



CODES
ARC CENTRE OF EXCELLENCE IN ORE DEPOSITS

ANNUAL
REPORT

20
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UNIVERSITY of
TASMANIA



Australian Government
Australian Research Council



VISION

To be the premier international research centre in ore deposit geology.

MISSION

Significantly advance collaborative and innovative ore deposit research for Australian and international researchers and the minerals industry.

GOALS

- Undertake and publish high-quality research.
- Lead the global minerals industry in research on the exploration and recovery of new mineral resources.
- Equip the Australian minerals industry with world-class graduates.
- Communicate the Centre's research to the wider research, industry and general communities.

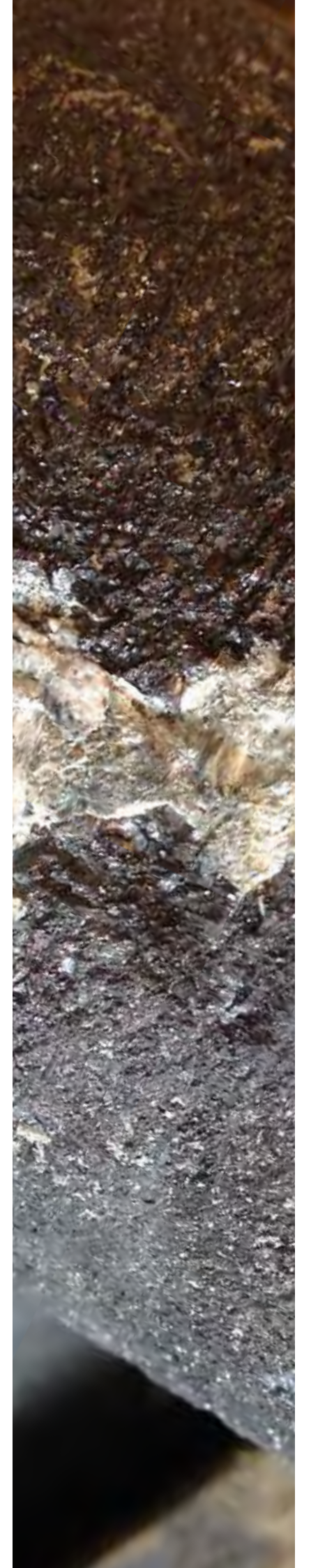
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PLEASE NOTE: in various places throughout this publication, imagery has been used for graphic purposes only. Captions have not been provided in these instances.

OPPOSITE PAGE FROM TOP: Glacial scene from CODES SEG Student Chapter field trip to Iceland; Ore Deposits of South America participants visiting the Yanacocha mine, Peru; Ore Deposits of South America field excursion group, 2015.

FRONT AND BACK COVER: Core yard at the Spence porphyry Cu-Mo deposit, northern Chile.



DIRECTOR'S REPORT



In my 2014 Director's Report, I described how our first year since the cessation of ARC Centre of Excellence funding had been one of the most successful in our history. However, the key question with any success is always 'can it be sustained?'. Although there were a number of reasons to be optimistic about 2015, there were also significant challenges that had the potential to make things go awry. While some of those challenges still remain, I am pleased to report that we came through our second year under the new funding scenarios and research models exceedingly well.

SEG-CODES 2015 CONFERENCE

Undoubtedly, one of the high points of the year was the Society of Economic Geologists (SEG) 2015 Conference held at Wrest Point. Despite the

downturn in the minerals industry, 742 delegates from 43 countries converged on Hobart at the end of September for an event that has since been described by the SEG as 'an unqualified success'. This statement was supported by extensive post-conference surveys, all of which revealed high satisfaction ratings.

This was the first time that this major conference had been held in Tasmania, and also the first time that the SEG had partnered with a university-based research group to co-host the event. It was a once in a lifetime opportunity for CODES to showcase the breadth of its research to the world, and our people certainly stepped up to the plate, providing 16 presenters, one panellist, six session chairs, 52 poster presentations, as well as leading two short courses and three field trips – to Indonesia, western Tasmania, and New South Wales. I was also very honoured to be asked to fill the role of Conference Chair.

By any criterion, this was a highly successful event and I wish to thank everyone at CODES for the immense contribution they made to this accomplishment. I also wish to thank

the sponsors, the conference co-ordinators (Conference Design), the staff at Wrest Point, my colleagues on the organising committee, the delegates, and all the external speakers and course leaders. Lastly, a special thank you to Brian Hoal and his team at the SEG, not just for the essential part they played in this event, but also for their ongoing support for CODES, exemplified by appointing us as joint hosts.

THE TMVC

Another significant event was the start of the ARC Industrial Transformation Research Hub, Transforming the Mining Value Chain (TMVC). The research hub was officially launched at a VIP function in September, and has already made significant progress, including the commencement of the AMIRA P1153 project: Applying the explorers' toolbox to discover porphyry and epithermal Cu, Au and Mo deposits, with field campaigns being initiated at new study sites in Sweden, the U.S.A. and Canada.

CRC ORE II

I am very pleased to report that the Australian Government has approved the application by CRC ORE to extend its tenure as a Co-operative Research Centre (CRC) for a further six years. As CODES was included as an Essential Research Participant in this application, this outcome ensures that the status of geomaterials as one of the Centre's three research Modules has been considerably strengthened. The key challenge for the CRC is to address the declining productivity in the minerals industry, and our expertise in areas such as geomaterials, ore deposit characterisation and modelling, and postgraduate training will play an essential role in achieving this objective over its extended tenure.



A full main auditorium at the SEG 2015 Conference.

RESEARCH MODULES

The Ore Deposits: Characterisation and Context Module continued its development in 2015, with 13 new or expanded research projects. This takes the total number of projects in the Module to 26, many of which had outcomes that had a direct impact on the potential discovery of new economic ore bodies. For example, the Drummond Peak Gold project has successfully identified ten new exploration targets; a study by Karin Orth, in collaboration with the Geological Survey of Western Australia, has raised the prospectivity of the Hart Dolerite for titanium, vanadium and iron across northern Western Australia's Kimberley district; and the Power of Pyrite project has led to potential vectors to ore being developed in at least four of the case study sites.

It was a relatively quiet year for the Geometallurgy Module with research being undertaken by HDR projects, but activities are expected to pick up considerably once CRC ORE II operations come into full swing in the latter part of 2016.

The Enabling Technologies Module continued to play an essential role in CODES operations, underpinning so many of our research initiatives. The laboratories, which already house some of the world's finest laser ablation analytical facilities, ensured that they will remain leaders in their field with a successful application to the University of Tasmania (UTAS) for funding to purchase and install a new generation Time-Of-Flight ICP-MS instrument. This purchase will significantly enhance CODES' capabilities in the rapidly developing field of imaging trace element

distributions in minerals using LA-ICP-MS.

The team from this Module also played a central part in AMAS XIII, the 13th biennial Australian Microbeam Analysis Symposium, which was hosted by CODES in the early part of the year. This major event in the field of microanalysis and imaging attracted 118 delegates from all around Australia, and included talks by over 50 of the world's leading experts. The symposium was led by Module Leader Leonid Danyushevsky, and Karsten Goemann from the UTAS Central Science Laboratory.

TRAINING

It was a good year for the Training Module, with 12 new enrolments for the HDR program, up from nine in 2014. This figure included a record high of nine Australian enrolments, which bettered the previous year's high of seven. While this increase may be in part due to people seeking to further their education in a tight jobs market, it is pleasing to see this positive trend continuing.

The Master of Economic Geology Program enjoyed another strong year, with the number of UTAS-based students active in the program equalling an all-time high of 52, complemented by a good throughput of completions and graduations.

There is no doubt that our students play an integral role in the success of our research projects, and particularly in disseminating our research outputs to audiences around the world. Their contribution to raising our profile on the world stage was once again evident in 2015, when they presented 25 papers and 30 poster presentations in Australia, Canada,

Chile, the Czech Republic, France and Peru. A commendable achievement.

PUBLICATIONS, INDUSTRY REPORTS AND CONFERENCE ABSTRACTS

It was a record year for publications. Refereed journal articles totalled 65, up from 55 the previous year, and not far behind the record of 69 achieved in 2013. However, when 15 chapters in books and an edited book are added to this figure, the grand total is 81, compared with 71 in 2013. It is also worth noting that many of these publications were published in journals of particular importance to applied economic geology research, including *Economic Geology*, *Mineralium Deposita* and *Ore Geology Reviews*. What makes this record output particularly pleasing is that it was achieved while our team maintained its high output of industry reports, which totalled 84, compared to 82 the previous year.

It was also a record year for conference abstracts, which totalled 147, which exceeds the previous best of 135 achieved in 2012.

AWARDS AND ACCOLADES

One of the most significant awards of the year was the announcement of the Government's Excellence in Research for Australia (ERA) rankings, in which UTAS Geology and Geophysics received a top mark of 5 out of 5 – referred to as 'well above world standard' in the ERA report. In addition, Earth and Marine Sciences at UTAS were placed in the top 100 of universities in the world in the QS World University rankings – the only areas within UTAS to get into the top 100.

These results highlight the importance of the earth sciences within the university, and how we rank as one of the world's leaders in this field.

From the moment he started his undergraduate studies, it was evident that Jacob Mulder had the potential to be an exceptional student. He has not disappointed. He has gone on to receive numerous awards, and attained the highest marks of any UTAS Earth Sciences Honours student on record, receiving the highly prized University Medal in the same year. Jacob has continued to build on this success as a postgraduate student. His achievements in the past year include two first author papers in high ranking journals (*Geology* and *Australian Journal of Earth Sciences*), and being awarded the prestigious Endeavour Postgraduate Scholarship by the Australian Government, which will result in him spending up to two years studying at the University of New Mexico under the guidance of the highly respected Professor Karl Karlstrom, starting in 2016.

Other notable achievements include PhD candidate Angela Escolme – best student presentation at the SEG 2015 Conference; Anya Reading – Fullbright Senior Scholar; Jay Thompson – the Dean's Award for Professional Staff; and PhD student Laura Jackson – best paper at the AusIMM Conference: Tailings and Mine Waste Management for the 21st Century.

I am also pleased to report that I completed my guest professorship at the GEOMAR Helmholtz Centre for Ocean Research in Kiel, Germany, as the recipient of the 2015 Research Excellence Professorship award from the Dr Werner Petersen Foundation.

END OF AN ERA

Ross Large retired at the end of 2015, although anyone who is acquainted with Ross will know that he won't be reaching for the 'pipe and slippers' any time soon.

Ross is recognised as a world leader in economic geology, publishing over 100 papers that invariably pushed the envelope, challenged the status

quo, and often introduced step-changes in geological thinking. He has received numerous accolades, including the AusIMM President's Award, the Haddon King Medal from the Australian Academy of Science, and the Lindgren Award, the Silver Medal and the BJ Skinner Award from the SEG. He has received the Distinguished Service Medal from UTAS, who have also bestowed the titles of Distinguished Professor and, more recently, Professor Emeritus on Ross. However, it is his role in CODES that is without doubt one of his finest achievements. Without Ross, CODES would not exist. It was his tenacity, foresight, leadership and perseverance that brought it into existence; and it was those same traits that ensured it grew to be a world leader in ore deposit research and postgraduate training. It hardly seems adequate, but I simply want to say a big thank you to Ross, on behalf of everyone at CODES, for the immense contribution he has made to the Centre over the best part of three decades. I am pleased to say that Ross has been retained in an honorary position, so long may his input continue; albeit in a reduced capacity.

STATISTICS AT A GLANCE 2015

Academic Research Staff	51
Postgraduate Students	129
Major Research Projects	42
Countries Involved	35
Publications in Refereed Journals	65
Research Reports to Industry	84
WORKSHOPS AND SHORT COURSES:	
Number	27
Countries	12
Attendees	1,562
FUNDING:	
Industry	\$1.71 million
UTAS	\$2.73 million
TMVC	\$2.74 million
WORLDWIDE COLLABORATIONS:	
Industry	47
Institutes and Universities	61

LOOKING FORWARD

We have every reason to feel positive about the year ahead. The TMVC research hub will gain momentum. CRC ORE II will come on stream, with a subsequent increase in collaborative research with CODES. The analytical laboratories will be further enhanced. We will also be pursuing a host of potential opportunities, including a partnership with Laurentian University in Canada for a high value research project named Metal Earth, an Industrial Transformation Training Centre in Mine Waste Characterisation, and a geoscience initiative in conjunction with Mineral Resources Tasmania and the Tasmanian Minerals and Energy Council. In addition, discussions are underway with Universitas Gadjah Maja, Indonesia, to run a joint Master of Economic Geology Degree.

2016 promises to be an exciting year.

J. Bruce Gemmell

Professor J Bruce Gemmell,
Director and Chief Operations Officer



OPPOSITE PAGE CLOCKWISE FROM TOP LEFT: Xin Xiao (Hefei University) leads across evaporites in the Salar de Atacama, Chile, during the South America field excursion; Stephanie Sykora in front of orbicular granite, Copiapo, Chile; tourmaline pyrite; chalcopyrite cemented breccia.

OVERVIEW AND RESEARCH STRUCTURE

IN SUMMARY

CODES was formed in 1989, and has been the Australian Research Council (ARC) Centre of Excellence in Ore Deposits since 2005. 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 51 highly qualified research staff and 129 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 47 industry companies, plus a host of joint research initiatives with 61 institutions and universities – 19 in Australia and 42 overseas. It currently has 42 major research projects spanning 35 countries, and is 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 84 reports to industry and conducting 27 short courses, workshops, conferences and field trips in 12 countries, spread across five continents.

OUTCOME-DRIVEN RESEARCH AND TRAINING

CODES has developed an integrated, four module research model, which provides a step-change in exploration techniques for metal discovery, new practices for sustainable mining, 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.

THE MODULES

The Ore Deposits: Characterisation and Context Module defines the geological, geochemical and geophysical features of ore deposits and their environments, in order to develop models that aid in the discovery of mineral resources at surface and under cover.

The Geometallurgy Module transforms how explorers and miners plan and predict mining and environmental activities, by providing new tools to guide these activities from the initial discovery through to end of mine life.

The Enabling Technologies

Module utilises a suite of cutting-edge instrumentation to develop analytical and computational techniques and tools to aid researchers with big data knowledge discovery, data reduction, modelling and interpretation.

The Training Module 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** – offers 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 that are international leaders in their field.

RESEARCH FACILITIES

CODES state-of-the-art 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 four 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 also has reciprocal 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.

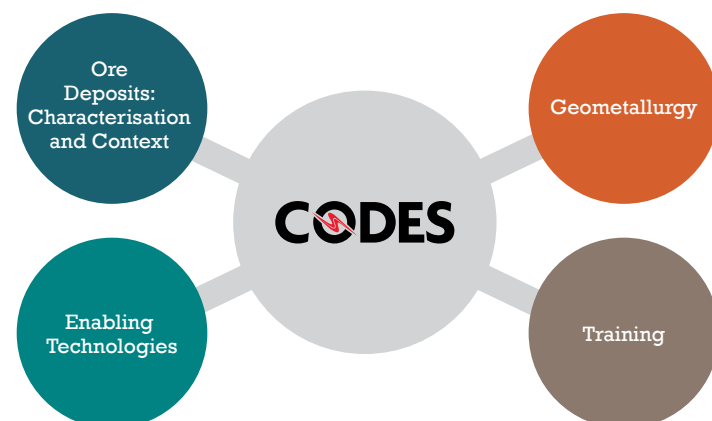
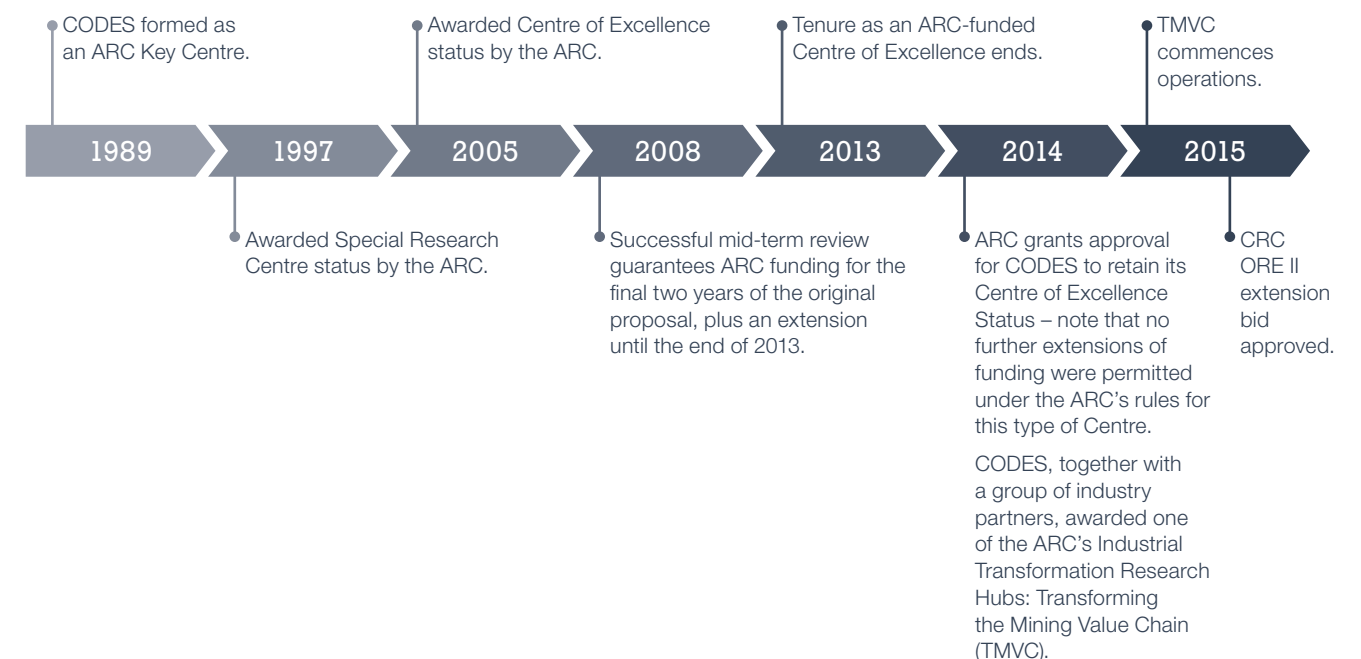
CODES' leading edge is based on the development of a number of unique analytical techniques and calibration standards, combined with employing staff with extensive expertise in analytical protocols and the interpretation of results.

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 this value chain, focussing on areas that will have a marked impact on the value of mineral resources. External organisations involved in the Hub are BHP Billiton, Corescan, Laurin Technic, Newcrest Mining, NICTA, and RWTH Aachen University, plus a consortium of national and international companies co-ordinated by AMIRA International.

TMVC commenced activities in mid-2015, which are covered later in this annual report.

TIMELINE



STAFF & MANAGEMENT

CENTRE DIRECTOR

Centre Director, Professor Bruce Gemmell, is responsible for the scientific leadership and operational management of the Centre. He is supported in these duties by Professor David Cooke (Deputy Director), 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.

ADVISORY BOARD

The Advisory Board meets 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.

SCIENCE PLANNING PANEL

The Science Planning Panel meets annually for a one-day forum of presentations relating to the Centre's scientific research progress and to discuss potential new research projects. The membership is wider than that of the Advisory Board and includes a representative from all partner companies. The Panel is designed to provide industry with an opportunity to influence future research directions of the Centre.

EXECUTIVE COMMITTEE

The Executive Committee consists of the Centre Director, Deputy Director, the Module Leaders, and the Communications Manager. It meets approximately six times a year, working closely with the Director to develop the Centre's goals, strategies and research directions.

STAFF MOVEMENTS 2015

APPOINTMENTS

Helen Scott has been appointed Manager for the ARC TMVC Research Hub. Her key duties include stakeholder relations, co-

ordinating training activities, and producing reports for industry and the ARC.

Dr Anita Parbhakar-Fox has been appointed as a Postdoctoral Research Fellow in Geoenvironmental Studies within the ARC TMVC Research Hub.

DEPARTURES

A total of five academic and professional staff left their positions during the year.

ACADEMIC STAFF

Dr Dan Gregory has attained a position at the University of California, Riverside.

Dr Jacqueline Halpin has moved to a position within the University at the Institute of Marine and Antarctic Studies (IMAS), but has been retained in an honorary position.

Professor Ross Large retired at the end of 2015, but has been retained in an honorary position.

PROFESSIONAL STAFF

Caroline Mordaunt – Administrative Assistant (part-time).

Jennifer Thompson has stepped down from her position as Laboratory Analyst to pursue a PhD within the ARC TMVC Research Hub.

STAFF AND MANAGEMENT

NAME		% IN CODES	TMVC
Director, Professor J Bruce Gemmell, BSc (UBC), MA, PhD (Dartmouth)	VHMS deposits and epithermal Au-Ag	100	•
Deputy Director, Professor David Cooke, BSc Hons (Latrobe), PhD (Monash)	Porphyry Cu-Au, fluid-rock geochemistry	50	•

ACADEMIC/RESEARCH STAFF AT UTAS

NAME		% IN CODES	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	20	
Dr Matt 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	
Professor Leonid Danyushevsky, PhD (Vernadsky Inst.)	Petrology, geochemistry, LA-ICP-MS analysis	50	•
Dr Garry Davidson, BSc Hons (ANU), PhD (UTAS)	Sulfur isotope geochemistry and Cu-Au ores	50	
Dr Paul Davidson, BSc Hons, PhD (UTAS)	Melt and fluid inclusions	Hon	
Dr Trevor Falloon, BSc Hons (Canterbury), BTeaching, PhD (UTAS)	Marine geoscience, petrology	Hon	
Professor David Green, BSc Hons, MSc, DSc, DLitt Hon (UTAS), PhD (Cambridge)	Experimental petrology	Hon	
Dr Jacqueline Halpin, BSc Hons (Melbourne), PhD (Sydney)	Metamorphic petrology, geochronology	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), PhD (UTAS)	Fluid inclusions, SE Asian metallogenesis	50	
Dr Chun-kit Lai, BSc, MPhil (HKU), PhD (UTAS)	Petrology, geochemistry and tectonics of SE Asia	Hon	
Professor Ross Large, BSc Hons (UTAS), PhD (UNE)	Volcanic-hosted and sediment-hosted base metal and gold ores	100	•
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 Karin Orth, BSc Hons (Monash), PhD (UTAS)	Volcanology	40	
Dr Anita Parbhakar-Fox, MSc Hons (London), PhD (UTAS)	Environmental geology, mineralogy, geochemistry	100	•
Associate 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	80	
Dr Jeff Steadman, BSc (Central Missouri), MSc (Iowa)	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 Lejun Zhang, BSc, PhD (HFUT)	Porphyry Cu-Au and HS epithermal	100	•

FROM LEFT: Jay Thompson, with Bruce Gemmell, after receiving the Dean's Award for Exceptional Performance by Professional Staff; Elena Lounejeva talking to Mike Whitbread from MMG at the Science Planning Meeting.



ACADEMIC/RESEARCH STAFF BASED AT COLLABORATIVE INSTITUTIONS/INDUSTRY

NAME		% IN CODES	TMVC
Dr John Bishop	Consultant	Hon	
Dr Daniel Bombardieri	Mineral Resources Tasmania	Hon	
Dr Tony Brown	Consultant	Hon	
Professor Ray Cas	Monash University	Hon	
Dr Kathy Ehrig	BHP Billiton	Hon	•
Associate Professor Jeff Foster	S2 Resources	Hon	
Neil Goodey	Corescan		•
Professor Mark Hannington	University of Ottawa	Hon	
Dr Stephen Hardy	NICTA		•
Dr Anthony Harris	Newcrest Mining	Hon	•
Professor Peter Hollings	Lakehead University	Hon	
Dr Julie Hunt	University of Liege	Hon	
Professor Bernd Lottermoser	RWTH Aachen University		•
Dr Andrew McNeill	Mineral Resources Tasmania	Hon	
Adele Seymon	AMIRA International		•
Michael Shelley	Laurin Technic		•
Dr Tony Webster	University of Queensland	Hon	
Dr Noel White	Consultant	Hon	
Dr Jamie Wilkinson	Natural History Museum, London	Hon	

TECHNICAL/ADMINISTRATIVE STAFF

NAME		% IN CODES	TMVC
Dr Ivan Belousov, BSc, MSc (Moscow), PhD (Vernadsky)	Research Associate- ARC TMVC Research Hub	100	•
Mr Steve Calladine	Communications Manager	100	
Mrs Michele Chapple-Smith	Lapidary Technician	40	
Mr Alex Cuison	Lapidary Technician	80	
Dr Sarah Gilbert, PhD, BSc Hons (UTAS)	Laser Ablation Technician- ARC TMVC Research Hub	100	•
Dr Jane Higgins, BIS, BAntSt Hons, PhD (UTAS)	Personal Assistant to the Director	90	
Mr Ian Little, BSc Hons (UTAS)	Maintenance, Field Equipment, and Safety Officer	50	
Ms Elena Lounejeva	Laboratory Analyst	100	
Mrs Katie McGoldrick	Laboratory Assistant	20	
Dr Paul Olin, BA (SOU), MSc, PhD (WSU)	Laser Ablation Technician- ARC TMVC Research Hub	100	•
Ms June Pongratz	Publications	5	
Mrs Claire Rutherford	Administrative Assistant	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	15	

Staff and students in 2015 – or at least those that were around on the day.



FROM LEFT: Professor Ross Large receiving his Distinguished Service Medal from the Vice-Chancellor, Professor Peter Rathjen; Deputy Chair of the Advisory Board, Paul Agnew from Rio Tinto, addressing delegates at the SEG 2015 Conference.

ADVISORY BOARD

NAME	
Chair: Paul Heithersay	Department of State Development, South Australia
Deputy Chair: Paul Agnew	Rio Tinto Exploration
Clive Baldock	Acting Dean, Faculty of Science, Engineering and Technology, UTAS
Richard Coleman	Pro Vice-Chancellor, Research Training, UTAS
David Cooke	CODES, UTAS
Paul Cromie	Anglo American
Iain Dalrymple	Teck Resources

EXECUTIVE COMMITTEE

NAME	
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

SCIENCE PLANNING PANEL
(ALSO INCLUDES THE EXECUTIVE COMMITTEE AND ALL CODES RESEARCH STAFF AND STUDENTS)

NAME	
Chair: Bruce Gemmell	Director, CODES, UTAS
Paul Agnew	Rio Tinto Exploration
Debora Araujo	Rio Tinto Exploration
Cynthia Awruch	Research Services, UTAS
Alfredo Bertens	QPX
John Bishop	Mitre Geophysics
Ralph Bottrill	Mineral Resources Tasmania
Richard Coleman	Pro Vice-Chancellor, Research Training, UTAS
Paul Cromie	Anglo American
Iain Dalrymple	Teck Resources
Kim Denwer	MMG
Mark Duffett	Mineral Resources Tasmania
Kathy Ehrig	BHP Billiton
Simon Enman	Unity Mining
David Green	Mineral Resources Tasmania
Anthony Harris	Newcrest Mining
Paul Heithersay	Department of State Development, South Australia

NAME	
Leonid Danyushevsky	CODES, UTAS
Kathy Ehrig	BHP Billiton
Bruce Gemmell	CODES, UTAS
Anthony Harris	Newcrest Mining
John Holliday	Holliday Geoscience
Andrew McNeill	Mineral Resources Tasmania
Aubrey Paverd	Buenaventura
Adele Seymon	AMIRA International
Noel White	Consultant

NAME	
Garry Davidson	Ore Deposits: Characterisation and Context Module Leader
Julie Hunt^	Geometallurgy Module Leader
Anya Reading	Training Module Co-leader / Coordinator Graduate Research
Robert Scott	Training Module Co-leader

^Committee member for part of year

NAME	
Steve Hill	Geological Survey of South Australia
John Holliday	Holliday Geoscience
Tony Hope	GHD
Stuart Hughes	GHD
James Johnson	Geoscience Australia
German Ojeda	QPX
Aubrey Paverd	Buenaventura
Anthony Reid	Geological Survey of South Australia
Adele Seymon	AMIRA International
Sumon Shahriah	CSIRO
Andrew Somers	SciAps Australia
Greg Timms	CSIRO
Steve Walters	CRC ORE
Sally Watson	IMAS, UTAS
Mike Whitbread	MMG
Jo Whitaker	IMAS, UTAS
Noel White	Consultant

CODES CO-HOSTS SEG 2015 CONFERENCE



FROM TOP: Premier of Tasmania, Will Hodgman, opening the conference; John and Christine Horrigan (SEG) with visitors to their booth; Tony Crawford (CODES), far right with Neil Williams (University of Wollongong) and his wife Margaret; Kathy Ehrig (BHP) and Andrew Davies (Teck) during a panel discussion; Sean Johnson talking to Johan Arif from J Resources Nusantara, Indonesia, at the CODES booth.

When the Premier of Tasmania, Will Hodgman, opened the SEG 2015 Conference at Wrest Point in Hobart on Sunday, September 27, it marked the first time that this major international event had been held in Tasmania, and only the second time it had come to Australia. It was also the first time that the Society of Economic Geologists (SEG) had entered into an equal partnership with a research organisation (CODES) for this annual conference, which is widely regarded by economic geologists as the most important event on the calendar.

Despite the current downturn in the minerals industry, and the long distances many people had to travel to reach Tasmania, the attendance exceeded all expectations with 742 delegates, from 43 countries, filling the conference facilities at the venue. The main conference ran for three days, but this was supplemented by two field trips and four short courses pre-conference, and three field trips and two short courses post-conference.

The main conference theme, *World-Class Ore Deposits: Discovery to Recovery*, combined the topics of exploration and discovery with a number of the geosciences, as well as geometallurgy, to cover a range of deposit types and major mines and districts. Spread over twenty sessions, in nine theme sessions, the technical program was delivered by an outstanding line up of keynote and volunteer speakers from around the world, who covered a wide array of subjects, and didn't shy away

from tackling the important, and at times controversial, issues facing the minerals industry. To illustrate this point, the main conference was rounded off with a special Controversies Session, which included a typically assured and enthusiastic talk by Professor Ross Large, intriguingly titled 'A neptunist's view in a world of magmatists'.

An innovation at this year's event was the introduction of a new style of keynote presentation, named the *Trifecta* talks. These highly popular presentations combined the discovery history, geology, and geometallurgy of four of the world's finest ore bodies: the Red Dog and Pebble deposits in Alaska, Olympic Dam in South Australia, and Ladolam in Papua New Guinea.

Student participation was actively encouraged by both the SEG and CODES, and the budding geoscientists certainly rose to the occasion with significant participation in the technical program, through both the oral and poster presentations. In addition, the CODES SEG Student Chapter organised a number of highly successful pre-conference activities, including a reception to welcome students from a diverse mix of cultural backgrounds.

In conjunction with the main technical program, the poster sessions attracted 262 entries – a record for an SEG Conference. The posters played a vital role by focussing on areas of research in economic geology that can lead to important practical issues of



CLOCKWISE FROM TOP: Conference Chair Bruce Gemmell addressing delegates at the opening session; Guests board the ferry to take them to MONA; Approximately 100 CODES friends and alumni gather at a special function to renew old acquaintances.

improved exploration concepts, discovery, mine geology and recovery (geometallurgy). There was also an extensive exhibition area that housed booths representing more than 40 mining companies and organisations. As co-host, CODES had a large booth in a prime position, which was manned by a host of staff and students, on a roster basis.

CODES staff and students also made major contributions to the overall conference proceedings, which included Bruce Gemmell as Conference Chair, plus 16 presenters and one panellist, six session chairs, 52 poster presentations, as well as leading two short courses and three field trips – to Indonesia, western Tasmania, and New South Wales.

The conference received widespread local media coverage, including a substantial article in the *Sunday Tasmanian* and several interviews on ABC Radio.

CODES wishes to thank the following people and organisations for making this event such a success.

- The Chairman Bruce Gemmell's colleagues on the organising committee: Noel White (consultant), Patrick Sack (Yukon Geological Survey), Zhaoshan Chang (JCU), Garry Davidson (CODES), Dan Wood (consultant), and Brian Hoal and Christine Horrigan (SEG).
- The CODES SEG Student Chapter, and the all the staff at CODES that played a part in the event.
- Ben Theissen and his team at Conference Design – the conference co-ordinators.
- The staff and management at Wrest Point.
- The sponsors (see list on this page).
- All the presenters, short course and field trip leaders, and the 742 delegates who came from far and wide to participate.

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OBJECTIVE

To describe the geological, geochemical and geophysical features of ore forming systems and terrains, and use this information to devise better means of discovering mineral resources at surface and under cover.



INTRODUCTION

The Ore Deposits: Characterisation and Context Module provides end-users with process-based models for the formation of high value metalliferous ore deposits and a framework to develop innovative new tools for determining the most prospective regions for exploration (fertility), and for targeting buried ore deposits (vectoring).

The Module was formed at the beginning of 2014 and is the result of the amalgamation of the Location, Formation and Discovery Programs, which had been in operation since 2006. This revised model retains CODES' core research strengths, while establishing a platform that allows projects to be developed that meet the evolving needs of the minerals industry. This is achieved through six themes, which reflects CODES' range of expertise and level of diversity in the field of hard-rock geology.

HIGHLIGHTS

In its second year since the transition from the Program structure, the Module continued to expand and develop, building on the solid and wide ranging research platform established in 2014.

The total figure of 26 projects within this Module report is up slightly from 25 in the previous year, which has been achieved despite some projects being transferred to the Discipline of Earth Sciences and the new ARC TMVC Research Hub. The total also includes 13 new or expanded research initiatives, demonstrating how the Module has evolved significantly during the year. Many of these projects were created as a result of initiatives reaching maturity and outgrowing the scope of project titles, creating the need for new projects that better reflect the evolving nature of the research.

Other highlights include:

PUBLICATIONS

It was another exceptional year for publications output, with researchers and students within the Module producing 61 published refereed journal articles, 15 chapters in books, and

one edited book. It is worthwhile to note that many of these publications were published in journals of particular importance to applied economic geology research, including nine in *Economic Geology*, eight in *Ore Geology Reviews*, and two in *Mineralium Deposita*. It is also worth noting that the figures exclude publications affiliated to the Discipline of Earth Sciences.

One of the highlights of this output was a manuscript published in the high ranking journal, *Geology*, by PhD student Jacob Mulder. Jacob's paper revealed that Tasmania was once linked to what we now recognise as North America and Antarctica during the time of the ancient supercontinent Nuna. The paper, and subsequent media release, received worldwide media attention, including a segment in the ABC TV's popular science program *Catalyst*, which will air in 2016.

Nathan Fox and co-authors also published a paper in *Geology* in 2015, describing a fundamental crustal link between the locations of volcanosedimentary rift basins and Cu-Au porphyry deposits in the Cadia district, NSW.

REPORTS TO INDUSTRY/ GOVERNMENT AGENCIES

In addition to the high number of publications produced during the reporting period, team members issued 38 reports to mining companies and government agencies, maintaining the Module's excellent performance in terms of technology transfer.

RESEARCH OUTCOMES

It was also a good year for research outcomes, with many projects having direct impacts on the potential discovery of new economic ore bodies. For example:

- A study by Karin Orth, in collaboration with the Geological Survey of Western Australia, has raised the prospectivity of the Hart Dolerite for titanium, vanadium and iron across northern Western Australia's Kimberley district.
- David Selley's research on the Gosowong low sulfidation epithermal gold system, Halmahera, Indonesia,

has led to the construction of a district-scale 3-D tectono-stratigraphic model, which provides a robust geometric template for ongoing exploration targeting.

- The work completed on the Power of Pyrite project led to a better understanding of the nature of mineralisation at all studied sites, with potential vectors to ore developed for at least four of the case studies. Six companies, plus GA and the GSSA, are now funding this project, and a total of six case studies have commenced.
- The Drummond Peak Gold project successfully identified ten new exploration targets.

Other key research outputs and achievements include:

- Honours student Sally Mattner took advantage of the temporary draining of Tasmania's Lake Rowallan to study Precambrian rock formations that had not been visible since the last Ice Age. The study is expected to shed light on the geological development of the whole of eastern Australia.
- Excellent progress has been made on recognising and answering major questions relating to the processes responsible for metal concentration and their duration in the formation of the supergiant Olympic Dam Cu-U-Au-Ag ore deposit.

AWARDS AND GRANTS

- PhD student Jacob Mulder was awarded the prestigious Endeavour Postgraduate Scholarship by the Australian Government, which will result in him spending up to two years studying at the University of New Mexico, under the guidance of Professor Karl Karlstrom.
- PhD candidate Angela Escolme was awarded the best student presentation at the SEG 2015 Conference in Hobart.
- Bruce Gemmell completed his guest professorship at the GEOMAR Helmholtz Centre for Ocean Research in Kiel, Germany, as the recipient of the 2015 Research Excellence Professorship award from the Dr Werner Petersen Foundation.

OPPOSITE PAGE: Chrysocolla (light green to blue) and malachite (dark green) cemented breccia from the oxide zone at the Kansanshi copper mine, NW Zambia.

THE MODULE TEAM



LEADER:
Garry Davidson

TEAM MEMBERS:

Sharon Allen, Ron Berry, Stuart Bull, Rebecca Carey, David Cooke, Matt Cracknell, Leonid Danyushevsky, Paul Davidson, Nathan Fox, Bruce Gemmell, Dan Gregory, Jacqueline Halpin, Alistair Harvey, Nic Jansen, Maya Kamenetsky, Vadim Kamenetsky, Ross Large, Jocelyn McPhie, Sebastien Meffre, Karin Orth, Anya Reading, Michael Roach, Robert Scott, David Selley, Jeff Steadman, Jay Thompson, Selina Wu, Khin Zaw, Lejun Zhang

PHD STUDENTS:

Olga Apukhtina, Richelle Awid Pascual, Mohd Basril Iswadi Bin Basori, Heidi Berkenbosch, Nathan Chapman, Alex Cherry, David Douth, Esmaeil Eshaghi, Matt Ferguson, Pedro Fonseca, Jodi Fox, Margy Hawke, Jacob Heathcote, Sam Holt, Wei Hong, Qiuyue Huang, Fumihiko Ikegami, Sean Johnson, Joseph Knight, Erin Lawlis, Elena Lounejeva, Charles Makoundi, Brian McNulty, Larriana Morgan, Indrani Mukherjee, Jacob Mulder, Evan Orovan, Naomi Potter, Marc Rinne, Subira Sharma, Nathan Steeves, Stephanie Sykora, Daniele Vergani, Sally Watson (IMAS), Toban Wild (Monash)

MASTERS STUDENTS:

Billy Beas, Jo Condon, Xuan Truong Le, Saranya Nuanla-Ong, Irma Vejelyte

HONOURS STUDENTS:

Chris Hildrew, Travis Holmes, Sally Mattner, Jordan Sheppard, Jonathan Traynor

COLLABORATORS:

ANGLO AMERICAN

Paul Cromie

AKITA UNIVERSITY, JAPAN

Akira Imai

ANGLOGOLD ASHANTI

Michael Nugus, Ross Pringle

ARGENT MINERALS

David Busch

BHP BILLITON

Kathy Ehrig, Danny Huisman

BOLIDEN MINERAL AB

Rodney Allen

BRITISH GEOLOGICAL SURVEY

Mike Crow

CAMECO RESOURCES

Penny Sinclair

CHIANG MAI UNIVERSITY, THAILAND

Phisit Limtrakun

CHULALAKORN UNIVERSITY, THAILAND

Abhisit Salam

CLUMP MOUNTAIN GEOSCIENCE

Pat Williams

COLORADO STATE UNIVERSITY, USA

Holly Stein

CONSULTANT

Neil Allen, Alexey Lygin

CSIRO

June Hill

CURTIN UNIVERSITY

Andrea Agangi, Ian Fitzsimons, Fred Jourdan

DEPARTMENT OF MINERAL RESOURCES, THAILAND

Somboon Khositanont

DIRECTORATE OF GEOLOGICAL SURVEY AND EXPLORATION, MYANMAR

Ye Myint Swe

DRUMMOND GOLD

Ed Eshuys

EAST YANGON UNIVERSITY, MYANMAR

Cho Cho Aye

EMMERSON RESOURCES

Hamish Johns, Grant Osborne

ENTERPRISE METALS

Frank Doedens, Dermot Ryan

FIRST QUANTUM MINERALS

Steve Beresford, Tim Ireland, Louis van Heerden

GEOFORSCHUNGSZENTRUM POTSDAM, GERMANY

Rainer Thomas

GEOLOGICAL SURVEY OF JAPAN

Kenzo Sanematsu

GEOLOGICAL SURVEY OF SOUTH AUSTRALIA

Rian Dutch, Adrian Fabris, Anthony Reid

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Julie Hollis, David Maidment, Christopher Phillips, Michael Wingate

GEOMAR, GERMANY

Sven Petersen

GEOSCIENCE AUSTRALIA

Geoff Fraser, David Huston, Roger Skirrow

GNS NEW ZEALAND

Cornel de Ronde

HANOI UNIVERSITY OF MINING AND GEOLOGY, VIETNAM

Hai Thanh Tran

HOLCOMBE COUGHLIN OLIVER

Nick Oliver

HOLLIDAY GEOSCIENCE

John Holliday

INSTITUTE OF TECHNOLOGY, INDONESIA

Andri Subandrio

INTREPID MINES

Tom Woolrych

MACQUARIE UNIVERSITY

Elena Belousova, Nathan Daczko

MAHASARAKHAM UNIVERSITY, THAILAND

Clive Burrett

MANDALAY UNIVERSITY, MYANMAR

Tin Aung Myint

MINERAL RESOURCES TASMANIA

Daniel Bombardieri, Clive Calver, Grace Cumming, Mark Duffett, John Everard, Andrew McNeill, Mike Vicary, Andy Wakefield

MONASH UNIVERSITY

Ray Cas, Mike Hall, Jeff Stilwell

NANYANG TECHNOLOGY UNIVERSITY, SINGAPORE

Yu Wang

NEWCREST MINING

Ben Ackerman, Mathieu Ageneau, Chris Allickson, Nick Fitzpatrick, Don Fraser, Karyn Gardner, Anthony Harris, Bridgette Hendersonhall, Fiona Karaut, Paul Kitto, Fraser MacCorquodale, Dominic Murphy, Paul Napier, Gustav Nortje, Charlotte Seabrook

NORTHERN TERRITORY GEOLOGICAL SURVEY

Dorothy Close, Andrew Wygralak

OZ MINERALS

Hamish Freeman

PIONEER RESOURCES

David Crook

RIO TINTO EXPLORATION

Bryan Bowden, Greg Clarke, Mawson Croaker

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RWTH AACHEN UNIVERSITY, GERMANY

Bernd Lottermoser

SANDFIRE RESOURCES

Richard Beckley, Paul Hilliard

S2 RESOURCES

Jeff Foster

TASMAN RESOURCES

Rob Smith

TINTINA RESOURCES

Bruce Hooper, Jerry Zieg

UNIVERSITI KEBANGSAAN, MALAYSIA

Mohd Basril Iswadi Basori, Wan Fuad Wan Hassan, Mohd Shafeea Leman

UNIVERSITI TEKNOLOGI, MALAYSIA

Mazlan Hashim, Amin Beiranvand Pour

UNIVERSITY COLLEGE OF SCIENCE, IRAN

Mirsaleh Mirmohammadi

UNIVERSITY OF BONN, GERMANY

Maria Kirchenbaur

UNIVERSITY OF BRITISH COLUMBIA, CANADA

Jim Mortensen

UNIVERSITY OF CENTRAL MISSOURI, USA

Mark Dudley, John Nold

UNIVERSITY OF GENEVA, SWITZERLAND

Robert Moritz

UNIVERSITY OF MALAYA, MALAYSIA

Azman Ghandi

UNIVERSITY OF MELBOURNE

Andy Gleadow, Barry Kohn, Roland Maas

UNIVERSITY OF NEW ENGLAND

Luke Milan

UNIVERSITY OF OTTAWA, CANADA

Mark Hannington

UNIVERSITY OF PADJAJARAN, INDONESIA

Mega Rosana

UNIVERSITY OF SYDNEY

Dietmar Müller, Simon Williams, Derek Wyman

UNIVERSITY OF TASMANIA

Mike Coffin, Karsten Goemann, Taryn Noble, Pat Quilty, Thomas Rodemann, Joanne Whittaker



CORE PROJECTS

THEME 1 ORE FERTILITY OF THE CRUST AND MANTLE

- Melt-melt immiscibility and the origin of magnetite-apatite deposits
- Tectonic and Cu-Au and Au mineralisation of western Myanmar-Sumatra Terrane^
- Architecture of the Birimian belts in Côte d’Ivoire^

THEME 2 VOLCANISM, AND ITS EFFECT ON ORE FORMING PROCESSES

- VHMS research – modern
- VHMS research – ancient
- Volcanology related to ore deposits^
- Paleoproterozoic mafic magmatism of the Kimberley Basin, Western Australia^

THEME 3 MAGMATIC-HYDROTHERMAL PROCESSES AND ORES

- Exploring the porphyry environment
- Olympic Dam
- Magmatic-hydrothermal volatile exsolution and mineralisation in Tasmanian Sn granites^

THEME 4 BASIN PROCESSES AND ORES

- McArthur Basin copper
- Kansanshi gold
- Uranium concentrations in basins

THEME 5 THE ORE AFFECTED CRUST

- The power of pyrite
- Drummond peak gold^
- DeGrussa VHMS vectoring^
- Integrating geology and geophysics for resources targeting^
- Metamorphic architecture of the western Gawler Craton
- Application of sulfide S and carbonate C-O isotopes to ore genesis and exploration^
- Australian hydrothermal IOCG and related deposits
- The characteristics and role of colloidal silica fluids in the formation of the Grieves Siding Pb-Zn prospect, western Tasmania^
- The geology, geochemistry and genesis of the Avebury Ni deposit: Implications for exploration^
- Geology and genesis of the Invincible gold deposit, St Ives^

THEME 6 DATES AND PLATES

- Building Tasmania: The Cambrian and beyond^
- Tectonic reconstruction of East Gondwana
- Structure of SE Australia using multiple geophysical methods

^ New project

Notes:

1. The Epithermal Deposits project has been amalgamated into other projects within this Module, as well as the TMVC section of this report.
2. It was reported in the 2014 Annual Report that the AMIRA P1153 project would be reported in this Module. However, it has since been decided that it falls under the TMVC.
3. The Basaltic Volcanoes, Rhyolitic Caldera Successions, and Trace Elements in the Ocean (TEO) projects are now being reported in the section of this Annual Report that is dedicated to CODES' close relationship with the Discipline of Earth Sciences.

PROJECT SUMMARIES

THEME 1 ORE FERTILITY OF THE CRUST AND MANTLE

MELT-MELT IMMISCIBILITY AND THE ORIGIN OF MAGNETITE-APATITE DEPOSITS

Leader: Paul Davidson

Collaborators: Mark Dudley, Mirsaleh Mirmohammadi, John Nold, Rainer Thomas

Melt-melt immiscibility covers a group of related processes in which melts at specific TPX conditions may spontaneously split into two or more mutually immiscible phases. In contrast to fractionation, melt-melt immiscibility is a sudden, intense, step-wise change in magma composition, which may rank with fractionation as a significant, if subordinate, driver of magma evolution, and thus crustal evolution.

There are numerous forms of melt-melt immiscibility, and this project began studying Fe-Ti oxide melt-silicate melt immiscibility (Kiruna-type magnetite-apatite deposits) and has gone on to concentrate on silicate melt-silicate melt immiscibility (pegmatites) with a view to understanding the generation of economically valuable ore-deposits. It is intended to separate these streams in future, with pegmatite research being conducted under the title of 'The origin of pegmatites and pegmatite-related ores', with the research into Kiruna-type deposits being reported under the revised 'IOCG deposits and related deposits' project.

During 2015, a paper by Rainer Thomas and Paul Davidson entitled 'Revisiting complete miscibility between silicate melts and hydrous fluids, and the extreme enrichment of some elements in the supercritical state – consequences for the formation of pegmatite and ore deposits' was accepted for publication in *Ore Geology Reviews*. A second paper is ready for submission.

TECTONIC AND Cu-Au AND Au MINERALISATION OF WESTERN MYANMAR-SUMATRA TERRANE

Leader: Khin Zaw

Team Members: Jacqueline Halpin, Ross Large, Sebastien Meffre

Students: Mohd Basril Iswadi Bin Basori, Joseph Knight, Xuan Truong Le, Charles Makoundi, Saranya Nuanla-Ong, Jordan Sheppard, Jonathan Traynor

Collaborators: Cho Cho Aye, Mohd Basril Iswadi Basori, Clive Burrett, Paul Cromie, Mike Crow, Azman Ghandi, Mazlan Hashim, Wan Fuad Wan Hassan, Akira Imai, Somboon Khositantont, Mohd Shafeea Leman, Phisit Limtrakun, Robert Moritz, Tin Aung Myint, Amin Beiranvand Pour, Mega Rosana, Abhisit Salam, Kenzo Sanematsu, Holly Stein, Andri Subandrio, Ye Myint Swe, Hai Thanh Tran, Yu Wang, Ian Watkinson

This research commenced in 2015, building on the successful Ore Deposits of SE Asia project, which came to a conclusion at the end of 2014. While the SE Asia project focussed on the geochronology, metallogenesis and deposit styles of mainland areas of the region, this new initiative looks specifically at the tectonic, Cu-Au, and Au mineralisation of the western Myanmar-Sumatra Terrane.

Highlights for 2015 include:

- Research by Honours student Jordan Sheppard in stratigraphically and palaeontologically well-constrained Devonian shales exposed along the Mandalay-Pyin Oo Lwin tract in the Northern Shan State, Myanmar, indicates a clear mass extinction event in the Upper Devonian, and significant changes (oxic to dysoxic and anoxic) in paleoredox conditions of the Devonian Ocean. The relativity plots of the zircons suggest the source and provenance of the Devonian sequence in Myanmar has a Gondwana affinity, as the peaks of the zircons confirm an affinity with the Sibumasu Terrane.
- LA-ICP-MS analyses and imaging of three types of pyrites, and fluid studies of the Palaeozoic shale/

sandstone-hosted Modi Taung orogenic gold deposit near Nay Pyi Taw, Central Myanmar, suggest at least two stages of enrichment of gold; both in the sedimentary environment and the later magmatic-metamorphic conditions, as evidenced by a change in fluid chemistry and hydrothermal source. Pb isotope analysis suggests that lead has been sourced from a crustal region and is likely to be attributed to post-collisional melting following the suture of the Sibumasu Terrane and the West Myanmar Terrane.

- Fieldwork and sampling conducted on major ore hosting lithologic volcanic/magmatic units. This sub-project, entitled 'Geodynamic and metallogenic setting of Cu-Au mineralisation in Myanmar: Implications for mineral exploration' was funded by a major Australian mining company. Laboratory analyses (XRF, LA-ICP-MS zircon dating) are in progress.

ARCHITECTURE OF THE BIRIMIAN BELTS IN CÔTE D’IVOIRE

Leader: David Selley

Team Member: Sebastien Meffre

Collaborators: Mathieu Ageneau, Anthony Harris, Paul Kitto, Dominic Murphy, Charlotte Seabrook

This Newcrest-sponsored project, initiated in August 2015, aims to generate a country-wide geologic template for Côte d’Ivoire that can be used to facilitate orogenic gold exploration at deposit to district scales. The work builds on major, multidisciplinary research by the WAXI consortium, led by the University of Western Australia and the University of the Witwatersrand, that has focussed on countries surrounding Côte d’Ivoire. The successful multi-faceted approach employed by WAXI, including analysis of regional datasets, targeted field traversing, and the generation of petrographic, geochronologic, and geochemical datasets, is being replicated in this project.

A preliminary structural template has been produced largely on the basis of geophysical and topographic data, which projects Birimian belts



FROM TOP: David Selley (centre) with Boris Gbeada (L) and Coulibaly Hadja Massia, both from Newcrest Mining, during field mapping in the Dabakala region, Côte d'Ivoire; Dominic Murphy (Newcrest Mining) astride a granite contact, Nzi River, Côte d'Ivoire; Brian McNulty underground at Myra Falls holding massive sulfide rock.

from Côte d'Ivoire's peripheries into its interior. Complementary field mapping in the west and north of the country has provided a near complete composite section through the Palaeoproterozoic stratigraphy. Geochronologic sampling of felsic and intermediate volcanic units from lower arc-related sequences, coupled with detrital zircon dating of upper basin levels, will underpin a robust chronostratigraphic framework, relating stratal growth to orogenic and magmatic events.

Initial work has generated one crystallisation age for a lower felsic interval, indicating that sampling and analytical methods are viable. Detailed structural analysis reveals phases of N- to NW-directed arc accretion, associated granitic magmatism, and exhumation of mid-crustal levels. Each phase records components of locally intense orogen-parallel stretch, as individual belts are progressively anticlockwise rotated and ultimately transposed into N- to NE-striking, crustal-scale tears.

THEME 2 VOLCANISM, AND ITS EFFECT ON ORE FORMING PROCESSES

VHMS RESEARCH – MODERN
Leader: Bruce Gemmell

Student: Heidi Berkenbosch

Collaborators: Cornel de Ronde, Andrew McNeill, Sven Petersen

Heidi Berkenbosch's PhD project at Brothers volcano, in the Tonga-Kermadec arc, continued in 2015. This collaborative project with GNS, 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 Cu isotopes geochemistry of the chimneys was published by *Mineralium Deposita* during the year.

Bruce Gemmell is continuing research on the Palinuro seafloor mineralising system in the Tyrrhenian Sea, Italy, which is an evolving intermediate to high sulfidation

massive sulfide. Bruce is using LA-ICP-MS analyses of the different paragenetic generations of pyrite to elucidate the evolving hydrothermal fluids responsible for the Palinuro mineralised occurrence. This research is being conducted in collaboration with Sven Petersen at GEOMAR, Germany.

VHMS RESEARCH – ANCIENT
Leader: Bruce Gemmell

Team Members: Ron Berry, Garry Davidson, Ross Large, Khin Zaw

Students: Mohd Basril Iswadi Bin Basori, Jo Condon, Margy Hawke, Brian McNulty, Nathan Steeves

Collaborators: Mark Hannington, Andrew McNeill, Jim Mortensen, Sven Petersen, Mike Vicary

The genesis of volcanic-hosted Cu-Pb-Zn-Ag-Au massive sulfide deposits is being investigated across the spectrum of massive sulfide deposit types, from typical seafloor VHMS (Zn-Pb-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 2015, research was undertaken on deposits at Fossey- Hellyer-Que-River-Mt Charter (Tasmania), DeGrussa and Jaguar (Western Australia), Greens Creek (Alaska), Myra Falls (Canada), Tasik Chini (Malaysia) and Bawdwin (Myanmar).

Nathan Steeves continued his PhD investigation of the Greens Creek VHMS deposit in southeast Alaska. The Greens Creek deposit is the top silver producing mine in the U.S. and one of the most significant massive sulfide deposits in the world. Massive sulfide lenses occur along with black dolostone and rift-related conglomerate at the base of a thick sequence of Late Triassic graphitic argillite, and unconformably overlie a footwall of altered Carboniferous mafic metavolcanic rocks, intruded by mafic-ultramafic rocks. Nathan is studying the mineralogy, metal distribution and geometallurgical characteristics of the complex ore bodies. Nathan presented results of his research at the SGA Conference

in France, and the SEG Conference in Hobart. The study is being conducted in collaboration with Mark Hannington from the University of Ottawa. Nathan also had a paper accepted in *Economic Geology* on the Glacier Creek Cu-Zn deposit, Alaska, which will be published in early 2016.

Brian McNulty commenced his PhD thesis on the geologic and structural setting of the West Block area at the Myra Falls VHMS deposit 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 other deposits in the area, with the aim of developing useful criteria for exploration in the Myra Falls District. Brian has undertaken underground mapping and core logging in order to describe the area's deposit mineralogy, textures, paragenesis and metal zoning.

Mohd Basril Iswadi Bin Basori was awarded his PhD in 2015 for his research on the geochemical, isotopic and genetic aspects of the Tasik Chini and related VHMS hydrothermal systems in Malaysia. Three manuscripts based on his research have been submitted and are currently in review.

Khin Zaw conducted geological research at the Bawdwin deposit in Northern Shan State, Myanmar. The deposit occurs as sub-vertical pipes in a rhyolitic volcanoclastic pile of Cambro-Ordovician age. The ore bodies are localised along N-S and NW-SE major rift structure in which dome-shaped rhyolite intrusions were emplaced.

Two student projects continued at Sandfire Resources' VHMS deposit at DeGrussa, WA. The first, a PhD project by Margy Hawke, is investigating the geologic, structural and geochronological setting of the deposits. Margy published a paper in 2015 in *Precambrian Research* on the geochronology of the DeGrussa VHMS deposit and associated mineralisation of the Yerrida, Bryah and Padbury Basins, Western Australia. She also presented results of her research at the SGA Conference in France, and the SEG Conference in Hobart. The second study is a Masters project by Jo Condon, which is concentrating

on the ore and gangue mineralogy, textures, paragenesis, and mineral chemistry of two of the ore lenses at DeGrussa. Jo submitted her thesis in 2015 and it is currently undergoing examination.

Former PhD student Susan Belford, in conjunction with Garry Davidson, Jocelyn McPhie and Ross Large, published the results of her investigation on the architecture of the Neoproterozoic Jaguar VHMS deposit, Western Australia: implications for prospectivity and the presence of depositional breaks in *Precambrian Research*. In addition, Susan and Garry contributed to another publication in *Precambrian Research* entitled 'A review of volcanic-hosted massive sulfide (VHMS) mineralization in the Archaean Yilgarn Craton, Western Australia: Tectonic, stratigraphic and geochemical associations'.

The first phase of a project aimed at improving the age and geochronological constraints on the development of the Mount Read Volcanic Belt (MRV) was completed, in collaboration with Jim Mortensen (UBC). Work included 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 paper was published in *Economic Geology* in 2015, entitled 'High-precision U-Pb zircon chronostratigraphy of the Mount Read Volcanic belt in Western Tasmania, Australia: Implications for VHMS deposit formation'. A second phase of age dating throughout the MRV is underway and results were presented at the SEG Conference in Hobart.

VOLCANOLOGY RELATED TO ORE DEPOSITS

Leader: Rebecca Carey

Team Members: Sharon Allen, Jocelyn McPhie

Students: Billy Beas, Pedro Fonseca, Chris Hildrew

Collaborator: Ray Cas

Pedro Fonseca's PhD project is focussed on the internal stratigraphy and architecture of the Mount Read Volcanics in western Tasmania. The stratigraphic and facies analyses

have allowed correlation between the host sequences to two of the Hellyer and Rosebery VHMS deposits. Pedro has also produced detailed reconstructions of the volcanic setting and volcano types for the periods before, during and after the VHMS mineralising events at these locations. Pedro's thesis will be submitted in early 2016.

Chris Hildrew undertook an Honours project at the Archean Nimbus Ag-Zn-Pb-Au deposit, Western Australia, supervised by visiting Professor Ray Cas, and sponsored by MacPhersons Resources. The project involved facies and stratigraphic analyses of the host succession in order to improve the exploration model, and to refine current ideas on the deposit genesis.

Master of Economic Geology student Billy Beas completed his thesis on the volcanology and geochronology of the Cenozoic volcanic succession that hosts gold and copper deposits in northern Peru. The project was sponsored by Minera La Zanja SRL. The district comprises diverse, subaerial, caldera-related rhyolitic ignimbrites, as well as dacitic and andesitic domes and high-level intrusions. Billy used U-Pb zircon dates to clarify the ages and duration of the main volcanic and mineralising episodes. He presented a summary of his results at the SEG Conference in Hobart.

Jocelyn McPhie is a member of an international team that won a grant from the Continental Scientific Drilling Project for the drilling of Surtsey, a famous Icelandic volcanic island created by offshore basaltic eruptions in 1963-67. The proposed drilling will recover core from the submarine part of the island, and involve sampling of fluids from the active hydrothermal system in the core of the volcano.

Jocelyn was also invited to co-author two chapters on submarine volcanism in the new edition of the *Encyclopaedia of Volcanoes*.

**PALEOPROTEROZOIC
MAFIC MAGMATISM OF THE
KIMBERLEY BASIN, WESTERN
AUSTRALIA**

Leader: Karin Orth

Collaborators: Julie Hollis, David Maidment, Christopher Phillips, Michael Wingate

This project leads on from the Carson-Volcanics Hart Dolerite Large Igneous Province (LIP) research (2012-2014) in the Kimberley, Western Australia, and involves assessment of the Carson-Volcanics Hart Dolerite LIP for a variety of commodities.

Ancient sills and dykes of the Hart Dolerite correlate with voluminous basalt of the Carson Volcanics to form the Hart-Carson LIP in the Kimberley. Two sedimentary basins host the LIP. The older Speewah Basin hosts sills and dykes, whereas the overlying lower Kimberley Basin is host to the volcanic unit. Stratigraphic mapping, volcanology and sampling for geochemistry and geochronology of the LIP have been completed across the region. At Speewah Dome, a Ti-V-Fe resource has been identified in a magnetite-enriched unit. The study identified similar magnetite-rich units exposed within the Hart Dolerite sills. The discovery raises the prospectivity of the Hart Dolerite for Ti-V-Fe across northern Western Australia's Kimberley district.

The prospectivity of the Hart Dolerite for Ti-V-Fe ore deposits was presented at the GSWA Open Day in Fremantle, and at the SEG Conference in Hobart. The new assessment will form part of the final report for this project, which will be published as a Geological Society of Western Australia record.

**THEME 3
MAGMATIC-
HYDROTHERMAL
PROCESSES AND ORES**

**EXPLORING THE PORPHYRY
ENVIRONMENT**

Leaders: David Cooke, David Selley

Team Members: Nathan Fox, Nic Jansen

Students: Erin Lawlis, Evan Orovan, Marc Rinne, Stephanie Sykora

Collaborators: Ben Ackerman, Chris Allickson, Nick Fitzpatrick, Karyn Gardner, Anthony Harris, Bridgette Hendersonhall, John Holliday, Fiona Karaut, Fraser MacCorquodale, Paul Napier

The team is working in close collaboration with Newcrest Mining in order to obtain new knowledge and maximise opportunities for the discovery of porphyry and epithermal related gold resources in the South West Pacific region. Research is being conducted that is advancing the conceptual models and exploration techniques at the relevant deposits and districts. This new knowledge is then passed directly to Newcrest geologists with onsite training. The close working relationship with Newcrest is facilitated by the company's strong leadership in research, both logistically and financially.

Stephanie Sykora's project at the Lihir gold deposit in Papua New Guinea aims to resolve the genesis of an anhydrite-rich zone at the deposit, and was earlier converted from an MSc to a PhD. In 2015, Stephanie focussed on understanding and quantifying gold deportment in pyrite from the porphyry and epithermal alteration domains at Lihir. She also completed two draft publications on her work at the deposit. The first manuscript covers the structure of anhydrite veins and cemented breccias, and the second the evolution of pyrite trace element compositions from porphyry and epithermal conditions: implications for ore genesis and mineral processing. Aspects of Stephanie's research were presented at the SGA

Conference in Nancy, France, and the SEG Conference in Hobart.

A PhD study by Evan Orovan was completed at the end of 2015, which has resulted in a well-constrained model that incorporates the volcano-tectonic, fluid and paragenetic evolution of the Namosi district, Fiji.

Erin Lawlis's PhD research is focussed on the construction of a geological framework and hydrothermal paragenesis for the Kapit NE ore zone at the Lihir Au deposit in Papua New Guinea. Work completed towards this aim includes analysis of results for geochronology and whole rock geochemistry, petrography and the drafting of lithological descriptions. A comprehensive model for the Lihir diatreme breccia complex has been completed.

David Selley's research on the Gosowong low sulfidation epithermal gold system, Halmahera, Indonesia, has led to the construction of a district-scale 3-D tectono-stratigraphic model. The model demonstrates a subtle, yet important change in regional dynamics during mineralisation stages, and provides a robust geometric template for ongoing exploration targeting. Research outcomes were presented at the SEG Conference in Hobart.

Nathan Fox's work on the Cadia Cu-Au district, NSW, culminated in a new understanding of the link between volcanosedimentary basin architecture and timing, and the formation of large porphyry Cu-Au systems, with findings published in the prestigious journal *Geology*.

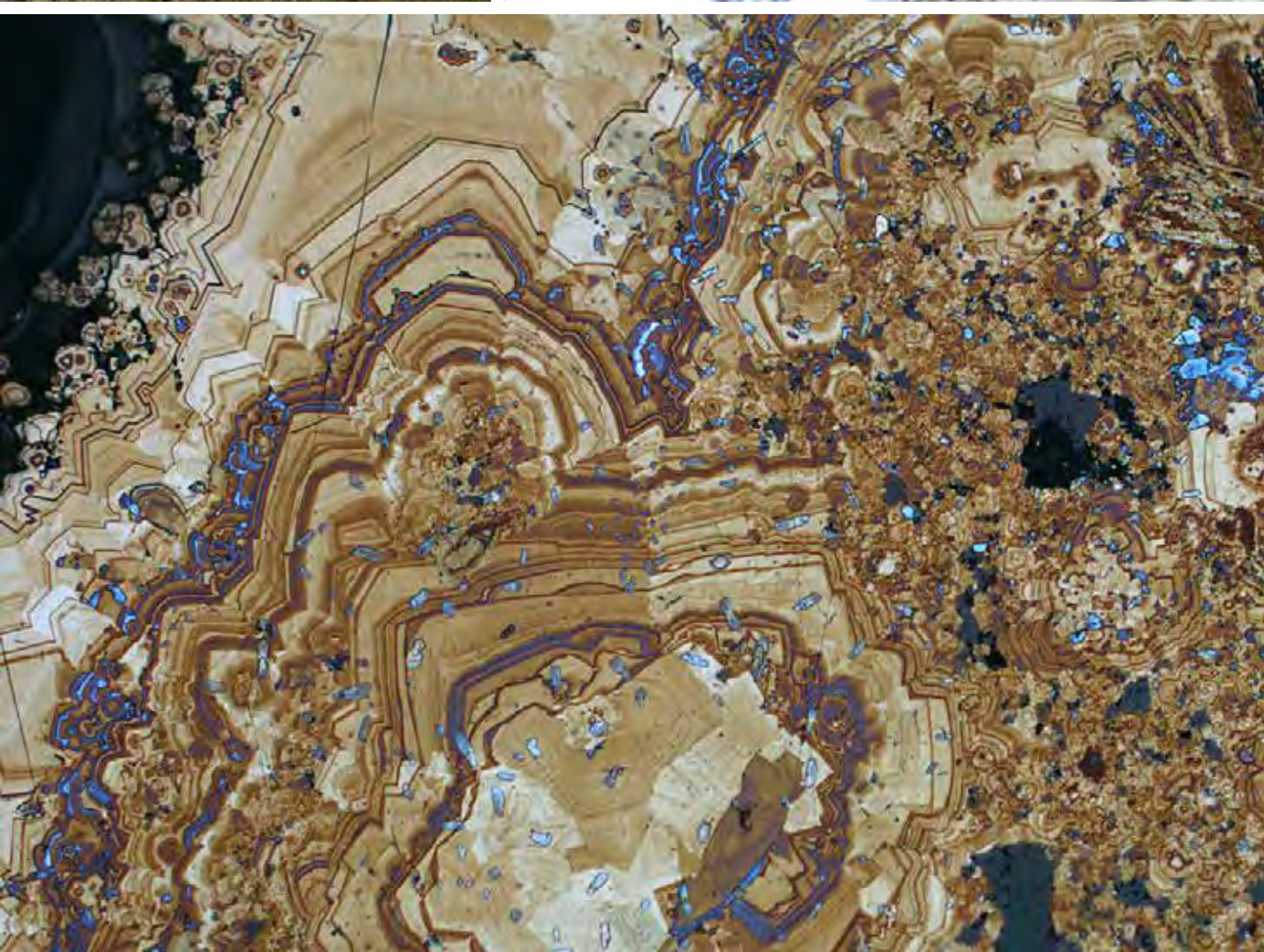
OLYMPIC DAM

Leader: Vadim Kamenetsky

Team Members: Maya Kamenetsky, Jocelyn McPhie, Sebastien Meffre, Jay Thompson

Students: Olga Apukhtina, Nathan Chapman, Alex Cherry, Matt Ferguson, Qiuyue Huang, Irma Vejelyte

Collaborators: Andrea Agangi, Elena Belousova, Kathy Ehrig, Maria Kirchenbaur, Roland Maas



OPPOSITE PAGE CLOCKWISE FROM TOP LEFT: Karin Orth choosing the best Hart Dolerite to sample for age dating with a mobile XRF; Stephanie Sykora inspecting the pit wall at the Lihir gold deposit, PNG; NaOCl etched pyrite with Au-As-rich zones; Layered basalt lava flows, Port Warrender, the Kimberley, WA.

Excellent progress has been made on recognising and answering major questions relating to the processes responsible for metal concentration and their duration in the formation of the supergiant Olympic Dam Cu-U-Au-Ag ore deposit. This deposit is one of the most enigmatic because it is polymetallic, and the economic elements and iron are concentrated within a breccia complex hosted by undeformed, weakly altered granite. Although the age of the granite is well established at ca. 1590 Ma, the timing of metal addition and accumulation is uncertain, largely because the context and textures of the ore are variable and indicative of several genetic processes. In addition to high-precision U-Pb ages of uraninite spreading over 1 Ga, the team is now confident that different rocks and mineral assemblages record post-1590 Ma tectonic, magmatic, sedimentary and hydrothermal events.

Major breakthroughs are identified below:

- Zircon in clasts of quartz-rich sandstone in the hematite-rich breccia (RD2751, 855-914 m) belong to three age populations (1612.9±9.1, 1732.7±5.5, 2485±30 Ma) that correspond to those of detrital zircon in the ca. 1425 Ma

Pandurra Formation (Cariewerloo Basin overlapping the Gawler LIP). The presence of Pandurra Formation in the breccia complex suggests brecciation and incorporation of sediments at <1425 Ma.

- The Sm-Nd dates of step-leached ore samples are similar to published whole rock data and define a ~1300 Ma apparent age, which is broadly supported by Rb-Sr isochrons for the same fractions. Sericite in ca. 1590 Ma basaltic dykes and picrite lavas at Olympic Dam has an age of 1128±19 Ma (Rb-Sr). A similar age is suggested by Pb isotope systematics of authigenic pyrite in a mafic sandstone belonging to bedded sedimentary facies, and galena in some mineralised samples.
- The Gairdner Dykes intruded the breccia complex at ca. 820 Ma, and are associated with coeval brecciation and circulation of syn- and post-magmatic fluids. This research is now published in *Precambrian Research* (Huang et al.) and *Contributions to Mineralogy and Petrology* (Apukhtina et al.). The related hydrothermal alteration is characterised by re-distribution

of Fe, Cu, Pb, P, REE etc. and precipitation of magnetite, apatite, titanite, pyrite, chalcopyrite and galena.

- The youngest ages (Ordovician, ca. 440-480 Ma) are recorded by (1) authigenic apatite (U-Pb dating) in the bedded sedimentary facies, including ironstones, (2) hydrothermal apatite and monazite (U-Pb dating) in the sulfide-bearing mineralisation associated with basaltic dykes, and (3) fluorite (Sm-Nd dating; Maas et al., 2011) from extensive fluorite-barite-siderite veins cross-cutting the breccia complex. Importantly, roughly Delamerian ages are reported for 'massive' uraninite (Ehrig et al., 2015).
- The post-1590 Ma brecciation, alteration and mineralisation events coincided with tectonic and magmatic events that affected the Gawler Craton margin in response to amalgamation and/or breakup of three supercontinents – Columbia (breakup 1.6-1.3 Ga), Rodinia (amalgamation 1.3-1.1, breakup 0.85-0.6 Ga) and Gondwana (amalgamation 0.6-0.3 Ga). The team attribute the extraordinary metal accumulation at Olympic Dam to a favourable position at the craton's margin, where multiple events of metal addition

PhD student Alex Cherry inspecting core samples at Olympic Dam.



Spectacular McArthur Basin geology captured by PhD student Larriana Morgan during an NTGS field trip.

and redistribution can be linked to supercontinent cycles. A possibility of post-1590 Ma uranium addition will be advocated based on $^{207}\text{Pb}/^{206}\text{Pb}$ of bulk rocks and sulfides.

- Concentrations of uranium (from 14 ppm to > 12 wt.%) and isotope compositions of U, Pb and Sm are studied across the entire deposit and reported in *Geochimica et Cosmochimica Acta* (Kirchenbaur et al.). The U isotope composition of most investigated samples ($\delta^{238}\text{U} = -0.56$ to $+0.04$ ‰) overlap within analytical uncertainty with the $\delta^{238}\text{U}$ of the possible U source, the ambient Roxby Downs granite ($\delta^{238}\text{U} = -0.18$ to -0.32 ‰).

The project has also not only generated a huge amount of geochemical and geochronological data within the deposit but also regionally. To date, the project outcomes are published in three papers and 17 conference proceedings (one keynote). A paper entitled 'Characteristics, origin and significance of Mesoproterozoic bedded clastic facies at the Olympic Dam Cu-U-Au-Ag deposit, South Australia' has been accepted for publication in *Precambrian Research*.

MAGMATIC-HYDROTHERMAL VOLATILE EXSOLUTION AND MINERALISATION IN TASMANIAN Sn GRANITES

Leader: David Cooke

Team Members: Nathan Fox, Lejun Zhang

Students: Travis Holmes, Wei Hong

Collaborators: David Huston, Roland Maas

The key objectives of this project in NW Tasmania are to:

- Develop a mineralogical paragenesis model and determine

if the mineral chemistry of tourmaline can be used as a useful vector to high-grade mineralisation.

- Resolve the sources of volatile components and depositional mechanisms associated with the formation of each type of hydrothermal phenomena in the roof zone of the Heemskirk Granite.

Paleozoic granitoids in Tasmania contain many textural features indicative of phenomena associated with the magmatic-hydrothermal transition, including world-class examples of UST textures and abundant tourmaline orbicules. These granitoids are associated with world-class tin and tungsten deposits and zoned Pb-Zn-Ag mineral districts. Based on detailed field geological mapping, it has been found that Sn-mineralised (Heemskirk) and barren (Pieman Heads) granites from western Tasmania have developed similar tourmaline-rich magmatic-hydrothermal features, including tourmaline patches, orbicules, cavities and veins. LA-ICP-MS analysis of tourmalines from both granites has revealed that tourmalines are preferentially enriched in Li, Be, Sn and transition elements compared to their granite hosts. Sn, Nb, Ta and REEs are more likely incorporated into tourmalines from the Heemskirk Granite, whereas the Pieman Heads tourmalines are characterised by enrichments of Zn, Co, Ga, Sr and Pb. Trace element ratios (Zn/Nb, Co/Nb, Sr/Ta, Co/La etc.) versus Sn in tourmaline appear to be robust tools for discriminating Sn-mineralised from barren granites.

PhD student Wei Hong delivered an oral presentation on the research at the SEG Conference in Hobart.

THEME 4 BASIN PROCESSES AND ORES

McARTHUR BASIN COPPER

Leader: Garry Davidson

Team Members: Stuart Bull, David Selley

Student: Larriana Morgan

Collaborators: Dorothy Close, Andrew Wygralak

This project began in mid-late 2014, sponsored wholly by the NTGS. Its aims were to develop an improved understanding of copper ore formation processes in the central western McArthur Basin. There are several 'camps', each with a cluster of deposits that individually display largely structural control. Most sit lower in the stratigraphy than the main Zn-Pb occurrences (such as the HYC Zn-Pb-Ag Deposit), either in the Tawallah Group, or in the lowermost McArthur Group, with a particular concentration in the Amelia Dolomite and Mallapunyah Formation.

In the reporting period, six drill holes were extensively logged and sampled at the NTGS core store in Darwin. The focus was on the Coppermine Creek prospect, with several unmineralised regional holes sampled for comparison. However, PhD student Larriana Morgan elected to discontinue her studies in August, and the direction of the project has now been re-evaluated, with an agreement with the NTGS that CODES will prepare a report on the work to date in 2016.



PhD student Jacob Heathcote inspects supergene ore in Kansanshi main pit, NW Zambia. Jacob is investigating the relationship between gold and copper in primary and supergene ores at the mine.

KANSANSHI GOLD

Leader: Robert Scott

Team Member: Garry Davidson

Student: Jacob Heathcote

Collaborators: Tim Ireland, Louis van Heerden

This research project, which commenced in early 2014, is solely funded by Kansanshi Mining Plc (KMP), a subsidiary of First Quantum Minerals. The aim of the research is to better understand the origins, distribution, mineral associations and paragenesis of gold at the Kansanshi Cu-Au deposit in NW Zambia. The Kansanshi mine is a globally significant copper producer, but also produces around 100,000 ounces of gold per year.

The primary objective is to improve deposit-scale understanding of gold distribution, mineral associations and paragenesis, in both primary (sulfide zone) and secondary (oxide zone) ores. Through detailed core

logging and pit mapping, and associated sampling (for whole rock geochemistry, petrography and micro-analytical studies) PhD student Jacob Heathcote aims to improve understanding of the geological controls on gold association and distribution throughout the mine. A key goal is to identify field-based geological criteria (e.g. alteration assemblages, vein composition and/or texture, structural features etc) that help identify and predict the distribution and extent of gold mineralised zones.

A major focus of Jacob's research in 2015 was to complete detailed petrographic and micro-analytical studies on previously collected samples. Over 125 samples have now been investigated by optical microscopy ± SEM. The number of gold grains found and characterised during the study is now triple the amount achieved at the start of the year. By cataloguing the habit and immediate mineral associations

of the gold, as well as the overall mineralogy, mineral paragenesis and texture of the samples, Jacob is working towards a robust paragenesis for gold in the primary ores at Kansanshi, and constraining the processes by which it was deposited.

A large suite of wall rock samples from a variety of lithologies, collected at variable distances from the mineralised veins, were also analysed by whole rock XRF and fire assay during the year. The aim of this work is to help constrain the composition of the mineralising fluids and to investigate links between chemical changes in the wall rocks (due to hydrothermal alteration) and the composition and mineralogy of the adjacent veins. The initial results provide significant new insights into the complex patterns of element mobility in the wall rocks during mineralisation, and have important implications for the genesis of the deposit as a whole.

URANIUM CONCENTRATIONS IN BASINS

Leader: Garry Davidson

Team Member: Sebastien Meffre

Collaborators: Karsten Goemann, Hamish Johns, Grant Osborne, Penny Sinclair

This project is focussed on researching the nature and causes of uranium concentration in sedimentary basins. Several basins were researched in 2015, with the following outcomes:

- A uranium forming link is being tested between the basement Tennant Creek inlier and the overlying rift packages of the Ooradidgee Basin. In this hypothesis, growth faults active at ~1852 Ma channelled basinal brines through IOCG magnetite-hematite ironstones, resulting in U precipitation. The work commenced as an Honours project by Hamish Johns, supported by Emmerson Resources, and continued through 2015 with internal funding.
- The previously reported Masters project on the Angularli U unconformity-style mineralisation of the McArthur Basin East Alligator Rivers Province did not progress in 2015. However, this initiative has been converted to a funded CODES-Cameco Resources collaborative research project that is testing a genetic model, and evaluating geochemical halo features of the province. The first samples were delivered in December.

THEME 5
THE ORE
AFFECTED CRUST

THE POWER OF PYRITE

Leaders: Ross Large, Jeff Steadman, Dan Gregory, Sebastien Meffre, Matt Cracknell

Collaborators: Rodney Allen, David Busch, David Crook, Frank Doedens, Adrian Fabris, Don Fraser, Anthony Harris, Bruce Hooper, Danny Huisman, David Huston, Gustav Nortje, Dermot Ryan, Tom Woolrych, Jerry Zieg

The objectives of the Power of Pyrite project are to help explorers gain new insights into the textural, mineralogical and elemental paragenetic history of their respective deposits and alteration footprints using pyrite trace element geochemistry and, where possible, to also provide geochemical vectors toward new ore bodies.

It was a successful year for the Power of Pyrite project, with a number of positive outcomes:

- Seven research reports were produced for the case study sites, characterising pyrite chemistry and target signatures for a vast range of mineral systems.
- Six companies, plus GA, and the GSSA, are now funding the power of pyrite vector project, and six case studies have commenced.
- Statistical software techniques were successfully applied in a number of case studies to provide a statistical verification for the geochemical vector parameters. The work completed has led to a better understanding of the nature of mineralisation at all studied sites, with potential vectors to ore developed for at least four of the case studies.
- Preliminary work commenced on deposits belonging to two additional industry sponsors.

This approach to the project is proving to be very successful in that it combines information on metal paragenesis, textural paragenesis, and Pb isotope signatures with pyrite vector geochemistry, even in cases when only minor mineralisation has been intersected.

DRUMMOND PEAK GOLD

Leaders: Ross Large, Dan Gregory

Team Member: Selina Wu

Collaborator: Ed Eshuys

Previous research at CODES indicated that sedimentary pyrite may be a source of gold for orogenic gold deposits (Large et al., 2009; 2011). Subsequent research indicated that at different times in Earth's history sedimentary pyrite was particularly enriched in gold and other associated elements (3000 Ma, 2700 Ma, 2500

Ma, 1000 Ma, 550 Ma and 430 Ma), which also corresponded with the age of host rocks for a number of major gold deposits (Large et al., 2015). The goal of this project was to determine where sedimentary and mafic volcanic units of these ages occur in Australia and whether new exploration targets could be generated in these areas.

The project successfully identified 10 new exploration targets based on the locations of the prospective source units and a combination of publically available geological maps, geophysical data and geochemical data. This project has now concluded.

DEGRUSSA VHMS VECTORING

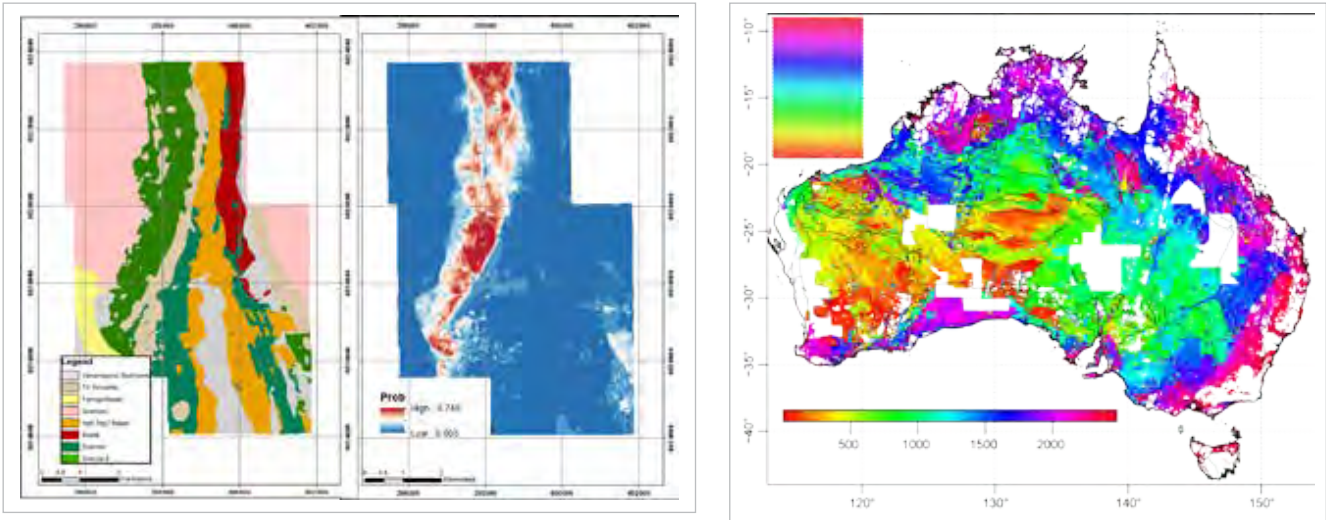
Leaders: Ross Large, Dan Gregory, Matt Cracknell

Collaborators: Richard Beckley, Paul Hilliard

The objective of the DeGrussa vectoring project is to determine whether the trace element content of chlorite, magnetite, hematitic sediments, and/or titanate, can be used to extend the footprint and vector towards the Proterozoic DeGrussa VHMS deposit in Western Australia.

A total of 400 titanite, 916 chlorite, 441 magnetite, 660 hematite and six sericite samples were analysed using LA-ICP-MS. All the analyses were processed using statistical software to determine if the trace element content of these minerals could be used to vector towards the ore body. Analyses were conducted on samples taken from drill holes at 190 m, 210 m, 515 m, 975 m, 1550 m, and 2105 m from known ore. A smaller number of samples were taken from sediments and mafic units in the footwall and hanging wall of the prospective stratigraphy to inform future research goals.

These results have increased the understanding of how the exhalative plume extended from the deposit, and what elements and minerals can be used to vector towards new deposits.



FROM LEFT: Lithologies classified by Random Forest, Class probability membership for class equals dolerite; SOM node distribution across Australia

INTEGRATING GEOLOGY AND GEOPHYSICS FOR RESOURCES TARGETING

Leader: Anya Reading

Collaborators: Daniel Bombardieri, Mark Duffett

This project was formerly named 'Integrated geology and geophysical modelling and exploration targeting in the Lyell-Rosebery region'. The name has been changed to better reflect the evolving scope of the research.

Daniel Bombardieri, from Mineral Resources Tasmania, continues his association with CODES through his development of 3D models of prospective regions of the state, using the advanced GOCAD computing and visualisation environment. In 2015, the Mt Lyell area model was further refined and geophysical work began on the northern region model. Daniel shares his valuable knowledge of several industry standard software environments with staff, and PhD and Honours students.

METAMORPHIC ARCHITECTURE OF THE WESTERN GAWLER CRATON

Leader: Jacqueline Halpin

Collaborators: Rian Dutch, Anthony Reid

The generation and preservation of hydrothermal or magmatic-related mineral systems is strongly depth dependent. This is because major changes in fluid pressure and composition occur as deeper

magmatic or metamorphic fluids interact with other fluids and structures as they reach shallower crustal levels. These changes in fluid chemistry result in the precipitation of ore minerals.

This project, sponsored by the Geological Survey of South Australia (GSSA), involves quantification of the pressure-temperature-time (P-T-t) history of selected key regions across the western Gawler Craton that can be used to infer crustal architecture and quantify crustal palaeo-depths. Outputs can be fed into prospectivity models to inform the practice of exploration.

In 2015, a manuscript based on the end-2014 report to GSSA on the evolution of the earliest Paleoproterozoic Mulgathing Complex in the north-central Gawler Craton was submitted to *Precambrian Research*.

A comprehensive metamorphic analysis was completed for basement rocks in a selection of key drill holes in the western Gawler Craton (Nawa and Fowler domains), and a final report was delivered to GSSA in November 2015. This project has now concluded.

APPLICATION OF SULFIDE S AND CARBONATE C-O ISOTOPES TO ORE GENESIS AND EXPLORATION

Leader: Garry Davidson

Team Member: Alistair Harvey

Collaborators: June Hill, Michael Nugus, Nick Oliver, Ross Pringle

Stable isotopes in carbonate and sulfide minerals can provide a large

array of constraints on the origin of ore systems. This project is aimed at expanding those applications, by combining mineral-specific C-O and S isotope data with spatial and paragenetic control, major and trace element analyses, and whole rock geochemical data.

The study site at the Sunrise Dam gold deposit in the Archean Yilgarn of Western Australia, solely funded by AngloGold Ashanti, is evaluating C-O isotope variation as a means of understanding the genesis of the orogenic ores, and its use as a halo tool. In 2015, a global database of C-O carbonate data in orogenic gold deposits was completed, which will be used to make comparisons with the results at Sunrise Dam. This work formed part of the preparation of the final report on the study site, which will be released in 2016.

A second activity in this project utilises sulfur isotopes to help constrain the genesis of the Paracatu gold deposit, Minas Gerais, Brazil, which is a slate-belt orogenic deposit. The very uniform sulfur isotope compositions of all sulfides (18-22 permil) provided evidence that the source of sulfur was either reduced seawater sulfur or biogenic sulfur from an extremely starved-basin setting, typical of many Neoproterozoic sequences; and that some mechanism resulted in efficient homogenisation of the sulfur inventory prior to deposition as ore sulfides. This research has been a collaboration with Nick Oliver, and

with co-authors a paper on the work was published in *Economic Geology* during the year.

AUSTRALIAN HYDROTHERMAL IOCG AND RELATED DEPOSITS

Leader: Garry Davidson

Team Members: Stuart Bull, Paul Davidson, Sebastien Meffre, Jay Thompson

Student: Subira Sharma

Collaborators: Bryan Bowden, Greg Clarke, Mawson Croaker, Geoff Fraser, Hamish Freeman, Thomas Rodemann, Roger Skirrow, Rob Smith, Pat Williams

IOCG research occurred on the Prominent Hill (SA), Vulcan (SA) and Mt Dore-Merlin (Qld) deposits during the year. A highlight was convening of an IOCG-focussed session by Garry Davidson at the international SEG Conference in Hobart, with 13 presentations and 24 posters.

Prominent Hill and Vulcan South

Abstracts on recent work at these sites was presented by Stuart Bull and Greg Clarke at the SEG Conference. Manuscripts for both presentations are in preparation.

Mt Dore-Merlin

Subira Sharma's PhD work on graphite in molybdenite ores at Merlin has culminated in submission of a paper to *Vibrational Spectroscopy* focussing on the application of the Raman instrument to these materials.

From 2016 onwards, research on iron oxide-apatite/Kiruna-style deposits will be reported in this project. The name of the project will also be shortened to 'IOCG deposits and related deposits'. Research on Olympic Dam will continue to be reported under its own project heading.

THE CHARACTERISTICS AND ROLE OF COLLOIDAL SILICA FLUIDS IN THE FORMATION OF THE GRIEVES SIDING Pb-Zn PROSPECT, WESTERN TASMANIA

Leader: Vadim Kamenetsky

Student: Richelle Awid Pascual

Collaborators: Neil Allen, Karsten Goemann, Bernd Lottermoser, Taryn Noble, Thomas Rodemann

This research presents an alternative mechanism to the formation of sphalerite in carbonaceous, sediment-hosted base metal deposits.

Widely accepted to form through direct crystallisation from an ore fluid, evidence is presented, and modelled, for the evolution of crystalline sphalerite from amorphous precursors within a Zn-rich peat at ambient conditions. The characteristics and role of precursors and the mechanisms related to a step-wise pathway to sphalerite formation have not been explored in natural samples, particularly in ore-hosting sedimentary environments. This research is of most interest to the study of ore genesis, as it expands the knowledge on early sulfide formation, particularly in low temperature base metal deposits. Furthermore, it is expected that the proposed formation mechanism will extend to several other metallic minerals that form in the near surface environment.

The coexistence of crystalline sphalerite and amorphous, non-stoichiometric Zn-rich phases in the metal-rich Grieves Siding peat in Tasmania, is inferred to represent a continuous evolution of metastable Zn-organic precursors to sphalerite. The research proposes possible mechanisms of the step-wise process commencing from heterogeneous nucleation of precursor phases on, and/or within, a Zn-rich clay substrate; recurring growth and maturation by aggregation, coalescence and impurity expulsion; culminating in transformation to sphalerite. Each step is observed to be a progression towards crystallinity and homogeneity, tending to ZnS. Moreover, a significant microbiological influence is implicated in the mineralisation process. The outcomes of this research are published in *Contributions to Mineralogy and Petrology* (Awid Pascual et al.) and have been submitted for publication in *Geology*.

THE GEOLOGY, GEOCHEMISTRY AND GENESIS OF THE AVEBURY Ni DEPOSIT: IMPLICATIONS FOR EXPLORATION

Leader: Vadim Kamenetsky

Team Members: Maya Kamenetsky, Sebastien Meffre

Collaborators: Steve Beresford, Jeff Foster, Karsten Goemann, Alexey Lygin, Roland Maas

The Awebury serpentinite-hosted Ni sulfide deposit in Tasmania is the largest known non-magmatic nickel deposit on Earth. A study to understand the sources of metals and fluids responsible for this style of economic mineralisation have been completed, and a paper on the research has been accepted for publication in *American Mineralogist*.

This work shows that serpentinisation of the Ni-bearing olivine in the Cambrian peridotites of the Mclvor Hill complex was followed by metasomatic transformation, assisted by heat and fluids supplied by a nearby Late Devonian granite intrusion. In the model, Ni was released from magmatic olivine during serpentinisation, rather than being remobilised from magmatic sulfides. The research confirms the viability of a new class of Ni sulfide deposits that are formed by metasomatic and/or hydrothermal modification of peridotites, rather than by magmatic processes.

This project has now concluded.

GEOLOGY AND GENESIS OF THE INVINCIBLE GOLD DEPOSIT, ST IVES

Leader: Robert Scott

Student: David Douch

Collaborator: Ray Cas

In 2015, David Douch commenced a PhD study, funded by Gold Fields, investigating the geology and genesis of the recently discovered >1 Moz Au Invincible deposit in the St Ives Goldfield, Kambalda, W.A. The Invincible deposit is located in a NW trending structural corridor known as the Speedway fault zone, and is hosted by black shale and underlying andesitic volcanoclastics



Merougil conglomerate at the Invincible deposit, WA.

at the top of the Black Flag Group; a 2680 – 2665 Ma package of predominantly felsic to intermediate volcano-sedimentary rocks. The Black Flag Group is overlain by the <2665 Ma Merougil sequence, which consists of arkosic/lithic sandstone, poorly sorted, polymict, pebble to boulder conglomerate, conglomeratic sandstone, and forms the immediate hanging wall of the Invincible deposit. Until the discovery of Invincible, the majority of the more than 12 M ounces of gold produced at St Ives was derived from the older (2720 – 2680 Ma) mafic Kambalda Sequence.

Major goals of this study are to:

- Refine and interpret the internal stratigraphy of the Black Flag and Merougil groups in the vicinity of the Invincible deposit.
- Determine the mineralogy and paragenesis of auriferous veins and altered wall rocks.
- Determine the structural setting, age and controls on gold mineralisation.
- Characterise the geochemical footprint of the deposit.
- Undertake comparisons with gold deposits hosted by mafic rocks (principally dolerites) of the Kambalda Sequence.
- Develop criteria for future exploration based on the results of this study. Of particular interest will be the interplay between structure and host rock characteristics in controlling the locations of deposits within the goldfield.

Excellent progress has been made in the first year of the project, which focussed on field work and analysis of Gold Fields' existing geochemical database for the deposit and surrounds. Approximately 23 km of drill core was logged, accessible exposures in open pits mapped, and samples for petrography, geochemistry, geochronology and microstructural studies collected and prepared. A major highlight was the completion of a provenance analysis based on clast types in conglomerates from the Black Flag and Merougil sequences at Invincible. The results of this study

aid stratigraphic delineation and have important implications for late basin development in this area and first unroofing of the 2662 Ma Kambalda Granodiorite.

THEME 6 DATES AND PLATES

BUILDING TASMANIA: THE CAMBRIAN AND BEYOND

Leaders: Jacqueline Halpin, Robert Scott, Sebastien Meffre

Team Member: Ron Berry

Students: Sally Mattner, Jacob Mulder

Collaborators: Clive Calver, Grace Cummings, Nathan Daczko, John Everard, Mike Hall

This research draws together a number of themes around the early (Precambrian to Cambrian) geological evolution of Tasmania, including the age, affinity and paleo-significance of the cryptic basement and overlying Proterozoic successions, to the accretion of the Tasmanian microcontinent onto the Gondwanan paleo-Pacific margin.

The project was previously named 'Age, affinity and provenance of Tasmanian Proterozoic metasedimentary successions'. The name has changed to better reflect the wider range of sub-projects that now fall within this research.

It was an exceptional year for PhD student Jacob Mulder. Highlights included:

- A paper published in *Geology* on research that uses U-Pb-Hf isotopes in zircon combined with paleocurrent data to identify the provenance of the lower-middle Rocky Cape Group of NW Tasmania. This work demonstrates sediments were derived from a combination of source terranes in SW Laurentia and East Antarctica that, along with NW Tasmania, were juxtaposed in the Proterozoic supercontinent Nuna. Jacob showed, through a comprehensive compilation of detrital zircon data, that the Australian mainland was unlikely to have been a prominent source region, supporting a paleo-



FROM LEFT: Robert Scott being interviewed by ABC TV in connection with the research at Rowallan Dam; Jacob Mulder (L) and Sally Mattner with supervisor Robert Scott.

position of NW Tasmania that differs from its location within Gondwana.

- As a result of the abovementioned research, a team from the ABC's *Catalyst* program visited CODES late in the year to film Jacob, and Jacqueline Halpin, for a segment to be aired in 2016. The team also filmed the researchers on location at Rocky Cape. The paper in *Geology* attracted widespread national and international media coverage, in addition to the *Catalyst* program.
- A paper published in the *Australian Journal of Earth Sciences* entitled 'The structure and metamorphism of the Red Point Metamorphic Complex—A newly discovered high-pressure metamorphic complex from the south coast of Tasmania', which was based on his 2013 Honours project.
- A paper 'in press' in *Gondwana Research* that examines the Cambrian tectonic evolution of Tasmania, and specifically the ophiolitic metamorphic sole rocks exposed in western Tasmania, which record the accretion of Tasmania to the margin of Gondwana in the Cambrian.
- Two presentations by Jacob (and co-authors) at the Geological Society of Australia Specialist Group in Tectonics and Structural Geology conference in Caloundra, Queensland.
- Jacob was awarded the prestigious Endeavour Postgraduate Scholarship by the Australian Government to spend up to two years studying for his PhD overseas at his nominated host institution. As a result, Jacob will spend much of 2016 at the University of New Mexico, under the guidance of Prof. Karl Karlstrom, where he

will further investigate the ancient links between Tasmania and SW Laurentia.

Other project highlights included:

- Sally Mattner's Honours project on the structure and metamorphism of the Mersey River metamorphic complex was thrust into the spotlight when a major lake within the complex was drained to allow for the upgrade to a power station. The temporary draining of Lake Rowallan exposed Precambrian rock formations that had not been visible since the last Ice Age. This provided Sally with a small, but invaluable window of opportunity to study the formations that are expected to shed light on the geological development of the whole of eastern Australia. The event was supported by a media release, which garnered widespread publicity.
- Jacqueline Halpin presented a talk at the American Geophysical Union Fall Meeting in San Francisco, USA, entitled 'Tasmania in Nuna: Witness to a ~1.4 Ga East Antarctica–Laurentia Connection'.

TECTONIC RECONSTRUCTION OF EAST GONDWANA

Leader: Jacqueline Halpin

Students: Sally Watson, Toban Wild

Collaborators: Mike Coffin, Nathan Daczko, Ian Fitzsimons, Andy Gleadow, Fred Jourdan, Barry Kohn, Luke Milan, Dietmar Müller, Pat Quilty, Jeff Stilwell, Joanne Whittaker, Simon Williams, Derek Wyman

The overall aim of this project is to integrate both onshore and offshore geological and geophysical data to produce holistic tectonic reconstructions for both the

amalgamation and break up of East Gondwana.

In 2015, the scope of this project expanded from the Perth Abyssal Plain, where research was first focussed after a very successful 2011 *RV Southern Surveyor* cruise, into the previously contiguous parts of Antarctica. This expansion was made possible through three new research grants from UTAS, the University of New England and the Australian Antarctic Division.

Major progress was made on understanding the tectonic evolution of the Perth Abyssal Plain, with two papers submitted for publication. The first by PhD student Sally Watson et al to *Gondwana Research* on the Dirck Hartog Ridge, and the second by Joanne Whittaker et al to *Earth and Planetary Science Letters* on Microcontinent formation driven by plate motion changes. Whole rock geochemical and isotope results for basalts from the Perth Abyssal Plain were also generated and a paper is in progress. New geochronological results on basement samples from East Antarctica, combined with plate modelling, have set the scene for a radical rethink of the amalgamation of East Gondwana, with two papers currently in preparation.

Other highlights in 2015 included:

- A presentation by Jacqueline Halpin at the XII International Symposium on Antarctic Earth Science (ISAES 2015) Conference in Goa, India in July.
- Two presentations by collaborator Nathan Daczko at the Geological Society of Australia Specialist Group in Tectonics and Structural Geology conference in Caloundra in November.



Collaborator, Andy Wakefield, from Mineral Resources Tasmania, installing passive seismic array equipment.

- A presentation by PhD student Sally Watson at the American Geophysical Union Fall meeting in San Francisco in December.
- Submission of a 3-year Marine National Facility application for ship time in the Eastern Indian Ocean on the *RV Investigator* (led by Joanne Whittaker).

This project has concluded within CODES, but research in this area will continue within UTAS with Jacqueline's move to the Institute of Marine and Antarctic Studies (IMAS).

STRUCTURE OF SE AUSTRALIA USING MULTIPLE GEOPHYSICAL METHODS

Leader: Anya Reading

Team Members: Matt Cracknell, Michael Roach

Student: Esmaeil Eshaghi

Collaborators: Daniel Bombardieri, Mark Duffett, Andy Wakefield

This project seeks to improve the understanding of the broad-scale structure of SE Australia, and is being conducted in collaboration with Mineral Resources Tasmania (MRT).

During 2015, further petrophysical data were collected from deep drill core samples housed in MRT's core store, to constrain geophysical modelling. Using multiple techniques, broad-scale modelling was carried out for eastern Australia, particularly of Moho depth constrained by magnetic Curie point. This work was presented at the Australian Society for Exploration Geophysicists meeting in Perth early in the year. Further significant progress was made in building detailed models for Tasmania, working closely with

geologists from MRT. The challenges of modelling potential fields in the offshore-onshore transition, and over large regional scales across this transition, were addressed.

LOOKING FORWARD

The Module will continue its evolution in 2016, with a number of projects either commencing, coming to a natural conclusion, moving to other areas, or progressing in new directions of research.

One of the projects coming to a conclusion is 'Exploring the porphyry environment', which has been running since 2009. This highly successful project has been operating in collaboration with Newcrest Mining to maximise opportunities for the discovery of porphyry and epithermal related gold resources in the South West Pacific region. Stephanie Sykora's PhD project on anhydrite zone at the Lihir gold deposit, PNG, which was being conducted within this project, will continue under the TMVC.

The Module will maintain its presence in Africa through projects in Côte d'Ivoire and Zambia. The Architecture of the Birimian Belts project will be developing a chemostratigraphic framework using whole rock geochemical analyses, building a petrophysical dataset to aid interpretation of geophysics, and refining the tectono-stratigraphic model for Côte d'Ivoire and neighbouring countries.

In addition to the work in Africa, the Module will also maintain its truly global footprint through projects in Australia, North America, South America, Europe, and Asia – where Khin Zaw will be conducting further negotiations with potential sponsors to continue and expand research activities in the SE Asian region.

It is also expected to be a milestone year for many of the students within the Module. Highlights of the year will include:

- PhD students Heidi Berkenbosch, Margy Hawke, Erin Lawlis, Evan Orovan and Subira Sharma are all expected to complete their theses, and Charles Makoundi will graduate.
- Master of Economic Geology student Jo Condon will also be graduating, as will Master of Science student Irma Vejelyte.
- Jacob Mulder (PhD) will commence his Endeavour Postgraduate Scholarship at the University of New Mexico, under the guidance of Professor Karl Karlstrom, where he will continue his groundbreaking research into the provenance and age of the upper Rocky Cape Group and Clark Group, and the relationship to source terranes in Laurentia.



Khin Zaw with David Meade, from Naga Exploration, at the Modi Taung gold deposit, Myanmar.

OBJECTIVE

To transform how explorers and miners plan and predict mining and environmental activities, by providing new tools to guide these activities from the initial discovery stage through the life of the project.



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 concentration of deleterious elements, hardness (crushability, grindability), mineral species and abundance, mineral liberation, metallurgical recovery, acid generating potential, neutralising potential and smelter enabling characteristics.

Geometallurgy uses integrated tools, methods and knowledge, with an emphasis on ore body knowledge, which can be utilised in mining and mineral processing. A key component is linking geology and mineral processing as inputs into mine planning, optimisation and ultimately valuation.

Over the past decade, the extent of research related to geometallurgy has significantly increased, 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^{III}) collaborative projects that ran from 2005 to 2013 and were successful in developing an array

of geometallurgical methods and protocols in the areas of mineralogy, comminution and flotation – which were subsequently tested on case study sites in active mines.

Although the GeM^{III} project has come to a successful conclusion, this work is continuing to be developed within the Geometallurgy Module. A large part of this research is also being carried out under the Optimising Geometallurgical Prediction Theme, which is one of the three themes established within the new Industrial Transformation Research Hub – Transforming the Mining Value Chain (TMVC).

HIGHLIGHTS

- The new ARC TMVC Research Hub commences operations, with a focus on geometallurgical and geoenvironmental research in two of the three Theme areas.
- Successful CRC ORE II application, which includes CODES as an Essential Partner.
- Anita Parbhakar-Fox appointed as Acting Module Leader.
- Former Module Leader, Julie Hunt, moves to the University of Liege in Belgium, but is retained as a University Associate and a collaborator.
- Technology transfer of GeM^{III} research continued, including presentations in Australia, Chile, France and Sweden.
- PhD student Cassady Harraden joins the new TMVC research team.



Ball mill at the Savage River mine.

OPPOSITE PAGE FROM TOP: Productora Cu-Au-Mo deposit, Chile; Processing plant at Renison tin mine, Tasmania.

THE MODULE TEAM



ACTING LEADER:
Anita Parbhakar-Fox

TEAM MEMBERS:

Ron Berry, Leonid Danyushevsky,
Sarah Gilbert, Sebastien Meffre

PHD STUDENT:

Angela Escolme

COLLABORATORS:

COPPER MINES OF TASMANIA

Lachlan Brown, Brendan McGee

CRC ORE

Nathan Fox, Taryn Noble

CRC ORE II

Ben Adair, Steve Walters

CSIRO

Louise Fisher

GRANGE RESOURCES

Tony Ferguson, Roger Hill

HOT CHILI

Melanie Leighton

JKMRC/UQ

Khoi Nguyen

MINERAL RESOURCES TASMANIA

David Green

SPECIM LTD.

Rainer Bärs, Kati Laakso

UNIVERSITY OF CAPE TOWN, SOUTH AFRICA

Dee Bradshaw

**UNIVERSITY OF EXETER, UK
/ RWTH AACHEN, GERMANY**
Elly van Veen, Bernd Lottermoser

**UNIVERSITY OF LIEGE,
BELGIUM**
Julie Hunt

**UNIVERSITY OF TASMANIA,
CENTRAL SCIENCE
LABORATORY**
Karsten Goemann

THE YEAR IN REVIEW

KEYSTONES IN PLACE

Two significant events occurred in 2015, which ensure the continued development of geometallurgical and geoenvironmental research within CODES over a sustained period.

TMVC

As foreshadowed in the previous annual report, the ARC TMVC Research Hub came on stream in mid-2015 and included geometallurgical and geoenvironmental research as two of its three focus areas, known as Themes.

Theme Two, entitled Optimising Geometallurgical Prediction, includes the geometallurgical characterisation of ores through automated core logging and spectral analysis of drill core, which is enabling 3-D exploration, mining and geometallurgical models to be developed that are continually updated as the exploration or resource drilling program continues. The TMVC is also conducting research that builds on the work that had been initiated in the previous GeM^{III} project, which fell within the old CODES' Recovery Program up to the end of 2013.

Theme Three is entitled Minimising Geoenvironmental Risks, and focuses on improving geoenvironmental characterisation practices across the whole life-of-mine chain. Projects include using hyperspectral data to predict geoenvironmental characteristics during mineral exploration, to geometallurgical characterisation of mine wastes to evaluate resource potential.

CRC ORE II

The second key event was the announcement by the Australian Government in May that the application by CRC ORE to extend its tenure as a Co-operative Research Centre (CRC) for a further six years had been accepted. As CODES was included as an Essential Research Participant in this application, this outcome ensures that the status of geometallurgy as one of the Centre's three research Modules has been considerably strengthened.

The key challenge for CRC ORE II is to address the declining productivity in the minerals industry, which is partly due to the propensity for mining companies to focus on quantity over quality during the previous mining boom. CODES expertise in areas such as ore deposit modelling, postgraduate training and ore characterisation will play a key role in the outputs of the CRC over its extended tenure.

The research performed by CRC ORE II is split into five programs: Define, Separate, Extract, Control, and Operate, with CODES working within the Define Program, which has the main objective of improving feed quality. There were still one or two administrative processes to be worked through at the end of 2015, but it is expected that these will be completed early in 2016, with CODES involvement in the CRC increasing as the year progresses.

TECHNOLOGY TRANSFER

Although the GeM^{III} project ended in mid-2013, the process of transferring the knowledge and expertise developed during the project's long life cycle continued in 2014 and into 2015. Examples of this knowledge transfer in 2015 included:

- PhD student Angela Escolme presented papers on her thesis studies, involving ore characterisation and geometallurgical modelling at the Productora copper-gold-molybdenum deposit in Chile, at the SGA Conference in Nancy, France, and the SEG Conference in Hobart, Australia.
- Anita Parbhakar-Fox delivered a presentation on behalf of Ron Berry, entitled 'Prediction of acid rock drainage (ARD) from calculated mineralogy', at the 10th ICARD/IMWA – the 10th International Conference on Acid Rock Drainage, held in Santiago, Chile.

A number of confidential research reports were presented to industry, including those related to waste rock management and characterisation of tailings, and the research on the ore characterisation and geometallurgical modelling at the Productora Cu-Au-Mo deposit in Chile.

SHORT COURSES

The Geometallurgy Module members provided significant inputs to two short courses during the year. In September, Julie Hunt, supported by Ron Berry, led a post-SEG 2015 Conference short course, entitled 'Drill core measurements and domaining for geometallurgy'. In the following month, Julie and Ron, together with Acting Module leader Anita Parbhakar-Fox, led the Master of Economic Geology Geometallurgy short course, which included a three-day field trip to northwest and western Tasmania. Invited presenters were Dee Bradshaw (University of Queensland/ University of Cape Town) and Melissa Humphries (School of Physical Sciences, UTAS). This course is covered in more detail in the Training Module section of this Annual Report.

POSTGRADUATE RESEARCH

PhD student Angela Escolme continued with her project entitled: Ore characterisation and geometallurgical modelling at the Productora Cu-Au-Mo deposit, Chile, which aims to determine relationships between ore textures, alteration and geochemical zonation patterns, and assess their impact on liberation behaviour and recovery response at the deposit.

Quantitative and predictive geometallurgical models of processing behaviour have now been developed, which integrate the existing 33 element ICP-AES database. In 2015, calculations of modal mineralogy from assay data were finalised and validated, and deposit-wide data for predicted ore classifications was modelled in 3D. Models were also developed to predict comminution parameters and copper recovery using the calculated modal mineralogy and geochemical database. Sample preparation for geochemical analysis is currently underway in order to develop a revised geological model. Oral presentations on the geometallurgy and geology of Productora were given at both the SEG and SGA conferences.

PhD student Cassady Harraden was transferred to the TMVC team during the year, and her research is reported within the TMVC's section of this report.

Processing operations at the Renison tin mine, Tasmania.



LOOKING FORWARD

It is anticipated that the final administrative processes for CODES' participation in CRC ORE II will be finalised early in 2016, which will signal the start of a significant increase in Module activities in the years ahead.

As activities within the new TMVC start to gather pace, collaborations between the two areas will further develop, specifically in relation to geometallurgical and geoenvironmental research.

Anita Parbhakar-Fox will continue as Acting Module Leader, with applications for the position expected to be considered in the latter half of the year.

Anita will help pursue geometallurgical and geoenvironmental AMIRA proposals, and one-on-one collaborations with industry and local stakeholders in 2016.

A highlight of 2016 will be the AusIMM GeoMet 2016 Conference at Perth's Pan Pacific Hotel in June. As a member of the Organising Committee, Anita has played a key role in securing speakers for the event, which include team members from both the Geometallurgy Module and the TMVC: Angela Escolme, Laura Jackson, Nathan Fox, and Cassady Harraden – plus Anita, who will also be co-leading a geoenvironmental workshop at the conference.

Angela Escolme's PhD study at the Productora deposit in Chile will be transferred to the TMVC from the beginning of the year. A key development in this project in 2016 will be the acquisition and interpretation of geochemical data (including radiogenic and stable isotopes, and mineral chemistry) to support a revised deposit model.

OPPOSITE PAGE CLOCKWISE FROM TOP LEFT: Geometallurgy short course participants at Donaghys Lookout, western Tasmania; Core samples at the Productora Cu-Au-Mo deposit, Chile; Geometallurgy short course participants visiting the Savage River mine.

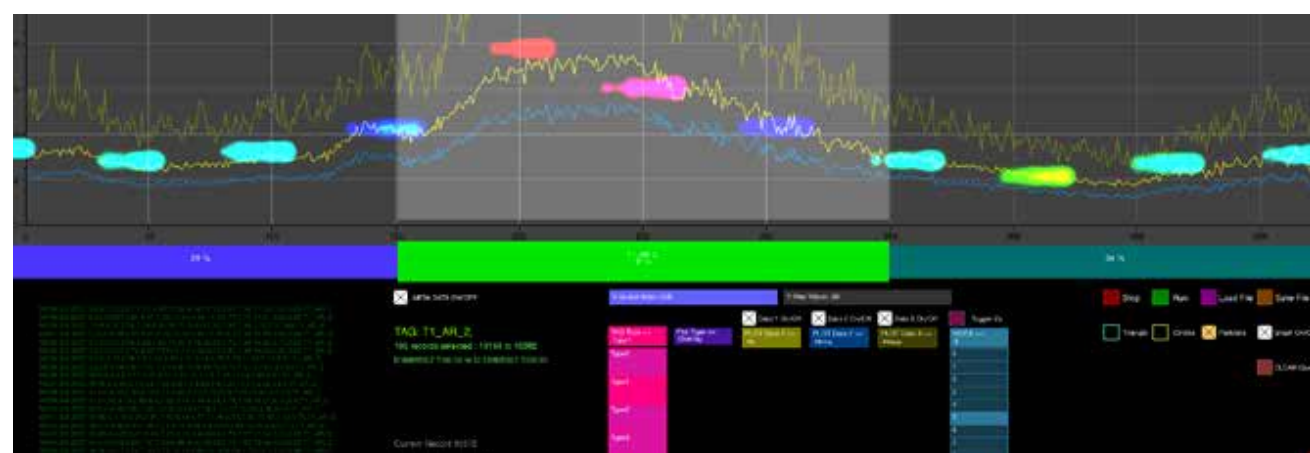
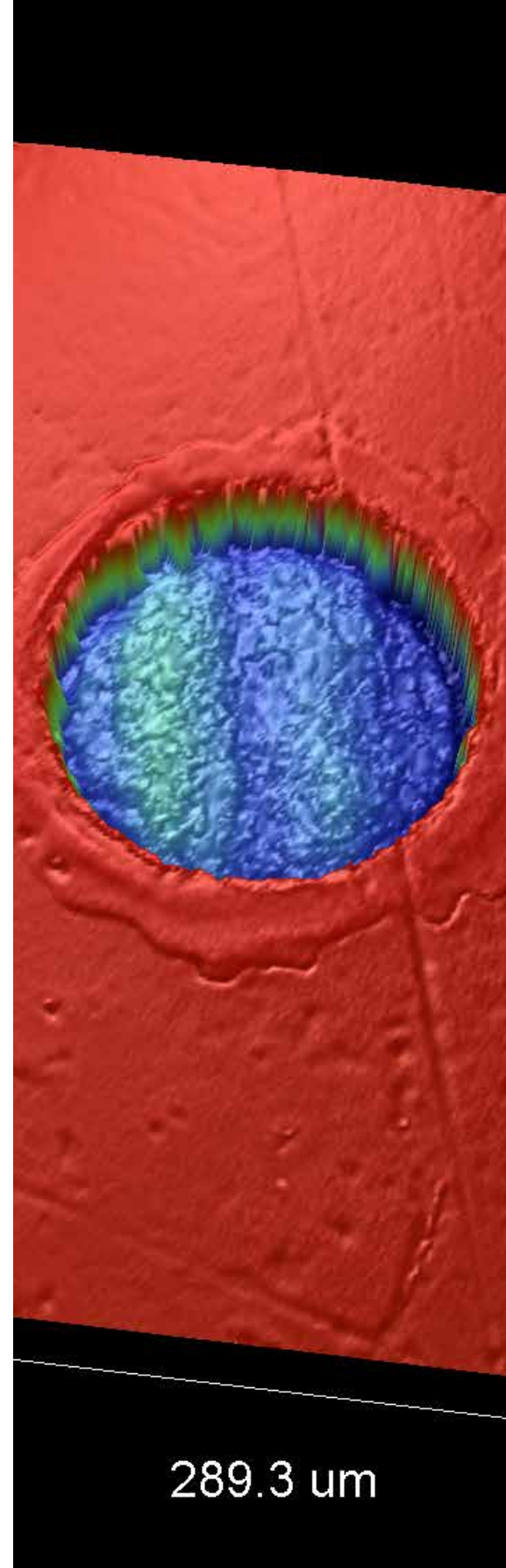


Drilling operations at the Productora Cu-Au-Mo deposit, Chile.

OBJECTIVES

Research activities within the Module are aimed at developing new analytical techniques and new computational algorithms for big data knowledge discovery, the modelling of crystallisation and melting processes, and analytical data reduction; thereby ensuring that the research is driven by innovative technology and CODES is at the cutting edge of analytical and computational developments of relevance to ore deposit research.

The Module also aims to provide CODES research staff and students with access to state-of-the-art micro-analytical equipment within Australia and overseas, and maintain their awareness of new analytical developments.



INTRODUCTION

The Enabling Technologies Module 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 big data knowledge discovery techniques. 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, development of algorithms for big data knowledge discovery, modelling of geological processes, analytical data reduction, and the development of new, user friendly software packages. In 2015, 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.

The computational projects include target generation from data-driven computations, computational knowledge discovery from high-dimensional (high-D) data, modelling of melting and crystallisation, and geodata visualisation.

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

HIGHLIGHTS

NEW EQUIPMENT FUNDING

In 2015, CODES made a successful application to the University of Tasmania (UTAS) for funding to purchase and install a new generation Time-Of-Flight ICP-MS instrument, from TOFWERK, which is capable of the simultaneous detection of virtually the entire periodic table, including all the elements applicable to this application. This will be the first TOFWERK instrument to be installed in Australia, and its addition to the technology facilities will significantly enhance CODES' capabilities in the rapidly developing field of imaging trace element distributions in minerals using LA-ICP-MS.

CODES was also successful with its application for funding to the Australian Research Council and UTAS for a new generation field-emission gun sub-micron resolution electron microprobe, which will provide for new capabilities for imaging and identification of micro-inclusions in minerals.

RESEARCH

The main research focus during the year centred on understanding the fundamentals of H₂O-free inductively-coupled plasma and refining algorithms for big data knowledge discovery. Analytical and computational developments included:

ANALYTICAL DEVELOPMENTS

- Investigation of ions energy in the ICP-MS has improved understanding of the instrumentation for laser ablation in geological materials.
- The installation of two new types of excimer laser ablation systems, 193nm ATL ArF and 248nm ATL KrF, has further expanded CODES' research and analytical capabilities.
- Changes to the operating procedures have resulted in a decrease of the matrix effects during Pb/U dating, leading to improved accuracy.

COMPUTATIONAL DEVELOPMENTS

- Development of robust and intuitive workflows in open source software for supervised and unsupervised learning approaches to geological modelling.
- Release of 'Tagger' – an application that enables interactive data analytics for geoscience.
- Foundation work continued on changepoint detection applied to spatial data.

AWARD

Jay Thompson was presented with the UTAS Faculty of Science Engineering and Technology Dean's Award for professional staff. Jay received the award for his contribution to the ongoing operations of the LA-ICP-MS and XRF facilities, and the overall R&D program within the CODES Analytical Laboratories.

AMAS XIII

CODES hosted AMAS XIII, the 13th biennial Australian Microbeam Analysis Symposium, in the early part of the year. The program commenced with two days of Pre-Meeting Workshops on February 9 and 10, which were immediately followed by the main symposium from February 11 to 13.

This major event in the field of microanalysis and imaging attracted 118 delegates from all around Australia, and included talks by over 50 of the world's leading experts. The symposium was led by Leonid Danyushevsky and Karsten Goemann (UTAS Central Science Laboratory). Leonid also conducted a Pre-Meeting Workshop on LA-ICP-MS, and team members Sarah Gilbert, Sebastien Meffre and Jay Thompson each gave talks during the main symposium.



THE MODULE TEAM



LEADER:
Leonid Danyushevsky

TEAM MEMBERS:

Ivan Belousov, Matt Cracknell, Sarah Gilbert, Elena Lounejeva, Sebastien Meffre, Paul Olin, Anya Reading, Sasha Stepanov, Jay Thompson

PHD STUDENTS:

Stephen Kuhn, Peter Morse, Jay Thompson

COLLABORATORS:

AGILENT TECHNOLOGIES

Fred Fryer

BHP BILLITON

Kathy Ehrig

ETH ZURICH, SWITZERLAND

Detlef Gunther, Joachim Koch

FIRST QUANTUM MINERALS

Tim Ireland, Chris Wijns

GOLD FIELDS

Andrew Foley

IOWA STATE UNIVERSITY, USA

Sam Houk

LAURIN TECHNIC

Michael Shelley

LAWRENCE BERKELEY NATIONAL LABORATORY, USA

Ric Russo

MOSCOW STATE UNIVERSITY, RUSSIA

Alexey Ariskin, Pavel Plechov

NEWCREST MINING

Anthony Harris

NORRIS SOFTWARE

Ashley Norris

UNIVERSITY OF TASMANIA

Christopher Lueg

UNIVERSITY OF MELBOURNE

Roland Maas

UNIVERSITY OF WAIKATO, NEW ZEALAND

Shaun Barker

QUEENSLAND UNIVERSITY OF TECHNOLOGY

Charlotte Allen

RIO TINTO

Paul Agnew, Alan Kobussen

CORE PROJECTS

THEME 1 ANALYTICAL DEVELOPMENTS

- Fundamentals of ICP-MS
- Fundamentals of laser ablation
- Element mapping by LA-ICP-MS
- Calibration standards for LA-ICP-MS
- LA-ICP-MS instrumentation development
- U-Pb dating

THEME 2 ALGORITHMS AND SOFTWARE FOR GEOCHEMICAL MODELLING AND ANALYTICAL DATA PROCESSING

- LA-ICP-MS data reduction software
- Modelling of crystallisation and melting processes

THEME 3 COMPUTATIONAL KNOWLEDGE DISCOVERY FOR GEOSCIENCE

- Target generation and geology map refinement from data-driven computation
- Technique development in computational knowledge discovery from High-D data
- Geodata analytics, visualisation and decisions

PROJECT SUMMARIES

THEME 1 ANALYTICAL DEVELOPMENTS

FUNDAMENTALS OF ICP-MS

Leaders: Jay Thompson, Leonid Danyushevsky

Team Members: Sarah Gilbert, Paul Olin

Collaborators: Fred Fryer, Sam Houk

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.

During 2015, the main focus was on:

- Testing a new Agilent 7900 ICP-MS for laser ablation applications. This instrument has several new design features that, upon investigation, proved to help increase sensitivity and lower instrumental backgrounds.
- Preparation of a manuscript dealing with ion energy measurements in the ICP-MS for laser ablation vs. conventional solution ICP-MS. Results highlight important differences between the two modes of operation. This is of importance because the instrumentation is designed around solution ICP-MS analyses, and the findings suggest that the current instrumentation may be further optimised for laser ablation. The results were presented by Jay Thompson at the European Winter Plasma Conference in Muenster, Germany.
- Conducting an investigation into the formation of oxide species in the ICP-MS during laser ablation vs. solution ICP-MS. Sarah Gilbert presented the results of this work at the European Winter Plasma Conference in Muenster, Germany. A manuscript is in the final stages of preparation.

FUNDAMENTALS OF LASER ABLATION

Leaders: Sarah Gilbert, Leonid Danyushevsky

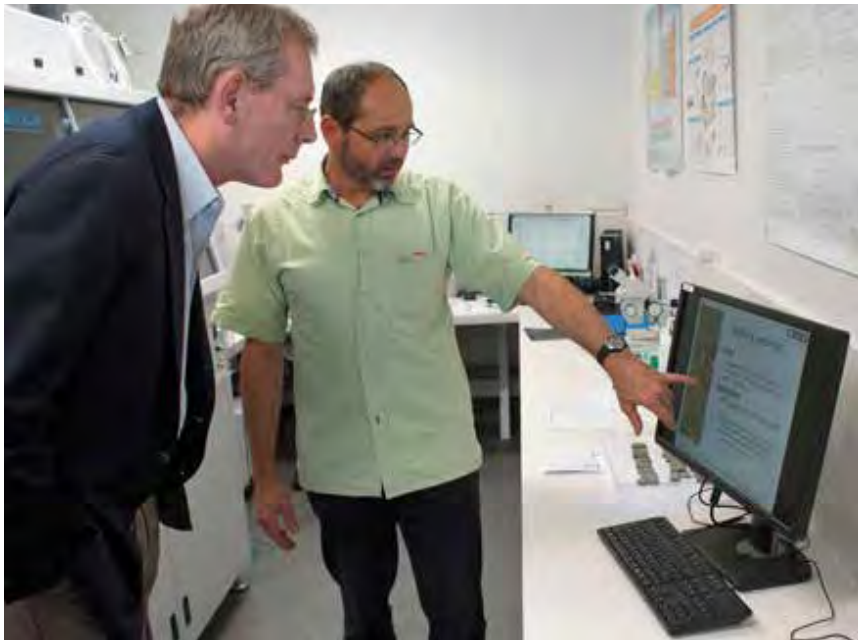
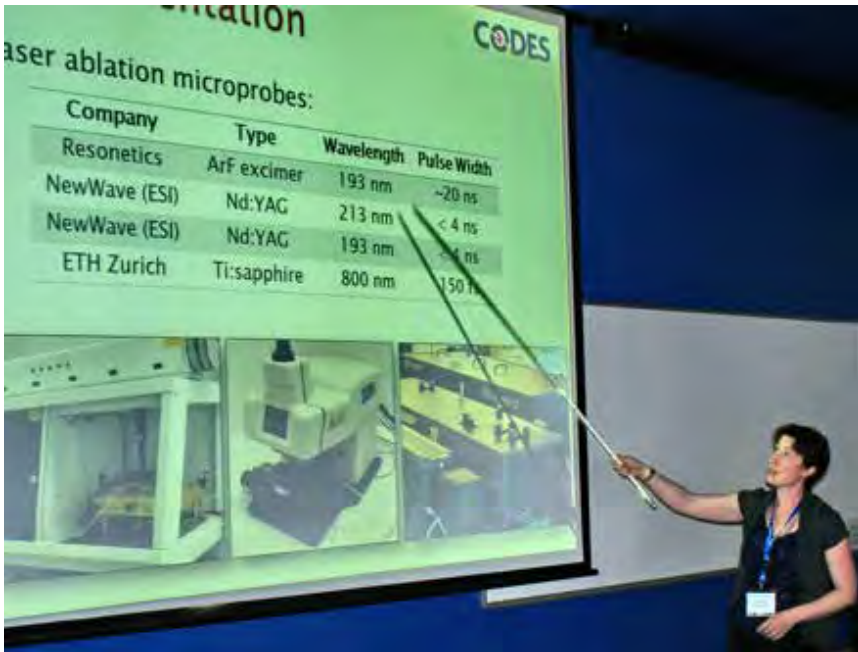
Team Members: Sebastien Meffre, Paul Olin, Jay Thompson

Collaborators: Charlotte Allen, Shaun Barker, Kathy Ehrig, Fred Fryer, Detlef Gunther, Joachim Koch, Ric Russo, Michael Shelley

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

In 2015, two new 4 ns pulse-width laser ablation systems (ArF 193 nm and KrF 248 nm excimer lasers) were installed, thus expanding the range of laser microprobes within the CODES Analytical Laboratories. Research was mainly focussed on understanding the impact of laser beam frequency, pulse width, and energy on the ablation of a range of sulfide minerals with small spot sizes. The main outcomes included:

- Improved capabilities for analysis of trace elements in copper-rich sulfide minerals by using the 248 nm 4 ns excimer laser, which reduces signal drop for small spot size analyses (beam size < 25 µm). Morphologies of ablation craters in sulfide minerals, produced by different laser microprobes, were compared using a high-resolution FE-SEM at the UTAS Central Science Laboratory, revealing variations in the amount and distribution of melted material.
- Ablation characteristics of pyrite are dependent on the amount and range of trace elements present as micro-inclusions. Pyrites with a large concentration of micro inclusions are characterised by a more regular ablation, leading to a different behaviour of sulfur.
- Demonstration of the ability of the high sensitivity 248 nm LA-ICP-MS system to characterise micron-scale gold rims on pyrite grains by utilising a small beam size (~4 µm).



FROM TOP: Mike Hamel, from Australian Scientific Instruments, aligning laser beams on the RESOLution laser probe; Sarah Gilbert presenting at the AMAS XIII Symposium; Sebastien Meffre (R) showing David Rainey, from BHP Billiton, the LA-ICP-MS facilities.

ELEMENT MAPPING
BY LA-ICP-MS

Leader: Sebastien Meffre

Team Members: Ivan Belousov, Leonid Danyushevsky, Sarah Gilbert, Sasha Stepanov

Key objectives are to develop new analytical procedures and algorithms for mapping the distribution of trace elements in geological materials by LA-ICP-MS.

In 2015, the main focus was on conducting an initial assessment of the requirements for the integration of data from digital cameras, short wave infrared spectrometers, Raman spectrometry, handheld pXRF spectrometers and LA-ICP-MS. Once integrated, this data will be used for extracting information on element deportment, mineral chemistry, and mineral association. It will also be used to acquire other important mineral-based information. For example, it will provide the ability to automatically distinguish between gold in solid solution, and gold in particles. These activities underpin several projects that will be occurring within the ARC TMVC Research Hub.

In 2016, the team will continue testing and refining the methods for:

- Automated mineral identification from images of elemental distributions in geological samples.
- Matrix correction algorithms during data reduction.

CALIBRATION STANDARDS
FOR LA-ICP-MS

Leaders: Ivan Belousov, Leonid Danyushevsky

Team Members: Sarah Gilbert, Paul Olin, Jay Thompson

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

During the year, a new calibration standard (STDGL3) for the analysis of sulfide minerals was developed and its homogeneity tested. The relative standard deviations (RSDs) at 50 μ m spatial resolution were within 5% for Au and Pt, 7% for Se, and 3% for most other elements.

Work has commenced on assessing matrix-dependent fractionation when using STDGL3 for the analysis of sulfides. The chosen approach is to use pressed pellets of finely ground sulfide mixes (<5 micron) of known composition as proxies for sulfide crystals, which involves determining the correction factors that will be applied to quantified results based on STDGL3. Currently, the testing involves a range of nanosecond pulse width laser ablation systems: 193 nm excimer lasers with variable pulse widths, a 213 nm Nd:YAG laser, and a 248 nm excimer laser.

The focus was on quantifying fractionation between metals and sulfur, and between volatile and refractory metals (e.g., Zn, Cd, W relative to Fe).

LA-ICP-MS INSTRUMENTATION
DEVELOPMENT

Leader: Leonid Danyushevsky

Team Members: Sarah Gilbert, Paul Olin, Jay Thompson

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.

The main activities during the year were related to understanding the effect of the design and configuration of the gas mixing funnel of the S-155 ablation cell, in combination with the length and configuration of the interface between the laser probe and ICP-MS, on the instrumentation wash-out times, aimed at improving imaging capabilities. These activities form part of the technological developments within the ARC TMVC Research Hub.

Testing of a simultaneous detection TOF-ICP-MS model (TOFWERK, Switzerland) has demonstrated its advanced capabilities for imaging applications with LA-ICP-MS. This instrument will be installed at CODES Analytical Laboratories in 2016.

U-PB DATING

Leader: Jay Thompson

Team Members: Leonid Danyushevsky, Sebastien Meffre

Collaborator: Roland Maas

This project investigates the causes of limitations to Pb/U dating of minerals by LA-ICP-MS, with the aim of improving 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 investigations into:

- The use of lower laser energy to decrease crater depth, element fractionation and matrix effects in the mineral zircon.
- The use of an optical profiler to improve accuracy by applying a correction to data based on precise crater depth measurements.
- Apatite matrix effects for Pb/U dating. Bulk digestion ID-MC-ICP-MS determination is used to understand the causes of matrix effects that are seen by LA-ICP-MS.
- The causes of ICP-MS U-Pb and Pb-Pb drift. Successfully resolving the causes has allowed for more reliable analyses over longer sessions, leading to common use of 24-hour long sessions.

THEME 2
ALGORITHMS AND
SOFTWARE FOR
GEOCHEMICAL
MODELLING AND
ANALYTICAL DATA
PROCESSING

LA-ICP-MS DATA REDUCTION
SOFTWARE

Leader: Leonid Danyushevsky

Team Members: Sarah Gilbert, Sebastien Meffre, Sasha Stepanov, Jay Thompson

Collaborators: Paul Agnew, Anthony Harris, Alan Kobussen, Ashley Norris

This project, partially co-funded by Newcrest Mining (until April 2014) and Rio Tinto (from December 2014)

as part of their support for the R&D program of the CODES Analytical Laboratories, 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 2015 were directed toward developing algorithms for identification of time-resolved signals free of micro-inclusions; advanced handling of time-resolved instrumentation backgrounds and calibrations; and algorithms for un-mixing time-resolved signals recorded during ablation of fine-grained mineral aggregates. A fully functional beta-version was installed for testing in-house, and at the Rio Tinto analytical facility.

MODELLING OF
CRYSTALLISATION AND
MELTING PROCESSES

Leader: Leonid Danyushevsky

Collaborators: Alexey Ariskin, Pavel Plechov

The aims of this project are to:

- Develop model-independent algorithms for tracking the behaviour of trace elements during magma generation and evolution processes.
- Conduct modelling of post-entrapment modifications in melt inclusions in minerals.
- Simulate processes of mantle and crustal melting, and melt crystallisation.
- Develop a range of general petrological tools. (These algorithms are continuously implemented in future versions of the 'Petrolog' software package).

In 2015, work continued on developing a new model for plagioclase-silicate

melt equilibrium under hydrous conditions at variable pressures, and incorporating a new model of sulfur solubility in silicate melts into the Petrolog3 software. An updated version of this software will be made available on the Petrolog home page in 2016 (<http://petrolog.web.ru>).

THEME 3
COMPUTATIONAL
KNOWLEDGE
DISCOVERY FOR
GEOSCIENCE

TARGET GENERATION AND
GEOLOGY MAP REFINEMENT
FROM DATA-DRIVEN
COMPUTATION

Leader: Matthew Cracknell

Team Member: Anya Reading

Student: Stephen Kuhn

Collaborators: Andrew Foley, Tim Ireland, Chris Wijns

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, for a given stage of a resource project's development (e.g., area selection, target prediction, resource evaluation, and resource development).

In 2015, through the use of robust methods for the selection of relevant variables and predictive model uncertainty quantification, this project has delivered accurate and informative geological models in the Eastern Goldfields region of Western Australia. These models will be used to independently validate existing geological maps, while also identifying mineralisation targets, especially in areas concealed by overlying geological strata.

TECHNIQUE DEVELOPMENT
IN COMPUTATIONAL
KNOWLEDGE DISCOVERY
FROM HIGH-D DATA

Leader: Anya Reading

Team Member: Matthew Cracknell

This project is aimed at computational knowledge discovery from high-dimensional (high-D) data.

During 2015, computational experiments were conducted on several projects relating to knowledge discovery from multi-layered data. Work of this nature is the 'sand pit' from which successful applied Earth informatics workflows emerge. One experiment looked at the potential for the use of changepoint methods on similar datasets to those that have been used successfully in other machine learning applications, such as the improvement of geological maps using lithology prediction on high-D data. These computational experiments will continue in 2016.

GEODATA ANALYTICS,
VISUALISATION AND
DECISIONS

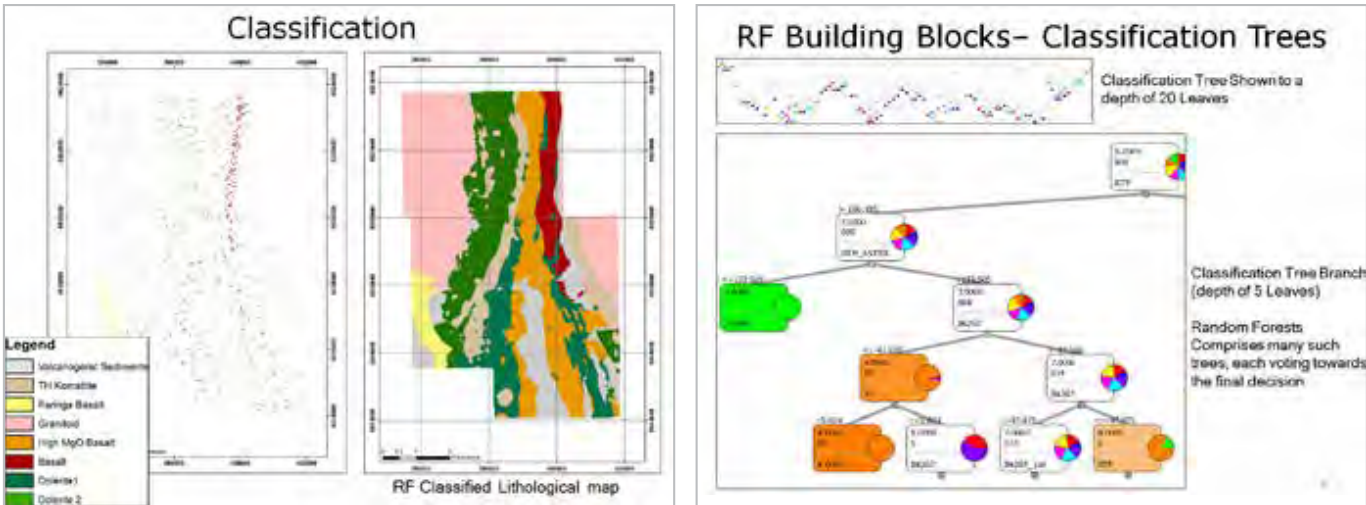
Leader: Anya Reading

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. By utilising the existing expertise in technique development and the practical application of methods in computational geophysics and Earth informatics, the project focusses on using the visualisation as part of the data inference process, rather than being simply a way of viewing the final output.

2015 saw the release of the beta version of the 'Tagger' application, developed by PhD student Peter Morse, for the reconnaissance analysis of large volumes of geosciences data. This application combines high-performance graphics with the ability to work with scientific format data located locally or on a cloud-based platform. Peter gave an invited talk at the 'IEEE International Symposium on Big Data Visual Analytics', held in Hobart. Amongst other topics, he presented an overview of the visualisation process behind the Pausiris Mummy exhibit (commissioned for the opening of MONA in 2011).



FROM LEFT: Classification results from the St Ives project (Left: sample data, right output/result); Classification Trees / Random Forests example from the software used to execute machine learning.

LOOKING FORWARD

During 2016, research activities within the Module will focus on continuing analytical and computational developments.

Analytical developments will include:

- Characterisation of the ablation process for a range of sulfide minerals, using the 248 nm excimer laser system.
- Finalising the development of the STDGL3 sulfide standard, and determination of correction coefficients for different laser systems and sulfide minerals.
- Testing of ablation cell designs, with the aim of developing a fast response, low memory cell for improved imaging capabilities and throughput.

Computational developments will include:

- The construction of informative models of the Zambian Copperbelt, through the integration of soil geochemical and airborne geophysical data.
- The trial of methods for detection of major lithology contacts under cover.

The addition of two significant items of equipment during 2016 will further enhance the technical facilities within CODES' Analytical Laboratories. The planned installation of a new Time-of-flight (TOF) ICP-MS will enable improved LA-ICP-MS imaging capabilities, while the new optical profiler will allow for routine crater depth measurements to be performed, leading to more accurate Pb/U dating applications.

Several papers will be submitted to international peer-reviewed journals, covering research on:

- Application of 'Tagger' to interactive data analytics for geoscience.
- Formation of oxide species in LA-ICP-MS.
- Matrix effects of U-Pb dating of apatites by LA-ICP-MS.

In addition to the Module activities, team members will be increasingly involved with the research being performed by the TMVC Research Hub. Assistance will focus on:

- Developing data processing algorithms for high data generating scanning sample characterisation equipment, such as the Corescan drill core logger.
- Applying big data approaches to geoenvironmental prediction.
- Building laser ablation sample cells capable of accommodating large sections of drill core.



LEADERS:
Robert Scott and
Anya Reading



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 work force.

INTRODUCTION

The Centre has developed 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 parts of the world to study at CODES, with many progressing to senior roles in the minerals industry, state and federal governments, and academia.

Training 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 throughout the other three Modules.

In recognition of these attributes, CODES has developed a Module within its structure dedicated solely to training. Areas covered under

this Module range from the Higher Degree by Research (HDR), Master of Economic Geology and Honours programs, through to a variety of short courses and workshops, most of which are aimed at re- and up-skilling of professionals in the minerals industry.

HIGHLIGHTS

It was another good year for the Training Module, which was marked by healthy enrolments for both the HDR and Master of Economic Geology programs. There were 12 new enrolments for the HDR program, up from nine in 2014. This figure included a record high of nine Australian enrolments, which bettered the previous figure of seven, set just last year.

The Master of Economic Geology Program enjoyed another strong year, with the number of UTAS-based students active in the program equalling an all-time high, complemented by a good throughput of completions and graduations.

Anya Reading was appointed as joint leader of the Module in January, taking over from Jocelyn McPhie who retired at the end of 2014. Anya's primary role will be as

Graduate Research Co-ordinator. Anya brings a wealth experience to the role, particularly in relation to HDR training and student liaison, ensuring a smooth handover from Jocelyn, who performed these duties with distinction for a number of years.

The postgraduate students continued to make major contributions to Centre activities during the year. For example, they produced 11 chapters in books, 22 refereed journal articles, and presented 25 papers and 30 posters at major international conferences in Australia, Canada, Chile, the Czech Republic, France and Peru.

A highlight of the CODES SEG Student Chapter's professional development program was the 19-day field trip to Iceland and Sweden, where the students enjoyed a hands-on learning experience on the mineralisation and alteration processes related to hydrothermal systems in ancient and modern volcanic terranes.

OPPOSITE PAGE CLOCKWISE FROM TOP LEFT: Jing Chen studying toconao ignimbrite in Chile, with San Pedro volcano in the background; Jessica Trezise (ANU) and Alice Shuster (University of Melbourne) on an Honours mapping camp in western Tasmania; Participants in the CODES Student Chapter field trip at the Leirhnjúkur lava flow field in northern Iceland.



FROM LEFT: Graduates Phil Gilmore (Master of Economic Geology), Jeff Steadman (PhD), and Sarah Gilbert (PhD).

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. Ninety per cent of HDR projects are integrated into the Centre's three research modules and the ARC TMVC Research Hub, and about 80% of the projects involve collaborations with the minerals industry.

CODES' success in attracting HDR students from overseas is underpinned by its international reputation as a research training centre. This success continued in 2015 with over 30 international students enrolled in the program, representing a total of 17 nationalities. However, even though the ratio of international students remained high, the trend of increasing enrolments for Australian students continued to gain momentum, with the intake of nine new domestic candidates beating the previous year's record high of seven. This is considered to be partly due to the challenging employment conditions that continue within Australia's minerals industry, plus the greater prevalence of scholarship opportunities for local applicants.

There was a total of 56 students enrolled in the program during 2015 (54 PhD and 2 MSc), which included 12 new PhD students. These new enrolments were comprised of Australian students Nathan Chapman,

David Douch, Matthew Ferguson, Laura Jackson, Joseph Knight, Josh Phillips, Naomi Potter, Jay Thompson and Jennifer Thompson, plus an international contingent of Amos Garay (Chile), Fumihiko Ikegami (Japan) and Brian McNulty (Canada). Seven PhD students and one MSc student had theses under examination, of which five PhD students graduated: Mohd Basril Iswadi Bin Basori, Sarah Gilbert, Jose Piquer, Marc Rinne, and Jeff Steadman.

One PhD candidate withdrew and several students had periods of suspension. While student numbers have increased slightly since 2014, the number of students submitting theses dipped slightly, which is expected to result in a spike in submissions in 2016.

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 and UTAS. 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.

The Centre's Master of Economic Geology Program enjoyed another

strong year in 2015, with the number of UTAS-based students active in the program equalling an all-time high, complemented by a good throughput of completions and graduations. Nine students graduated: Billy Beas, Lynelle Beinke, Peter Duerden, Phil Gilmore, Xuan Truong Le, Neil Macalalad, Michael Musialike, Stephanie Robertson and Edward Summerhayes. In addition, Imam Malik, Maria Faustino and Joanna Condon completed their degrees late in the year, and will be eligible to graduate in 2016. These departures have been balanced by an intake of eleven new students, with another two lapsed students also re-joining the program. This brings the total number of UTAS-based students active in the program to a record equalling 52 – and with a marked increase in enquiries from prospective students towards the end of the year, the signs are good that this success will be carried forward into 2016.

CODES ran three Master of Economic Geology short courses (units) during the year, in line with its usual biennial model of scheduling. Despite challenging circumstances in the minerals industry, attendance figures were only slightly down in comparison with the same courses held in previous years.

ORE DEPOSITS OF SOUTH AMERICA

In March, David Cooke, David Selley and Bruce Gemmell led a group of 17 people to Chile and Peru for *Ore Deposits of South America*. Participants in this unit are not only treated to remarkable geology and spectacular scenery but, most importantly, also gain

first-hand experience in one of the premier mineral provinces of the world. Deposit types visited included porphyry, epithermal, IOCG, skarn and MVT deposits, and the trip included visits to some of the world's largest mines.

ORE DEPOSIT GEOCHEMISTRY, HYDROLOGY AND GEOCHRONOLOGY

Nathan Fox and David Cooke devised a packed program for the second short course of the year. *Ore Deposit Geochemistry, Hydrology and Geochronology*, held in June, was attended by 22 Masters students, with class numbers swelled further by the attendance of up to 15 CODES Honours and PhD students, who attended all or part of the short course. The course is designed to introduce participants to a range of geochemical, isotopic, hydrological, and geochronological techniques used to interpret ore genesis and ore forming environments. The unit was delivered by a mixture of CODES

and invited presenters with a diverse spread of expertise. The invited experts were Rick Sibson (Otago University), Shaun Barker (University of Waikato), Phil Blevin (Geological Survey of NSW), Lesley Wyborn (Geoscience Australia), and respected minerals industry consultants, Scott Halley and Nick Oliver.

GEOMETALLURGY

The final unit for the year was held over the last two weeks of October, attracting 15 participants. *Geometallurgy* was ably led and organised by Ron Berry, Julie Hunt, and Anita Parbhakar-Fox. Invited presenters were Dee Bradshaw (University of Queensland/ University of Cape Town) and Melissa Humphries (School of Physical Sciences, UTAS). The course covered key aspects of this highly specialised field, including rock properties, sample selection, mineralogy, comminution and mineral processing, statistical analysis and modelling, environmental issues, and finances. The short course

included a three-day field trip to northwest and western Tasmania, visiting the ALS Laboratory in Burnie, Grange Resources' Savage River iron ore mine, and Bluestone Mines Tasmania's Renison tin mine. CODES extends its gratitude to the staff at each of these facilities for arranging visits that were both enjoyable and highly informative. Special thanks also go to both Ron (retired) and Julie (now with Université de Liège, Belgium), who voluntarily gave up their time to, once again, run a very successful short course, which they first delivered in 2012.

THE PROGRAM FOR 2016:

- 6 – 20 March: Volcanology and Mineralisation in Volcanic Terrains (KEA703 / KEA708)
- 30 May – 10 June: Exploration in Brownfield Terrains (KEA705 / KEA710)
- 17 – 28 October: Ore Deposit Models and Exploration Strategies (KEA701 / KEA712)



CLOCKWISE FROM LEFT: Students on the Geometallurgy short course testing the acid forming potential of mine waste; Maria Lourdes M. Faustino standing on evaporites in Valle de la Luna, Chile; Walter Lozano Garcia Naranjo (Peru) . Franco Ferreyra (Argentina) and Stephanie Sykora at the Chuquicamata mine in Chile.

HONOURS PROGRAM

The Honours program was co-ordinated by Garry Davidson and David Selley, who administered 20 students in the first half of the year and 12 thereafter, taking into account students that either enrolled or completed mid-year.

Out of this cohort, Adam Abersteiner joined the group from the Australian National University, Melanie Haycroft from the University of New South Wales, Jake Moltzen from the University of Adelaide, and Murray Brownrigg and Mark Giddings, both from James Cook University. The remaining students came to the program via an undergraduate degree at the University of Tasmania.

The program saw four departures prior to thesis completion, which is an unusually high number. As it has been rare to have even one departure from this program during an academic year, this is expected to be an anomalous occurrence, restricted to 2015.

The projects covered most of the subject areas, with only classical sedimentology not represented. The distribution was economic geology (5), geophysics (4), igneous geochemistry (3), environmental geology (2), volcanology (2), ocean chemistry (2), structural geology (1), geochronology (1), and paleobiology (1). Ten of the projects were based in Tasmania, five on the mainland, and six overseas, including Myanmar (2), South Africa/Finland, SW Pacific, Japan and New Caledonia. One highlight of the year was the completion of a study by Jake Moltzen into methods of identifying different carbonate varieties in the field and laboratory, carried out under the supervision of Anita Parhbakar-Fox and Nathan Fox. The study was of a particularly high quality and attracted interest from a wide group of researchers.

Sponsoring companies and organisations included the Australian Research Council, CBH Resources, CRC ORE, GHD, Lottah Mining, MacPhersons Resources, Mineral Resources Tasmania, National Prosperity Company, Sandfire

Resources, Signature Gold, Unity Mining, the Université de la Nouvelle-Calédonie, the Vanuatu Geological Survey, and Venture Minerals. In addition, a large proportion of the project work was supported by the supervisors' internal, university-based project 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

In 2015, CODES offered one 8-day short course as part of the Minerals Tertiary Education Council (MTEC) Minerals Geoscience Honours program, and two 5-day short courses as part of the Victorian Institute of Earth and Planetary Sciences (VIEPS) Honours coursework program.

EXPLORATION FIELD SKILLS MAPPING CAMP (in partnership with MTEC)
Course Leader: Robert Scott

Course Demonstrators: Sean Johnson, Jacob Mulder, Evan Orovan, Josh Phillips, Nathan Steeves, Selina Wu

The Exploration Field Skills (EFS) mapping camp provides participants with the opportunity to develop skills in geological mapping, core logging and structural analysis, within a mineral exploration context.

During the eight-day camp in western Tasmania, participants mapped, interpreted and ultimately assessed the exploration potential of a 4–5 km² area of Cambrian Mount Read Volcanics. The rock sequence exposed in the mapping area is very similar to those that host the Rosebery and Hercules volcanic-hosted massive sulfide (VHMS) deposits, located 5 and 10 km further north, respectively.

One day of the camp was spent at MMG's exploration core yard in

Tullah, where students inspected three of the eight diamond drill holes previously drilled in the mapping area, and learned structural and lithologic core logging techniques. One of the drill holes examined intersected a narrow low-grade Zn-Pb mineralised interval. Participants evaluated textural, structural, mineralogical and geochemical features of this interval, and together with an assessment of its stratigraphic position, decided whether it is more likely to be related to Cambrian VHMS or Devonian (structurally-controlled) mineralisation.

Data collected during field mapping and core logging were used to unravel the stratigraphy and structure of the area, as well as the nature and extent of any hydrothermal alteration. This information provided the basis for an assessment of the exploration potential, with participants asked to identify any previously untested areas in which base metal deposits could feasibly occur within 500 m of the surface.

The eight-day camp was held twice, in February and March, with a total of 48 students from eight universities participating.

Due to the current downturn in the minerals industry, and the concomitant reduction of funding to MTEC, 2015 sadly saw the demise of MTEC's long-running and very successful Minerals Geoscience Honours (MGH) program. The program offered nine, week-long, short courses (including EFS) to 4th and 5th year geoscience students throughout Australia. MTEC funding subsidised student travel to attend up to two short courses, and greatly offset the cost of course delivery for the participating universities. Many hundreds of Australian geoscience students have benefited greatly from their participation in this innovative program. While very disappointed to witness the end of the MGH, CODES gratefully acknowledges MTEC's previous financial support and substantial contribution to geoscience education in Australia. From 2016 onwards, the Exploration Field Skills Mapping Camp will be offered once a year, in February, as part of the VIEPS coursework program.



Participants on the Honours Exploration Field Skills Mapping Camps – first camp bottom left, and second camp group at the top. **BOTTOM RIGHT:** Students discuss ore deposit samples at the VIEPS Ore Deposit Models course.

ORE DEPOSIT MODELS (in partnership with VIEPS)
Course Leader: David Selley

Course Presenters: David Cooke, Garry Davidson, Bruce Gemmell, Robert Scott, David Selley, Jeff Steadman

In May, 12 students attended the five-day Ore Deposit Models Honours-level 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.
 - Epithermal, porphyry copper and skarn.
 - Iron-oxide copper gold.
 - Sediment-hosted and orogenic gold.
 - Sediment hosted uranium, copper and lead-zinc.

Each day of the short course involved a mixture of lectures and practical

exercises. Lectures covered the general characteristics and setting of the aforementioned deposit types, as well as the various genetic models that have been put forward 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 (in partnership with VIEPS)

Course Presenter: Leonid Danyushevsky

Also in May, 17 students attended the five-day 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 effects of pressure and H₂O 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.

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. **APUKHTINA, OLGA.** SA

Stable isotopes (C, S and O) and halogens (Cl, F) in gangue and ore minerals at Olympic Dam: Evaluation of mantle and crustal contributions to mineralisation.

3. **AWID-PASCUAL, RICHELLE.** TAS

The characteristics and role of colloids in the mineral formation in Grievess Siding Zn-Pb peat, western Tasmania.

4. **BAKER, WAYNE.** WA (HONS)

Lithostratigraphy and facies architecture of the footwall to the DeGrussa volcanic hosted massive sulfide deposit, Western Australia.

5. **CAVE, BEN.** VIC

A metamorphic course for tungsten in metasedimentary-hosted orogenic gold deposits.

6. **CAVILL, CHLOE.** VIC (MASTERS)

Geochemical classification of orebearing/metalliferous fluids of the Costerfield region, Victoria.

7. **CHAPMAN, NATHAN.** SA

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

8. **CHERRY, ALEXANDER.** SA

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

9. **CONDON, JOANNA.** WA (MASTERS)

Mineral characterisation of the DeGrussa deposit: Implications for mining, milling and exploration.

10. **DOUTCH, DAVID.** WA

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

11. **ESHAGHI, ESMAEIL.** TAS

3D petrophysical and geophysical modelling of west and northwest Tasmania.

12. **FERGUSON, MATT.** SA

Regional metal and fluid sources for IOCG mineralisation around Olympic Dam, and geology, geochronology and mineral-chemical zonation of the Wirrda Well deposit.

13. **FOX, JODI.** TAS

Basaltic volcanic successions in Tasmania and on Heard Island.

14. **GILMORE, PHIL.** NSW (MASTERS)

Exhalative horizons and volcanic-associated massive sulfide mineralisation in the Ordovician Giralambone Group, New South Wales.

15. **HARDWICK, BRENDAN.** WA (MASTERS)

Sulfide textures at Tropicana Gold Mine: Relationship to deposit genesis, gold deportment and implications for ore processing, exploration, and environment.

16. **HARRADEN, CASSADY.** NSW*

Geotechnical and geometallurgical assessment of the Cadia East deposit using Corescan automated logging technology.

17. **HAWKE, MARGY.** WA

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

18. **HAYCROFT, MELANIE.** NSW (HONS)

The eastern mineralisation, Broken Hill, NSW.

19. **HILDREW, CHRIS.** WA (HONS)

Understanding the nature of the host rock succession to the Archean Nimbus Ag-Zn-Pb-Au deposit, WA.

20. **HOLMES, TRAVIS.** TAS (HONS)

Geometry, timing and controls on alteration and mineralisation at the Big Wilson Tin Prospect, NW Tasmania.

21. **HONG, WEI.** TAS

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

22. **HUANG, QIUYUE.** SA

Mafic magmatism in the Gawler Craton: Distribution, composition, timing, sources and tectonic setting.

23. **JACKSON, LAURA.** NSW*

Domaining of geoenvironmental properties in drill core.

24. **LOWER, CHANTELE.** SA (MASTERS)

An aspect of the geology of the Olympic Dam deposit.

25. **MATTNER, SALLY.** TAS (HONS)

Structure and metamorphism of the Mersey River metamorphic complex.

26. **McADAM, WILL.** TAS (HONS)

A geophysical interpretation of the Mole Creek area, Tasmania.

27. **McCORMACK, REUBEN.** TAS (HONS)

Geophysical assessment of potential magnetite skarn mineralisation at the L13 Prospect, Highclaire, Northwest Tasmania.

28. **McMAHON, CLAIRE.** TAS

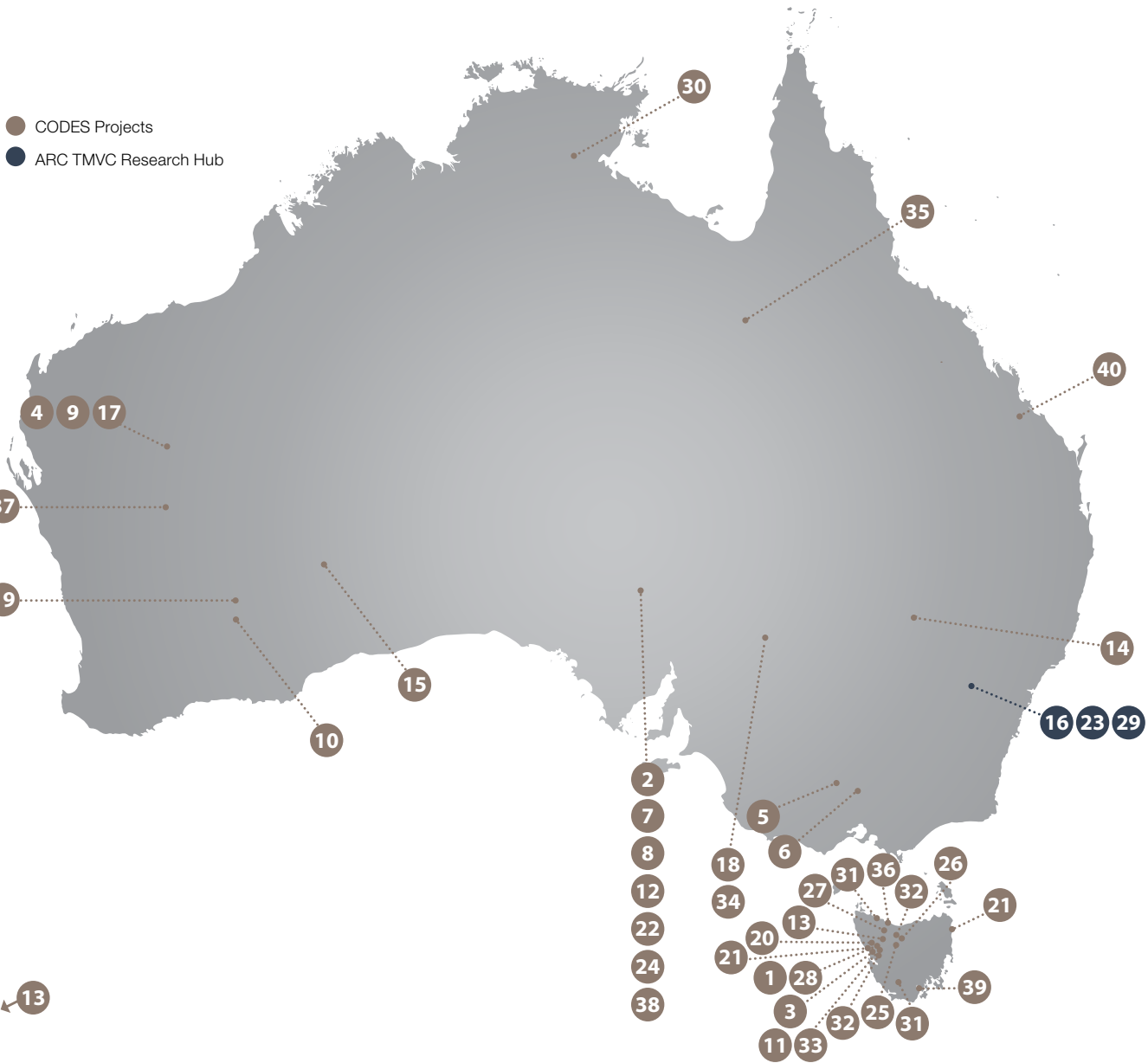
Distribution of, and controls upon, pyrite trace element content of hydrothermal alteration zones at Hercules VHMS ore deposit, Tasmania and NICO IOCG ore deposit, Northwest Territories, Canada.

29. **MORRISON, JOANNE.** NSW (MASTERS)*

Cadia East multi-element lithogeochemistry: Evaluation of trace element deportment important to processing.

30. **MUKHERJEE, INDRANI.** NT

Pyrite trace element chemistry of black shales of the "boring billion" period.



31. **MULDER, JACOB.** TAS
From Nuna to Gondwana: An evaluation of the early tectonic history of Tasmania.

32. **OSTERSEN, THOMAS.** TAS
Multi-scale geoelectric, and combined geophysical, investigations of Tasmania and Southeast Australia.

33. **PEREIRA DA FONSECA, PEDRO.** TAS
Facies analysis and correlations in complex mineralised submarine volcanic successions: Mount Read Volcanics, western Tasmania.

34. **ROGERS, BRONSON.** NSW (HONS)
Environmental significance of the Broken Hill Gossan: A mineralogical and geochemical study.

35. **SHARMA, SUBIRA.** QLD
Evaluation of links between Merlin-style Mo-Re mineralisation and magmatism in the Cloncurry fold belt, Queensland: Implications for exploration.

36. **SMITH, MARK.** TAS (HONS)
Distribution, nature of sediments and depth to bedrock in Bass Strait, in the region of Burnie Port.

37. **STEADMAN, JEFFREY.** WA
BIFs, black shales, and gold deposits: A re-evaluation.

38. **VEJELYTE, IRMA.** SA (MASTERS)
Geological evolution of the Wirrda Well Prospect, Gawler Craton, South Australia.

39. **WARN, LESLIE.** TAS (HONS)
Gravity and magnetic modelling of the Cygnet area, Tasmania.

40. **WHITNEY, BEN.** QLD (HONS)
Geological framework and characteristics of the Specimen Hill high sulfidation epithermal system, southern Queensland, Australia.

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. FINLAND, SOUTH AFRICA (HONS)

Petrographic and melt inclusion constraints on the petrogenesis and composition of kimberlites from Finland and South Africa.

2. BAKER, FABIAN. ARMENIA (MASTERS)

Amulsar HSE Au deposit, Armenia.

3. BASORI, MOHD BASRIL ISWADI BIN. MALAYSIA

Geology of volcanic hosted massive sulfide (VHMS) deposits in Central Belt, Peninsular Malaysia.

4. BEAS CACERAS, BILLY. PERU (MASTERS)

Volcanic stratigraphy at La Zanja Mining District in the northern Peruvian Andes, Cajamarca, Peru.

5. BENAVIDES, SEBASTIAN. ARGENTINA (MASTERS)

Characterisation of phyllic assemblages at Taca Taca Bajo, Argentina.

6. BERKENBOSCH, HEIDI. NEW ZEALAND

Geochemistry of hydrothermal mineral chimneys from Brothers volcano, Kermadec Arc.

7. CALDERON-TIPIANI, CESAR. PERU (MASTERS)

Chanca low sulfidation deposit, Peru.

8. CAVE, BEN. CANADA, NEW ZEALAND

A metamorphic course for tungsten in metasedimentary-hosted orogenic gold deposits.

9. CELIZ, DJOHANNE. PHILIPPINES (MASTERS)

The geology, alteration, and mineralisation of the Sagay deposit in northern Negros, Philippines.

10. CHEN, JING. CHINA

The geology, mineralisation, alteration and fluid evolution of Zijinshan ore field, Fujian Province, China.

11. DRAAYERS, EVAN. SW PACIFIC (HONS)

Detailed mineralogy of boninite and arc-tholeiite lavas from the Hunter Ridge: Implications for plumbing system and magma generation processes.

12. ESCOLME, ANGELA. CHILE

Ore characterisation and geometallurgical modelling at the Productora Cu-Au-Mo deposit, Chile.

13. FAUSTINO, MARIA LOURDES M. PHILIPPINES (MASTERS)

Intrusive history and genesis of Bayugo porphyry copper-gold deposit, Surigao Del Norte, Philippines.

14. 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.

15. HARRISON, RACHEL. INDONESIA

Tumpangpitu porphyry Au-Cu-Mo and high-sulfidation epithermal Au-Ag deposit, Tujuh Bukit project, SE Java, Indonesia - geology, alteration and mineralisation.

16. 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.

17. HOLT, SAM. USA

Understanding of basaltic eruption dynamics and mechanisms: Effusive and explosive eruptions in Hawaii.

18. IKEGAMI, FUMIHIKO. NEW ZEALAND

2012 submarine silicic eruption of Havre volcano and implications for ancient submarine successions in Australia.

19. JIMENEZ TORRES, CARLOS ANDRES. PHILIPPINES

Bantug lithocap, Negros Island, Philippines: Mineralogy, textures, and chemistry.

20. JOHNSON, SEAN. FINLAND, ESTONIA, SWEDEN, RUSSIA

The trace element content and sulfide chemistry of metalliferous black shales.

21. KAMVONG, TEERA. THAILAND, LAOS

Geology and genesis of porphyry-skarn Cu-Au deposits at the Northern Loei and Truong Son Fold Belts, Thailand and Laos.

22. KNIGHT, JOSEPH. MYANMAR

The geodynamic and metallogenic setting of Cu-Au mineralisation in Myanmar: Implications for mineral exploration.

23. KUTKIEWICZ, ANNA. USA (MASTERS)

Trace element chemistry of chalcopyrite in the Viburnum Trend MVT deposits, USA.

24. LAWLIS, ERIN. PNG

Au-bearing pyritic ore of Lihir, Papua New Guinea: Its physiochemical character and nature of the causative fluids.

25. LE, XUAN TRUONG. VIETNAM (MASTERS)

Geological setting and mineralisation characteristics of the Me Xi gold deposit, Quang Tri Province, Central Vietnam.

26. MACALALAD, NEIL. INDONESIA (MASTERS)

Geology, alteration, mineralisation and vectoring to porphyry centre in the Aisasjur prospect, Irian Jaya, Indonesia.

27. MAKOUNDI, CHARLES. MALAYSIA

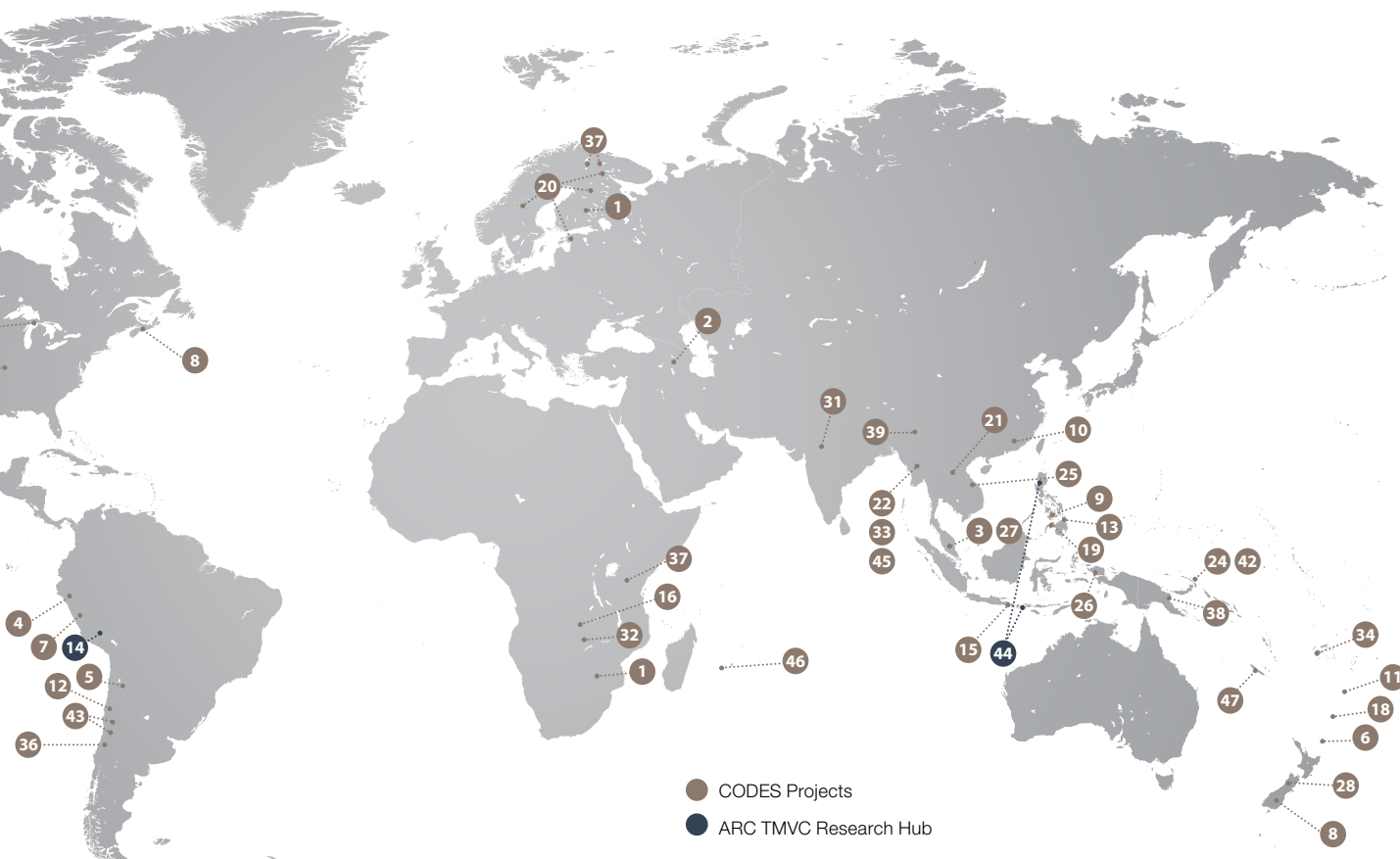
Geochemistry of carbonaceous black shale, sandstone, and chert in Malaysia: Insights into gold source rock potential.

28. McLELLAND, REBEKAH. NEW ZEALAND (MASTERS)

Gold mineralisation at the Reefton Goldfield, New Zealand.

29. 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.



30. McNULTY, BRIAN. CANADA

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

31. MUKHERJEE, INDRANI. INDIA

Pyrite trace element chemistry of black shales of the "boring billion" period.

32. MUSIALIKE, MICHAEL. ZAMBIA (MASTERS)

The geological setting and mineralisation characteristics of the Dunrobin deposit, Zambia.

33. NUANLA-ONG, SARANYA. MYANMAR (MASTERS)

Paragenesis, pyrite geochemistry and ore fluids at Htongyi gold veins, Myanmar.

34. OROVAN, EVAN. FIJI

Geology, geochemistry and genesis of the Namosi porphyry Cu-Au deposits, Fiji.

35. PHILLIPS, JOSHUA. USA*

Geologic and geochemical vectors to mineralisation at the Resolution porphyry Cu-Mo deposit, Arizona.

36. PIQUER ROMO, JOSE MEULEN. CHILE

Structural geology of the Andes of Central Chile: Evolution, controls on magmatism and the emplacement of giant ore deposits and implications for exploration.

37. POTTER, NAOMI. TANZANIA, FINLAND, RUSSIA

An investigation into the genesis of intrusive and extrusive carbonatitic melts.

38. RINNE, MARC. PNG

Geology and genesis of the contrasting Wafi-Golpu porphyry-epithermal deposit, Papua New Guinea.

39. SHEPPARD, JORDAN. MYANMAR (HONS)

Trace element variations in Devonian shale in Northern Shan State, Myanmar.

40. STEADMAN, JEFFREY. USA

BIFs, black shales, and gold deposits: A re-evaluation.

41. STEEVES, NATHAN. USA

Ore genesis of the Greens Creek VHMS Deposit, Alaska: Implications for mining, milling and exploration.

42. SYKORA, STEPHANIE. PNG

Geological, structural, geochemical and genetic significance of the anhydrite zone at the Lihir gold deposit, Papua New Guinea.

43. TESTA, FRANCISCO. ARGENTINA, CHILE

Tourmaline breccia pipes: San Francisco de los Andes, Argentina and Rio Blanco-Los Bronces, Chile.

44. THOMPSON, JENNIFER. INDONESIA, PHILIPPINES*

Detailed investigation into carbonate minerals in geochemical dispersion halos around Cu, Au and Mo porphyry deposits to identify potential indicators of deposit location beyond what is possible in whole rock geochemistry.

45. TRAYNOR, JONATHON. MYANMAR (HONS)

Genesis of Modi-Momi Taung orogenic gold deposit in central Myanmar: Constraints from structure, wall rock alteration and mineral chemistry.

46. 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.

47. WHITTEN, MATTHEW. NEW CALEDONIA (HONS)

Formation de Kone: Recording the final stages of Gondwana break up in New Caledonia.



Jay Thompson, who is a member of CODES technical staff, and also pursuing his PhD studies, which includes a lab based project related to LA-ICP-MS.

LAB-BASED PROJECTS

Unless marked otherwise, student projects shown here are PhDs.

GAL, MARTIN

The development of array and single station methods for the analysis of on-land ambient seismic signals from deep ocean storms and coastal sources.

GILBERT, SARAH

Development of analytical methods and standard reference materials for analysis of trace elements and isotopic ratios in sulfides.

KUHN, STEPHEN

The application of machine learning algorithms for lithological mapping and minerals targeting in key ore deposit settings.

LOUNEJEVA, ELENA

Geochemical study of three marine sediments sequences corresponding to the Late Permian-Early Triassic stratigraphic boundary.

MOLTZEN, JAKE (HONS)

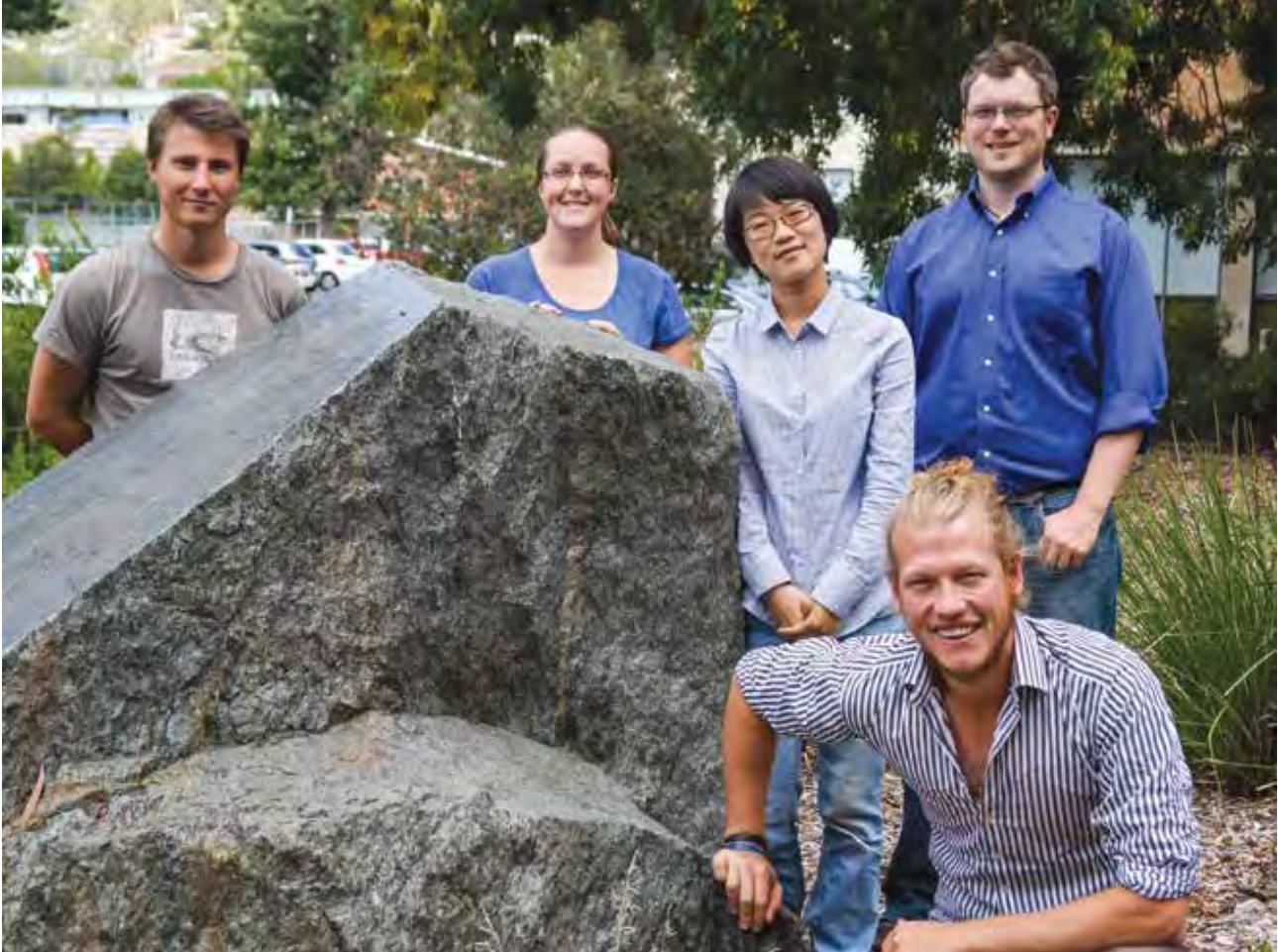
Integrated techniques for rapid drill core mineralogical characterisation.

MORSE, PETER

Combined computational and human interaction strategies in knowledge generation from spatial and spatiotemporal information.

THOMPSON, JAY

Understanding the specifics of H₂O-free aerosol behaviour in the inductively-coupled plasma in geochemical LA-ICPMS applications involving U/Pb dating and accurate trace element analysis in silicate minerals and glasses.



The current CODES SEG Student Chapter Committee. Back row, from left Josh Phillips, Jennifer Thompson, Jing Chen and Brian McNulty. Front row Nathan Chapman.

SOCIETY OF ECONOMIC GEOLOGISTS (SEG) STUDENT CHAPTER

The CODES SEG Student Chapter is an integral part of the Centre, whose activities have a wide ranging and positive impact in so many areas of its operations. It plays a vital role in creating a welcoming environment for students who come to CODES from widely differing cultural backgrounds, and ensures that their time spent at the university is both enjoyable and professionally rewarding. It also makes a significant contribution to raising the profile of CODES, and disseminating its research outputs internationally. The past year has been exceptional in terms of all these attributes and outputs, with just some of the highlights listed below.

CONFERENCES AND EXHIBITIONS

One of the key areas where the students contribute to enhancing CODES' profile is by presenting papers at international conferences, and 2015 was a particularly productive period in this regard. During the year students presented at conferences in Australia, Canada, Chile, the Czech Republic,

France, Germany, Peru and the USA. In total, students presented 25 papers and over 30 posters at high profile events including the Goldschmidt, SGA, and SEG 2015 Conferences, and the IUGG General Assembly. A special mention goes to Sean Johnson who delivered talks at the Goldschmidt, SGA and SEG conferences.

The students also play an important role in CODES' participation in exhibitions. In the past year, its members assisted with reception desk and general duties at the AMAS XIII – the 13th biennial Australian Microbeam Analysis Symposium, and shared booth duties at both the SGA Conference in Nancy, France, and the SEG Conference in Hobart. At the latter conference, they not only set-up and managed their own student chapter booth, they also organised a geological walking tour 'in the footsteps of Charles Darwin', plus a number of social activities – and still found time to assist with manning the CODES booth, roving microphone duties, and the preparation of delegate satchels.

PUBLICATIONS

The students made an exceptional contribution to the dissemination of CODES' research through various publications during the year. In total, they contributed to 11 chapters in books (all Sean Johnson) and 22 refereed journal articles. Highlights of these outputs were first author papers by Heidi Berkenbosch (*Mineralium Deposita*), Margy Hawke (*Precambrian Research*), Qiuyue Huang (*Precambrian Research*), Jose Piquer (*Economic Geology*), Jeff Steadman (*Economic Geology*), and Jacob Mulder (two papers: *Australian Journal of Earth Sciences* and *Geology*).

PROFESSIONAL DEVELOPMENT

The highlight of the year's professional development activities was the field trip to Iceland and Sweden, conducted in partnership with Lakehead University in Canada, and sponsored by the SEG, AMIRA International, the Geological Association of Canada, the Institute on Lake Superior Geology, and the UTAS Postgraduate Society.



FROM LEFT: CODES SEG Student Chapter members and friends at the welcome function prior to the SEG 2015 Conference; PhD student, Jacob Mulder, recipient of the Endeavour Postgraduate Scholarship for study in the USA.

The participants started the excursion in Iceland, taking a roughly circular route, beginning in Reykjavik, then moving up and around the northern areas, before returning via the remote central highlands to take in the recent Holuhraun lava flow and spectacular Laki Fissure. Other highlights included exploring the subterranean geology of a 1.4 km lava tube, having lunch in a volcanic cinder cone, seeing some astounding plinian deposits at the Askja crater, and visits to a collapsed lava lake, a rift valley, and several lava fields and waterfalls. They even managed an evening 'dip' in a river freshly heated by recent volcanic activity.

Highlights of the Sweden leg of the journey included a trip to the island of Uto, in the Stockholm archipelago, which included stops at historic iron and silver mines. Back on the mainland, they also visited the historic Sala Silver Mine, and the Garpenberg mine, owned by New Boliden, which produces complex ores containing zinc, lead, silver, copper, and gold. Other highlights included visits to the world-class Skellefte VHMS district, the huge Aitik gold-copper deposit, and the Kirunvana magnetite-apatite deposit.

The field trip was led by David Cooke and Jocelyn McPhie from CODES, and Peter Hollings from Lakehead University, Canada.

The students were also successful in attracting a number of expert external speakers to CODES during the year, who conducted presentations on a diverse range of geological topics. Guest speakers included John Bishop and Kate Hine, from Mitre Geophysics; and Dan Wood from the University of Queensland.

SOCIAL EVENTS

Social events play a vital role in helping students settle into life on campus, particularly those from interstate and overseas. They also help to develop a sense of camaraderie within the group, and establish friendships that often endure long after graduation.

Events organised by the Student Chapter in 2015 included wine tastings and a charity fundraiser for the victims of the Nepal earthquake. In addition, Student Chapter members assisted with the Christmas BBQ and participated in a host of other social events including weekly soccer games, ice hockey, indoor volleyball, badminton and squash, and a movie night. There were also a number of get-togethers to celebrate... well, just about anything really. Slightly more serious gatherings were their ever-popular fortnightly Talking Geology Informally on Fridays (TGIF) sessions in the CODES Conference Room, which adhered to a winning formula of a 20-minute talk, a 20-minute slide show of images, followed by snacks, beverages and socialising.

Although the Student Chapter is mostly comprised of PhD students, it also plays an important role in welcoming other postgraduate students. For example, in 2015 the Chapter welcomed new Honours students with a traditional barbeque, and organised welcome drinks for the predominantly industry-based students who participated in the two on-campus Master of Economic Geology short courses. They also organised a number of social events allied to the SEG 2015 Conference, including a highly successful reception to welcome students from around the world, and a quintessential Aussie 'sausage sizzle'.



PhD student Sean Johnson presenting at the SEG 2015 Conference.

AWARDS AND GRANTS

It was another successful year in terms of grants and awards, with the following students receiving recognition:

- Jacob Mulder – The Australian Government's 2016 (awarded in 2015) Endeavour Postgraduate Scholarship for study in the USA. Jacob plans to spend up to 10 months at his host institution, the University of New Mexico, in 2016. Jacob will be involved in exciting field work across SW USA, collaborating with world-renowned experts, and making use of world-class laboratory facilities as part of his PhD studies. He will particularly be focussing on the ancient geological links between Tasmania and the SW USA.
- Richelle Awid-Pascual, Jing Chen, Maria Lourdes M. Faustino, Wei Hong – SEG Hugh E. McKinstry Student Research Awards.
- Laura Jackson – SEG Foundation 2015 Graduate Student Fellowship Award. Laura was also awarded best paper at the AusIMM Conference: Tailings and Mine Waste Management for the 21st Century.
- Angela Escolme – awarded 'Best Student Presentation' at the SEG 2015 Conference.

COURSES FOR INDUSTRY

CODES introduced a series of specialised courses, aimed primarily at mining companies looking for an effective means of improving the skills of their workforce with minimal disruption to work schedules. The first of these courses, Geophysics for Geologists and Engineers, was introduced in 2013, which was

augmented by Advances in Geo-logging in 2014.

Although the concept for these courses continues to receive widespread support from the minerals industry, the current downturn in operating conditions has naturally had an impact on enrolments. As a result, it was decided to hold one course in 2015, and then place a temporary hold on the program in 2016, with a resumption anticipated when conditions improve.

GEOPHYSICS FOR GEOLOGISTS AND ENGINEERS

Course Presenters:

CODES: Michael Roach

GHD: Hugh Tassell

In February, CODES again partnered with GHD, one of the world's leading engineering, architectural and environmental consulting companies, to present the Geophysics for Geologists and Engineers short course at UTAS.

Six participants attended the six-day course, which provided an up-to-date overview of the application of geophysical methods in mineral exploration, mining, geotechnical investigations, and environmental assessments.

The course is designed to provide geoscientists and engineers with the necessary background to understand and use a wide variety of geophysical methods, and to develop skills in technique selection, survey design, data acquisition and interpretation. A key focus is the practical application of geophysical methods to solve a range of small- and large-scale geological and geotechnical problems. The course included a mixture of classroom presentations, demonstrations of geophysical equipment and exercises in data acquisition, computer analysis and modelling.

LOOKING FORWARD

The current trends in postgraduate training at CODES are expected to continue in 2016.

While the HDR program should maintain a relatively high proportion of international students, it is anticipated that the recent successes in attracting Australian students will be sustained, partly due to the prevailing economic climate in the minerals industry.

The difficult operating environment for the industry has also resulted in a temporary hold being placed on the courses for industry program. However, CODES will be closely monitoring the business conditions, with a view to restarting activities in 2017.

Funding to MTEC has also suffered due to the downturn, sadly resulting in the cessation of the long-running national Mineral Geoscience Honours program. As a consequence, from 2016 onwards, the Exploration and Field Skills Mapping Camp will be run once a year, and offered as part of the VIEPS coursework program. However, a proposal is also being considered to develop an expanded version of this course, to be offered as part of the Master of Economic Geology program.

The Master of Economic Geology Program is scheduled to have a full offering of three short courses, including Volcanology and Mineralisation in Volcanic Terrains, which encompasses field-based activities in New Zealand and Tasmania. Overall admissions to the Masters program are expected to remain close to the record levels achieved in recent years. However, unit enrolments are expected to fall due to a decrease in the average number of units taken per student, per year and a significant reduction in the cross-institutional intake. Although the milestone of 100 completions was achieved in the current reporting period, the official celebration for the 100th Master of Economic Geology graduate will take place at the first graduation ceremony of 2016.

Discussions are underway with Universitas Gadjah Maja, Indonesia, to run a joint Master of Economic Geology Degree. The two-year program will be a mix of classroom- and field-based studies and a research thesis. The proposal is for the program to be conducted in Indonesia and Australia, with teaching duties shared between the two universities.

The SEG Student Chapter is planning to have another full schedule of social and professional development events, the highlight of which will be a field trip to Myanmar.



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 that they currently work 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.

INTRODUCTION

The 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 Hub'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 Billiton, Corescan, Newcrest Mining, and a consortium of global companies co-ordinated by AMIRA International. Other organisations affiliated with the initiative include Laurin Technic, National Information Communications Technology Australia (NICTA) and RWTH Aachen University in Germany.

HIGHLIGHTS

The TMVC commenced operations on June 30th 2015 after the signing of the collaboration agreement by the Administering Organisation and Partner Organisations. The research hub was officially launched on the 24th of September by Professor Aiden Byrne (ARC), Senator David Bushby and Professor Mike Calford (UTAS). While the recruitment of postdoctoral research fellows, professional staff and PhD students has occupied a significant portion of the first six months of operation, this has provided fruitful results with the establishment of a critical mass of personnel essential to the successful implementation of the research program.

Other highlights in TMVC's relatively short period of operation include:

- Successful launch of the AMIRA P1153 project: Applying the explorers' toolbox to discover porphyry and epithermal Cu, Au and Mo deposits. Field campaigns initiated at new study sites in Sweden, U.S.A. and Canada.
- Development of a tool that has the potential to revolutionise geometallurgical data acquisition, replacing the laborious manual geotechnical logging procedures that currently form the industry standard, and allowing large volumes of consistent geotechnical data to be acquired through automated core logging.
- TMVC activities extensively showcased at the SEG 2015 Conference in Hobart.



OPPOSITE PAGE CLOCKWISE FROM TOP LEFT: Nathan Fox, Jake Moltzen and Laura Jackson at Mineral Resources Tasmania's core shed; Lejun Zhang inspecting samples at Boliden's core house in Sweden; Ore stockpiles and conveyor system at a TMVC study site.

ABOVE: TMVC Launch FROM LEFT: CEO of the ARC, Aiden Byrne; TMVC Director David Cooke being interviewed by the media; Senator David Bushby.

THE TMVC TEAM



DIRECTOR:
David Cooke

TEAM MEMBERS:

CODES: Mike Baker, Ivan Belousov, Ron Berry, Matt Cracknell, Leonid Danyushevsky, Nathan Fox, Bruce Gemmell, Sarah Gilbert, Ross Large, Sebastien Meffre, Paul Olin, Anita Parbhakar-Fox, Anya Reading, Lejun Zhang

AMIRA INTERNATIONAL: Adele Seymon

BHP BILLITON: Kathy Ehrig

CORESCAN: Neil Goodey

HITLAB: Henry Duh

LAURIN TECHNIC: Michael Shelley

NEWCREST MINING: Anthony Harris

NICTA: Stephen Hardy

RWTH AACHEN UNIVERSITY: Bernd Lottermoser

PHD STUDENTS:

CODES: Amos Garay, Cassady Harraden, Carlos Jimenez, Laura Jackson, Josh Phillips, Francisco Testa, Jennifer Thompson

IMPERIAL COLLEGE LONDON, UK: Adam Pacey

MASTERS STUDENTS:

LAKEHEAD UNIVERSITY, CANADA

Ayat Baig, Wes Lueck, Emily Smyk

COLLABORATORS:

CONSULTANT

Noel White

GUANGZHOU INSTITUTE OF GEOCHEMISTRY, CHINA

Huayong Chen, Jinsheng Han

HEFEI UNIVERSITY OF TECHNOLOGY, CHINA

Shiwei Wang, Dayu Zhang, Taofa Zhou

LAKEHEAD UNIVERSITY, CANADA

Peter Hollings

NATURAL HISTORY MUSEUM, UNITED KINGDOM

Jamie Wilkinson

NEWCREST MINING

Karyn Gardener, Fiona Karaut, James Lett, Paul Napier, Ann Winchester

UNIVERSITY OF LIEGE, BELGIUM

Julie Hunt

CORE PROJECTS

The Hub 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 Hub is tackling through three principal research themes:

THEME 1 DETECTING PROXIMITY TO ORE (FOOTPRINTS)

- Applying the explorers' toolbox to discover porphyry and epithermal Cu, Au and Mo deposits (AMIRA P1153)

THEME 2 OPTIMISING GEOMETALLURGICAL PREDICTION

- Geometallurgical developments evolving from the GeM^{III} project
- Geotechnical and geometallurgical assessment of the Cadia East deposit using Corescan automated core logging technology

THEME 3 MINIMISING GEOENVIRONMENTAL RISKS

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

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, Nathan Fox, Lejun Zhang

Students: Ayat Baig, Amos Garay, Carlos Jimenez, Wes Lueck, Adam Pacey, Josh Phillips, Jose Piquer, Emily Smyk, Francisco Testa, Jennifer Thompson

Collaborators: Huayong Chen, Jinsheng Han, Peter Hollings, Shiwei Wang, Noel White, Jamie Wilkinson, Dayu Zhang, Taofa Zhou

The AMIRA P1153 project, which is being conducted in collaboration with researchers from Lakehead University, the Natural History Museum, Guangzhou Institute of Geochemistry, and Hefei University of Technology, will develop 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 both 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.

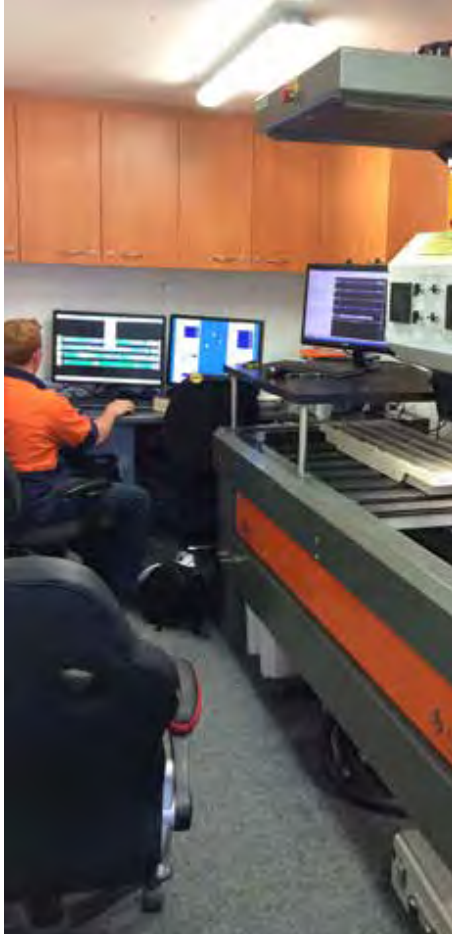
The main outcomes will be tools for testing the fertility of mineral districts, and for vectoring to mineralised centres. These will involve the use of key alteration minerals from green rock, white rock and lithocap environments. Cost-effective field-based methods will also be developed that can be applied by explorers who do not have access to suitable laboratory facilities for LA-ICP-MS analyses.

Following the commencement of the project in mid-2015, the research team has initiated field campaigns at new study sites in Sweden, U.S.A. and Canada. Three new graduate research projects based at CODES will form key components of the overall research project, i.e. Josh Phillips (Resolution porphyry Cu-Mo deposit), Jennifer Thompson (Carbonate mineral chemistry) and Amos Garay (Las Bambas porphyry Cu-Mo-Au and Cu-skarn district).

Students who did not complete their research within AMIRA P1060, the forerunner to this new initiative, will report their final results within AMIRA P1153. José Piquer published a manuscript from his PhD study in *Economic Geology* in December, 2015.

The AMIRA P1153 team at the project's inaugural meeting.





FROM LEFT: High resolution hyperspectral images of drill core are collected using Corescan's automated system; Chalcopyrite on a broken quartz vein surface.

THEME 2 OPTIMISING GEOMETALLURGICAL PREDICTION

GEOMETALLURGICAL DEVELOPMENTS EVOLVING FROM THE GEM^{III} PROJECT

Leader: Ron Berry

This research is focussed on advancing work that had been initiated in the previous GeM^{III} project, but had not yet reached a stage where it was ready for release to the mining industry. Major activities in 2015 were:

- Software for measuring structure from oriented core, developed in AMIRA P843A, was tested, debugged and upgraded for public release. A manuscript is in preparation to accompany this program.
- New streamlined Excel spreadsheets, using linear programming and weighted least squares methods, were prepared for the calculation of mineralogy from mine assay data. A manuscript is in preparation to accompany these spreadsheets.

- A program to test the line scan methods for documenting core mineralogy was designed and funding approved. Testing of LIBS and laser Raman methodologies on drill core has commenced.

Excel spreadsheets were developed to use for teaching underlying principles of sampling and data mining methods in geometallurgical situations. These products were tested in short courses.

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

Leaders: Sebastien Meffre, Michael Roach, Ron Berry

Team Members: Matt Cracknell, Neil Goodey

Student: Cassady Harraden

Collaborators: James Lett, Ann Winchester

The goal of this PhD project by Cassady Harraden is to determine the correlation between CorescanTM data and measured deportment data, processing parameters

and geotechnical conditions. Hyperspectral data will be used to determine functional proxies that will ultimately be built into predictive algorithms and applied to the mine-wide dataset to produce geometallurgical domains. These domains can then be modelled in 3D and integrated with the Cadia Mine's current geologic, structural and geometallurgical models.

A major breakthrough was made late in the year, when the researchers developed a new tool for utilising automated core logging technology to extract geotechnical index parameters. The new tool has the potential to revolutionise geometallurgical data acquisition, replacing the laborious manual geotechnical logging procedures that currently form the industry standard, and allowing large volumes of consistent geotechnical data to be acquired through automated core logging. After a pilot study, the tool is now being up-scaled to enable it to be implemented during a major program of automated core scanning by Newcrest Mining and Corescan in 2016. Results of the pilot study will be released at the 3rd International Geometallurgy Conference in 2016.

THEME 3 MINIMISING GEOENVIRONMENTAL RISKS

MINERALOGICAL DOMAINING OF LOW GRADE AND NO GRADE ZONES USING AUTOMATED DRILL CORE LOGGING

Leader: Anita Parbhakar-Fox

Team Members: David Cooke, Nathan Fox, Neil Goodey, Anthony Harris, Bernd Lottermoser

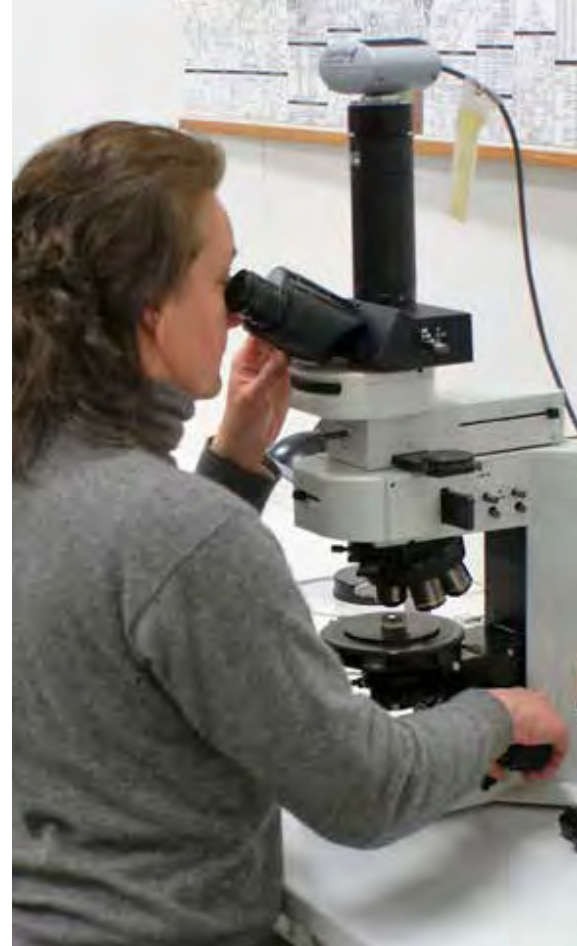
Student: Laura Jackson

Prediction of acid rock drainage (ARD) 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 how ARD might evolve and the role of secondary minerals in metal cycling in the surficial environment. This research is developing a protocol by which different mineralogical techniques can be effectively integrated to allow for mineralogical and textural information pertinent to environmental characterisation to be obtained from intact-waste materials (i.e., drill core materials, tailings as received).

Method development of these techniques has involved two site visits. A preliminary site assessment and geology study was undertaken during the first visit, while the second visit specifically focussed on using Corescan to gain hyperspectral data. Two hundred and forty-seven samples, representative of two major drill holes through the deposit, have been selected for the method development stage. Following the field campaigns, further analyses is being undertaken, including hardness testing, ARDI, UV fluorescence and carbonate staining. Following completion of these studies, 30 subsequent samples will be chosen for detailed mineralogical and geochemical analyses.



FROM TOP: Geoenvironmental characterisation of waste rock using the net acid generation test; Kinetic cell.



INTRODUCTION

The Discipline of Earth Sciences falls under the School of Physical Sciences, within the Faculty of Science Engineering and Technology at the University of Tasmania (UTAS). Although the Discipline is a separate entity to CODES, the two areas have been inextricably linked since the latter was formed in 1989. From the outset, the two areas have enjoyed a harmonious and constructive relationship, creating a synergy that has undoubtedly benefitted both groups over the years. This co-operation has been possible because most academic staff, and many technical and administrative staff, hold joint appointments in both areas. There is no better example of this symbiotic relationship than Leonid Danyushevsky, who is Head of Discipline, while also playing a pivotal role in CODES as Leader of the Enabling Technologies Module.

In support of this close relationship, it was decided to allocate a section of this issue of the CODES Annual Report to showcase the significant number of projects that are being conducted within the Discipline and, in most cases, in collaboration with the Centre of Excellence.

In 2015, the Discipline developed a strategic plan aligned to its relationship with CODES, and the strategic objectives of the School, the Faculty, and the University as a whole. The current research strengths within the Discipline are listed below:

MARINE GEOSCIENCE

Marine geoscience is classed within two of the University's priority areas, and the Discipline has consistently demonstrated its research strengths in this area for a prolonged and sustained period of time. Recent successful funding applications via the ARC's National Competitive Grants Programme are testament to its capabilities in this area, as is the exceptional level of related research outputs, including a number of high profile publications and conference presentations. The current focus in

this field of research is on:

- Trace metal ocean chemistry through time.
- Marine geophysics.
- Submarine and ocean island volcanism and magmatism.
- Global tectonics and sedimentary basins.
- Ocean storm seismology.

DEEP TIME EARTH

Over the past three years, the Discipline has branched out into research related to deep time, which is ideally suited to its proven strengths in the geology, geochemistry and geophysics of ancient continental provinces and marine sedimentary sequences – fields where the Discipline has gained international recognition for its research, resulting in numerous high profile publications and conference presentations.

The current focus is on:

- Paleooceanography/palaeontology.
- Geochronology.
- Sedimentary and mineral chemistry.
- Ocean chemistry modelling.
- The origin of life.
- Biogeochemistry.
- Seismology.
- Volcanism and magmatism.

COMPUTATIONAL AND ANALYTICAL GEOSCIENCE

Research in this area is developing new computational and analytical approaches, and evolving data-led research that enables advances in other areas of the Earth sciences. The analytical geoscience aspect of these studies is undertaken in close collaboration with the UTAS Central Science Laboratory. Current research directions include:

- New algorithms and visualisation approaches to working with Big Data.
- Development of human / computer interaction paradigms for knowledge discovery.
- Integrated 3D Earth modelling.
- Development of seismic array analysis algorithms.
- Integrated informatics and inverse theory approaches to geophysical modelling.

- Optimising decision making from spatial information.
- Development of micro-analytical approaches.

The Discipline is known for its consistent output of innovative publications, and the delivery of high profile conference presentations related to these areas of research.

MANTLE STRUCTURE, DYNAMICS AND GEOCHEMISTRY

This field of research has been prominent at UTAS since the 1970s and has earned the Discipline a high-profile international reputation. Current research is focussed on the following areas:

- Origin of kimberlites and lamproites.
- High pressure and temperature experimental petrology.
- Lithospheric structure and fluid pathways.
- Global tectonics.
- Origin of Large Igneous Provinces.
- Seismic tomography.
- Global geophysics.
- Computational geoscience.

VISION

To be internationally recognised for research and educational excellence in Earth sciences by maintaining and increasing the Discipline's national and international reputation and rankings.

OBJECTIVES

- Generate knowledge through innovation and research excellence.
- Provide the highest quality undergraduate education and graduate training in Earth sciences.
- Contribute to the national and international standing of the School of Physical Sciences and CODES.
- Maintain and improve the Discipline's reputation as a major source of professional geoscientists; thereby addressing the evolving needs of the nation, with a focus on the National Research Priority Areas.



FROM TOP: Drone used as part of the AusGeol project; Laura Jackson sampling tailings at the Scotia mine, eastern Tasmania; Dan Gregory being filmed by ABC TV in connection with research related to ocean oxidisation in ancient oceans.

HIGHLIGHTS

FELLOWSHIPS

Rebecca Carey began her prestigious Australian Research Council 3-year postdoctoral DECRA fellowship, which is focussed on submarine volcanology and hydrothermal systems on the modern seafloor.

SHORT COURSES

Ross Large organised a short course entitled 'Ore deposits, atmosphere oxygenation and evolution of life: how they are related', which was presented by an international team as part of the SEG 2015 Conference in Hobart.

PUBLICATIONS AND CONFERENCE PRESENTATIONS

A paper presenting a new model for the origin of Group II kimberlites was published in *Nature Communications* by Vadim Kamenetsky and co-authors.

A paper describing the first occurrence of magmatic halite in mantle-derived carbonatite melts was published in *Geology* by Vadim Kamenetsky and co-authors.

A series of papers published by Ross Large and co-authors used LA-ICP-MS analyses of marine pyrite in black shales to reveal systematic changes in trace element concentrations in the oceans through time. These changes have great significance because they can be related to the evolution of life and cycles of marine ore deposits.

Anya Reading and Martin Gal delivered an invited talk, entitled 'Improved detection and location of ocean microseism signals using array techniques', at the American Geophysical Union Fall Meeting in San Francisco.

OTHER RESEARCH OUTCOMES

Michael Roach led the development of the Virtual Library of Australia's Geology.

Anya Reading was part of a team that developed new constraints on the tectonic evolution of southeastern Australia using ambient seismic tomography techniques.

Rebecca Carey was a co-chief scientist of a research voyage to the submarine Havre volcano.

The CRC ORE team developed a new plant bioaccessibility test, which was trialled at the Wheal Maid tailings storage facility, UK.

Anita Parbhakar-Fox and Laura Jackson identified rehabilitation options for the Old Tailings Dam at the Savage River mine in Tasmanian. A presentation related to this research won Best Paper at the AusIMM Tailings and Mine Waste Management conference in Sydney.

Patrick Quilty described five new mollusc species from the classic Marine Plain deposit in the Vestfold Hills, East Antarctica.

Rebecca Carey visited the Hawaiian Volcano Observatory, as well as Stromboli volcano, Italy for deployment of monitoring equipment.

Anita Parbhakar-Fox led a project characterising waste rock materials at the Savage River mine (Grange Resources) supporting the adoption of alternative waste handling approaches.

THE DISCIPLINE OF EARTH SCIENCES TEAM

DISCIPLINE HEAD:

Leonid Danyushevsky

STAFF MEMBERS:

CONTINUING APPOINTMENTS AT UTAS:

Academic: Rebecca Carey, David Cooke, Garry Davidson, Bruce Gemmell, Vadim Kamenetsky, Ross Large, Anya Reading, Michael Roach

Professional: Isabella von Lichten, Ian Little, Deborah Macklin

FIXED-TERM AND HONORARY APPOINTMENTS:

Academic: John Aalders, Sharon Allen, Trevor Falloon, Nathan Fox, Dan Gregory, Jacqueline Halpin, Julie Hunt, Peter McGoldrick, Jocelyn McPhie, Taryn Noble, Karin Orth, Patrick Quilty, Robert Scott, David Selley

PHD STUDENTS:

Jodi Fox, Martin Gal, Sam Holt, Qiuyue Huang, Fumihiko Ikegami, Laura Jackson, Sean Johnson, Elena Lounejeva, Charles Makoundi, Indrani Mukherjee, Naomi Potter, Daniele Vergani

HONOURS STUDENTS:

Adam Abersteiner, Bronson Rogers, Jake Moltzen

COLLABORATORS:

ABERDEEN UNIVERSITY, UK

Nicholas Rawlinson

AUSTRALIAN NATIONAL UNIVERSITY

Richard Arculus, Stephen Cox, Penny King, Simone Pilia, Hrvoje Tkalcic, Greg Yaxley

BROWN UNIVERSITY, USA

Ryan Portner

CASCADES VOLCANO OBSERVATORY, USA

Michael Poland

CURTIN UNIVERSITY

Andrea Agangi, Fred Jourdan

FLINDERS UNIVERSITY

John Long

FROGTECH

Lynn Pryer

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Peter Haines, Charles Hickman

GEOMAR, GERMANY

Steffen Kutterolf

GEOSCIENCE VICTORIA

Ross Cayley

GNS NEW ZEALAND

Fabio Caratori-Tontini

GRANGE RESOURCES

Tony Ferguson, Roger Hill

HAWAIIAN VOLCANO OBSERVATORY, USA

Tim Orr, Matthew Patrick

INSTITUTE OF THE EARTH'S CRUST, RUSSIA

Alexei Ivanov

INSTITUTE OF GEOLOGY AND MINERALOGY, RUSSIA

Alexander Golovin

JAMSTEC, JAPAN

Iona McIntosh, Alex Nicholls

INSTITUTE OF VOLCANOLOGY AND SEISMOLOGY, RUSSIA

Alexander Belousov

JAPANESE NATIONAL MUSEUM OF NATURE AND SCIENCE

Kenichiro Tani

MACQUARIE UNIVERSITY

Elena Belousova

MINERAL RESOURCES TASMANIA

Clive Calver, Grace Cumming, Mark Duffett, John Everard, Andrew McNeill, Andy Wakefield

MURORAN INSTITUTE OF TECHNOLOGY, JAPAN

Yoshihiko Goto

NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH, NEW ZEALAND

Richard Wysoczanski

OREGON STATE UNIVERSITY, USA

Robert Duncan

OXFORD UNIVERSITY, UK

Jane Barling

REUNION ISLAND OBSERVATORY, FRANCE

Andrea DiMuro

SEOUL NATIONAL UNIVERSITY, SOUTH KOREA

Jung-Woo Park

SMITHSONIAN INSTITUTION, USA

Richard Fiske

UNIVERSITY OF BARCELONA, SPAIN

Marc Campeny, Amaia Castellano

UNIVERSITY OF BRITISH COLUMBIA, CANADA

Dominique Weis

UNIVERSITY OF CALIFORNIA BERKELEY, USA

Michael Manga

UNIVERSITY OF EXETER, UK

Bernd Lottermoser, Elly van Veen

UNIVERSITY OF HAWAII, USA

Bruce Houghton

UNIVERSITY OF MELBOURNE

Andrea Guillani, Roland Maas, Sandra McLaren, Ashton Soltys

UNIVERSITY OF NOTRE DAME, USA

Wei Chen

UNIVERSITY OF OTAGO, NEW ZEALAND

James White

UNIVERSITY OF QUEENSLAND

Charles Verdel, Kevin Welsh

UNIVERSITY OF SYDNEY

Maria Seton

UNIVERSITY OF TASMANIA

Mike Coffin, Karsten Goemann

UNIVERSITY OF TORONTO, CANADA

James Mungall

UNIVERSITY OF UTAH, USA

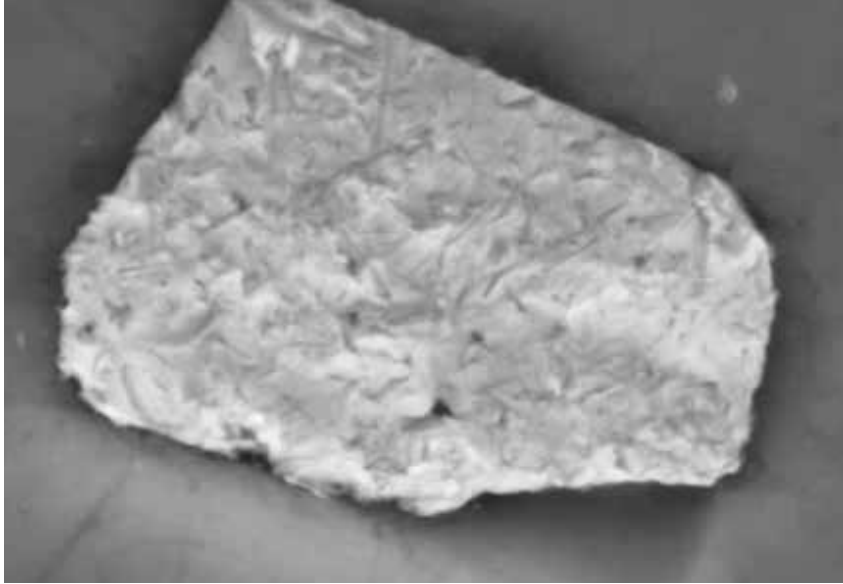
Keith Koper

UNIVERSITY OF WESTERN AUSTRALIA

Annette George

WOODS HOLE OCEANOGRAPHIC INSTITUTION, USA

Daniel Fornari, Adam Soule



FROM TOP: Electron microscope image of the Pt-Fe alloy (~Pt_{0.83}Fe_{0.17}) in Cr-spinel phenocryst from a picrite lava (Ambae Island, Vanuatu); Pumping of tailings into a dam, western Tasmania; Taryn Noble (CRC ORE), Elly van Veen (University of Exeter), Anita Parbhakar-Fox and Bernd Lottermoser (then University of Exeter) at the Cannington Mine, Queensland.

CORE PROJECTS

- Beneath Bass Strait: Ambient seismic tomography
- Seismic array investigations of ocean storms
- Determination of magma ascent rates for subduction zone volcanoes
- 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
- Trace elements in ancient oceans
- Submarine volcanology
- Subaerial volcanology
- AusGeol – A virtual library of Australia's geology
- Geology and paleontology of Antarctica and the Southern Ocean
- Characterising pyrite chemistry at the Old Tailings Dam, western Tasmania: Evaluating tailings reprocessing as a management option
- Savage River: Kinetic trials of waste rock materials
- Kinetic testing of waste rock, Savage River, Tasmania
- Geochemical and mineralogical characterisation of the abandoned Scotia mine, northern Tasmania
- Kinetic trials of Scotia mine tailings: An evaluation of water quality
- CRC ORE- Environmental Indicators

PROJECT SUMMARIES

BENEATH BASS STRAIT: AMBIENT SEISMIC TOMOGRAPHY

Leader: Anya Reading

Collaborators: Ross Cayley, Mark Duffett, Simone Pilia, Lynn Pryer, Nicholas Rawlinson

This project is being conducted in collaboration with ANU, Mineral Resources Tasmania, Geoscience Victoria, and FROGTECH, and is funded by the ARC Linkage Program.

Major outputs of the project were published in 2015, including evidence of the influence of a microcontinent trapped in the Pacific margin of Gondwana, which had a big impact on the subsequent formation of the Lachlan Orogen. The evidence comes from employing ambient seismic tomography techniques, using data collected during a major field campaign (2011-2013) run jointly with ANU. Having established the structure of the crust in this complex area of the Australian continent, further seismological data analysis will reveal the lower crust and mantle structure to provide new constraints on the controversies remaining regarding the regional geology of southeast Australia.

SEISMIC ARRAY INVESTIGATIONS OF OCEAN STORMS

Leader: Anya Reading

Student: Martin Gal

Collaborators: Keith Koper, Hrvoje Tkalčić

This project aims to gain a better understanding of the dynamics of ocean storms, using seismic array investigations.

Significant progress was made during the year. PhD student Martin Gal implemented the 'CLEAN' algorithm, which is used widely in radio astronomy, to improve the detection of ocean microseisms – the cause of ambient seismic noise. The computer programs have been developed for use on 1-component and also

3-component data. They have been applied to data from Australian seismic arrays and allow a much more complete picture of the ambient seismic wavefield to be understood.

DETERMINATION OF MAGMA ASCENT RATES FOR SUBDUCTION ZONE VOLCANOES

Leader: Ivan Belousov

Team Members: Rebecca Carey, Leonid Danyushevsky

Collaborator: Alexander Belousov

This project aims at constraining the rate at which magma ascends from the storage region at depth in the Earth's crust to the surface, which is a critical parameter governing the style and intensity of volcanic eruptions. Existing data suggest that the ascent rates vary over three orders of magnitude (0.1–30 metres/second), depending on eruption styles. This research is currently funded under the UTAS Research Enhancement Grants Scheme.

The technique employed is based on studies of melt embayments in phenocrysts in lavas. Melt in the embayments is re-equilibrating with the melt surrounding the crystal through diffusion processes. Volatile contents in the surrounding melt decreases during magma ascent due to degassing. Therefore, diffusion profiles of volatile components from the centre of embayments towards the outside melt can be used to determine rates of magma ascent.

In 2015, the ascent rates were examined for the Karymsky and Tolbachik volcanoes (Kamchatka) in Russia. Both volcanoes are characterised by rapid magma ascent via a fissure. Melt embayments and melt inclusions in olivine phenocrysts were exposed and prepared for measurement of diffusion profiles, using a NanoSIMS technique at the Centre for Microscopy, Characterisation and Analysis (UWA). This technique is able to measure contents of volatile species (H₂O, CO₂, Cl, SO₂, F) with high spatial resolution (<1 micron). Major element compositions of melt embayments and host olivines were measured at

the UTAS Central Science Laboratory, and trace element contents were measured using LA-ICP-MS techniques at CODES. The data will be used to assess rates of ascent of magmas and evolution paths of primary melts.

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

Leader: Vadim Kamenetsky

Team Member: Maya Kamenetsky

Students: Adam Abersteiner, Qiuyue Huang

Collaborators: Andrea Agangi, Elena Belousova, Karsten Goemann, Alexander Golovin, Andrea Giuliani, Alexei Ivanov, Roland Maas, James Mungall, Jung-Woo Park, Ashton Soltys, Greg Yaxley

This project is aimed at understanding the relationship between kimberlites and diamonds, and between flood basalts and sulfide mineralisation, by linking mantle structure, composition, and temperature to the melting processes that generate these mantle-derived magmas.

The outcomes have been published in several high-profile publications during the year. A paper in *Nature Communications* addressed the origin of Group-II kimberlites (orangeites) through a study of MARID (mica-amphibole-rutile-ilmenite-diopside) xenoliths from the Bultfontein kimberlite in South Africa. This demonstrated that orangeites can be formed during melting a MARID-rich lithospheric mantle.

An experimental study published in *Geochimica et Cosmochimica Acta* proposed that interaction between a silicate mantle rock and a natrocarbonatite melt results in carbonate-silicate liquid immiscibility, which forms globules of a CO₂-rich silicate melt. On decompression, the dispersed silicate melt phase ensures a continuous supply of CO₂ bubbles, which decrease density, increase buoyancy and promote the rapid ascent of the magmatic emulsion.

A paper in *Geology* addressed the origin of platinum-group element

(PGE) mineralisation associated with primitive magmas by analysing inclusions of Pt-Fe and Os-Ir alloys in Cr-spinel phenocrysts, which are interpreted to precipitate directly from a range of melt compositions formed in supra-subduction intraplate settings. These inclusions helped to constrain melt saturation in PGE-rich phases as a function of temperature and fugacity of oxygen and sulfur.

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

Leader: Vadim Kamenetsky

Team Member: Maya Kamenetsky

Students: Adam Abersteiner, Naomi Potter

Collaborators: Elena Belousova, Marc Campeny, Amaia Castellano, Wei Chen, Andrea Guiliani, Roland Maas, Greg Yaxley

The project is aimed at understanding 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. Currently, this project is funded by an ARC Discovery grant.

Research published in *Nature Communications* presented evidence for the alkaline nature of parental carbonatite melts, based on studies of magnetite-hosted melt inclusions. A linked study published in *Geology* reported the occurrence of primary halite in mantle-derived carbonatite magmas. Recent results on Angolan carbonatites have demonstrated that they were emplaced at 0.65 ± 0.05 Ma, thus linking their origin to the present-day re-activation of the Cretaceous Lucapa rift in Angola.

A series of experiments was aimed at constraining the causes of the rapid ascent of carbonate-rich melts to the surface, which suggested that carbonate-silicate liquid immiscibility had significant implications for magma evolution through melt-crystal reactions, liquid unmixing, effervescence of CO_2 and related dramatic decreases in viscosity.

TRACE ELEMENTS IN ANCIENT OCEANS

Leader: Ross Large

Team Members: Leonid Danyushevsky, Dan Gregory, Jaqueline Halpin, Peter McGoldrick, Sebastien Meffre, Jeff Steadman

Students: Sean Johnson, Elena Lounejeva, Charles Makoundi, Indrani Mukherjee

Collaborators: Clive Calver, Peter Haines, Charles Hickman, John Long

This project uses analytical LA-ICP-MS technology developed at CODES to track changes in the trace element history of sedimentary pyrite through the Precambrian and Phanerozoic. Currently, this project is funded by an ARC Discovery grant, and is being conducted in collaboration with members of the CODES Ore Deposits: Characterisation and Context Module.

During 2015, the marine pyrite analytical database was increased from 3,000 to over 5,000 LA-ICP-MS analyses. This database has a unique potential to supply information on ocean nutrient supply through time, pO_2 variations in the atmosphere, and trends in bio-essential trace elements.

Four significant papers were published during the year:

- An overview of the chemical composition of sedimentary pyrite and chemical criteria for distinguishing sedimentary pyrite from other types of pyrite.
- A study of the gold content of marine pyrite has, for the first time, assessed the gold content of paleo-oceans through time and revealed a low gold content of the oceans in the mid-Proterozoic compared to the Archean and Phanerozoic.
- Trace elements contained in marine pyrite were used to reveal cycles of bio-essential nutrient trace element supply and define periods when the oceans were nutrient-rich, which were followed by periods when they were nutrient-poor. A relationship between tectonics, nutrient supply, pO_2 and evolution of marine life was proposed.

- A follow-up paper showed that during the nutrient-poor periods the global ocean was severely depleted in the bio-essential element selenium, ultimately causing three of the five mass extinction events in the Phanerozoic.

SUBMARINE VOLCANOLOGY

Leader: Rebecca Carey

Team Members: Sharon Allen, Jocelyn McPhie, Karin Orth

Student: Fumihiko Ikegami

Collaborators: Fabio Caratori-Tontini, Richard Fiske, Daniel Fornari, Bruce Houghton, Michael Manga, Iona McIntosh, Alex Nicholls, Adam Soule, Kenichiro Tani, James White, Richard Wysoczanski

The Discipline has developed an international reputation for its research into ancient volcanic successions and VHMS deposits. This project expands on the scope of this research by looking at the theme of modern submarine volcanic environments. Currently, this project is funded by an ARC DECRA Fellowship awarded to Rebecca Carey.

Rebecca Carey and PhD student Fumihiko Ikegami participated in a ship-based voyage to the southern Kermadec arc, which was conducted by the Institute for Water and Atmospheric Research, New Zealand. The cruise focussed on structures, volcanology and geothermal systems associated with rhyolite caldera successions of this segment of the arc.

Collaborator Kenichiro Tani and Rebecca Carey were successful in applying for research ship time with the Japanese Marine Science and Technology Institute to visit three submarine volcanoes in the Izu-Bonin volcanic arc, south of Japan. Kenichiro and PhD student Fumihiko Ikegami will take part in this expedition in May 2016, and will explore these rhyolitic caldera volcanoes using underwater vehicles.

Rebecca Carey was invited to co-author a chapter in the second edition of the *Encyclopaedia of Volcanoes*, which is the field's leading



FROM LEFT: Jocelyn McPhie and Jodi Fox at Cape Grim, Tasmania; Lava lake within Kilauea caldera, Hawaii.

reference publication. Rebecca was also a Chief Editor of an AGU Monograph on Hawaiian volcanism.

International visitors included Visiting Scholar Thorvaldur Thordarson from the University of Iceland, who collaborated with Rebecca Carey and Jocelyn McPhie, and presented two public lectures. In addition, two PhD students visited UTAS to work with Rebecca on projects related to submarine volcanology projects. The students were from the University of Hawaii, USA, and the University of Otago, New Zealand.

SUBAERIAL VOLCANOLOGY

Leader: Rebecca Carey

Team Members: Trevor Falloon, Jocelyn McPhie, Karin Orth

Students: Jodi Fox, Sam Holt, Naomi Potter, Daniele Vergani

Collaborators: Richard Arculus, Mike Coffin, Grace Cumming, Andrea DiMuro, Robert Duncan, John Everard, Yoshihiko Goto, Bruce Houghton, Fred Jourdan, Steffen Kutterolf, Andrew McNeill, Tim Orr, Matthew Patrick, Michael Poland, Ryan Portner, Dominique Weis, James White

The Discipline's research in subaerial volcanology covers a wide range of magma types occurring in modern and ancient volcanic environments. Current research is being conducted by four PhD students, and includes projects in various global locations where active hot spot volcanism is taking place: Hawaii, Reunion Island,

Kerguelen Plateau and the Etna and Stromboli volcanoes in Italy.

PhD student Jodi Fox continued her research on the Cenozoic volcanism of Cape Grim on Tasmania's northwest coast, in collaboration with Mineral Resources Tasmania. Jodi has discovered that the Cape Grim volcanic succession comprises of units that were likely all deposited in a submarine setting, and were relatively rapidly emplaced. Currently Ar/Ar dating of the Cape Grim succession is underway, which will allow Jodi to more accurately place Cape Grim volcanism in the context of Cenozoic volcanism in Tasmania and Australia.

Findings from Sam Holt's projects on rootless cone and Hawaiian volcanism were presented at the International Union of Geophysics and Geology General Assembly in Prague, and the Fall AGU meeting in San Francisco. In December, Rebecca and Sam participated in an international multidisciplinary monitoring campaign of the physical and degassing processes of the lava lake at Kilauea volcano, Hawaii. Sam will be conducting research on the characterisation of the lava lake's rheology.

Daniele Vergani continued his research on Piton de la Fournaise volcano, Reunion Island. The explosive eruption and production of a rootless cone on the island, together with its observation and characterisation, have enabled him to uncover magma-water interaction processes that result in this spectacular eruption style. Daniele will present his research results at a conference in 2016.

Both the Hawaiian Volcano Observatory and Stromboli volcano were visited during the year in order to deploy monitoring equipment.

AUSGEOL – A VIRTUAL LIBRARY OF AUSTRALIA'S GEOLOGY

Leader: Michael Roach

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

The AusGeol project is funded for a two-year period (February 2015 - February 2017) through an Innovation and Development Grant from the Federal Office of Learning and Teaching, with additional contributions from universities and government geoscience organisations.

The project is generating a virtual library of Australia's Geology, with the aim of providing free virtual access to significant outcrops across the Australian continent for secondary, tertiary and professional education, as well as public outreach.

The library delivers a variety of immersive visualisations including: full 3D photorealistic models, 'deep zoom' imagery, full spherical panoramas, 360 degree video and virtual tours of geological sites. All visualisations can be accessed and downloaded from the AusGeol.org website.

The project is also generating lesson plans, and teaching and learning objects, for tertiary and secondary education. The AusGeol database currently includes virtual objects from approximately 2000 sites across Australia.

GEOLOGY AND PALEONTOLOGY OF ANTARCTICA AND THE SOUTHERN OCEAN**Leader:** Patrick Quilty**Team Members:** Trevor Falloon, Sebastien Meffre**Student:** Jodi Fox**Collaborators:** Jane Barling, Robert Duncan, Maria Seton

A major achievement of this project has been description of the Pliocene marine mollusc fauna from the classic Marine Plain deposit in the Vestfold Hills, East Antarctica. This includes description of five new species of great value to the understanding of the evolution of Antarctic molluscs. A paper on the subject is currently in the final proof stage.

Work continued on the volcanic history of the region between Heard Island and Kerguelen Plateau. A paper is in the final stages of preparation.

Other projects include micropaleontology of samples from:

- The South Rennell Trough off northeastern Australia.
- Around Norfolk Island (based on the collection from *RV Southern Surveyor* cruise SS03/01).
- An Eltanin marine sediment core E27-23 southwest of Macquarie Island.

CHARACTERISING PYRITE CHEMISTRY AT THE OLD TAILINGS DAM, WESTERN TASMANIA: EVALUATING TAILINGS REPROCESSING AS A MANAGEMENT OPTION**Leader:** Anita Parbhakar-Fox**Collaborator:** Andy Wakefield

This project aims at characterisation of sulfide minerals in historic mine tailings to determine if there is any economic value in reprocessing the material using modern practices. At the Old Tailings Dam (OTD), western Tasmania, 38 million tonnes of pyritic tailings were deposited from 1967 to 1982. Materials collected across the site were examined using LA-ICP-MS as a first-pass technique to establish the potential for metallurgical reprocessing. Elevated concentrations of cobalt,

a critical metal, were identified in pyrite. Considering this finding, in-depth economic evaluations to establish the benefits of cobalt extraction should be undertaken.

This may represent the best option for rehabilitating this historic site.

ENVIRONMENTAL CHARACTERISATION OF NORTH PIT WASTE ROCK, SAVAGE RIVER, TASMANIA**Leader:** Anita Parbhakar-Fox**Team Member:** Nathan Fox**Collaborators:** Tony Ferguson, Roger Hill

This research focussed on using static geochemical tests on a range of waste materials collected from North Pit of the Savage River mine to determine the geochemical response of blending various waste types at different ratios. This investigation was undertaken to assist with the design of long-term kinetic trials using these specific waste materials, i.e., to determine appropriate blend ratios. Both static testwork and kinetic trial data will provide an indication of whether, from a geochemical perspective, alternative waste handling methods are suitable at this operation.

KINETIC TESTING OF WASTE ROCK, SAVAGE RIVER, TASMANIA**Leader:** Anita Parbhakar-Fox**Team Member:** Nathan Fox**Collaborators:** Tony Ferguson, Roger Hill

The aim of this project is to determine the long-term geochemical behaviour of mine waste materials in order to understand how they might behave in a real physical waste rock pile. Understanding the long-term geochemical behaviour of future waste rock materials at the earliest stages of mining operations (e.g., exploration) is critical for minimising environmental risks. To achieve this aim, materials from a new exploration project at the Savage River mine operations, representative of different mine wastes, are being subjected to three-year column leach testing experiments. A weekly heating cycle is

adopted, with weekly assessments of water quality (pH and EC) and monthly assessments of the water chemistry (elemental content and sulfate).

GEOCHEMICAL AND MINERALOGICAL CHARACTERISATION OF THE ABANDONED SCOTIA MINE, NORTHERN TASMANIA**Leader:** Anita Parbhakar-Fox**Team Member:** Nathan Fox**Student:** Laura Jackson**Collaborator:** Andy Wakefield

This research project identified sources of acid rock drainage at the abandoned Scotia Mine. Tailings materials (under water covers) from three repositories were sampled, along with a range of soil and tailings materials from around the site (up to 1.5 m depth). These were characterised using a range of geochemical and mineralogical tests at CODES and Mineral Resources Tasmania analytical laboratories. The outcomes of this project helped identify potential environmental risks posed by these waste materials.

KINETIC TRIALS OF SCOTIA MINE TAILINGS: AN EVALUATION OF WATER QUALITY**Leader:** Anita Parbhakar-Fox**Team Member:** Nathan Fox**Collaborator:** Andy Wakefield

This project focussed on determining, through kinetic testing, how acid generating tailings at the abandoned Scotia Mine would behave long-term when capped with lime additives to control acid mine drainage formation. Materials from different tailings storage repositories were subjected to thirty-week column leach testing using a weekly heating cycle. Weekly assessments of water quality (pH and EC) were made along with monthly water chemistry assessments (elemental content and sulfate). In addition, mineralogical changes were tracked throughout the testing. The outcomes of this project will guide the rehabilitation of this legacy site.

CRC ORE- ENVIRONMENTAL INDICATORS**Leader:** Anita Parbhakar-Fox**Team Members:** John Aalders, Nathan Fox, Julie Hunt, Taryn Noble**Students:** Laura Jackson, Jake Moltzen, Bronson Rogers**Collaborators:** Bernd Lottermoser, Elly van Veen

This project was focussed on designing accurate tests that predicted waste types with greater certainty, more knowledge and at lower cost. The project was completed in 2015.

The underlying aims of the project were to support:

- More effective mineral processing.
- Greater environmental performance of mining operations.
- Better storage of waste.
- Improved mine closure outcomes.

Through extensive laboratory testwork, and research on individual case study projects, a new architecture of integrative, staged acid rock drainage (ARD) testing was developed by the Environmental Indicators team. Better ARD prediction starts with improving the definition of geoenvironmental models and waste units, followed by a range of low-cost and rapid tests for the screening of samples, conducted on site and prior to the performance of established tests and advanced analyses using state-of-the-art laboratories. ARD prediction supports more accurate and cost-effective waste management during operation, and ultimately less costly mine closure outcomes. New tests and protocols developed include:

- Enhanced laboratory tests.
- Microwave Assisted Thermal Energy (MATE) pH test.
- Computed Acid Rock Drainage (CARD) risk grade assessment protocol.
- Low-cost test to predict the bioaccessible form of environmentally significant elements that could elute from mine waste materials.
- Predictive waste classification.
- Improved geochemical and mineralogical characterisation of dust.
- Characterisation of mineral dust properties.
- Geometallurgical indicators for predicting ARD.

LOOKING FORWARD

The coming year is expected to be a busy and highly productive period for the Discipline, with a number of key activities planned across a number of areas, including:

RESEARCH

- Investigation of the deep structure beneath Bass Strait using receiver function methods.
- Participation in three research voyages to the Izu-Bonin volcanic arc (2) and Heard Island.
- Preparation for a Chapman Conference titled: Submarine volcanology: New Approaches and Research Frontiers. This prestigious international conference is run under the auspices of the American Geophysical Union's Chapman Program, and will be held in Hobart between January 30 and February 3, 2017. The program will focus on the next decade of research in submarine volcanism.

PUBLICATIONS AND CONFERENCE PRESENTATIONS

- Findings on the estimation of the ascent rate of magmas for two volcanoes in Kamchatka will be submitted for publication.
- The latest results on the origin of the Angolan carbonatites are being prepared for publication in *Nature*.
- A review of the role of carbonatite liquids in mantle metasomatism and magmatism will be submitted for publication in *Earth and Planetary Science Letters*.
- Research on a new proxy for ocean acidification in deep time will be submitted for publication and presented at a conference.

HIGHER DEGREE BY RESEARCH COMPLETIONS

- Graduation of PhD student Sam Holt.

OUTREACH

There was a full and varied program of outreach activities in 2015, which included a range of community favourites, augmented by a number of new initiatives.

SCIENCE EXPERIENCE

Activities began in January with the Science Experience initiative, which has become a regular feature of the early part of the outreach calendar. This national program provides the opportunity for Year 9 and 10 students to participate in a series of hands-on science activities under the guidance of researchers. This year's visit was led by Sebastien Meffre, with support from Karin Orth and Sasha Stepanov, and included a look at a variety of Tasmanian rocks using petrological microscopes, a demonstration of LA-ICP-MS processes, and an interactive practical exercise in which the students placed fossils in order of the history of the Earth.

LIVE LINK TO VOYAGE TO HAVRE VOLCANO

In March and April, a link was placed on the CODES website enabling schoolchildren to follow Rebecca Carey on her voyage to the Havre volcano in the Kermadec Arc, New Zealand. Dr Carey was part of an international team of researchers, whose key objective was to investigate the seafloor deposits of a remarkable submarine eruption that occurred in 2012, which turned out to be the largest event of its type ever recorded. The schoolchildren were directed to the website via communications in collaboration with the Bookend Trust.

UTAS OPEN DAY

Staff and students played a major role in the University's annual Open Day in August. Activities included volcanology presentations, a microscopic tour of the rocks of Tasmania, a seismic demonstration, a hands-on simulation of a mass extinction using inflatable dinosaurs and soft rubber balls ('meteorites')

– plus a 'packed to the rafters' presentation on mass extinctions by Ross Large.

LORDS OF THE PUB

One of the most successful (and fun) events of the year was when Ross Large, Indrani Mukherjee and Jeff Steadman, AKA Gandalf, Galadriel, and Aragorn, gave three highly entertaining talks as part of the national Science in the Pub program. Using the Lord of the Rings as their theatrical vehicle, the trio took the audience through Earth's history of evolution and mass extinctions from 3.2 billion years ago, right up to the present day. The event was held at Hobart's New Sydney Hotel, and was 'standing room only'.

A PROJECT WITH LEGS

Curator of the Rock Library, Izzy von Lichtan, continued to make significant contributions to the Bookend Trust's Sixteen Legs project, which is bringing the mysterious and extraordinary world of Tasmania's underground cave systems to the community. During the year, she helped with the production of the movie 'Sixteen Legs: Enter the Cave', by making spider-related props that were used during filming. In addition, when the project exhibition went on the road, she travelled to Ulverstone in Tasmania's north, and Naracoote in South Australia, to help erect displays of two giant spiders, which she had built.

SCIENTISTS IN SCHOOLS

Izzy also continued with her involvement with the CSIRO's Scientists in Schools program, which aims to create and support long-term partnerships between school teachers and scientists. In March, she participated in a networking forum aboard the *Lady Nelson* on Hobart's River Derwent, where she was able to share ideas on future outreach activities with school teachers and other scientists in the program.



CLOCKWISE FROM TOP: Sasha Stepanov guides Science Experience students on a geological journey through the rocks of Tasmania; Gandalf (Ross Large) addressing a full house at the Science in the Pub event; Jeff Steadman, Indrani Mukherjee and Ross Large in full costume at the event.

SCHOOL VISITS

The year saw the usual mix of visits by various pre-tertiary institutions, including The Hutchins School, Dover District High, Huonville High, and Rosetta Primary School. In addition, Rebecca Carey visited Corpus Christi Catholic School to give a talk on submarine volcanoes.

PUBLIC LECTURES

Ross Large, Karin Orth and Indrani Mukherjee each gave presentations to the general public as part of the Royal Society of Tasmania Winter Lecture Series, within the theme of 'Middle Earth – the Slingshot of Life'. Each lecture was attended by over 300 people.

MEDIA

In addition to coverage in specialised media, it was a particularly prolific year for general media coverage, with

a number of stories making headlines, both locally and worldwide.

Rebecca Carey's trip to the Havre volcano featured prominently in the *Mercury* and *Examiner* newspapers, and via an interview on ABC Radio. Rebecca was also interviewed by Sydney's 2UE radio station in relation to a new island that had formed in Tonga.

Further afield, Khin Zaw was interviewed by Myanmar's MRTV television station after giving a keynote address at a major geological conference in the country.

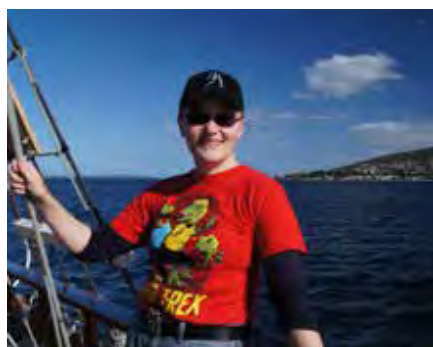
Honours student Sally Mattner took advantage of the temporary draining of Tasmania's Lake Rowallan to study Precambrian rock formations that had not been visible since the last Ice Age, which received coverage by ABC TV.

Ross Large and his team announced that they had discovered a new

technique to estimate the amount of gold present in ancient oceans, attracting extensive international media coverage, particularly on the Indian subcontinent.

The ARC TMVC Research Hub launch received widespread local coverage, including interviews on WIN, Southern Cross and ABC Radio. This was immediately followed by the launch of the SEG Conference, co-hosted by CODES, which received similar coverage, including a substantial article featuring Director Bruce Gemmell in the *Sunday Tasmanian*.

Finally, towards the end of the year, researchers Jacqueline Halpin and Jacob Mulder revealed links between Tasmania, Antarctica and the ancient Nuna supercontinent, which received extensive national and international media exposure, including filming for an episode of ABC TV's *Catalyst* program, which is set to air in 2016.



FROM TOP: Michael Roach giving a seismic demonstration at the UTAS Open Day; Children simulating a mass extinction at the UTAS Open Day; Students from Dover District High performing a viscosity test; Izzy onboard the *Lady Nelson* for a networking forum.

INDUSTRY LINKS & RESEARCH COLLABORATIONS

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 2015, the group of CODES' industry partners comprised of five Australian and international mining companies: Anglo American, Buenaventura, Newcrest Mining, Rio Tinto, and Teck Resources.

Partner companies provide support of up to \$75,000 in cash per year to the core research budget of the Centre. Senior representatives of these companies sit on the Science Planning Panel, along with

other government and university researchers. This panel meets annually to discuss the results of CODES' research and potential directions for new research.

INDUSTRY PARTNERSHIP OPPORTUNITIES

CODES offers a range partnership opportunities that can be tailored to company requirements. Although all partnership agreements expired when CODES tenure as a funded ARC Centre of Excellence concluded at the end 2013, many companies have signed new agreements. These renewed commitments are testament to the value that companies place in a partnership with CODES, especially considering the current tough operating conditions in the minerals industry.

Major benefits of a partnership agreement 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. For further details of partnership opportunities, contact the Director, Bruce Gemmell:

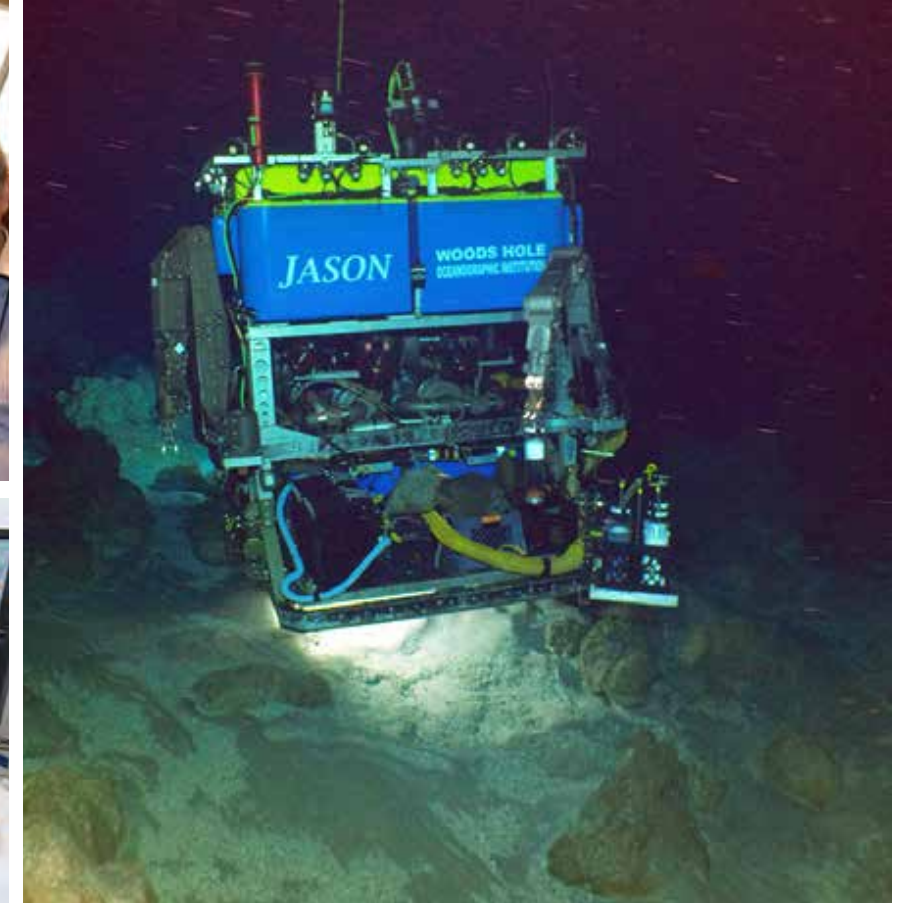
E. bruce.gemmell@utas.edu.au
Tel. +61 3 6226 2893.

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 2015 it funded AMIRA P1153 Applying the explorers' toolbox to discover porphyry and epithermal Cu, Au and Mo deposits, which is being conducted within the new ARC TMVC Research Hub.

RESEARCH COLLABORATIONS AND INTERNATIONAL VISITORS PROGRAM

In 2015, CODES further cemented its reputation for cultivating research collaborations with other Australian and international research organisations. Throughout the year, collaborative research was conducted with 42 international and 19 national organisations.



OPPOSITE PAGE CLOCKWISE FROM TOP LEFT: PhD student Stephanie Sykora with Andrew Wurst (L), Barrick Gold, and Andrew Davies, Teck Resources at the SEG 2015 Conference; The Jason ROV (remotely operated vehicle) in action during Rebecca Carey's expedition to the Kermadec arc; Mike Baker (R), with Roger Nordin, Boliden, visiting the Boliden mine in Sweden; Long-time collaborator, Valeriy Maslennikov, Russian Academy Sciences, making use of CODES laboratory facilities.

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 geometalurgy, 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 modules are transferred to end-users via regular research meetings, research reports, monographs, books, digital presentations and software packages, where appropriate. In 2015, 84 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 2015.

- Altered volcanic rocks: A guide to description and interpretation (2005). Authors: C Gifkins, W Herrmann and R Large (56 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 (41 copies).
- Giant ore deposits: Characteristics, genesis and exploration. CODES Special Publication 4 (2002). Editors: D Cooke and J Pongratz (13 copies).
- New developments in Broken Hill-type deposits. CODES Special Publication 1 (1996). Editors: J Pongratz and G Davidson (1 copy).
- The geology and origin of Australia's mineral deposits (2000). Authors: M Solomon and D Groves (8 copies).

- The geology of the Broken Hill Pb-Zn-Ag deposit, NSW, Australia (2006). Author: A Webster (1 copy).
- 24ct Au workshop. CODES Special Publication 5 (2004). Editors: D Cooke, C Deyell and J Pongratz (6 copies).
- Volcanic environments and massive sulfide deposits (2000). Editors: JB Gemmell and J Pongratz (3 copies).
- Volcanic textures: A guide to the interpretation of textures in volcanic rocks (1993). Authors: J McPhie, M Doyle and R Allen (73 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 27 events in these categories were held at various locations around the world, including Chile, China, Germany, Iceland, Indonesia, Malaysia, Myanmar, Peru, Philippines, Sweden and the USA.

Total attendance by industry geologists, academic researchers and postgraduate students was 1,562, with 36 different presenters from CODES involved in delivering the lectures.

2015 SHORT COURSES, WORKSHOPS, CONFERENCES AND FIELD TRIPS LED BY CODES

TITLE	PRESENTERS^	NO.^	LOCATION	DATE
Geophysics for Geologists and Engineers	Michael Roach , Hugh Tassell	6	CODES, Hobart	2 – 7 February
MTEC - Exploration Field Skills Mapping Camp	Evan Orovan, Robert Scott, Nathan Steeves, Selina Wu	24	Queenstown, Tasmania	8 – 15 February
Australian Microbeam Analysis Symposium (AMAS) XIII. Pre-Symposium LA-ICP-MS Workshop	Leonid Danyushevsky , Bence Paul, Jon Woodhead	14	CODES, Hobart	9 February
Australian Microbeam Analysis Symposium (AMAS) XIII	>50 presenters, including Sarah Gilbert, Sebastien Meffre, Jay Thompson	118	CODES, Hobart	11 – 13 February
MTEC - Exploration Field Skills Mapping Camp	Sean Johnson, Jacob Mulder, Josh Phillips, Robert Scott	24	Queenstown, Tasmania	8 – 15 March
Ore Deposits of South America	David Cooke, Bruce Gemmell, Jose Piquer, David Selley	17	Chile and Peru	13 – 27 March
Characteristics, Settings and Genesis of High Sulfidation and Porphyry Deposits	David Cooke	50	Universidad Nacional de Ingenieria, Lima, Peru	28 March
27th International Association of Geochemistry Symposium Short Course – Isotopes in Mineral Exploration	David Cooke , Kurt Kyser, Matt Laybourne, Ryan Mathur, Ed Van Hees, Rich Wanty	18	Arizona, USA	19 April
VIEPS - Ore Deposit Models	David Cooke, Garry Davidson, Bruce Gemmell, Robert Scott, David Selley, Jeff Steadman	12	CODES, Hobart	11 – 15 May
VIEPS - Practical Igneous Petrology	Leonid Danyushevsky	17	CODES, Hobart	18 – 22 May
AMIRA P1060 Workshop	Mike Baker, Lejun Zhang	10	CODES, Hobart	3 June
Ore Deposit Geochemistry, Hydrology and Geochronology Short Course	Mike Baker , Shaun Barker, Ron Berry , Phil Blevin, David Cooke, Tony Crawford, Leonid Danyushevsky, Garry Davidson, Nathan Fox , Scott Halley, Sean Johnson, Ross Large, Sebastien Meffre , Nick Oliver, Robert Scott , Rick Sibson, Leslie Wyborn, Lejun Zhang	37	CODES, Hobart	8 – 19 June
SE Asia: Tectonics and Ore Deposits	Khin Zaw	54	West Yangon University, Myanmar	22 July
Tectonics and Ore Deposits of SE Asia	Khin Zaw	28	Universiti Teknologi Malaysia (UTM)	30 July
SEG Student Chapter Field Trip to Iceland and Sweden	David Cooke , Peter Hollings, Jocelyn McPhie	22	Iceland and Sweden	4 – 21 August
Deposits of the Gold-rich Ordovician Alkalic Porphyry and Epithermal Province, Macquarie Arc, NSW. Pre-Conference Field Trip – SEG 2015 Conference	Nathan Fox , Anthony Harris	21	Orange, NSW	23 – 25 September
AMIRA P1153* Geochemistry Workshop One	David Cooke , Simon Gatehouse, Tim Ireland, Josh Phillips , Adele Seymon, Noel White, Jamie Wilkinson, Lejun Zhang	22	CODES, Hobart	25 September
Ore Deposits, Atmosphere Oxygenation and Evolution of Life: How They Are Related. Pre-Conference Short Course – SEG 2015 Conference	James Farquhar, Dan Gregory, Sean Johnson , Kurt Konhauser, Ross Large , John Long, Elena Lounejeva , Tim Lyons, Valeriy Maslennikov, Peter McGoldrick, Indrani Mukherjee , Patrick Sack, David Selley, Jeff Steadman , Fernando Tornos	37	Hobart	26 – 27 September

Delegates at the Australian Microbeam Analysis Symposium (AMAS) XIII.



TITLE	PRESENTERS^	NO.^	LOCATION	DATE
SEG 2015 Conference	>100 presenters/Chairs, including David Cooke, Leonid Danyushevsky, Garry Davidson, Angela Escolme, Bruce Gemmell, Dan Gregory, Wei Hong, Julie Hunt, Sean Johnson, Vadim Kamenetsky, Ross Large, Indrani Mukherjee, Robert Scott, David Selley	742	Hobart	27 – 30 September
Drill Core Measurements and Domaining for Geometallurgy. Post-Conference Short Course – SEG 2015 Conference	Ron Berry, Julie Hunt, Michael Roach	16	Hobart	1 October
Porphyry and Epithermal Systems of the Sunda Banda Arc, Indonesia. Post-Conference Field Trip – SEG 2015 Conference	David Cooke, Rachel Harrison, Adi Maryono, Iryanto Rompo	17	Java, Lombok and Sumbawa, Indonesia	1 – 8 October
Geometallurgy Short Course	Ron Berry, Dee Bradshaw, Sandrin Feig, Nathan Fox, Sarah Gilbert, Melissa Humphries, Julie Hunt, Anita Parbhakar-Fox, Thomas Rodemann, Jay Thompson	15	CODES, Hobart	19 – 30 October
AMIRA P1153* Workshop for Freeport-McMoRan	David Cooke	15	Manilla, Philippines	7 November
Ore Deposit Models and Exploration	Zhaoshan Chang, Huayong Chen, David Cooke, Rich Goldfarb, Dave Leach, Chusi Li, Steve Scott, Noel White, Kaihui Yang	141	Xi'an, China	10 – 14 November
Volcanic Successions	Patrick Hayman, Rebecca Carey, Ray Cas	20	Merimbula, NSW	16 – 20 November
AMIRA P1153* Geochemistry Workshop Two	David Cooke, Tim Ireland, Josh Phillips, Adele Seymon, Mike Whitbread, Jamie Wilkinson, Lejun Zhang	15	CODES, Hobart	1 December
Magmatic-Hydrothermal Ore Deposits	Bruce Gemmell	50	Kiel, Germany	16 – 17 December

^ CODES presenters in bold. ^^ Number of attendees. * ARC TMVC Research Hub

A practical session of the Ore Deposit Geochemistry, Hydrology and Geochronology short course.



PERFORMANCE INDICATORS

PERFORMANCE MEASURES IN 2014 – 2018 STRATEGIC PLAN

	TARGET	2015
Research Findings		
Publications in international journals	50pa	65
Percentage of publications in high quality international journals	70%	85%
Reports to industry collaborators	80pa	84
Special Issues and / or research monographs	1 per 2 years	2 (2014)
Invitations to give keynote conference presentations	10pa	2
Papers at national / international meetings	70pa	147
Research Training and Professional Education		
Percentage of HDR students attracted from interstate	25%	20%
Percentage of HDR students attracted from overseas	65%	64%
Number of Honours students in CODES' modules	15	5
Number of HDR students in CODES' modules	50	41
Percentage of students in projects linked with industry	80%	75%
Professional short courses/workshops for industry	4pa	27
International, National and Regional Links and Networks		
CODES' national or international conferences / workshops	1 per 2 years	2
Registrants at CODES' conferences / workshops	600pa	1562
End-user Links		
Frequency of meetings with industry representatives	15pa	20
National Benefit		
CODES' research has input into a major mineral discovery	1 per 5 years	9 in 27 years

FINANCES

2015 INCOME

Total CODES income was \$8.5 million (see Table 1). This was derived principally from the combined income sources of the ARC TMVC Research Hub (32%), UTAS (32%) and industry (20%) (see Figure 1). The main income streams over time are compared in Figure 2, showing the recovery following the commencement of the ARC TMVC Research Hub's funding.

SUMMARY OF THE MAIN INCOME STREAMS TO CODES IN 2015:

- ARC TMVC Research Hub: The combined income sources for the TMVC amounted to \$2.7 million in 2015, comprising of funding from the ARC (\$2.1 million), industry Partner Organisations (\$584k), and Host Institution (\$64k). The figure for the ARC includes funding covering the period from 2013 to 2015, which was dispersed to the Budget Centre in 2015.
- Industry income: Industry funding of \$1.7 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).

- Host institution support: Funding from UTAS in 2015 was up compared to the adjusted* figure for 2014, mostly due to an increase in operating grant support. UTAS funding relates primarily to research salaries, PhD scholarships and income earned by the Centre from research output.

**An adjustment has been made to the 2014 UTAS income figure to reflect that \$64k of funding reported was due to the ARC TMVC Research Hub. The revised UTAS figure of \$2,356,155 for 2014 is now reflected in the adjusted figures and graphics contained in this current report.*

2016 INCOME ESTIMATES

The total income figure is anomalous in 2015, as it includes funding for the ARC TMVC Research Hub that was backdated to 2013. While this will result in a comparative drop in funding levels from the ARC for the TMVC in 2016, industry funding for the AMIRA P1153 project will increase (funding in 2015 was for a six month period only). Other funding into CODES is expected to remain similar to 2015.

TABLE 1
CASH INCOME FINANCIAL STATEMENT 2015

ARC TRANSFORMING THE MINING VALUE CHAIN RESEARCH HUB	
ARC Industrial Transformation Research Project	2,093,344
Partner Organisations	584,000
- AMIRA P1153	268,800
- BHP Billiton Olympic Dam	150,000
- Newcrest Mining	165,200
Host Institution	63,869
	2,741,213
ARC GRANTS	
Discovery Grants	169,991
	169,991
OTHER COMMONWEALTH GOVERNMENT	
Specific Projects	140,245
Student Projects	7,000
	147,245
STATE GOVERNMENT	
Miscellaneous	1,362
	1,362
INDUSTRY/PRIVATE	
CODES Industry Partners	302,500
Minerals Council of Australia (MCA/MTEC)	67,400
Directly Funded Research Projects	836,625
Directly Funded Student Projects	501,381
Miscellaneous	4,299
	1,712,205
CONTRACTS/CONSULTANCIES/REVENUE RAISING	
Short Courses	121,505
Book Sales	29,013
Miscellaneous (incl. Analytical Services)	740,105
	890,624
UNIVERSITY OF TASMANIA - HOST INSTITUTION SUPPORT	
Operating Grant	1,521,727
Scholarships and Tuition Fee Waivers	1,097,240
Strategic Projects	114,026
Miscellaneous	1,000
	2,733,994
OTHER INCOME SOURCES/INTEREST	
Overseas Governments	10,465
Society of Economic Geologists - Student Scholarships	9,247
Student Support	1,032
Specific Projects	42,850
Miscellaneous	13,366
	76,959
TOTAL ANNUAL INCOME	8,473,593

FIGURE 1
TOTAL CASH INCOME 2015

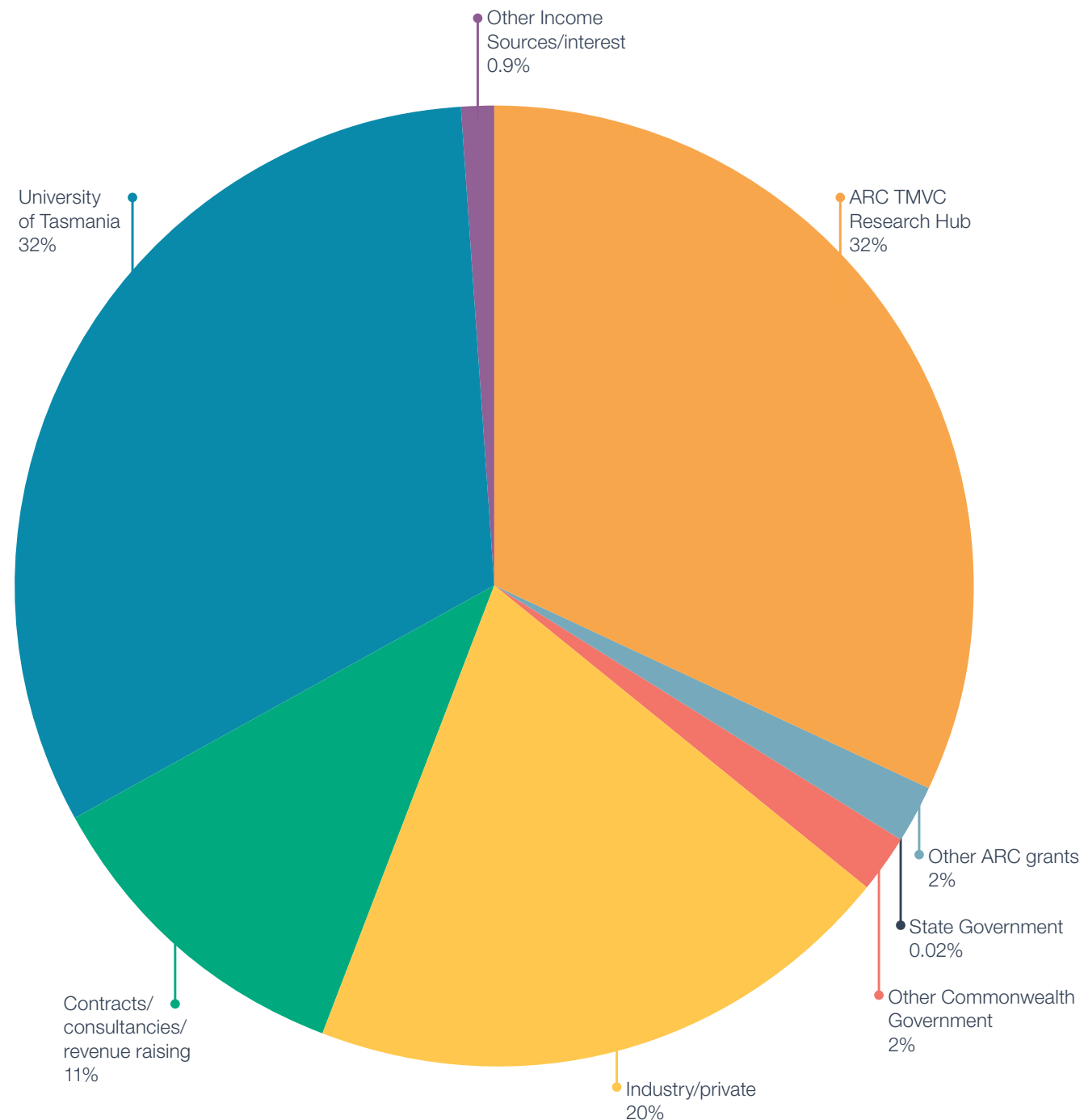
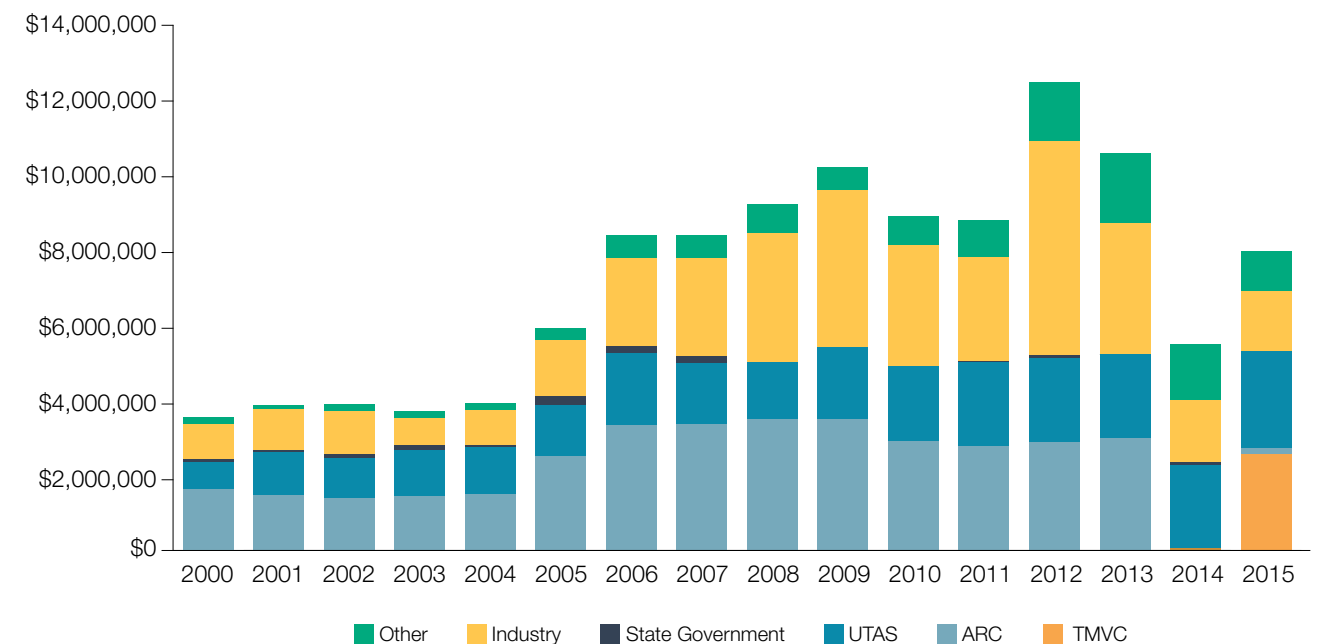


FIGURE 2
COMPARISON OF CODES
MAIN INCOME STREAMS 2000–2015



**NOTES TO, AND FORMING
PART OF, THE FINANCIAL
STATEMENTS FOR 2015**

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. All Financial Statements shown here have been reviewed by UTAS Central Finance.

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 2015, or centrally administered for CODES RHD students (as in the case of scholarships and tuition fee waivers).



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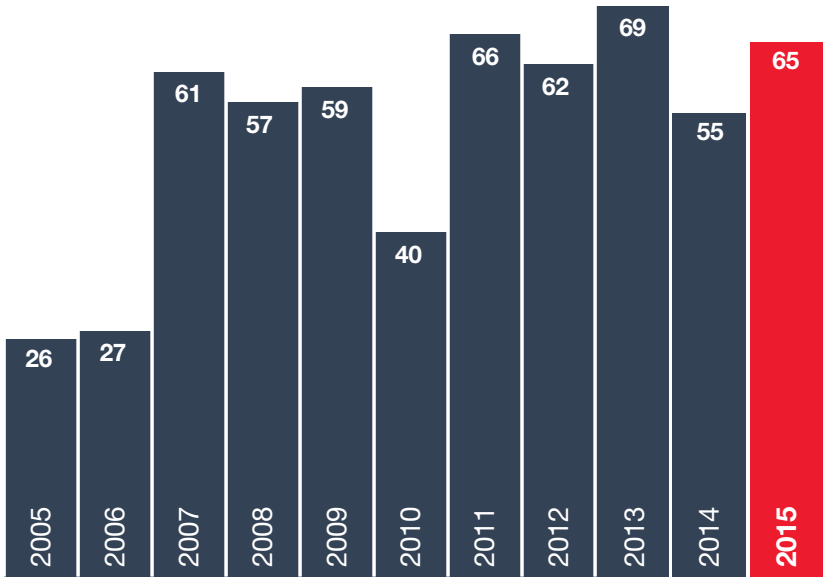
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DISCIPLINE OF EARTH SCIENCES

In addition to the publications affiliated to CODES, listed above, CODES' staff also made significant contributions to publications produced via their work within the Discipline of Earth Sciences. These publications are marked with a hash.

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Parbhakar-Fox, A., Aalders, J., Fox, N., Jackson, L., and Lottermoser B.G., 2015, Assessing acid rock drainage potential of footwall materials at the Rosebery Mine: Technical Report 091 for CRC ORE, Brisbane, Australia, 132 p.

Parbhakar-Fox, A., 2015, Characterising pyrite chemistry at the Old Tailings Dam: Evaluating tailings reprocessing as a management option: Report for the Savage River Rehabilitation Programme, Department of Primary Industries, Parks, Water and the Environment, Tasmania, 53 p.

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APPENDICES

POSTGRADUATE STUDENTS 2015

BACHELOR OF SCIENCE (HONOURS) (21)

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Adam Abersteiner ^	V.Kamenetsky	Petrographic and melt inclusion constraints on the petrogenesis and composition of kimberlites from Finland and South Africa	ARC
Wayne Baker ^	Cas, McPhie	Lithostratigraphy and facies architecture of the footwall to the DeGrussa volcanic hosted massive sulfide deposit, Western Australia	Sandfire Resources
Corey Bellchambers §	G.Davidson, Meffre	Pyrite trace element and isotopic zonation at the Henty Au deposit, Tasmania	Unity Mining
Murray Brownrigg §	Large	Investigating Tasmanian black shale and associated pyrite for evidence of the SPICE event	
Evan Draayers ^	Danyushevsky	Detailed mineralogy of boninite and arc-tholeiite lavas from the Hunter Ridge: Implications for plumbing system and magma generation processes	UTAS
Mark Giddings §	V.Kamenetsky	Investigating non-magmatic solutions to the chromitite genesis conundrum: A petrological and geochemical study of Hidaka Mountain chromite bearing peridotites and Horoman Massif Ophiolite	
Melanie Haycroft ^	G.Davidson, Plimer (UAdelaide)	The eastern mineralisation, Broken Hill, NSW	CBH Resources
Chris Hildrew ^	Cas, McPhie	Understanding the nature of the host rock succession to the Archean Nimbus Ag-Zn-Pb-Au deposit, WA	MacPhersons Resources
Travis Holmes ^	Cooke, Baker, Fox	Geometry, timing and controls on alteration and mineralisation at the Big Wilson Tin Prospect, NW Tasmania	Venture Minerals
Sally Mattner ^	Scott	Structure and metamorphism of the Mersey River metamorphic complex	
Will McAdam ^	Roach, Duffett (MRT)	A geophysical interpretation of the Mole Creek area, Tasmania	MRT
Reuben McCormack ^	Roach	Geophysical assessment of potential magnetite skarn mineralisation at the L13 Prospect, Highclaire, Northwest Tasmania	Lottah Mining, GHD
Jake Moltzen ^	Parbhakar-Fox, Fox	Integrated techniques for rapid drill core mineralogical characterisation	CRC ORE
Bronson Rogers ^	Fox, Parbhakar-Fox	Environmental significance of the Broken Hill Gossan: A mineralogical and geochemical study	CRC ORE
Jordan Sheppard ^	Zaw, Large	Trace element variations in Devonian shale in Northern Shan State, Myanmar	ARC
Mark Smith ^	Roach, Tassell (GHD)	Distribution, nature of sediments and depth to bedrock in Bass Strait, in the region of Burnie Port	GHD
Peter Tongue §	McGoldrick	Taphonomy and depositional environment of Horodyskia williamsii fossils from the Cassiterite Creek Quartzite, Tasmania	
Jonathon Traynor ^	Zaw, Large	Genesis of Modi-Momi Taung orogenic gold deposit in central Myanmar: Constraints from structure, wall rock alteration and mineral chemistry	National Prosperity Company
Leslie Warn ^	Roach, G.Davidson	Gravity and magnetic modelling of the Cygnet area, Tasmania	
Ben Whitney	Zhang, G.Davidson	Geological framework and characteristics of the Specimen Hill high sulfidation epithermal system, southern Queensland, Australia	Signature Gold
Matthew Whitten ^	Meffre	Formation de Kone: Recording the final stages of Gondwana break up in New Caledonia	Université de la Nouvelle-Calédonie

MASTER OF ECONOMIC GEOLOGY (52)

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Michael Adams		coursework only	
Fabian Baker	Cooke	Amulsar HSE Au deposit, Armenia	Lydian International
Billy Beas Caceras ^	McPhie, Gemmell	Volcanic stratigraphy at La Zanja Mining District in the northern Peruvian Andes, Cajamarca, Peru	Cia de Minas Buenaventura SAA/ Minera La Zanja SRL
Lynelle Beinke ^		coursework only	
Sebastian Benavides	Cooke	Characterisation of phyllic assemblages at Taca Taca Bajo, Argentina	First Quantum
Christopher Booth		coursework only	
Cesar Calderon-Tipiani	Gemmell	Chanca low sulfidation deposit, Peru	Buenaventura
Wayne Carter		coursework only	
Glen Cathers		coursework only	
Chloe Cavill	G.Davidson	Geochemical classification of orebearing/metalliferous fluids of the Costerfield region, Victoria	Mandalay Resources
Djohanne Celiz	Cooke	The geology, alteration, and mineralisation of the Sagay deposit in northern Negros, Philippines	Freeport-McMoRan Exploration Corporation
Joanna Condon #	Gemmell	Mineral characterisation of the DeGrussa deposit: Implications for mining, milling and exploration	Sandfire Resources
Richard Cotton		coursework only	
Lucas Doherty		coursework only	
Peter Duerden ^		coursework only	
Eric Dutch		coursework only	
Daniel Ervin		coursework only	
Pablo Farias		coursework only	
Maria Lourdes M. Faustino #	Cooke	Intrusive history and genesis of Bayugo porphyry copper-gold deposit, Surigao Del Norte, Philippines	DFAT, Philex Mining, SEG
Franco Ferreyra		coursework only	
Arga Firmansyah		coursework only	
Daniel Foulds		coursework only	
Phil Gilmore ^	G.Davidson	Exhalative horizons and volcanic-associated massive sulfide mineralisation in the Ordovician Girilambone Group, New South Wales	Geological Survey of NSW
David Groombridge		coursework only	
Brendan Hardwick	TBD	Sulfide textures at Tropicana Gold Mine: Relationship to deposit genesis, gold deportment and implications for ore processing, exploration, and environment	AngloGold Ashanti
Kyle Hodges		coursework only	
Jonathon Hoye		coursework only	
Kyle Hughes		coursework only	
Danny Huisman		coursework only	
Anna Kutkiewicz	Large	Trace element chemistry of chalcopyrite in the Viburnum Trend MVT deposits, USA	Doe Run
Thomas Langley		coursework only	
Xuan Truong Le ^	Zaw	Geological setting and mineralisation characteristics of the Me Xi gold deposit, Quang Tri Province, Central Vietnam	Axiom Mining, Hanoi University of Mining and Geology , Ore Deposits of SE Asia Project
Chantelle Lower	Ehrig (BHPBilliton)	An aspect of the geology of the Olympic Dam deposit	BHP Billiton
Walter Lozano Garcia Naranjo		coursework only	

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Neil Macalalad ^	Cooke	Geology, alteration, mineralisation and vectoring to porphyry centre in the Aisasjur prospect, Irian Jaya, Indonesia	Anglo American
Imam Malik #		coursework only	
Rebekah McLelland	Scott	Gold mineralisation at the Reefton Goldfield, New Zealand	Oceana Gold
Joanne Morrison *	Berry	Cadia East multi-element lithogeochemistry: Evaluation of trace element deportment important to processing	Newcrest Mining
Michael Musialike ^	Scott	The geological setting and mineralisation characteristics of the Dunrobin deposit, Zambia	Copperbelt University
Alexei Nicholls		coursework only	
Saranya Nuanla-Ong	Zaw	Paragenesis, pyrite geochemistry and ore fluids at Htongyi gold veins, Myanmar	Ore Deposits of SE Asia Project, National Prosperity Company
Chris Piggott		coursework only	
Thomas Ralston		coursework only	
Alan Riles		coursework only	
Stephanie Robertson ^		coursework only	
Christopher Shanley		coursework only	
Markus Staubmann		coursework only	
Edward Summerhayes ^		coursework only	
Chris Thaus		coursework only	
Nevil Vanderslink		coursework only	
Peter Watson		coursework only	
Onur Yilmaz ^		coursework only	

MASTER OF SCIENCE (2)

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Eyob Andemeskel	Selley	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
Irma Vejelyte #	V.Kamenetsky, McPhie, Ehrig (BHPBilliton)	Geological evolution of the Wirrda Well Prospect, Gawler Craton, South Australia	UTAS, CoE, BHP Billiton, ARC

Core yard at Productora Cu-Au-Mo deposit, northern Chile.



DOCTOR OF PHILOSOPHY (54)

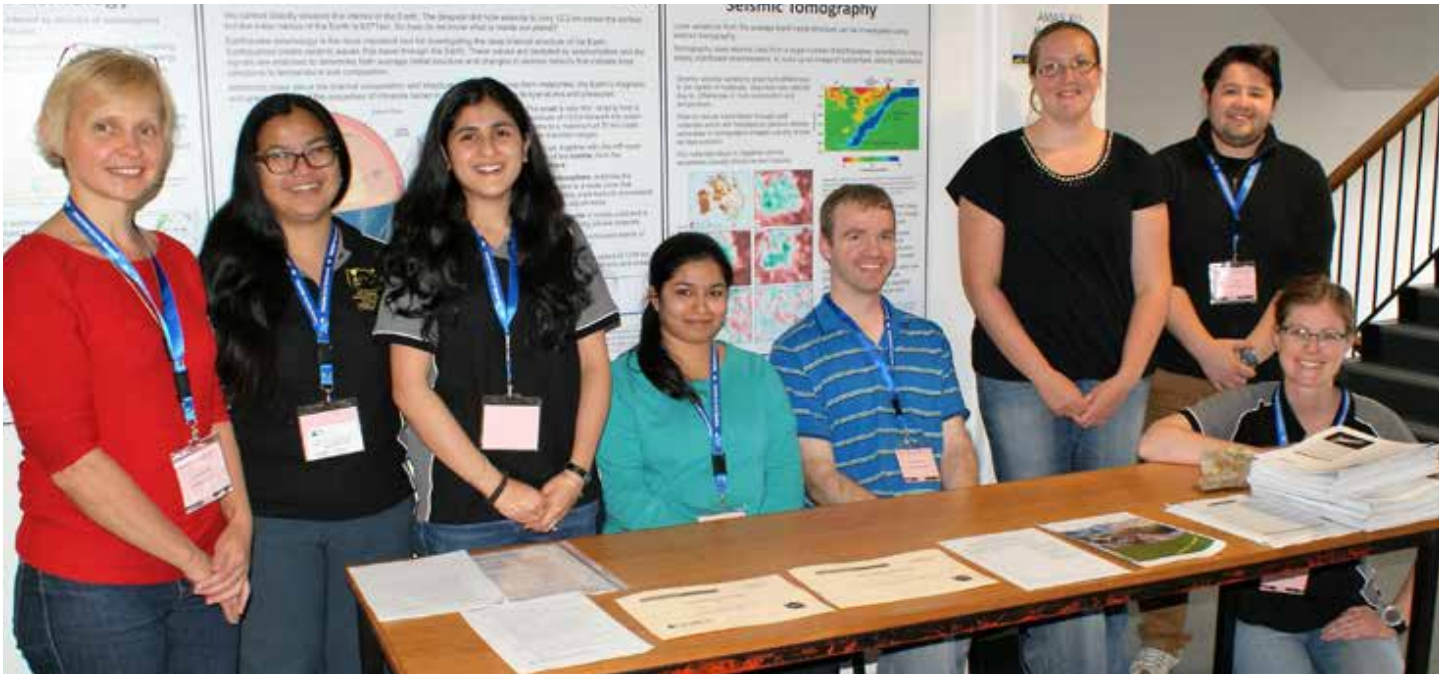
STUDENT	SUPERVISORS	PROJECT	SUPPORT
Olga Apukhtina	V.Kamenetsky, McPhie, Maas (UMelb)	Stable isotopes (C, S and O) and halogens (Cl, F) in gangue and ore minerals at Olympic Dam: Evaluation of mantle and crustal contributions to mineralisation	BHP Billiton Olympic Dam, UTAS
Richelle Awid-Pascual	V.Kamenetsky, Goemann, Noble, N.Allen (consultant)	The characteristics and role of colloids in the mineral formation in Grieves Siding Zn-Pb peat, western Tasmania	CoE, UTAS, CRC ORE
Mohd Basril Iswadi Bin Basori ^	Zaw, Large	Geology of volcanic hosted massive sulfide (VHMS) deposits in Central Belt, Peninsular Malaysia	Malaysian Govt, Ore Deposits of SE Asia Project
Heidi Berkenbosch	Gemmell, McNeill (MRT), Christie (GNS Science)	Geochemistry of hydrothermal mineral chimneys from Brothers volcano, Kermadec Arc	CoE, GNS Science, UTAS, SEG, AusIMM, Australian Synchrotron
Ben Cave	Large, Danyushevsky	A metamorphic course for tungsten in metasedimentary-hosted orogenic gold deposits	UTAS, CoE
Nathan Chapman	Meffre, V.Kamenetsky	Pb-isotopic insights into the crustal evolution and metallogenesis of the Gawler Craton	ARC, BHP Billiton
Jing Chen	Cooke, Zhang	The geology, mineralisation, alteration and fluid evolution of Zijinshan ore field, Fujian Province, China	UTAS, Chinese Govt, SEG, Zijin Mining
Alexander Cherry	V.Kamenetsky, McPhie, Ehrig (BHPBilliton)	Petrology, provenance and composition of bedded sedimentary facies in the Olympic Dam deposit	UTAS, ARC, BHP Billiton
David Douth	Scott, Cas	The geology and geological controls on gold mineralisation at the Invincible deposit, St Ives Gold Mine, Kambalda, WA	St Ives Gold
Angela Escolme	Cooke, Hunt, Berry	Ore characterisation and geometallurgical modelling at the Productora Cu-Au-Mo deposit, Chile	UTAS, Hot Chili, CSIRO, AusIMM
Esmail Eshaghi	Reading, Roach	3D petrophysical and geophysical modelling of west and northwest Tasmania	UTAS
Matt Ferguson	V.Kamenetsky, Meffre, Ehrig (BHPBilliton)	Regional metal and fluid sources for IOCG mineralisation around Olympic Dam, and geology, geochronology and mineral-chemical zonation of the Wirrda Well deposit	UTAS, ARC, BHP Billiton
Jodi Fox	McPhie, Carey	Basaltic volcanic successions in Tasmania and on Heard Island	UTAS, CoE, ANZIS, Australian Antarctic Science Program, Betty Mayne Scientific Research Fund For Earth Sciences
Martin Gal	Reading, Ellingsen (Physics)	The development of array and single station methods for the analysis of on-land ambient seismic signals from deep ocean storms and coastal sources	UTAS
Amos Garay *	Cooke	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
Sarah Gilbert ^	Danyushevsky, Large	Development of analytical methods and standard reference materials for analysis of trace elements and isotopic ratios in sulfides	CoE, CODES, Agilent Technologies
Cassady Harraden *	Meffre, Berry	Geotechnical and geometallurgical assessment of the Cadia East deposit using Corescan automated logging technology	UTAS, TMVC, Newcrest, Corescan
Rachel Harrison	Cooke	Tumpangpitu porphyry Au-Cu-Mo and high-sulfidation epithermal Au-Ag deposit, Tujuh Bukit project, SE Java, Indonesia - geology, alteration and mineralisation	UTAS, SEG
Margy Hawke	Gemmell, Large, G.Davidson	Geological evolution of the DeGrussa Cu-Au VHMS deposit, Western Australia	UTAS, Sandfire Resources
Jacob Heathcote	Scott, G.Davidson	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

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Sam Holt	Carey, McPhie	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	Magmatic-hydrothermal volatile exsolution and mineralisation in Tasmanian Sn granites	UTAS, CoE, SEG, Geoscience Australia
Qiuyue Huang	V.Kamenetsky, McPhie, Allen	Mafic magmatism in the Gawler Craton: Distribution, composition, timing, sources and tectonic setting	UTAS, CoE, BHP Billiton, ARC
Fumihiko Ikegami	Carey, McPhie	2012 submarine silicic eruption of Havre volcano and implications for ancient submarine successions in Australia	UTAS, ARC, US National Science Foundation
Laura Jackson *	Parbhakar-Fox, Cooke, Fox	Domaining of geoenvironmental properties in drill core	ARC TMVC, UTAS
Carlos Andres Jimenez Torres	Cooke, White, Baker	Bantug lithocap, Negros Island, Philippines: Mineralogy, textures, and chemistry	UTAS Foundation, AMIRA P1060
Sean Johnson	Large, Meffre, McGoldrick	The trace element content and sulfide chemistry of metalliferous black shales	UTAS, CoE, Mining Institute of Scotland, ANZIC- IODP, ECORD, NERC, Talvivaara Mining, GTK, SEG
Teera Kamvong #	Zaw, Meffre	Geology and genesis of porphyry-skarn Cu-Au deposits at the Northern Loei and Truong Son Fold Belts, Thailand and Laos	IPRS, ARC Linkage, CoE, SEG, PanAust, Ore Deposits of SE Asia Project
Joseph Knight	Zaw, Large	The geodynamic and metallogenic setting of Cu-Au mineralisation in Myanmar: Implications for mineral exploration	
Stephen Kuhn	Reading, Cracknell, Roach	The application of machine learning algorithms for lithological mapping and minerals targeting in key ore deposit settings	UTAS, CODES
Erin Lawlis	Cooke	Au-bearing pyritic ore of Lihir, Papua New Guinea: Its physiochemical character and nature of the causative fluids	Newcrest Mining, UTAS, SEG
Elena Lounejeva	Danyushevsky, Large	Geochemical study of three marine sediments sequences corresponding to the Late Permian-Early Triassic stratigraphic boundary	ARC, CODES
Charles Makoundi #	Zaw, Large	Geochemistry of carbonaceous black shale, sandstone, and chert in Malaysia: Insights into gold source rock potential	IPRS, UTAS, Ore Deposits of SE Asia Project
Claire McMahon	G.Davidson	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, G.Davidson	Geology and genesis of the mineral deposits of the Myra Falls VHMS District, Canada	Nyrstar
Larriana Morgan §	G.Davidson, Bull, Selley	Controls on copper mineralising process in the central McArthur Basin, NT (Redbank Package), and its implications for the metallogeny of extensional basins	NTGS, UTAS
Peter Morse	Reading, Lueg (Computing)	Combined computational and human interaction strategies in knowledge generation from spatial and spatiotemporal information	UTAS, CODES
Indrani Mukherjee	Large, Halpin, Meffre	Pyrite trace element chemistry of black shales of the "boring billion" period	UTAS, SEG, AMIRA
Jacob Mulder	Meffre, Halpin, Berry, Scott	From Nuna to Gondwana: An evaluation of the early tectonic history of Tasmania	UTAS, CODES
Evan Orovan	Cooke, Harris	Geology, geochemistry and genesis of the Namosi porphyry Cu-Au deposits, Fiji	CODES, Newcrest Mining, SEG , Namosi Joint Venture
Thomas Ostersen	Reading, Roach, Thiel (GSSA)	Multi-scale geoelectric, and combined geophysical, investigations of Tasmania and Southeast Australia	UTAS, CODES, MRT, U Adelaide, Geoscience Australia, GSSA

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Pedro Pereira da Fonseca	McPhie, McNeill (MRT), Relvas (GeoFCuL)	Facies analysis and correlations in complex mineralised submarine volcanic successions: Mount Read Volcanics, western Tasmania	Portuguese Govt (FCT), CoE
Joshua Phillips *	Cooke	Geologic and geochemical vectors to mineralisation at the Resolution porphyry Cu-Mo deposit, Arizona	ARC TMVC, AMIRA P1153, Rio Tinto, Resolution Copper Ltd
Jose Meulen Piquer Romo ^	Cooke, Berry, Scott	Structural geology of the Andes of Central Chile: Evolution, controls on magmatism and the emplacement of giant ore deposits and implications for exploration	Chilean Govt, Codelco, AMIRA P1060
Naomi Potter	V.Kamenetsky, Goemann, M.Kamenetsky	An investigation into the genesis of intrusive and extrusive carbonatitic melts	UTAS, ARC
Marc Rinne ^	Cooke, Jansen	Geology and genesis of the contrasting Wafi-Golpu porphyry-epithermal deposit, Papua New Guinea	Newcrest Mining, Harmony Gold, Morobe Mining Joint Venture, UTAS
Subira Sharma	G.Davidson, Cooke	Evaluation of links between Merlin-style Mo-Re mineralisation and magmatism in the Cloncurry fold belt, Queensland: Implications for exploration	UTAS, Inova Resources
Jeffrey Steadman ^	Large, Bull, G.Davidson	BIFs, black shales, and gold deposits: A re-evaluation	CoE, CSIRO, Integra Mining
Nathan Steeves	Gemmell, Large, Hannington (UOttawa)	Ore genesis of the Greens Creek VHMS Deposit, Alaska: Implications for mining, milling and exploration	Hecla Mining, UTAS
Stephanie Sykora	Cooke, Selley	Geological, structural, geochemical and genetic significance of the anhydrite zone at the Lihir gold deposit, Papua New Guinea	Newcrest Mining, UTAS
Francisco Testa	Cooke, Baker	Tourmaline breccia pipes: San Francisco de los Andes, Argentina and Rio Blanco-Los Bronces, Chile	UTAS, AMIRA P1060
Jay Thompson	Danyushevsky, Meffre	Understanding the specifics of H ₂ O-free aerosol behaviour in the inductively-coupled plasma in geochemical LA- ICPMS applications involving U/Pb dating and accurate trace element analysis in silicate minerals and glasses	
Jennifer Thompson *	Cooke, Danyushevsky, Meffre	Detailed investigation into carbonate minerals in geochemical dispersion halos around Cu, Au and Mo porphyry deposits to identify potential indicators of deposit location beyond what is possible in whole rock geochemistry	UTAS AMIRA P1153
Daniele Vergani	Carey, McPhie	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

* Affiliated with the ARC TMVC Research Hub # Degree completed, not yet graduated ^ Graduated § Withdrawn/terminated

Student assistants at the AMAS XIII Symposium, from left: Irma Vejelyte, Richelle Awid-Pascual, Indrani Mukherjee, Subira Sharma, Jeff Steadman, Jennifer Thompson, Sean Johnson, and Cassidy Harraden.



MAJOR EXTERNALLY FUNDED RESEARCH PROJECTS^

ARC INDUSTRIAL TRANSFORMATION RESEARCH HUB GRANTS 2015

INVESTIGATORS	PROJECT	FUNDING BODY	PERIOD	ARC FUNDING FOR 2015	PARTNER FUNDING FOR 2015	UTAS FUNDING FOR 2015
Cooke, Danyushevsky, Duh, Gemmell, Large, Meffre, Reading, Harris (Newcrest), Seymon (AMIRA), Ehrig (BHP Billiton), Goodey (Corescan), Hardy (NICTA), Lottermoser (Aachen), Shelley (Laurin Technic)	Transforming the mining value chain	ARC, AMIRA International, BHP Billiton Olympic Dam, Newcrest Mining, UTAS	2015 - 2020	\$2,093,344	\$584,000	\$63,869

ARC DISCOVERY GRANTS 2015

INVESTIGATORS	PROJECT	PERIOD	ARC FUNDING FOR 2015
Large	Pyrite: A deep-time capsule of ocean chemistry and atmosphere oxidation	2015 - 2017	\$169,991

INDUSTRY AND OTHER EXTERNALLY FUNDED RESEARCH GRANTS 2015

INVESTIGATORS	PROJECT	FUNDING BODY	PERIOD	FUNDING FOR 2015
Cooke, Jansen, Selley, Harris (Newcrest)	Exploring the porphyry environment	Newcrest Mining Limited	July 2009 - 2016	\$323,723
Large, Danyushevsky	Research and development in mineral deportment and exploration	Newcrest Mining Limited	2012 - 2016	\$235,000
Large, Gregory, Steadman	DeGrussa vectoring project	Sandfire Resources	2015 - 2016	\$162,917
Scott, G.Davidson, Heathcote (student)	Gold distribution and association at the Kansanshi copper-gold deposit Zambia	Kansanshi Mining	2014 - 2017	\$103,000
Danyushevsky, TBA (student)	PhD project title TBD	Laurin Technic	2015 - 2018	\$98,000 **
Large, Meffre, Gregory	South Australia pyrite, hematite and magnetite fingerprint database	Geological Survey of South Australia	2012 - 2015	\$55,000
Scott, Cas, Douth (student)	The geology and geological controls on gold mineralisation at the Invincible deposit, St Ives Gold Mine, Kambalda, WA	St Ives Gold	2015 - 2018	\$55,000
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	2015 - 2017	\$51,000
Gemmell, G.Davidson, McNulty (student)	Geology and genesis of the mineral deposits of the Myra Falls VHMS District, Canada	Nyrstar Myra Falls	2015 - 2017	\$50,000
Halpin	Metamorphic architecture of the central-northern Gawler Craton	Geological Survey of South Australia	2015	\$49,101
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 - 2016	\$47,000
Danyushevsky	LAM data reduction software development	Rio Tinto	2014 - 2016	\$45,000
Large, G.Davidson, Meffre, Belousov	Development and application of a Yilgarn pyrite and magnetite fingerprint database	Geological Survey of Western Australia	2012 - 2015	\$39,000
Cooke, Hunt, Berry, Escolme (student)	Ore characterisation and geometallurgical modelling at the Productora Cu-Au-Mo deposit, Chile	Hot Chili	2013 - 2016	\$25,858
		CSIRO	2014 - 2016	\$7,000

INVESTIGATORS	PROJECT	FUNDING BODY	PERIOD	FUNDING FOR 2015
Zaw, Large, Knight (student)	The geodynamic and metallogenic setting of Cu-Au mineralisation in Myanmar: Implications for mineral exploration	Anglo American	2015 - 2016	\$24,403
Cooke, Chen (student), Fan (visitor), Zhang, Zhou (visitor)	Porphyry and skarn mineralisation in China	Hefei University of Technology	2015 - 2016	\$35,000
Large, Gregory, Steadman, Wu	Peak gold project	Drummond Gold	2014 - 2015	\$18,985
Cas, McPhie, Hildrew (student)	Understanding the nature of the host rock succession to the Archean Nimbus Ag-Zn-Pb-Au deposit, WA	MacPhersons Resources	2015	\$10,000
G.Davidson, Cooke, Sharma (student)	Evaluation of links between Merlin-style Mo-Re mineralisation and magmatism in the Cloncurry fold belt, Queensland: Implications for exploration	Inova Resources	2013 - 2016	\$10,000
Sanematsu (visitor)	Granite geochemistry and related REE deposits in Southeast Asia	Japan Society for the Promotion of Science	2013 - 2015	\$6,740
Gemmell, Large, G.Davidson, Hawke (student)	Geological evolution of the DeGrussa Cu-Au VHMS deposit, Western Australia	Sandfire Resources	2012 - 2016	\$6,267
Zhang, G.Davidson, Whitney (student)	Geological framework and characteristics of the Specimen Hill high sulfidation epithermal system, southern Queensland, Australia	Signature Gold	2015 - 2016	\$5,836
Cooke, Zhang, Fox, Hong (student)	Magmatic-hydrothermal volatile exsolution and mineralisation in Tasmanian Sn granites	Society of Economic Geologists	2015	\$5,706
Roach, McCormack (student)	Geophysical assessment of potential magnetite skarn mineralisation at the L13 Prospect, Highclaire, Northwest Tasmania	Lottah Mining	2015	\$5,000
Roach, Tassell (GHD), Smith (student)	Distribution, nature of sediments and depth to bedrock in Bass Strait, in the region of Burnie Port	GHD	2015	\$5,000
Cooke, Faustino (student)	Intrusive history and genesis of Bayugo porphyry copper-gold deposit, Surigao Del Norte, Philippines	Society of Economic Geologists	2015	\$3,541
Cas (Monash), McPhie, Baker (student)	Lithostratigraphy, facies architecture, alteration and geochemistry of the footwall to the DeGrussa volcanic hosted massive sulfide deposit	Sandfire Resources	2014 - 2015	**
Orth	Paleoprotozoic mafic magmatism of the Kimberley Basin, Western Australia	Geological Survey of Western Australia	2014 - 2015	**
McNeill, Feig, Falloon, D.H.Green	Sulfur and metal evolution in parental mid ocean ridge basalt magmas	IODP (via Australian National University)	2012 - 2015	**
V.Kamenetsky, McPhie, Apukhtina (student)	Stable isotopes (C, S and O) and halogens (Cl, F) in gangue and ore minerals at Olympic Dam: Evaluation of mantle and crustal contributions to mineralisation	BHP Billiton Olympic Dam Corp	2012 - 2015	**

^ projects with greater than \$2,000 external funding per year,

** all project funding received, project still active

++ full project funding received in one year

VISITORS 2015

INDUSTRY VISITORS

NAME	COMPANY
Paul Agnew	Rio Tinto Exploration
German Ojeda Alvarez	Quantum Pacific Exploration (QPX)
Debora Araujo	Rio Tinto Exploration
Billy Beas	Compania de Minas Buenaventura
Alfredo Bertens	Quantum Pacific Exploration (QPX)
John Bishop	Mitre Geophysics
James Cannell	MMG Limited
Rob Chorlton	Laboratory Analysers Australia
Peter Clifton	Cameca Instruments
Gisela Cobenas	First Quantum Minerals
Pierre-Yves Corre	Cameca Instruments
Paul Cromie	Anglo American
Iain Dalrymple	Teck Resources
Kim Denwer	MMG
Simon Dominy	MG Gold
Kathy Ehrig	BHP Billiton
Ed Eshuys	Drummond Gold
Marc Fimeri	Adept Turnkey
David First	Freeport McMoRan
Nicholas Fitzpatrick	Newcrest Mining
Fred Fryer	Agilent Technologies Australia
Karyn Gardner	Newcrest Mining
Simon Gatehouse	BHP Billiton
Neil Goodey	Corescan
Scott Halley	Mineral Mapping
Anthony Harris	Newcrest Mining
Roland Hill	Quantum Pacific Exploration (QPX)
Kate Hine	Mitre Geophysics
John Holliday	Holliday Geoscience
Tony Hope	GHD
Tim Ireland	First Quantum Minerals

NAME	COMPANY
Ulrich Kesten	Sympatec
Tom Kotzer	Cameco
John Landmark	Anglo American
Jim Lang	Hunter Dickinson
Daniel Lester	Grange Resources
Joe Lograsso	Antofagasta
Vitaly Lozbin	JEOL
Richard Lynch	Institute of Mine Seismology
Charles Magee	Australian Scientific Instruments
Ashley Norris	Norris Software
Nick Oliver	Holcombe Coughlin Oliver Consultants
Gerrit Olivier	Institute of Mine Seismology
Aubrey Paverd	Compania de Minas Buenaventura
Paul Polito	Anglo American
David Rainey	BHP Billiton
Francois Robert	Barrick Gold
Robbie Rowe	NextGen Geological
Adele Seymon	AMIRA International
Trevor Shaw	Mt Isa Mines – Glencore
Mike Shelley	Laurin Technic
Penny Sinclair	Cameco
Nicholas Smith	PassiveX
Andrew Somers	SciAps
Hideyuki Takahashi	JEOL
David Thomas	Cameco
Alan Vaughan	Midland Valley Exploration
Mike Whitbread	MMG
Noel White	Consultant
Andrew Wurst	Barrick Gold
Gerard Zaluski	Cameco

NATIONAL ACADEMIC AND GOVERNMENT VISITORS

NAME	INSTITUTION
Charlotte Allen	Queensland University of Technology
Leslie Almberg	Monash University
Eloise Beyer	Geological Survey Northern Territory
Phil Blevin	Geological Survey of NSW
Ralph Bottrill	Mineral Resources Tasmania
Graham Carr	CSIRO
Ray Cas	Monash University
Richard Chopping	Geoscience Australia
Stephen Cox	Australian National University
Mark Duffett	Mineral Resources Tasmania
Diego Garcia-Bellido	University of Adelaide
Andrea Giuliani	University of Melbourne
David Green	Mineral Resources Tasmania
Shin-Chan Han	University of Newcastle
John Harkin	Tas. State Government (DPIPWE)
Paul Heithersay	Department of State Growth, SA
Robert Hough	CSIRO
David Huston	Geoscience Australia
James Johnson	Geoscience Australia
Craig Lindley	Data 61 / CSIRO

NAME	INSTITUTION
John Long	Flinders University
Roland Maas	University of Melbourne
Cam McCuaig	Centre for Exploration Targeting, UWA
Sandra McLaren	University of Melbourne
Bob Musgrave	NSW Geological Survey
Anthony Reid	Geological Survey of South Australia
Barry Reno	Geological Survey Northern Territory
Érika Suellen Santiago	University of Western Australia
Sumon Shariar	CSIRO
Greg Timms	CSIRO
Andrew Tomkins	Monash University
Charles Verdel	University of Queensland
Benjamin Wade	University of Adelaide
Andrew Wakefield	Mineral Resources Tasmania
Malcolm Walter	University of New South Wales
Dan Wood	University of Queensland
Leslie Wyborn	Geoscience Australia
Greg Yaxley	Australian National University

INTERNATIONAL ACADEMIC AND GOVERNMENT VISITORS

NAME	INSTITUTION
Chris Ballhaus	University of Bonn, Germany
Shaun Barker	University of Waikato, New Zealand
Dee Bradshaw	University of Cape Town, South Africa
Huayong Chen	Guangzhou Institute of Geochemistry, China
Yu Fan^	Hefei University of Technology, China
Lennart Fischer^	University of Hannover, Germany
Gillian Foulger	Durham University, UK
John Goodge	University of Minnesota Duluth, USA
Mark Hannington	University of Ottawa, Canada
Rainer Helmig	University of Stuttgart, Germany
Pete Hollings	Lakehead University, Canada
Julie Hunt	University of Liege, Belgium
Anika Husen^	University of Hannover, Germany
Mohammad Jalali^	Amirkabir University of Technology, Iran
Xingzhong Ji	China University of Geosciences
Bruce Julian	Durham University, UK
Kurt Konhauser	University of Alberta, Canada
Yubang Li	Chinese Academy of Sciences
Bernd Lottermoser	RWTH Aachen University, Germany
Bryan Lovell	University of Cambridge, UK
Tim Lyons	University of California, USA
Wojtek Majewski	Institute of Paleobiology, Poland
Valeriy Maslennikov	Russian Academy of Sciences

NAME	INSTITUTION
Hansruedi Maurer	ETH, Switzerland
Robert Moritz	University of Geneva, Switzerland
Jim Mortensen	University of British Columbia, Canada
Kiyooki Niida	University of Hokkaido, Japan
Adam Pacey	Imperial College London, UK
Amin Beiranvand Pour	Universiti Teknologi Malaysia (UTM)
Huanchun Qu^	China University of Geosciences
Mega Rosana	University of Padjajaran, Indonesia
Rick Russo	Lawrence Berkeley National Laboratory, USA
Patrick Sack	Yukon Geological Survey, Canada
Howie Scher	University of South Carolina, USA
Richard Sibson	University of Otago, New Zealand
Emily Smyk	Lakehead University, Canada
Thorvaldur Thordarson	University of Iceland
Fernando Tornos	Spanish Space Agency
Fangyue Wang	Hefei University of Technology, China
Jamie Wilkinson	National History Museum, UK
Yuling Xie	University of Science and Technology, China
Lin Ye	China University of Geosciences
Michael Zelenski	Institute of Experimental Mineralogy, Russia
Georg Zellmer	Massey University, New Zealand
Taofa Zhou	Hefei University of Technology, China



VISITORS TO CODES, FROM LEFT: David Rainey, BHP Billiton; Rick Russo, Lawrence Berkeley National Laboratory, USA; Thorvaldur Thordarson, University of Iceland; Ulrich Kesten, Sympatec.



CODES

ARC Centre of Excellence in Ore Deposits
University of Tasmania

Private Bag 79, Hobart, Tasmania, 7001, Australia
Tel: +61 (0) 3 6226 2472 Fax: +61 (0) 3 6226 2547

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OPPOSITE PAGE: The Rio Blanco copper mine in northern Peru – one of the stops on the Ore Deposits of South America short course.



THIS REPORT INCLUDES SECTIONS ON
THE ARC RESEARCH HUB - TRANSFORMING
THE MINING VALUE CHAIN, AND THE
UTAS DISCIPLINE OF EARTH SCIENCES