (right) talks with Mike Whitbread from Rio Tinto, one of the CODES sponsors for 2017.*



# Technology transfer

## OBJECTIVES

- Involve end-users (exploration and mining companies) in research planning, research evaluation and research adoption.
- Promote technology transfer so that innovative research outcomes are accessible to end-users.
- Comply with the national principles of intellectual property management for publicly funded research.

## TECHNOLOGY TRANSFER ACTIVITIES

CODES undertakes strategic and applied research into ore deposits (characterisation and context) and geometallurgy, and the development of innovative enabling technologies to support these research endeavours. These initiatives create knowledge, processes, methods and solutions for the minerals industry and ore deposit researchers – locally, nationally and internationally.

Research results and technical developments in the applied research programs are transferred to end-users via regular research meetings, research reports, monographs, books, digital presentations and software packages, where appropriate. In 2017, 126 research reports were presented to industry clients. Meetings were also held to present and discuss progress and adoption of research results.

## PUBLICATIONS TARGETED AT END-USERS

CODES also delivers knowledge and applications to end-users and the wider scientific community through a selection of special publications that represent the culmination of major research efforts by the Centre's staff. The following publications were sold during 2017.

- *Altered volcanic rocks: A guide to description and interpretation* (2005). Authors: C Gifkins, W Herrmann and R Large (26 copies).
- *Basins, fluids and Zn-Pb ores*. CODES Special Publication 2 (1999). Editors: O Holm, J Pongratz and P McGoldrick (3 copies).
- *Geophysical signatures of copper-gold porphyry and epithermal gold deposits, and implications for exploration* (2011). Author: T Hoschke (26 copies).
- *Giant ore deposits: Characteristics, genesis and exploration*. CODES Special Publication 4 (2002). Editors: D Cooke and J Pongratz (1 copy).
- *The geology and origin of Australia's mineral deposits* (2000). Authors: M Solomon and D Groves (7 copies).
- *The geology of the Broken Hill Pb-Zn-Ag deposit, NSW, Australia* (2006). Author: A Webster (2 copies).

- *24ct Au workshop*. CODES Special Publication 5 (2004). Editors: D Cooke, C Deyell and J Pongratz (1 copy).
- *Volcanic environments and massive sulfide deposits* (2000). Editors: JB Gemmell and J Pongratz (6 copies).
- *Volcanic textures: A guide to the interpretation of textures in volcanic rocks* (1993). Authors: J McPhie, M Doyle and R Allen (40 copies).

## SHORT COURSES, WORKSHOPS, CONFERENCES AND FIELD TRIPS FOR END-USERS

Short courses, workshops, conferences and field trips continued to play a key role in the Centre's technology transfer activities. Throughout the year, a total of 22 events in these categories were held at various locations around the world, including Canada, Chile, China, India, Indonesia, Myanmar and New Zealand.

Total attendance by industry geologists, academic researchers and postgraduate students was 760, with 34 different presenters from CODES involved in delivering the lectures or leading the conferences or field trips.

*BELOW: Participants of the highly successful 'Ores in Magmatic Arcs – Indonesia' short course, which ran as part of the CODES MEconGeol program for the first time in 2017, pictured at Mount Ijen, Indonesia, in March. The climb up to the top of Mount Ijen took place in the early morning, and the face masks are to protect participants from the volcanic gases.*





## 2017 SHORT COURSES, WORKSHOPS, CONFERENCES AND FIELD TRIPS LED BY CODES

TITLE	PRESENTERS	NO.	LOCATION	DATE
AGU Chapman Conference: Submarine Volcanism	<b>Rebecca Carey</b> , Ray Cas, Mike Coffin, <b>Martin Jutzeler</b> , <b>Jocelyn McPhie</b> , Karin Orth	100+	Hobart	29 January–3 February
Cenozoic Submarine Basaltic Volcanism, post-AGU Chapman Conference field trip	<b>Jodi Fox</b> , <b>Jocelyn McPhie</b>	15	Northwestern Tasmania	4–7 February
Exploration Field Skills Mapping Camp (VIEPS)	<b>Martin Jutzeler</b> , <b>Robert Scott</b>	13	Hobart, Western Tasmania	5–12 February
Gold17, pre-conference short course: Epithermal Mineralisation	<b>David Cooke</b> , Stuart Simmons	30	Rotorua, New Zealand	19–20 February
Ores in Magmatic Arcs – Indonesia (MEconGeol short course)	<b>David Cooke</b> , Rachel Harrison, Iryanto Rompo, <b>Lejun Zhang</b>	21	Indonesia	19–31 March
VMS and SEDEX Zn-Pb Deposits: Features, Genesis and Exploration, presented to Hindustan Zinc Ltd., Udaipur, India	Mihir Deb, <b>Ross Large</b>	40	Udaipur, India	4–6 April
Volcanic successions in Northland New Zealand: a Miocene equivalent of the Kermadec arc, field trip to Northland, New Zealand	<b>Martin Jutzeler</b>	9	Auckland, New Zealand	16 April
Ore Deposit Models (VIEPS)	<b>Mike Baker</b> , <b>Sean Johnson</b> , <b>Chris Large</b> , <b>Ross Large</b> , <b>Brian McNulty</b> , <b>Evan Orovan</b> , <b>Robert Scott</b> , <b>David Selley</b> , <b>Jeff Steadman</b> , <b>Lejun Zhang</b>	17	CODES, Hobart	Late May
Practical Igneous Petrology (VIEPS)	<b>Leonid Danyushevsky</b>	8	CODES, Hobart	Late May
Ore Deposit Geochemistry, Hydrology and Geochronology (MEconGeol short course)	<b>Mike Baker</b> , Shaun Barker, <b>Ron Berry</b> , Phil Blevin, <b>David Cooke</b> , Stephen Cox, <b>Tony Crawford</b> , <b>Leonid Danyushevsky</b> , Scott Halley, <b>Sebastien Meffre</b> , Nick Oliver, <b>Robert Scott</b> , <b>Jeff Steadman</b> , Leslie Wyborn, <b>Lejun Zhang</b>	42	CODES, Hobart	12–23 June
Introduction to X-ray diffractometry and Rietveld refinement using Topas	<b>Nathan Fox</b> , Ian Madsen	10	CODES, Hobart	3–7 July
SGA post-conference workshop: Recent advances in micro-analytical techniques applied to ore deposits	<b>Mike Baker</b> , <b>David Cooke</b>	17	Quebec, Canada	24–25 August
Environmental Geology Field Techniques (VIEPS)	<b>Matthew Cracknell</b> , <b>Angela Escolme</b> , <b>Nathan Fox</b> , <b>Laura Jackson</b> , <b>Thomas Ostensen</b> , <b>Anita Parbhakar-Fox</b>	10	Hobart, Eastern Tasmania	5–8 September
SEG Beijing pre-conference workshop: Porphyry Copper, Gold and Molybdenum Deposits	<b>David Cooke</b> , Peter Hollings	32	Beijing, China	16–17 September
Advances in Geologging	<b>Ron Berry</b> , <b>Martin Jutzeler</b> , <b>Evan Orovan</b> , <b>Robert Scott</b>	5	Hobart, Eastern Tasmania	18–22 September
SEG Beijing post-conference field trip: Porphyry and Epithermal Systems of the Sunda-Banda Arc, Indonesia	Adi Maryono, Iryanto Rompo, <b>Noel White</b> , <b>Lejun Zhang</b>	23	Indonesia	21–27 September
Geometallurgy (MEconGeol short course)	<b>Ron Berry</b> , Naomi Boxall, <b>Matthew Cracknell</b> , <b>Angela Escolme</b> , Sandrin Feig, <b>Nathan Fox</b> , John Glen, <b>David Green</b> , <b>Cassady Harraden</b> , <b>Laura Jackson</b> , Luke Keeney, Angus McFarlane, <b>Sebastien Meffre</b> , <b>Anita Parbhakar-Fox</b> , Michael Scott, <b>Jay Thompson</b> , Steve Walters	27	CODES Hobart, and Western Tasmania	23 October–3 November
Porphyry workshop	<b>David Cooke</b>	30	U Austral, Chile	3 November
Inaugural Myanmar Applied Sciences Association (MAESA) Conference field trip	Lin Thu Aung, Cho Cho Aye, Tin Aung Myint, Kyaw Thu, <b>Khin Zaw</b>	17	Mandalay-Sagaing, Shan State, Myanmar	4–8 November
12th Annual Workshop – Ore Deposit Models and Exploration	<b>David Cooke</b> , <b>Noel White</b> , <b>Lejun Zhang</b>	250+	Changshan, China	12–17 November
9th AMD Workshop '17, Zeehan field trip	<b>Sarah Gilmour</b> , <b>Anita Parbhakar-Fox</b>	20–30	Burnie, Tasmania	22 November
SEG-CODES Student Chapter Field Trip – Geology of Northwestern and Western Tasmania	Ralph Bottrill, <b>Cassady Harraden</b> Carl Jackman, <b>Jacob Mulder</b>	19	Northwestern and Western Tasmania	10–17 December

# Performance indicators

## PERFORMANCE MEASURES IN 2014–2018 STRATEGIC PLAN

	TARGET	2017
<b>Research Findings (CODES and Earth Sciences)</b>		
Publications in international journals	50pa	83
Percentage of publications in high-quality international journals	70%	89%
Reports to industry collaborators	80pa	126
Special Issues and/or research monographs	1 per 2 years	1
Invitations to give keynote conference presentations	10pa	7
Papers at national/international meetings	70pa	84
<b>Research Training and Professional Education</b>		
Percentage of HDR students attracted from interstate	25%	24%
Percentage of HDR students attracted from overseas	65%	41%
Number of Honours students in CODES' programs	15	16
Number of HDR students in CODES' programs	50	56
Percentage of students in projects linked with industry	80%	76%
Professional short courses/workshops for industry	4pa	22
<b>International, National and Regional Links and Networks</b>		
CODES' national or international conferences/workshops	1 per 2 years	1
Registrants at CODES' conferences/workshops	600pa	760
<b>End-user Links</b>		
Frequency of meetings with industry representatives	15pa	30
<b>National Benefit</b>		
CODES' research has input into a major mineral discovery	1 per 5 years	9 in 29 years

OPPOSITE PAGE: Looking east at some of the iconic Rocky Cape Group outcrop in the Rocky Cape National Park, Tasmania, during the CODES SEG Student Chapter field trip, 2017.







# Finances

## 2017 INCOME

Total CODES income was \$6.9 million (see Table 1). This was derived principally from UTAS (27%), the combined income sources of the ARC TMVC Research Hub (31%), and industry (19%) (see Figure 1). The main income streams over time are compared in Figure 2, showing a drop in overall income to CODES in 2017 when compared to 2016, predominantly in UTAS and Other funding streams.

Summary of the main income streams to CODES in 2017:

- Host institution support: Funding from UTAS in 2017 was \$1.8 million, down compared to the figure for 2016, mostly due to a decrease in PhD scholarship funding (living and tuition fees) from central sources. UTAS funding relates primarily to research salaries, PhD scholarships and income earned by the Centre from research output.
- ARC TMVC Research Hub: The combined income sources for the TMVC amounted to \$2.1 million in 2017, comprising of funding from the ARC (\$821k), industry Partner Organisations (\$853k), Host Institution (\$130k), and other sources including Additional Funder Projects (\$320k).
- Industry income: Industry funding of \$1.3 million comprises funding related to Industry Partner support, industry funded student projects, and other research projects. This figure does not include industry-based support for the ARC TMVC Research Hub (see above).

## 2018 INCOME ESTIMATES

There is expected to be growth in funding to CODES with several new research projects expected to come online during 2018. Industry funding to the TMVC is also expected to remain strong.

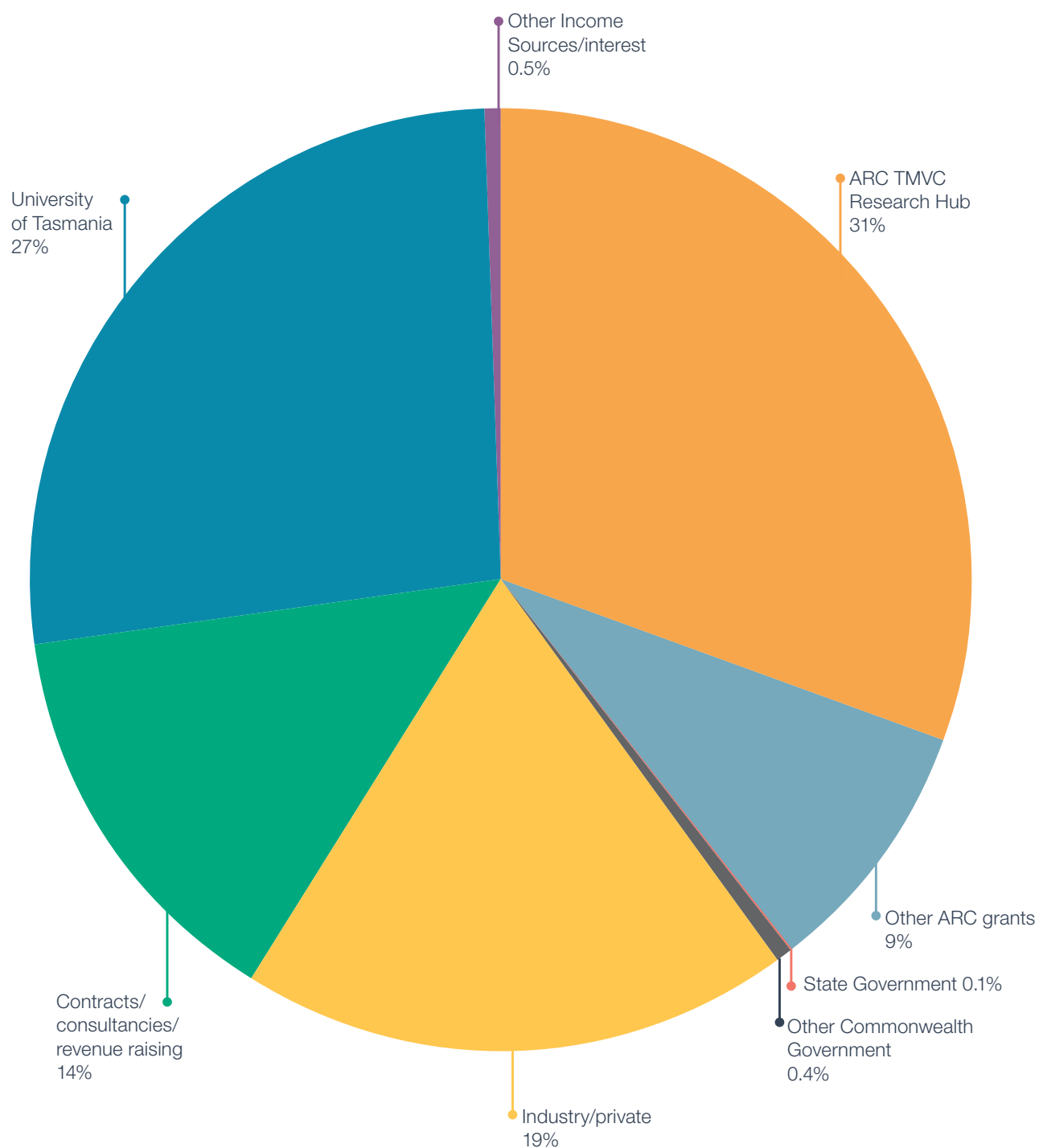




**TABLE 1: CASH INCOME FINANCIAL STATEMENT 2017**

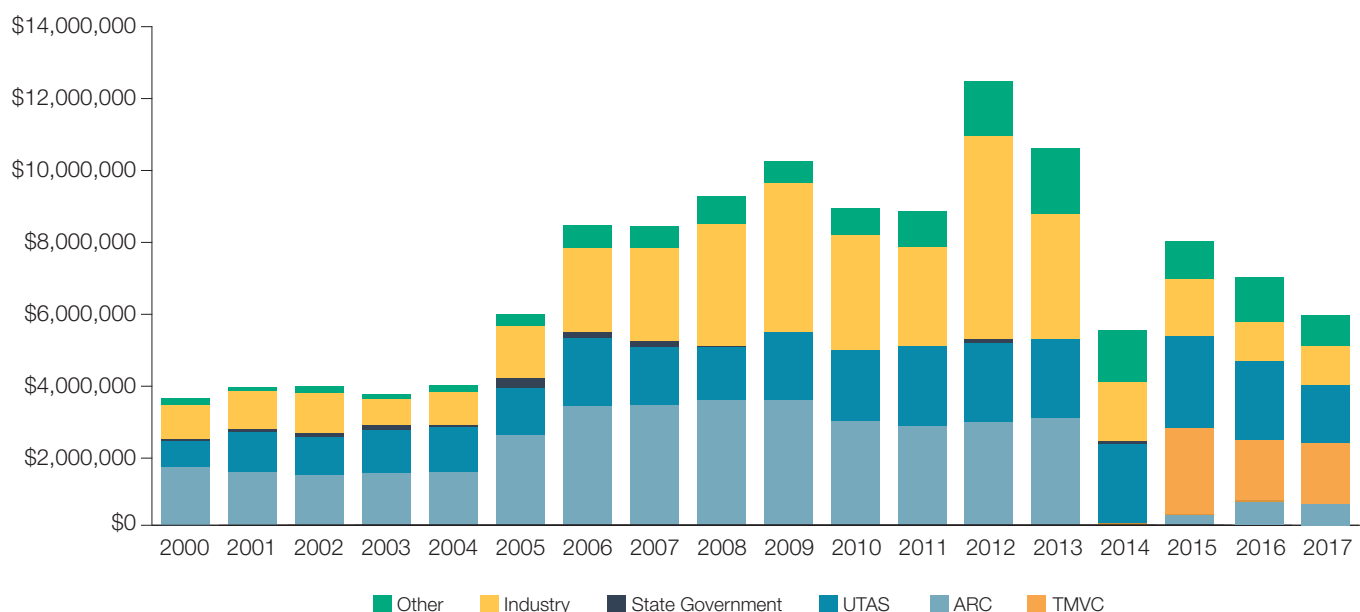
<b>ARC TRANSFORMING THE MINING VALUE CHAIN RESEARCH HUB</b>	
ARC Industrial Transformation Research Project	821,290
Partner Organisations	852,800
– AMIRA	537,600
– BHP	150,000
– Newcrest Mining	165,200
Host Institution	130,238
Additional Funder Projects	255,205
Miscellaneous	64,609
	<b>2,124,141</b>
<b>OTHER ARC GRANTS</b>	
Discovery Grants	169,290
Linkage Grants	415,598
	<b>584,888</b>
<b>OTHER COMMONWEALTH GOVERNMENT</b>	
Specific Projects	19,000
Student Projects	9,040
	<b>28,040</b>
<b>STATE GOVERNMENT</b>	
Specific Projects	5,000
	<b>5,000</b>
<b>INDUSTRY/PRIVATE</b>	
CODES Industry Partners	235,000
Cooperative Research Centre Projects	109,867
Directly Funded Research Projects	542,043
Directly Funded Student Projects	377,347
Miscellaneous	4,540
	<b>1,268,796</b>
<b>CONTRACTS/CONSULTANCIES/REVENUE RAISING</b>	
Short Courses	92,769
Symposiums	14,149
Book Sales	16,680
Miscellaneous (incl. Analytical Services)	846,907
	<b>970,504</b>
<b>UNIVERSITY OF TASMANIA – HOST INSTITUTION SUPPORT</b>	
Operating Grant	816,484
Scholarships and Tuition Fee Waivers	835,943
	<b>1,838,385</b>
<b>OTHER INCOME SOURCES/INTEREST</b>	
Overseas Governments	250
Society of Economic Geologists – Student Scholarships	4,640
Student Support	5,563
Specific Projects	18,757
Miscellaneous	2,455
	<b>31,664</b>
<b>TOTAL ANNUAL INCOME</b>	<b>6,851,419</b>

**FIGURE 1**  
**TOTAL CASH INCOME 2017**





**FIGURE 2**  
**COMPARISON OF CODES**  
**MAIN INCOME STREAMS 2000–2017**



### NOTES TO, AND FORMING PART OF, THE FINANCIAL STATEMENTS FOR 2017

The financial pages of this Annual Report were prepared by Helen Scott (ARC TMVC Research Hub Manager). Data for the financial statements was extracted from UTAS systems, particularly its finance system.

### INCOME STATEMENT EXPLANATIONS

The income figures in Table 1 represent actual income recorded in the University's finance system, transferred internally from UTAS to CODES during 2017, or centrally administered for CODES RHD students (as in the case of scholarships and tuition fee waivers).



# 2017 publications

## CHAPTERS IN BOOKS (41)

Aung Zaw Myint, **Khin Zaw**, Ye Myint Swe, Yonezu, K., Cai, Y., Manaka, T., and Watanabe, K., 2017, Geochemistry and geochronology of granites hosting the Mawchi Sn-W deposit, Myanmar: Implications for tectonic setting and emplacement, Chapter 17, in Barber, A.J., Khin Zaw, and Crow, M.J. (eds), Myanmar: Geology, resources and tectonics: London, The Geological Society, p. 385–400.

Barber, A.J., **Khin Zaw**, and Crow, M.J., 2017, Preface, in Barber, A.J., Khin Zaw, and Crow, M.J. (eds), Myanmar: Geology, resources and tectonics: London, The Geological Society.

Barber, A.J., **Khin Zaw**, and Crow, M.J., 2017, The pre-Cenozoic tectonic evolution of Myanmar, Chapter 31, in Barber, A.J., Khin Zaw, and Crow, M.J. (eds), Myanmar: Geology, resources and tectonics: London, The Geological Society, p. 687–712.

**Berry, R.F., Danyushevsky, L.V., Goemann, K., Parbhakar-Fox, A., and Rodemann, T.**, 2017, Micro-analytical technologies for mineral mapping and trace element deportment, in Lottermoser, B., (ed.), Environmental indicators in metal mining: Switzerland, Springer, p. 55–72.

Crow, M.J., and **Khin Zaw**, 2017, Geochronology in Myanmar (1964–2017), in Barber, A.J., Khin Zaw, and Crow, M.J. (eds), Myanmar: Geology, resources and tectonics: London, The Geological Society, p. 713–759.

Ehrig, K., **Kamenetsky, V.S., McPhie, J., Cook, N.J., and Ciobanu, C.L.**, 2017, Olympic Dam iron oxide Cu-U-Au-Ag deposit, in Phillips, G.N., (ed.), Australian ore deposits, Sixth edition: Melbourne, Australasian Institute of Mining and Metallurgy, p. 601–610.

**Fox, N., Parbhakar-Fox, A., and Lottermoser, B.**, 2017, Prediction of metal mobility from sulfidic waste rocks using micro-analytical tools, Baal Gammon, Northern Australia, in Lottermoser, B., (ed.), Environmental indicators in metal mining: Switzerland, Springer, p. 243–262.

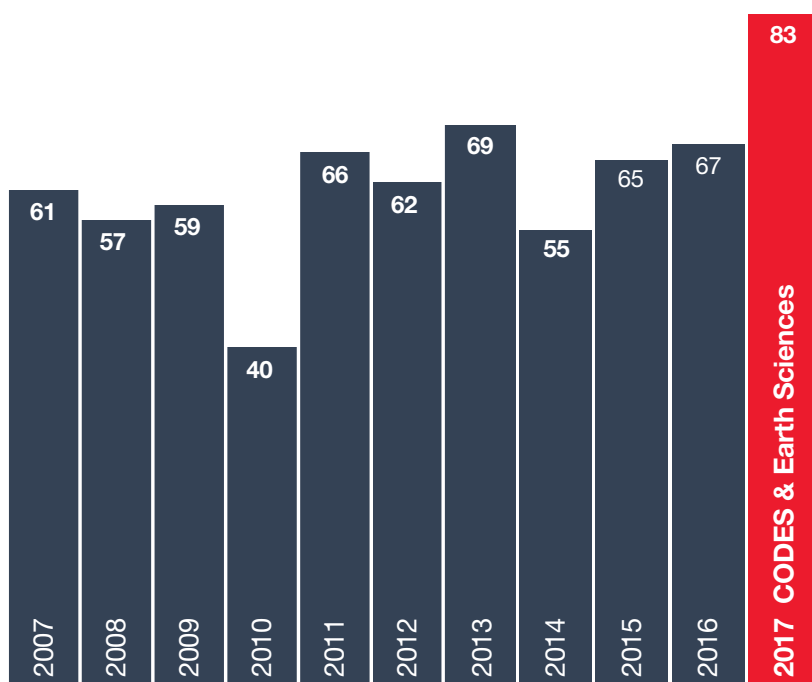
**Fox, N., Parbhakar-Fox, A., and Lottermoser, B.**, 2017, Prediction of metal mobility from sulfidic waste rocks using micro-analytical tools, Spray, Tasmania, in Lottermoser, B., (ed.), Environmental indicators in metal mining: Switzerland, Springer, p. 263–277.

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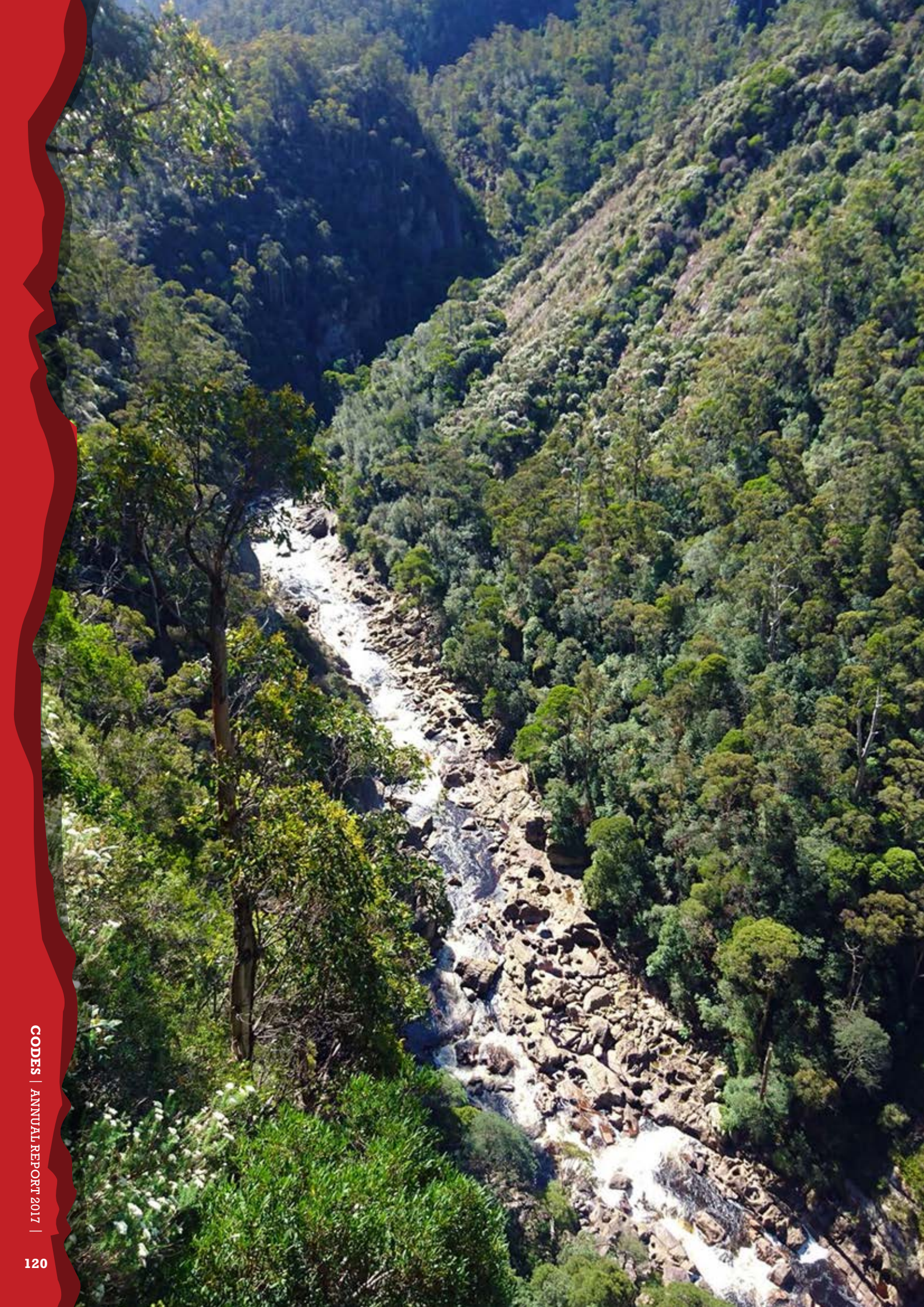
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*OPPOSITE PAGE: View of the Leven River at Leven Canyon, notable for the continuous stratigraphic section passing through Gordon Limestone, Moina Sandstone, Roland Conglomerate and older Cambrian Gog Range Greywacke.*

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*OPPOSITE PAGE: PhD student Jodi Fox with Argentinian conference attendee and postgraduate student Mirta Quiroga standing atop Plum Pudding Rock (a Miocene basanite megapillow) at Stanley, Tasmania, during a post-Chapman Conference field trip in early 2017.*







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*ABOVE: Tasmania's northwest coast, taken during the CODES SEG Student Chapter field trip; the rocks are the nearly flat-lying Wynyard Tillite comprised of laminated sediments with pebbly beds and soft sediment deformation responsible for irregular, non-cylindrical folds.*

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*OPPOSITE PAGE: Regolith cover overlying altered Ordovician volcanic rocks at the E42 gold deposit, Cowal, NSW.*







# Appendices

## CODES POSTGRADUATE STUDENTS 2017

### BACHELOR OF SCIENCE (HONOURS) (16)

STUDENT	SUPERVISORS	PROGRAM	PROJECT	SUPPORT
Matt Bodini §	Roach, Tassell (GHD)	6	Evaluation of petrophysical and mineralogical proxies for rock strength with particular emphasis on civil engineering practice	GHD
Rebekah Cornelius *#	Parbhakar-Fox	2	Geoenvironmental characterisation of the Lill-Laverberget Cu-Au porphyry deposit in Laver, Sweden	Boliden Mineral, ARC TMVC
Hannah Couper *	Escolme, Cooke, Berry	2	Geology and geometallurgical characterisation of the high Au, low Cu material at West Dome, Telfer Cu-Au mine, WA	ARC TMVC, Newcrest Mining
Jonathon Donaghy ^	Roach, Scott	3, 6	Creating sedimentological logs from 3D models of outcrop	
Sarah Gilmour *	Parbhakar-Fox, Fox	2	Mineralogical and geochemical characterisation of historical slag: evaluating environmental impacts and economic significance	ARC TMVC, MRT, AusIMM, MMG, CMT
Stewart Jackson	Lotter (IMS), Gal	6	Finite difference wavefield modelling for mining scale seismology	Institute of Mine Seismology
Kathryn Job ^	Roach, Meffre, Musgrave (GSNSW)	3, 6	A palaeomagnetic analysis of the Palaeozoic orocline model for Tasmania	MRT, ARC Linkage, CSIRO
Colin Jones *	Orovan, Cooke	1	The magmatic hydrothermal transition at Bluestone Bay, Freycinet Peninsula, Tasmania	ARC TMVC, UTAS Foundation
Richard (Sigmund) Lloyd	Meffre, Steadman	1, 3	Comparison of the mineralogy and geochemistry of altered rocks in the Woodlawn and Oberon areas, NSW	ARC Linkage, Heron Resources
Robert McLaine *#	Parbhakar-Fox, Fox	2	Determining bioaccessibility risks at the historic Aberfoyle tailings site, North East Tasmania: Opportunities for effective rehabilitation	ARC TMVC, MRT
Ryan McMann	Cas, Olin	4	A syn-depositional sill intrusive model for the Golden Mile Dolerite, Kalgoorlie, WA	GSWA
Rhiannan Mundana	Whittaker (IMAS), Carey, Johnson	4	The geological evolution of the Cascade Seamount: implications for understanding the opening of the Tasman Gateway	UTAS, IMAS
Ben Ridgers	Meffre	1, 3	Pb isotopic characterisation of ore deposits and prospects from NE Tasmania	ARC Linkage
Riquan Ropli	Meffre, Steadman	1, 3, 4	Age and paragenesis of the Hill 800 prospect, Victoria	ARC Linkage
Thomas Schaap ^	Roach, Tassell (GHD)	6	Geophysical investigation into Sørsdal Glacier, East Antarctica	Australian Antarctic Division
Mark Sinfield	Webster	3	Litho-structural control and origin of mineralisation at Carbonate Ridge – Broken Hill, NSW	Perilya

\* Affiliated with the ARC TMVC Research Hub # Degree completed, not yet graduated ^ Graduated § Withdrawn/terminated

*BELOW: Members of the CODES SEG Student Chapter near Trial Harbour, Tasmania, standing at the contact between the Red and White Heemskirk granites.*





## MASTER OF ECONOMIC GEOLOGY (41)

STUDENT	SUPERVISORS	PROGRAM	PROJECT	SUPPORT
Michael Adams			coursework only	
Robert Ayres			coursework only	
Sebastian Benavides ^	Cooke, Zhang	1	Characterisation of sericitic alteration at the Taca Taca Bajo porphyry deposit, Argentina	First Quantum
Christopher Booth			coursework only	
Kim Boundy			coursework only	
Kenneth Bush			coursework only	
Jimmy Carranza Meza			coursework only	
Wayne Carter ^			coursework only	
Glen Cathers			coursework only	
Chloe Cavill	G.Davidson, Scott	1	Geochemical classification of ore fluids, Costerfield Sb-Au deposit, Victoria	Mandalay Resources
Jesse Clark			coursework only	
Daniel Cronin			coursework only	
Roseanna Dale			coursework only	
Lieth de Selincourt			coursework only	
Paul Edmonds			coursework only	
Franco Ferreyra	Cooke		TBA	
Arga Firmansyah	Cooke	1	Geology and mineralisation of the Trenggalek district, East Java, Indonesia	PT Pamapersada Nusantara
Daniel Foulds			coursework only	
David Groombridge			coursework only	
David Haddow			coursework only	
Brendan Hardwick	Meffre, Doyle (AngloGold Ashanti)	1, 3	Ore mineral textures and their implication for gold genesis and deportment at the Tropicana Gold Mine, Western Australia	AngloGold Ashanti
Kyle Hodges			coursework only	
Kyle Hughes	Meffre	1, 3	Paragenesis of the Dobroyde Deposit, central NSW	ARC Linkage
Corey Jago	Meffre, Cooke	1, 3	Toward an understanding of the temporal, spatial and mineralogical characteristics of the Northparkes Alkaline Porphyry Deposits, New South Wales	ARC Linkage
Sitthinon (Gun) Kultaksayos	Meffre	3	Provenance of Early to Mid-Paleozoic sediments in Western Tasmania	ARC Linkage
Anna Kutkiewicz ^			coursework only	
Thomas Langley			coursework only	
Esther Little			coursework only	
Walter Lozano Garcia Naranjo			coursework only	
David Mallon	TBA		TBA	
Todd McGilvray			coursework only	
Joanne Morrison ^*	Berry	2	Cadia East multi-element lithogeochemistry: Evaluation of trace element deportment important to processing	Newcrest Mining
Alexei Nicholls ^			coursework only	
Alister Orton			coursework only	
Chris Piggott			coursework only	
Nicholas Poznik			coursework only	
Thomas Ralston			coursework only	
Juan Diego Rojas Lopez	Escolme	1	Origin, characteristics and age of mineralisation of the Ollachea orogenic gold deposit, Region Puno, southeastern Peru: Implications for exploration	PRONABEC, Minera IRL
Christopher Shanley			coursework only	
Markus Staubmann			coursework only	
Luke Timmermans			coursework only	

\* Affiliated with the ARC TMVC Research Hub ^ Graduated

## MASTER OF EXPLORATION GEOSCIENCE (1)

STUDENT	SUPERVISORS	PROGRAM	PROJECT	SUPPORT
Peerapong Sritangsirikul	Meffre	3	Tectonic evolution and ore deposit prospectivity of the Rockley Volcanics, NSW, Australia	Thai Royal Government Scholarship

## MASTER OF SCIENCE (1)

STUDENT	SUPERVISORS	PROGRAM	PROJECT	SUPPORT
Eyob Andemeskel #	Selley	3, 4	Litho- and chemo-stratigraphic, structural and mineral prospectivity aspects of the Rosebery Group, an enigmatic Cambrian volcano-sedimentary succession on Tasmania's west coast	MMG

## DOCTOR OF PHILOSOPHY (56)

STUDENT	SUPERVISORS	PROGRAM	PROJECT	SUPPORT
Adam Abersteiner	V.Kamenetsky, M.Kamenetsky, Goemann (CSL)	4	Kimberlites and diamonds: Understanding their petrogenesis and uncovering the identity of their source composition	UTAS, ARC Discovery
Ayesha Ahmed *	Cooke, Baker, Orovan	1	The effect of pressure/depth on propylitic alteration mineral chemistry in the porphyry environment	AMIRA P1153, ARC TMVC, UTAS, AusIMM
Richelle Awid-Pascual ^	G.Davidson, V.Kamenetsky, Goemann (CSL), Noble (IMAS)	3	The evolution of Zn-Pb-Fe-bearing minerals in the Grieves Siding peat, western Tasmania	CoE, UTAS, CRC ORE
Heidi Berkenbosch ^	Gemmell, McNeill (MRT), Christie (GNS Science)	4	Geochemistry of hydrothermal mineral chimneys from Brothers volcano, Kermadec Arc	CoE, GNS Science, UTAS, SEG, AusIMM, Australian Synchrotron
Nathan Chapman	Meffre, V.Kamenetsky	4	Pb-isotopic insights into the crustal evolution and metallogenesis of the Gawler Craton	ARC Linkage, BHP
Jing Chen *	Cooke, Zhang	1	The geology, mineralisation, alteration and structural evolution of Zijinshan ore field, Fujian Province, China	UTAS, China Scholarship Council, ARC TMVC, SEG, Zijin Mining
Alexander Cherry	V.Kamenetsky, McPhie, Ehrig (BHP)	3, 4	Petrology, provenance and composition of bedded sedimentary facies in the Olympic Dam deposit	UTAS, ARC Linkage, SEG, BHP
Rob Davidson	Gemmell, Cooke	1	Geology and genesis of the San Sebastian vein system, Durango, Mexico	Hecla Mining, UTAS
David Douth	Scott, Cas	1, 3, 4	The geology and geological controls on gold mineralisation at the Invincible deposit, St Ives Gold Mine, Kambalda, WA	St Ives Gold
Evan Draayers	Danyushevsky	4	The boninite magma genesis debate: Assessing the role of mantle sources associated with intra-plate magmatism in the generation of boninitic magmas above subduction zones	UTAS
Peter Duerden	Meffre, Cooke	1, 3	Geological framework and metallogenesis of the Northern Molong Volcanic Belt, Lachlan Orogen, New South Wales	ARC Linkage, Alkane Resources
Angela Escolme *^	Cooke, Hunt, Berry	1, 2	The geology, geochemistry and geometallurgy of Productora Cu-Au-Mo deposit, Chile	UTAS, Hot Chili, CSIRO, AusIMM, ARC TMVC
Esmail Eshaghi ^	Reading	6	Geophysical investigations of Tasmania at multiple scales	UTAS
Matt Ferguson	V.Kamenetsky, Ehrig (BHP), Meffre	4	Late stage magmatic-hydrothermal evolution of A-type Hiltaba event rocks in the Gawler Craton	UTAS, ARC Linkage, BHP, SEG, GSA
Jodi Fox	McPhie, Carey	4	Submarine basaltic intraplate volcanism	UTAS, CoE, ANZIS, Australian Antarctic Science Program, MRT, Linnean Society of NSW

\* Affiliated with the ARC TMVC Research Hub # Degree completed, not yet graduated ^ Graduated



## DOCTOR OF PHILOSOPHY (56) cont.

STUDENT	SUPERVISORS	PROGRAM	PROJECT	SUPPORT
Martin Gal ^	Reading, Ellingsen (Physics)	6	Seismic array analysis of ocean induced microseisms	UTAS, ARC Discovery
Amos Garay *	Cooke, Baker, Zhang	1	Magnetite and epidote chemistry and textures at Las Bambas Cu-Au-Fe skarn, Peru: Assessing district and deposit-scale fertility – implications for ore genesis and exploration	AMIRA P1153, ARC TMVC, UTAS Foundation, SEG
Cassady Harraden *	Meffre, Berry, Cracknell	2	Geotechnical and geometallurgical assessment by Corescan and complementary microanalytical techniques	UTAS, ARC TMVC, Newcrest Mining, Corescan
Rachel Harrison *#	Cooke, Zhang	1	The Tumpangpitu porphyry gold-copper-molybdenum and high-sulfidation epithermal gold-silver deposit, Tujuh Bukit, southeast Java, Indonesia	UTAS, SEG, ARC TMVC
Margy Hawke ^	Gemmell, Large, G.Davidson	1, 4	Geological evolution of the DeGrussa Cu-Au VHMS deposit, Western Australia	UTAS, Sandfire Resources
Jacob Heathcote	Scott, G.Davidson	1, 3	Gold distribution and association at the Kansanshi copper-gold deposit Zambia: Processes responsible for gold precipitation and implications for ore zone delineation and recovery	First Quantum Minerals
Sam Holt	Carey, McPhie	4	Understanding of basaltic eruption dynamics and mechanisms: Effusive and explosive eruptions in Hawaii	UTAS, CoE, Hawaiian Volcano Observatory, USGS, CSL
Wei Hong ^	Cooke, Zhang, Fox	1	Magmatic-hydrothermal volatile exsolution and mineralisation in Tasmanian Sn granites	UTAS, CoE, SEG, Geoscience Australia
Shawn Hood *	Cracknell, Reading	6	Machine learning and automated geoscientific analyses for the spatial characterisation of metalliferous ore deposits	UTAS, ARC TMVC, Gold Fields Australia, Saracen Mineral Holdings, SEG
Fumihiko Ikegami	Carey, McPhie	4	2012 submarine silicic eruption of Havre volcano and implications for ancient submarine successions in Australia	UTAS, ARC, US National Science Foundation
Amery Jackson	Fox, Cracknell, Parbhakar-Fox	2	Geometallurgical controls on grade-by-size fractionation in gold systems with applications to Grade Engineering®	CRC ORE
Laura Jackson *	Parbhakar-Fox, Cooke, Fox	2	Mineralogical domaining of low grade and no grade zones using automated drill core logging	ARC TMVC, UTAS, Newcrest Mining, Corescan
Torsten Jensen §	Scott, Meffre, Selley	3	Devonian gold mineralisation in NE Nevada, USA: Critical primer to a world-class gold district?	CODES, UTAS
Carlos Andres Jimenez Torres ^	Cooke, White, Baker	1	Bantug lithocap, Negros Island, Philippines: Mineralogy, textures, and chemistry	UTAS Foundation, AMIRA P1060
Sean Johnson ^	Large, Meffre, McGoldrick	1, 3	The geochemistry of metalliferous black shales: Understanding primary enrichments, metamorphic processes and the role of metalrich black shales in archiving earth evolution	UTAS, CoE, Mining Institute of Scotland, ANZIC-iodp, ECORD, NERC, Talvivaara Mining, GTK, SEG
Joseph Knight	Orovan, Zhang, Cooke	1	The geodynamic and metallogenic setting of base- and precious-metal mineralisation in Myanmar: Implications for Cu and Au exploration	Anglo American
Stephen Kuhn *	Reading, Cracknell	6	Lithological mapping for mineral exploration using machine learning	UTAS, CODES, ARC TMVC, First Quantum Minerals, Gold Fields, ASEG, AIG
Erin Lawlis	Cooke	1	Au-bearing pyritic ore of Lihir, Papua New Guinea: Its physiochemical character and nature of the causative fluids	Newcrest Mining, UTAS, SEG
Christopher Leslie	Meffre, Cooke, Steadman	1, 3	Porphyry and epithermal deposits of Cowal District, New South Wales	ARC Linkage, UTAS, Evolution Mining
Elena Lounejeva	Steadman, Large	3	Geochemical signature of syngenetic and diagenetic pyrite from marine sediments as a paleo-environmental tool	ARC Discovery, CODES

\* Affiliated with the ARC TMVC Research Hub # Degree completed, not yet graduated ^ Graduated § Withdrawn/terminated

## DOCTOR OF PHILOSOPHY (56) cont.

STUDENT	SUPERVISORS	PROGRAM	PROJECT	SUPPORT
Claire McMahon	G.Davidson, Danyushevsky	1	Distribution of, and controls upon, pyrite trace element content of hydrothermal alteration zones at Hercules VHMS ore deposit, Tasmania and NICO IOCG ore deposit, Northwest Territories, Canada	ARC
Brian McNulty	Gemmell, Fox	1, 4	Geology and genesis of the mineral deposits of the Myra Falls VHMS District, Canada	Nyrstar, UTAS
Stephen Meyer	Reading, Bassom (Mathematics)	6	A model-based approach to the interpretation of seismicity associated with mass mining	Institute of Mine Seismology
Peter Morse	Reading, Lueg (Computing)	6	Interactive visualisation for data inference in the geosciences	UTAS, CODES, ARC TMVC
Indrani Mukherjee #	Large, Halpin (IMAS), Meffre	1, 3	Pyrite trace element chemistry of black shales of the "boring billion" period	UTAS, SEG, AMIRA, CODES
Jacob Mulder ^	Meffre, Halpin (IMAS), Berry, Scott	1, 3	From Nuna to Gondwana: An evaluation of the early tectonic history of Tasmania	UTAS, CODES
Sibele Cristina do Nascimento *	Parbhakar-Fox, Cracknell, Cooke	2	Geoenviromental characterisation of historic mine tailings: Evaluating opportunities for reprocessing	ARC TMVC, UTAS
Thomas Ostensen	Reading, Cracknell	6	Geoelectric structure of the Tasmanian lithosphere	UTAS, CODES, MRT, U Adelaide, Geoscience Australia, GSSA
Joshua Phillips *	Cooke, Scott, Baker	1	Geologic and geochemical vectors to mineralisation at the Resolution porphyry Cu-Mo deposit, Arizona	ARC TMVC, AMIRA P1153, Rio Tinto, Resolution Copper Ltd
Naomi Potter	V.Kamenetsky, Goemann (CSL), M.Kamenetsky	4	An investigation into the genesis of intrusive and extrusive carbonatitic melts	UTAS, ARC Discovery
Thomas Schaap	Meffre, Whittaker (IMAS), Roach, Cracknell	3, 6	Plate tectonic modelling of the Early Palaeozoic evolution of South Eastern Australia	ARC Linkage, UTAS
Subira Sharma	G.Davidson, Cooke	1	Evaluation of the links between Merlin-style Mo-Re mineralisation and magmatism in the Cloncurry fold belt, Queensland: Implications for exploration	UTAS, Chinova Resources
Tobias Staal	Reading, Whittaker (IMAS), Halpin (IMAS)	6	Seismic and geological constraints on the lithospheric structure of Antarctica	Antarctic Gateway Partnership
Nathan Steeves	Gemmell, Large, Hannington (UOttawa)	1, 4	Ore genesis of the Greens Creek VHMS Deposit, Alaska: Implications for mining, milling and exploration	Hecla Mining, UTAS
Yi Sun *	Zhang, Escolme, Cooke	1, 2	Mineralogical, textural, geochemical characterisation and geometallurgical models of Lepanto Quartz – Pyrite – Gold vein and breccia system, Philippines	ARC TMVC, UTAS, Lepanto Consolidated
Stephanie Sykora *^	Cooke, Selley	1	Origin, evolution and significance of anhydrite-bearing vein arrays and breccias, Lienetz orebody, Lihir gold deposit, Papua New Guinea	Newcrest Mining, CODES, TMVC, UTAS
Francisco Testa #	Cooke, Baker	1	Tourmaline breccia pipes: San Francisco de los Andes, Argentina and Rio Blanco-Los Bronces, Chile	UTAS, AMIRA P1060
Jay Thompson	Danyushevsky, Meffre	5	Understanding the specifics of H <sub>2</sub> O-free aerosol behaviour in the inductively-coupled plasma in geochemical LA-ICP-MS applications involving U/Pb dating and accurate trace element analysis in silicate minerals and glasses	
Jennifer Thompson *	Cooke, Danyushevsky, Meffre	1	Carbonate mineral chemistry in epithermal and porphyry hydrothermal systems	UTAS, AMIRA P1153, ARC TMVC, SEG
Daniele Vergani	Carey, McPhie	4	The 2007 explosive activity at Piton de la Fournaise volcano (Reunion): Constraints on the eruptive processes by the volcanological study of the erupted deposits	UTAS, CoE, Reunion Volcano Observatory
Tristan Wells	Meffre, Cooke, Steadman	1, 3	Geochemistry and cathodoluminescence of magmatic apatite and zircon as vectors to mineralised centres within the Lachlan Fold Belt	ARC Linkage, UTAS, CODES, NorthParkes

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# MAJOR EXTERNALLY FUNDED RESEARCH PROJECTS^

## ARC INDUSTRIAL TRANSFORMATION RESEARCH HUB GRANTS 2017

INVESTIGATORS	PROJECT	FUNDING BODY	PERIOD	ARC FUNDING FOR 2017	PARTNER FUNDING FOR 2017	UTAS FUNDING FOR 2017	MISC FUNDING FOR 2017
Cooke, Danyushevsky, Jiang, Gemmell, Large, Meffre, Reading, Harris (Newcrest), Seymon (AMIRA), Ehrig (BHP), Goodey (Corescan), Lottermoser (Aachen), Shelley (Laurin Technic)	Transforming the mining value chain	ARC, AMIRA International, BHP Billiton Olympic Dam, Newcrest Mining, UTAS	2015–2020	\$821,290	\$852,800	\$130,238	\$64,609

## ADDITIONAL FUNDER PROJECTS WITHIN THE ARC TMVC RESEARCH HUB 2017

INVESTIGATORS	PROJECT	FUNDING BODY	PERIOD	FUNDING FOR 2017
Cooke, White, Zhang, Gemmell, Testa	Geological and geochemical vectors to low sulfidation epithermal gold mineralization, Cerro Negro district, Deseado Massif, Argentina	Oro Plata SA	2017–2018	\$69,854
Zhang	Geochemical and mineralogical vectors to the ore at Bilihe-Hadamiao district, Inner Mongolia, China	Peking University	2017–2018	\$20,000
		Inner Mongolia Mining Technology Research Institute	2017–2018	\$45,610
Parbhakar-Fox, Brough (Petrolab UK)	Integrated kinetic testing for best practice mine waste characterisation	Australian Academy of Technology and Engineering	2017–2018	\$48,950
Parbhakar-Fox, Cornelius (student)	Establishing effective mineralogical and geochemical techniques for geoenvironmental characterisation: Laver, Sweden	Boliden Mineral AB	2017–2018	\$36,512
Cooke, Baker, Zhang, Garay (student)	Magnetite and epidote chemistry and textures at Las Bambas Cu-Au-Fe skarn, Peru: Assessing district and deposit-scale fertility – implications for ore genesis and exploration	UTAS Foundation	2015–2018	\$8,000
Orovan, Cooke, Jones (student)	The magmatic hydrothermal transition at Bluestone Bay, Freycinet Peninsula, Tasmania	UTAS Foundation	2017	\$5,000
		Colin Jones	2017	\$3,000
Parbhakar-Fox, Fox, Gilmour (student)	Mineralogical and geochemical characterization of historical slag	Mineral Resources Tasmania	2017–2018	\$4,715
Parbhakar-Fox	Evaluation of NAG pH testing: Tracking reaction pathways and products	Grange Resources	2016–2017	\$4,545
Parbhakar-Fox	Savage River: Kinetic trials of waste rock materials, Long Plains, Tasmania	Grange Resources	2015–2018	\$4,519
Parbhakar-Fox, Fox, McLaine (student)	Determining bioaccessibility risks at the historic Aberfoyle tailings site, northeast Tasmania: Opportunities for effective rehabilitation	Mineral Resources Tasmania	2017	\$4,500

## ARC LINKAGE GRANTS 2017

INVESTIGATORS	PROJECT	FUNDING BODY	PERIOD	ARC FUNDING FOR 2017	PARTNER FUNDING FOR 2017
Kamenetsky, McPhie, Meffre, Maas (UMelb), Ehrig (BHP)	The supergiant Olympic Dam U-Cu-Au-REE ore deposit: Towards a new genetic model	ARC, BHP Billiton Olympic Dam	2014–2018	\$0	\$350,000
Meffre, Whittaker (IMAS), Norman (ANU), Cracknell, Belousova (Macquarie), Collins (UoN), Arundell (IMEx Consulting), Cooke	Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia	ARC, Rio Tinto, Alkane Exploration, Sandfire Resources, Evolution Mining, Geoscience Australia, Geological Survey of New South Wales, Heron Resources, Mineral Resources Tasmania, Northparkes Mines, New South Resources, AngloGold Ashanti, Geological Survey of Victoria, Emmerson Resources	2016–2019	\$169,290	\$115,000

## ARC DISCOVERY GRANTS 2017

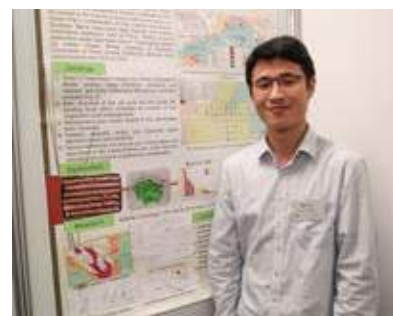
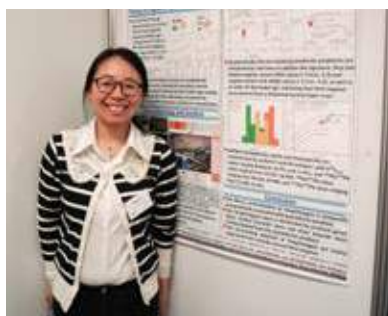
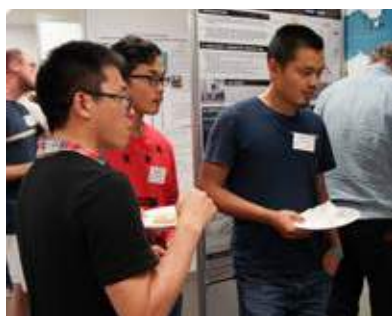
INVESTIGATORS	PROJECT	PERIOD	ARC FUNDING FOR 2017
Large, Danyushevsky, Halpin (IMAS), Meffre	Pyrite: A deep-time capsule of ocean chemistry and atmosphere oxidation	2015–2017	\$160,764
Reading, Koper (Utah)	Are ocean storms impacting Australia becoming more severe?	2015–2018	\$134,495

## ARC DISCOVERY EARLY CAREER RESEARCHER AWARDS 2017

INVESTIGATORS	PROJECT	PERIOD	ARC FUNDING FOR 2017	UTAS FUNDING FOR 2017
Carey	The role of hydrostatic pressure in modulating submarine silicic eruptions	2015–2019	\$120,339	\$43,161

## CRC PROJECTS 2017

INVESTIGATORS	PROJECT	PERIOD	CRC FUNDING FOR 2017	UTAS FUNDING FOR 2017
Cooke, Gemmell	CRC ORE II Participant funding	2015–2021	\$0	\$100,000
Fox, Gemmell	CRC ORE II – Predictive geometallurgy controls on grade by size	2016–2019	\$114,166	\$0
Berry, Danyushevsky, Thompson, Rodemann (CSL)	CRC ORE II – Geometallurgical applications for sorting by surface analysis: review of status	2016–2017	\$8,076	\$0





## INDUSTRY AND OTHER EXTERNALLY FUNDED RESEARCH GRANTS 2017

INVESTIGATORS	PROJECT	FUNDING BODY	PERIOD	FUNDING FOR 2017
Steadman, Large	Pyrite and pyrrhotite as ore vectors and stratigraphic markers for orogenic gold, Carlin gold, VHMS, IOCG, sediment-hosted copper, and stratiform zinc targets	Sandfire Resources, Enterprise Metals, Pioneer Resources, Boliden Mineral, Argent Minerals, Intrepid Mines	2015–2017	\$102,000
Scott, Cas, Douch (student)	The geology and geological controls on gold mineralisation at the Invincible deposit, St Ives Gold Mine, Kambalda, WA	St Ives Gold	2015–2018	\$54,998
Gemmell, Fox, McNulty (student)	Geology and genesis of the mineral deposits of the Myra Falls VHMS District, Canada	Nyrstar Myra Falls	2015–2017	\$50,000
Gemmell, Large, Hannington (UOttawa), Steeves (student)	Ore genesis of the Greens Creek VHMS Deposit, Alaska: Implications for mining, milling and exploration	Hecla Mining Company	2013–2017	\$48,000
Scott, G.Davidson, Heathcote (student)	Gold distribution and association at the Kansanshi copper-gold deposit, Zambia	Kansanshi Mining	2014–2017	\$25,000
Cas, Olin, McMann (student)	A syn-depositional sill intrusive model for the Golden Mile Dolerite, Kalgoorlie, WA	Geological Survey of Western Australia	2017	\$9,040
Reading, Meyer (student)	Mine seismology using model-based processing	Institute of Mine Seismology	2017–2019	\$5,000
Kamenetsky, Ehrig (BHP), Meffre, Ferguson (student)	Late-stage magmatic-hydrothermal evolution of A-type Hiltaba event rocks in the Gawler Craton	Society of Economic Geologists Foundation	2017	\$4,640
Bull, Selley, G.Davidson	Controls on copper mineralising processes in the McArthur Basin, NT, and its implications for the metallogeny of extensional basins	Northern Territory Geological Survey	2016–2017	**
Cooke, Zhang, Xiao (visitor)	Porphyry and skarn mineralisation in China	Hefei University of Technology	2015–2018	**
Danyushevsky, Johnson	Development of fundamental aspects of laser-ablation analysis applied to geological problems	Laurin Technic	2015–2018	**
Johnson, Noble (IMAS), Olin, Meffre, Grice (Curtin), Large	The establishment of ocean anoxia and ocean acidification during the PETM: Understanding the biological and chemical response on a regional and global scale	IODP (via Australian National University)	2016–2018	**
Orovan, Zhang, Cooke, Knight (student)	The geodynamic and metallogenic setting of base- and precious-metal mineralisation in Myanmar: Implications for Cu and Au exploration	Anglo American	2015–2018	**
Orth, G.Davidson	Determination of the temporal relationship between the pyrite-silica-sericite alteration, and spatially associated uranium mineralisation, at Angularli Deposit, East Arnhem Land	Cameco	2015–2017	**
Zhang	Exploration tools and genesis of the lithocaps in Eastern China	Hefei University of Technology	2016–2017	**

^ projects with greater than \$2,000 external funding per year \*\* all project funding received, project still active

*OPPOSITE PAGE: (left column) Lejun Zhang from CODES (left) chats with Jian Ma and Chau Wu, both visiting PhD students from China who carried out research with us during 2017.*

*(Middle column) Visiting Chinese PhD student Xue Gao standing alongside her poster, which was presented at the 2017 CODES Annual Review meeting in December.*

*(Right column) And visiting PhD student Bin Lin, also from China, standing alongside his poster, which was presented at the same meeting.*

# VISITORS 2017

## INDUSTRY VISITORS

NAME	COMPANY
Sharolyn Abelo	St Barbara
Paul Agnew	Rio Tinto
Debora Araujo	Rio Tinto
Olga Borovinskaya	TOFWERKS
Ian Bowen	Nu Plasma
Dane Burkett	Olympus
Jane Capp	OMI
Chris Creagh	Elementos
Keith Deverell	Consultant
Christian Ehlendorf	Anglo American
Kathy Ehrig	BHP
David First	FML
Simon Gatehouse	BHP
John Glen	ALS Global
Sam Habib	Olympus
Anthony Harris	Newcrest
Mary Harris	Newcrest
Terry Hoschke	Newcrest
Tim Ireland	FQML
Petrus Jenbe	St Barbara
Henry Korowa	St Barbara
Punit Kumar	Rio Tinto

NAME	COMPANY
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Neil Macalalad	Anglo American
Ian Madsen	Consultant
Ashley Norris	Norris Software
Julius Pakule	St Barbara
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Adele Seymon	AMIRA
Trevor Shaw	Glencore
Michael Shelley	Laurin Technic
Leo Subang	Lepanto Consolidated
Koya Suto	Terra Australis Geophysics
Stephanie Sykora	First Quantum
McLean Trott	QPX
Mike Tucker	Balmoral Resources
Rob Wall	ioGAS
Steve Walters	BHP
Michael Whitbread	Rio Tinto
Noel White	Consultant
Rob Wood	Reflex/ioGAS
Mashiyyatt Wima	St Barbara

## NATIONAL ACADEMIC AND GOVERNMENT VISITORS

NAME	INSTITUTION
Ben Adair	CRC ORE
Ralph Bottril	Mineral Resources Tasmania
Naomi Boxall	CSIRO
Marina Costelloe	Geoscience Australia
Stephen Cox	ANU
Andrea Gerson	ANU/University of Melbourne
Paul Heithersay	Department of State Development, SA Govt
Haolan Hong	James Cook University
Carsten Laukamp	CSIRO
Rong Liu	SIMS Facility, Western Sydney University
Ian Madsen	CSIRO
Colin McRae	CSIRO

NAME	INSTITUTION
Andrew McNeill	Mineral Resources Tasmania
Angus MacFarlane	CSIRO
Nick Morgan	Australian Antarctic Division
Jennifer Parnell	Mineral Resources Tasmania
Michael Reid	Mineral Resources Tasmania
Sean Reynolds	Bureau of Meteorology
Kate Robertson	Geological Survey of South Australia
Michael Scott	CRC ORE
Roger Smart	University of South Australia
Stephan Thiel	Geological Survey of South Australia
John Walshe	CSIRO
Steve Walters	CRC ORE
Greg Wilke	CRC ORE



## INTERNATIONAL ACADEMIC AND GOVERNMENT VISITORS

NAME	INSTITUTION
Alexander Belousov	Institute of Volcanology and Seismology, Russia
Nick Derome (student)	Lakehead University, Canada
Carmen Gaina	Geological Survey of Norway
Xue Gao (student)	China University of Geosciences, Beijing
Emily Gerner (student)	Lakehead University, Canada
Dan Gregory	University of California, Riverside, USA
Ed Harvey	US National Park Service, Water Resources Division
Mari Kivinen	Geological Survey of Finland (GTK)
Yuzhong Liao (student)	China University of Geosciences, Beijing
Bin Lin (student)	China University of Geosciences, Beijing
Jun Liu	Institute of Mineral Resources, Chinese Academy of Geological Sciences
Zhibo Liu	Chinese Academy of Geological Sciences
Jian Ma (student)	China University of Geosciences, Wuhan
Kathryn MacWilliams (student)	University of British Columbia, Canada

NAME	INSTITUTION
Jose Piquer	Universidad de Austral, Chile
Mirta Quiroga (student)	National University of Salta, Argentina
Ken Rubin	University of Hawaii, USA
Yang Song	Institute of Mineral Resources, Chinese Academy of Geological Sciences, China
Peter Sorjonen-Ward	Geological Survey of Finland (GTK)
Junxing Tang	Chinese Academy of Geological Sciences
Hari Tsikos	Rhodes University, South Africa
Joseph Vrzovski (student)	Lakehead University, Canada
Dan Wood	University of Queensland
Chao Wu (student)	Guangzhou Institute of Geochemistry, Chinese Academy of Sciences
Xin Xiao (student)	Hefei University of Technology, Anhui
Feng Xiong (student)	Institute of Geochemistry, Chinese Academy of Sciences
Chris Yeomans (student)	University of Exeter, UK

BELOW: Nathan Fox talks with Mary Harris, a senior geologist from Newcrest.









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ISSN 1440-6411

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Editing: Caroline Mordaunt

Design: Before Creative

Printing: Mercury Walch

[utas.edu.au/codes](http://utas.edu.au/codes)

*OPPOSITE PAGE: (Top left) The world's largest acidic crater lake (pH < 0.3), Mt Ijen volcano, Java, Indonesia. (Top right) Liesegang weathering rinds in diatreme breccia clasts, Lombok, Indonesia. (Bottom) Ores in Magmatic Arcs course leader Rachel Harrison (left) and Master of Economic Geology students Hana Lee, Anna Kutkiewicz and Kyle Hughes returning from Pulau Merah island, where a porphyry Cu-Au stockwork is exposed on the foreshore, Tujuh Bukit district, Java, Indonesia.*

