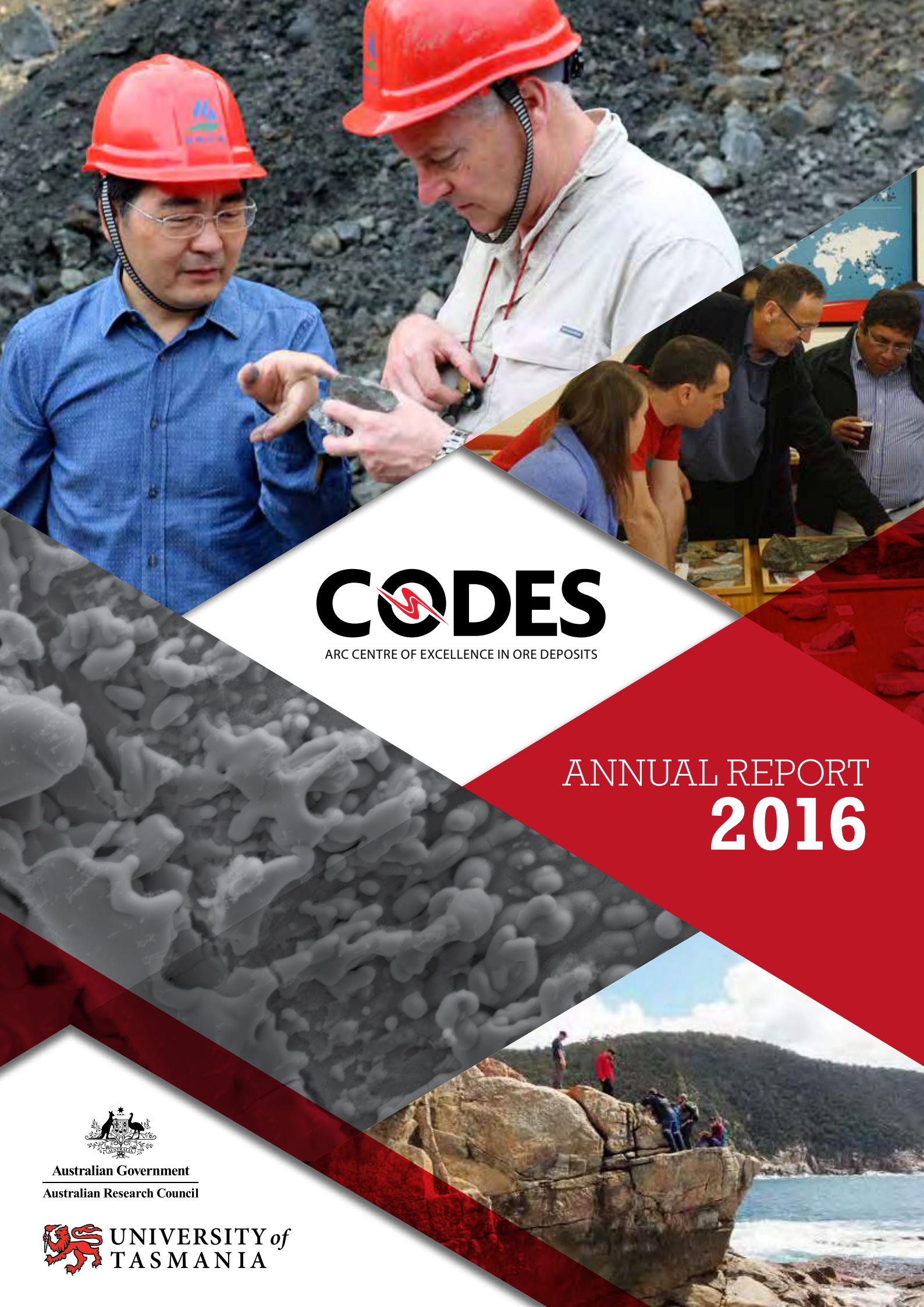




CODES

ARC CENTRE OF EXCELLENCE IN ORE DEPOSITS

ANNUAL REPORT 2016



Australian Government
Australian Research Council



UNIVERSITY of
TASMANIA



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 CLOCKWISE FROM TOP: Participants in the VIEPS Ore Deposit Models course; TOFWERK Time of Flight equipment; Honours student Rebecca Clifton (left), with Anita Parbhakar-Fox (centre) being taken on a guided tour of Norske Skog by Peter Kearney; Colorado River flowing through Granite Gorge in the Grand Canyon. Photo taken during Jacob Mulder's stay in the USA.

FRONT COVER CLOCKWISE FROM TOP LEFT: Director Bruce Gemmell (right) with Taofa Zhou, Hefei University of Technology, during a visit to China; David Cooke (second from right), leading a practical session during the Ore Deposits and Exploration Strategies short course; Ore Deposits and Exploration Strategies short course participants during a field trip to the Freycinet Peninsula, Tasmania.

BACK COVER FROM TOP: The Baw Mar open pit ruby-sapphire mine, Myanmar; PhD student Stephanie Sykora during a field trip to the Freycinet Peninsula, Tasmania.

DIRECTOR'S REPORT

It has been a good year for CODES, marked by positive outcomes across a broad spectrum of performance measures.

AWARDS AND ACCOLADES

It is fitting that I start my roundup by giving prominence to awards and accolades, because without doubt one of the major highlights of the year was Emeritus Professor Ross Large and his Trace Elements in Ancient Oceans team winning a highly prestigious Eureka Prize. The groundbreaking research that earned them the gong linked major evolution and extinction cycles with a drop in the concentration levels of trace elements in ancient oceans, particularly in respect to selenium.

I indicated in my last report that Ross's 'retirement' at the end of 2015 did not mean he was going to ride off into the sunset any time soon, and this outstanding achievement certainly illustrates that point. The award also exemplifies the collaborative nature of our research, with the team including members from the University of California Riverside, the Russian Academy of Sciences and Flinders University.

While the award for Ross and his team may have been the icing on the cake, it was far from the only highlight of the year in terms of recognition for our staff.

Emeritus Professor David Green received the 2016 R.M. Johnston Memorial Medal, which is awarded by the Royal Society of Tasmania to a scholar of great distinction in any field within its purview. Professor Green is indeed a scholar of great distinction, and the medal is a thoroughly deserved addition to the extensive list of accolades earned throughout his long and highly distinguished career.

Professor Pat Quilty, another of our highly decorated researchers, received the Phillip Law Medal from Australian National Antarctic Research Expeditions (ANARE) for his outstanding contribution to Antarctic affairs and the Antarctic community.

Anya Reading received just reward for her exceptional work in teaching and geophysics with a promotion to Professor. Anya received a Fulbright Senior Scholarship last year, and is due to start her extended visit to the University of Colorado early in 2017 as part of that scholarship.

A summary of accolades would not be complete without an acknowledgement of our young postgrads making their mark on the world stage. This year, a special mention goes to PhD students Angela Escolme and Cassady Harraden who were co-recipients of the award for 'Best Paper by a Young Scientist' at the GeoMet 2016 international conference in Perth.

I am also very pleased to report that I have been elected as a future President of the SEG. The SEG is the world's oldest, largest and most influential organisation in the fields of economic geology and mineral deposit discovery, and I consider it a great honour to be chosen as its president. The appointment spans three years. I will be President Elect in 2017, President in 2018, and Past President in 2019.

THE TMVC

The TMVC Research Hub gained significant impetus in its first full year of operations, strengthening its team, and progressing research initiatives across all its themes and key performance areas.

For example, the AMIRA P1153 team initiated field campaigns around the world, at sites in Canada, the USA, Chile, Peru and Serbia. A highlight of this research has been the refinement of techniques for detecting proximity to mineralisation in lithocaps, with the findings already conveyed to collaborating companies via a series of on-site meetings. This type of direct and responsive technology transfer is a hallmark of our research across all areas of our operations, and will continue to be integral to our success in the future.

CRC ORE

The activities of CRC ORE under its extended six-year tenure also started to gather pace. The CRC held its inaugural Annual Assembly in Perth during November, where I was invited to deliver a presentation on CODES' role as an Essential Research Participant. Earlier in the year, CRC ORE Director Ben Adair and Chief Technologist Steve Walters attended our Science Planning Meeting, where Steve gave a presentation on the objectives of the CRC.

Although only a small amount of research was conducted by CODES late in the year, activities are expected to increase considerably over the next twelve months.

THE RESEARCH MODULES

The Ore Deposits: Context and Characterisation Module included 23 projects, spread across a diverse range of geological fields. This high number was achieved through new initiatives being introduced to take the place of studies that had reached natural conclusions. This ongoing regeneration to maintain a critical mass of projects is a healthy sign for this module, and for the future of CODES.

One of these new initiatives is the ARC Linkage project, led by Sebastien Meffre, which is investigating the ore deposits and tectonic evolution of the Lachlan Orogen, in SE Australia. This exciting new project is being conducted in collaboration with five universities, four geological surveys and ten mining industry partners, and aims to increase economic mineral discoveries in the area.

A project that came to an end in 2016 was 'Exploring the Porphyry Environment'. After eight highly successful years, this extensive research project has made a significant contribution to the knowledge base for relevant deposits in the South West Pacific region, thereby maximising opportunities for the discovery of porphyry and epithermal related gold resources. David Cooke and David Selley are to be commended for leading these



studies, and special thanks go to Newcrest Mining for their collaborative and financial support.

The Analytical Laboratories, which are integral to the Enabling Technologies (ET) Module, underpin all our activities, and make a significant contribution to our reputation of being a world leader in ore deposit research. Therefore, it is critical that we plan for ongoing investment in the very latest equipment to ensure that we maintain and enhance our competitive advantage. A key part of this investment plan came to fruition during the year with the installation of the new generation TOFWERK Time-Of-Flight Inductively Coupled Mass spectrometry instrument – the first time that this model had been installed in Australia. This state-of-the-art installation has substantially increased the range and speed of our measurement processes, and greatly enhanced the quality of data for mineral dating.

Also in the ET Module, it was good to see that the team received funding from Laurin Technic for a two-year research project, which will play a key role in the development of fundamental aspects of laser-ablation analysis applied to a range of geological problems.

CONFERENCES, EXHIBITIONS, WORKSHOPS AND FIELD TRIPS

CODES has always played a prominent role at conferences related to geosciences and the minerals industry, and 2016 was no exception. We had booths at Roundup in Vancouver, GeoMet in Perth, AESC in Adelaide, and shared booth facilities with Mineral Resources Tasmania (MRT) at PDAC in Toronto.

In addition to the numerous talks delivered at conferences around the world, our researchers played pivotal roles in the organisation of many of these events. For example, Professor David Cooke was Vice Chair of the Geochemistry of Mineral Deposits Gordon Research Conference, held at Les Diablerets, Switzerland; Dr Anita Parbhakar-Fox was a member of the organising committee for GeoMet 2016 in Perth; and Professor Khin Zaw made a significant contribution to the organisation of the 3rd Myanmar Mining Summit in Yangon. Furthermore, CODES staff and students led a total of 27 workshops, field trips and short courses in Asia, Oceania, Europe and North America.

This high level of involvement plays a huge role in promoting the CODES brand, disseminating our research, and transferring our findings to the minerals industry in order to deliver tangible, and positive, economic outcomes.

NEW PARTNERSHIP PROGRAM

Following feedback from our Advisory Board and Science Planning Panel, we revised our Industry Partnership Program to be better aligned with the evolving needs of current and potential partners. The new package offers a range of cost effective options, improved benefits and more flexibility. Partners can now sign-up on a year-to-year basis, rather than the three-year commitment of the past. Another key benefit for Partners is access to our world-class geoanalytical laboratories, with included services



CLOCKWISE FROM TOP LEFT: Cassady Harraden (left) and Angela Escolme with their joint awards for 'Best Paper by a Young Scientist' at GeoMet 2016; Part of the Eureka Prize-winning team (back row, from left) Jeff Steadman, Aleksandr (Sasha) Stepanov, Jacqueline Halpin, Elena Lounejeva, (front row, from left) Indrani Mukherjee, Sean Johnson, Leonid Danyushevsky and Ross Large; Declan Radford hones his delivery during the new Honours Presentations Skills Workshop; Alumni Jacqueline Blackwell (left) and Tim Stublely with Amelia Rainbow on the CODES booth at Roundup 2016 in Vancouver.

increasing with the investment level – Silver, Gold or Platinum.

The new program was introduced to potential partners in the latter part of the year, to come into effect January, 2017. Initial response has been very positive.

PUBLICATIONS AND INDUSTRY REPORTS

Our output of refereed journal articles increased to 67, just two short of the record of 69 set in 2013. We also retained our status as the leading academic group to publish in *Economic Geology*, only marginally behind the USGS, with predictions that we will pass their overall output in 2017. This is a remarkable achievement, especially when considering our consistently high output in terms of reports to industry. Our output for these reports was 134 in 2016, which is a significant increase on 2015 and well above the ARC Performance Indicator of 80.

MEDIA COVERAGE

It was another good year for CODES in the media, with extensive coverage across all communications platforms. Highlights included the extensive coverage of our success in the Eureka Award; the airing on ABC TV's *Catalyst* program of Jacqueline Halpin and Jacob Mulder's research revealing links between Tasmania, Antarctica and the ancient Nuna supercontinent; and the feature on ABC TV's *Australia Wide* program, showing how studies by our students are helping to mitigate environmental issues caused by old mining practices in western Tasmania.

THE YEAR AHEAD

The signs are good that 2017 will be a period of continued growth for CODES, with a number of initiatives either starting, being proposed, or gathering pace.

An attractive addition to the Master of Economic Geology Program is being introduced early in the year. Ores in Magmatic Arcs builds on the success of Ore Deposits of South America by expanding the location options to include Indonesia, where participants will visit world-class porphyry and epithermal deposits over a two-week period.

A number of initiatives with considerable potential will be progressed, including a proposal for a new Industrial Transformation Training Centre in Advanced Mine Waste, and the possibility of being part of the bid for the MinEx CRC, which proposes to focus on 3D drilling for the discovery and definition of mineral deposits. In addition, late in 2016, we were named as a Secured Partner in Metal Earth; a new Canadian research initiative led by Laurentian University.

We have strengthened our ties with MRT considerably in recent times, and this collaboration is expected to be enhanced even further through the Mining Sector Innovation Program. This joint initiative between CODES, MRT and the Tasmanian Mineral and Energy Council will deliver industry-focussed outcomes in a number of areas within the state, including mine rehabilitation and remediation, development of best practice guidelines for acid mine drainage, and improving the understanding of landslip reactivation.

We will also be expanding on a number of other research initiatives including building on early successes using the newly installed Time of Flight equipment; fostering a collaboration with the University of Bristol on the characterisation of plagioclase reference material; and investigating the significance and extent of Devonian gold mineralisation in the Carlin District.

I wish to thank our students, staff and all our collaborators in industry and academia for their support in 2016, and look forward to the challenges and opportunities that lie ahead in 2017.

STATISTICS AT A GLANCE 2016

Academic Research Staff	51
Postgraduate Students	119
Major Research Projects	51
Countries Involved	27
Publications in Refereed Journals	67
Research Reports to Industry	134
WORKSHOPS AND SHORT COURSES	
Number	27
Countries	11
Attendees	767
FUNDING	
Industry	\$1.3 million
UTAS	\$2.6 million
TMVC	\$1.9 million
WORLDWIDE COLLABORATIONS	
Industry	61
Institutes and Universities	59

VALE KATIE AND GARRY

While this report was being compiled, we sadly lost two of our dearest and most respected staff members with the passing of Katie McGoldrick and Dr Garry Davidson.

GARRY JAMES DAVIDSON

Garry had been with CODES from its inception in 1989, during which time he made an immense contribution to the Centre's success and had a profound influence on the hundreds of students who were fortunate to fall under his supervision and tutelage.

Garry was extremely popular with his students. His love of geology, boundless enthusiasm, and unshakeable belief that the glass is always half full, inspired generations of geoscientists, many of whom have gone on to be appointed to senior roles in industry and academia.

In addition to his undoubted teaching skills, Garry was an exceptional geologist, who was known internationally for his ground-breaking research in areas such as hydrogeology, sediment-hosted ore deposits, stable isotope science and IOCG deposits. He took a lead role in many major conferences, including SEG 2015, and was a prodigious producer of a variety of publications, including refereed journal articles, chapters in books, conference abstracts, and industry reports. After completing his BSc in Geology at ANU, Garry spent a number of years in exploration, which gave him the insights to understand what the minerals industry needs in terms of reporting and technology transfer. After gaining valuable mining experience, he came to UTAS, where he studied for his PhD under the supervision of Ross Large.

Garry also played a leading role in the Tasmanian Division of the Geological Society of Australia, where he was known for continually driving new initiatives, and enthusiastically spruiking the wonders of geology to whomever he came in contact – and more specifically through public outreach activities, of which he was an avid participant.

In recent years, Garry carried a heavy workload, spread across research, teaching, student supervision and Honours co-ordination. He was also leader of the largest research module within CODES, containing 23 major national and international projects, which include collaborations with 29 mining companies and 44 universities, institutes and government departments. Even with such a large workload, Garry maintained a cheery demeanour throughout, treating everyone with considerable respect and kindness. It was impossible not to be touched by Garry's unwaveringly positive outlook on life.

He will be deeply missed, but his spirit lives on through the legacy of his research and, most significantly of all, the many students that he educated, encouraged, entertained, and 'infected' with his irrepressible love of geology.

CATHERINE (KATIE) MCGOLDRICK

Katie McGoldrick was a dedicated and talented Laboratory Assistant, whose extensive knowledge and skills were of immeasurable value to research staff and students. Katie, who had been with CODES since 1998, was an extremely popular member of staff, who was always friendly and willing to share her extensive knowledge of her job with students and researchers.

Katie balanced her working life with looking after four children, and husband Peter, who was a senior member of the CODES research team for many years. As the children grew, she assumed more roles, using her innate organisational skills to ensure a highly efficient service to the Analytical Laboratories, which are so vital to the research activities of CODES and Earth Sciences. Although Katie worked mainly in the practical aspects of laboratory work, she was always willing to help-out wherever needed, including the production of the early annual reports, AMIRA reports and assisting with the day-to-day administration duties of the technical areas where she worked.

Katie will be sorely missed, but never forgotten.

Both Katie and Garry died after brave fights with cancer, which had returned after periods of remission.



PROFILE AND RESEARCH STRUCTURE

AN OVERVIEW

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 119 postgraduate students, further cementing its position as the largest university-based team of ore deposit researchers in the world.

Highly productive worldwide collaborations have been developed with over 61 industry companies, plus a host of joint research initiatives with 59 institutions and universities – 14 in Australia and 45 overseas. It currently has 51 major research projects spanning 27 countries, and all seven continents. It is also the leading academic group to publish in *Economic Geology*. In the past year, it maintained its reputation for delivering excellence in technology transfer by producing 134 reports to industry and conducting 27 short courses, workshops, conferences and field trips in 11 countries, spread around the world.

INDUSTRY-FOCUSSED 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.

RESEARCH STRUCTURE – 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.

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*

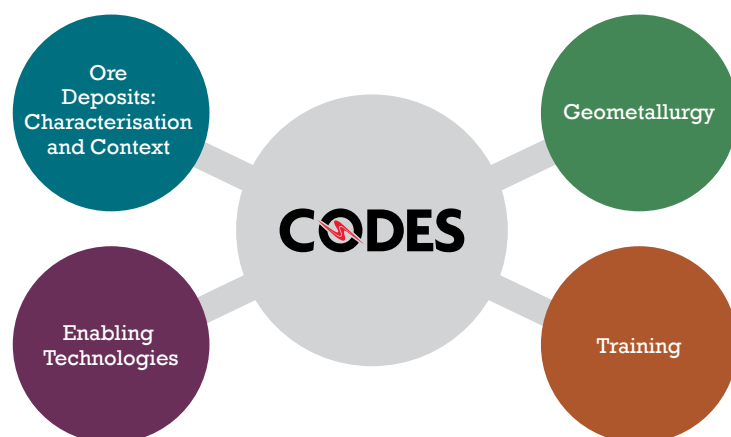
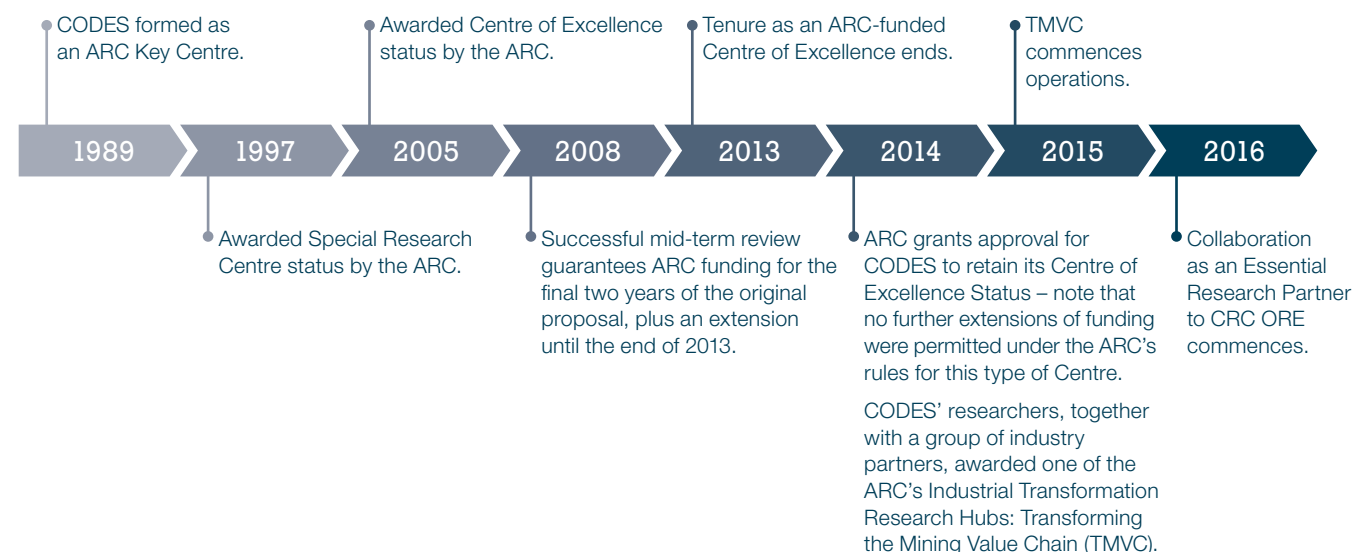
CODES is home to an Australian Research Council Industrial Transformation Research Hub, entitled Transforming the Mining Value Chain (TMVC). The Hub encompasses a wide array of activities from exploration, discovery, ore deposit characterisation, and environmental assessment, through to mining, ore processing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

TMVC activities are covered later in this annual report.

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.

TIMELINE



OPPOSITE PAGE FROM LEFT: PhD student Brian McNulty (far right) visiting the Greens Creek mine in Alaska; Students fossicking in the Phaungdaw Quarry, Myanmar

FROM LEFT: Part of the laser ablation facilities; Master of Economic Geology students performing practical exercises.

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. He is supported in these duties by Professor Leonid Danyushevsky, Deputy Director.

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, the Communications Manager, and the TMVC Research Hub 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 2016

APPOINTMENTS

Dr Martin Jutzeler, who completed his PhD at CODES in 2012, has been appointed as a Lecturer and to conduct research related to volcanology and clastic sedimentology. Martin was previously with the National Oceanography Centre in the UK.

Dr Evan Orovan completed his PhD during the year, and was appointed by the TMVC Research Hub as a Postdoctoral Research Fellow, working in Theme 1 – Detecting proximity to ore (footprints).

Dr Sean Johnson also completed his PhD during the year, and was appointed as a Postdoctoral Research Fellow in LA-ICP-MS.

DEPARTURES ACADEMIC STAFF

Dr David Selley has vacated his position as Research Fellow, but has been retained in an honorary capacity.

PROFESSIONAL STAFF

Dr Sarah Gilbert has left her position as Laser Ablation Technician at the TMVC Research Hub to take up an appointment at the University of Adelaide.

SENIOR 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, metallurgy	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	
Professor David Green, BSc Hons, MSc, DSc, DLitt Hon (UTAS), PhD (Cambridge)	Experimental petrology	Hon	
Dr Jacqui Halpin, BSc Hons (Melbourne), PhD (Sydney)	Metamorphic petrology, geochronology	Hon	
Dr Sean Johnson, BSc Hons (St. Andrews), PhD (UTAS)	Geochemistry, LA-ICP-MS, sedimentology, marine geoscience	100	
Dr Martin Jutzeler, MSc (U Lausanne), PhD (UTAS)	Volcanology and clastic sedimentology	50	
Dr Maya Kamenetsky, PhD (UTAS)	MLA-SEM, metallurgy, 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	20	
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	Hon	•
Dr Peter McGoldrick, BSc Hons, PhD (Melbourne)	Ore deposits and their halos	Hon	
Professor Jocelyn McPhie, BA Hons (Macquarie), PhD (UNE)	Volcanic facies architecture and volcanic textures	Hon	
Associate Professor Sebastien Meffre, BSc Hons, PhD (Sydney)	Petrology and tectonics of the SW Pacific	100	•
Dr Evan Orovan, BSc Hons (Carleton), PhD (UTAS)	Porphyry environment, mineral chemistry and hydrothermal geochemistry	100	•
Dr Karin Orth, BSc Hons (Monash), PhD (UTAS)	Volcanology	40	
Dr Anita Parbhakar-Fox, MSc Hons (London), PhD (UTAS)	Environmental geology, mineralogy, geochemistry	100	•
Professor Anya Reading, BSc Hons (Edinburgh), PhD (Leeds)	Geophysics, seismology, computational methods	50	•
Dr Michael Roach, BSc Hons (Newcastle), PhD (UTAS)	Geophysical responses of ore deposits	20	
Dr Robert Scott, BSc Hons, PhD (Monash)	Structural geology, gold deposits / MTEC Senior Lecturer and Masters Program Coordinator	70	
Dr David Selley, BSc Hons (Adelaide), PhD (UTAS)	Structural geology, basin analysis, ore deposit modelling	Hon	
Dr Jeff Steadman, BSc (Central Missouri), MSc (Iowa)	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: Delegates enjoying a break in proceeding during the Science Planning Meeting; Sean Johnson aboard RV Investigator during a research cruise to the Cascade Seamount.

ACADEMIC/RESEARCH STAFF BASED
AT COLLABORATIVE INSTITUTIONS/INDUSTRY

NAME		% IN CODES	TMVC
Dr John Bishop	Consultant	Hon	
Dr Daniel Bombardieri	Mineral Resources Tasmania	Hon	
Professor Ray Cas	Monash University	Hon	
Kathy Ehrig	BHP Billiton	Hon	•
Associate Professor Jeff Foster	S2 Resources	Hon	
Neil Goodey	Corescan		•
Professor Mark Hannington	University of Ottawa	Hon	
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 / Imperial College 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 Manager	80	
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 Michelle Makoundi	Laboratory Assistant	40	
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 Lichtan, BSc Hons (UTAS)	Curator / Administrative Assistant	25	

ADVISORY BOARD

NAME	
Chair: Paul Heithersay (Could not attend 2016 meeting)	Department of State Development, South Australia
Deputy Chair: Paul Agnew (Chair of 2016 meeting)	Rio Tinto Exploration
Richard Coleman	Pro Vice-Chancellor, Research Infrastructure, UTAS
David Cooke	CODES, UTAS
Paul Cromie	Anglo American
Leonid Danyushevsky	CODES, UTAS

NAME	
Andrew Davies	Teck
John Dickey	Head, School of Physical Sciences, UTAS
Kathy Ehrig	BHP Billiton
Bruce Gemmell	CODES, UTAS
David Green	Mineral Resources Tasmania
Anthony Harris	Newcrest Mining
Adele Seymon	AMIRA International
Noel White	Consultant
Brian Yates	Dean, Faculty of Science Engineering and Technology, UTAS

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
Garry Davidson	Ore Deposits: Characterisation and Context Module Leader

NAME	
Anita Parbhakar-Fox	Acting Geometallurgy Module Leader
Anya Reading	Training Module Co-leader / Coordinator Graduate Research
Helen Scott	ARC TMVC Research Hub Manager
Robert Scott	Training Module Co-leader

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

NAME	
Chair: Bruce Gemmell	Director, CODES, UTAS
Ben Adair	CRC ORE
Paul Agnew	Rio Tinto Exploration
Daniel Bombardieri	Mineral Resources Tasmania
Ralph Bottrill	Mineral Resources Tasmania
Paul Cromie	Anglo American
Andrew Davies	Teck
John Dickey	Head, School of Physical Sciences, UTAS
Mark Doyle	AngloGold Ashanti
Mark Duffett	Mineral Resources Tasmania
Kathy Ehrig	BHP Billiton
David First	Freeport McMoRan
Geoff Fraser	Geoscience Australia
David Green	Mineral Resources Tasmania
Dan Gregory	University of California

NAME	
Anthony Harris	Newcrest Mining
Tony Hope	GHD
Robert Hough	CSIRO
Craig Lindley	CSIRO
Ping-Ping Liu	National Taiwan University
Adele Seymon	AMIRA International
Penny Sinclair	Cameco
Greg Smith	CSIRO
Andrew Somers	SciAps Australia
Steve Turner	Newmont
Steve Walters	CRC ORE
Tom Wesby	First Quantum Minerals
Mike Whitbread	MMG
Noel White	Consultant

CLOCKWISE FROM TOP LEFT: Anya Reading, who was promoted to Professor during the year; Karin Orth with David Green at a function to celebrate Professor Green receiving the 2016 R.M. Johnston Memorial Medal; attendees at the 2016 Science Planning Meeting.



MODULE

ORE DEPOSITS: CHARACTERISATION AND CONTEXT

► OBJECTIVES

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.

► HIGHLIGHTS

CONTINUED CYCLE OF COMPLETION AND RENEWAL

In the three years since its inception, the Module has consistently retained a critical mass of over 20 projects, spread across a diverse range of geological fields. That trend continued in 2016, with the Module comprising 23 projects, which is down by just two, despite seven projects being concluded, placed on hold, or merged by the end of the previous year.

The projects within the Module also continued to have an impact around the world, as the following small sample of highlights illustrates:

> Africa

In Zambia, a robust geochemical proxy for predicting gold grade has been developed via Jacob Heathcote's PhD project at the Kansanshi deposit.

The Newcrest-sponsored 'Architecture of the Birimian belts in Côte d'Ivoire' project, led by David Selley, came to a successful conclusion with the development of a chronostratigraphic framework for the West African country.

> South West Pacific

Another Newcrest-supported project came to an end during the year.

The highly successful 'Exploring the porphyry environment' project, led by David Cooke and David Selley, has been running since 2009, making a significant contribution to the knowledge base for relevant deposits in the South West Pacific region, thereby maximising opportunities for the discovery of porphyry and epithermal related gold resources.

> SE Asia

Khin Zaw continued to play a key role in the SE Asia region. At the 3rd Myanmar Mining Summit, held in Yangon during October, he delivered the introduction to the pre-summit workshop, presented three talks, chaired day three, moderated a panel discussion, and made a significant contribution to the organisation of the event. He also led the CODES SEG Student Chapter's annual international field trip, which this year was to Myanmar.

> North America

Bruce Gemmell co-led a two-day VHMS workshop and a five-day field trip to VHMS and orogenic gold deposits at the GAC-MAC 2016 Conference, held at the Yukon College Campus, Whitehorse, Canada. PhD students Nathan Steeves and Brian McNulty presented papers at the main conference, held from June 1-3. Nathan was also co-leader of the post-conference field trip.

PhD student Jacob Mulder spent most of 2016 at the University of New Mexico, USA, working under the supervision of renowned geologist Professor Karl Karlstrom on the links between early Tasmania and SW Laurentia. These studies formed part of a prestigious Endeavour

► 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.

OPPOSITE PAGE FROM CENTRE, RIGHT: Kathy Ehrig (BHP), William Keyser (PhD student, University of Adelaide), and Nathan Chapman (PhD student, CODES) at Olympic Dam; PhD student Joe Knight sampling from a prospect found in Myanmar. Although the district is well known for hosting epithermal Cu-Au deposits, this is the first evidence of porphyry-style Cu-Au-Mo mineralisation.

ABOVE: Lake Lefroy, Western Australia – area of research for David Douch's PhD project.

ORE DEPOSITS: CHARACTERISATION AND CONTEXT

Postgraduate Scholarship, which he received from the Australian Government the previous year. During his stay, Jacob delivered two oral presentations at the 2016 Geological Society of America conference in Denver, Colorado, including an invited talk in the session 'Tectonics of Mesoproterozoic basins'.

Research by Robert Scott and PhD student Torsten Jensen, in the Carlin District, NE Nevada, has revealed that the presence of syn-sedimentary or early diagenetic gold-bearing layers in the Wispy unit may have important implications for the genesis of the Eocene deposits hosted at this stratigraphic level.

> Australia

New research initiatives include an exciting ARC Linkage project, led by Sebastien Meffre, investigating the ore deposits and tectonic evolution of the Lachlan Orogen, in SE Australia. The project, being conducted in collaboration with five universities, four geological surveys and ten mining industry

partners, aims to increase economic mineral discoveries in the area.

Garry Davidson made a significant contribution towards the research publication in *Lithos* by Coggon et al. which outlined hydrothermal contributions to global biogeochemical cycles. This research utilised insights from the Macquarie Island ophiolite, via results on the Sr isotope perspective of fluid flow in the ~10 Ma mid-ocean ridge crust.

LEADER Garry Davidson

CLUMP MOUNTAIN GEOSCIENCE
Pat Williams

COLORADO STATE UNIVERSITY, USA
Holly Stein

CONSULTANTS
Neil Allen, Wally Herrmann

CURTIN UNIVERSITY
Andrea Agangi, William Collins

DEPARTMENT OF MINERAL RESOURCES, THAILAND
Pol Chaodumrong, Somboon Khositantont

DIRECTORATE OF GEOLOGICAL SURVEY AND EXPLORATION, MYANMAR
Ye Myint Swe

DRUMMOND GOLD
Ed Eshuys

EAST YANGON UNIVERSITY, MYANMAR
Cho Cho Aye

EMMERSON RESOURCES
Grant Osborne

ENTERPRISE METALS
Frank Doedens, Dermot Ryan

FIRST QUANTUM MINERALS
Tim Ireland, Louis van Heerden

GEOFORSCHUNGSZENTRUM POTSDAM, GERMANY
Rainer Thomas

GEOLOGICAL SURVEY OF JAPAN
Kenzo Sanematsu

GEOLOGICAL SURVEY OF NSW
John Greenfield, Robert Musgrave

GEOLOGICAL SURVEY OF SOUTH AUSTRALIA
Adrian Fabris, Steve Hill

GEOMAR, GERMANY
Sven Petersen

HONOURS STUDENTS:
Kathryn Job, Sigmund Lloyd, Tristan Wells

COLLABORATORS:
AKITA UNIVERSITY, JAPAN
Akira Imai

ANGLO AMERICAN
Dave Braxton, Paul Cromie, Neil Macalalad

ANGLOGOLD ASHANTI
Fraser Clark, Sue Finlayson, Michael Nugus

ARGENT MINERALS
David Busch, Todd McGilvray

AUSTRALIAN NATIONAL UNIVERSITY
Marc Norman

BHP BILLITON
Kathy Ehrig

BRITISH GEOLOGICAL SURVEY
Mike Crow

CAMECO RESOURCES
Penny Sinclair, Ben Walsh

CHIANG MAI UNIVERSITY, THAILAND
Phisit Limtrakun, Sampan Singharajwarapan

CHINOVA RESOURCES
Mark McGeogh

CHULALAKORN UNIVERSITY, THAILAND
Abhisit Salam

▶ THE MODULE TEAM

TEAM MEMBERS:

Ron Berry, Stuart Bull, Rebecca Carey, Ben Cave, David Cooke, Matt Cracknell, Leonid Danyushevsky, Paul Davidson, Nathan Fox, Bruce Gemmell, Jacqueline Halpin, Maya Kamenetsky, Vadim Kamenetsky, Ross Large, Jocelyn McPhie, Sebastien Meffre, Evan Orovan, Karin Orth, Anya Reading, Michael Roach, Robert Scott, David Selley, Jeff Steadman, Sasha Stepanov, Jay Thompson, Khin Zaw, Lejun Zhang

PHD STUDENTS:

Olga Apukhtina, Richelle Awid-Pascual, Heidi Berkenbosch, Nathan Chapman, Alex Cherry, David Douth, Esmaeil Eshaghi, Matt Ferguson, Pedro Fonseca, Margy Hawke, Jacob Heathcote, Wei Hong, Qiuyue Huang, Torsten Jensen, Sean Johnson, Joe Knight, Erin Lawlis, Christopher Leslie, Charles Makoundi, Brian McNulty, Indrani Mukherjee, Jacob Mulder, Evan Orovan, Subira Sharma, Nathan Steeves, Stephanie Sykora

MASTERS STUDENTS:

Eyob Andemeskel, Jo Condon, Kyle Hughes, Corey Jago, Sitthinnon Kultaksayos, Peerapong Sritangsirikul

ORE DEPOSITS: CHARACTERISATION AND CONTEXT

GEOSCIENCE AUSTRALIA

Geoff Fraser, David Huston, Roger Skirrow

GNS NEW ZEALAND

Isabelle Chambeftor, Cornel de Ronde

GOLD FIELDS

Matthew Crawford, Leon Grimbeek, Gary Sparks

HANOI UNIVERSITY OF MINING AND GEOLOGY, VIETNAM

Hai Thanh Tran

HOLCOMBE COUGHLIN OLIVER

Nick Oliver

IMEX CONSULTING

Mark Arundell

INSTITUTE OF TECHNOLOGY, INDONESIA

Andri Subandrio

INTREPID MINES

Tom Woolrych

MACQUARIE UNIVERSITY

Elena Belousova, Nathan Daczko

MANDALAY RESOURCES

Josh Greene

MANDALAY UNIVERSITY, MYANMAR

Tin Aung Myint

MANITOBA GEOLOGICAL SURVEY, CANADA

Marc Rinne

MINERAL RESOURCES TASMANIA

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

MMG

Kim Denwar

MONASH UNIVERSITY

Barrie Bolton, Ray Cas

NANYANG TECHNOLOGY UNIVERSITY, SINGAPORE

Grahame Oliver

NEW BOLIDEN

Rodney Allen, Georgian Manuc, Roger Nordin

NEWCREST MINING

Mathieu Ageneau, Karyn Gardner, Anthony Harris, Paul Kitto, Dominic Murphy, Charlotte Seabrook

NORTHERN TERRITORY GEOLOGICAL SURVEY

Dorothy Close, Andrew Wygralak

OZ MINERALS

Hamish Freeman

PACIFICO MINERALS

Barrie Bolton, David Pascoe

PIONEER RESOURCES

David Crook

RIO TINTO EXPLORATION

Bryan Bowden, Greg Clarke, Mawson Croaker

ROYAL HOLLOWAY UNIVERSITY OF LONDON, UK

Tony Barber, Ian Watkinson

RUSSIAN ACADEMY OF SCIENCES

Valeriy Maslennikov

RWTH AACHEN UNIVERSITY, GERMANY

Bernd Lottermoser

SANDFIRE RESOURCES

Bruce Hooper

SHAHROOD UNIVERSITY OF TECHNOLOGY, IRAN

Fardin Mousivand

TARBIAT MODARES UNIVERSITY, IRAN

Sajjad Maghfouri

TASMAN RESOURCES

Rob Smith

TERRAMIN AUSTRALIA

Ken Cross

TINTINA RESOURCES

Jerry Zieg

UNITED STATES GEOLOGICAL SURVEY

Poul Emsbo

UNIVERSITI KEBANGSAAN, MALAYSIA

Mohd Basril Iswadi Bin Basori, Mohd Shafeea Leman

UNIVERSITY OF ADELAIDE

Cristiana Ciobanu, Nigel Cook

UNIVERSITY OF BONN, GERMANY

Chris Ballhaus, Maria Kirchenbaur

UNIVERSITY OF BRITISH COLUMBIA, CANADA

Jim Mortensen

UNIVERSITY OF CALIFORNIA RIVERSIDE, USA

Dan Gregory

UNIVERSITY OF GENEVA, SWITZERLAND

Robert Moritz

UNIVERSITY OF MALAYA, MALAYSIA

Azman Ghandi

UNIVERSITY OF MELBOURNE

Roland Maas

UNIVERSITY OF NEW MEXICO, USA

Karl Karlstrom

UNIVERSITY OF OTTAWA, CANADA

Mark Hannington

UNIVERSITY OF PADJAJARAN, INDONESIA

Mega Rosana

UNIVERSITY OF SOUTHAMPTON, UK

Rosalind Coggon

UNIVERSITY OF TASMANIA

Christian Dietz, Karsten Goemann, Taryn Noble, Thomas Rodemann, Joanne Whittaker

► PROJECTS

THEME 1 – ORE FERTILITY OF THE CRUST AND MANTLE

- > Pegmatites and Pegmatite-related ores[^]
- > Tectonic and Cu-Au and Au mineralisation of Western Myanmar-Sumatra Terrane
- > Architecture of the Birimian belts in Côte d'Ivoire
- > Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia[^]

THEME 2 – VOLCANISM, AND ITS EFFECT ON ORE FORMING PROCESSES

- > VHMS research – modern
- > VHMS research – ancient
- > Volcanology related to ore deposits

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
- > Ore deposit cycles and ocean/atmosphere conditions[^]
- > Significance and extent of Devonian gold mineralisation in NE Nevada, USA: a critical primer to a world-class gold district?[^]

THEME 5 – THE ORE AFFECTED CRUST

- > The power of pyrite
- > Integrating geology and geophysics for resources targeting
- > Application of sulfide S and carbonate C-O isotopes to ore genesis and exploration
- > IOCG and related deposits^{^^}
- > The characteristics and role of colloidal silica fluids in the formation of the Grieves Siding Pb-Zn prospect, western Tasmania
- > Geology and genesis of the Invincible gold deposit, St Ives

THEME 6 – DATES AND PLATES

- > Building Tasmania: The Cambrian and beyond
- > Structure of SE Australia using multiple geophysical methods

[^] New project

^{^^}Previously named Australian hydrothermal IOCG and related deposits

► PROJECT SUMMARIES

THEME 1 – ORE FERTILITY OF THE CRUST AND MANTLE

PEGMATITES AND PEGMATITE-RELATED ORES

Leader: Paul Davidson

Collaborator: Rainer Thomas

This new initiative is examining melt-melt immiscibility in felsic silicate melts, in the formation of pegmatites and pegmatite-related ore deposits. The work builds on the research conducted under the Melt-Melt Immiscibility and the Origin of Magnetite-Apatite Deposits project, which has now come to a conclusion.

Pegmatites are noted for the presence of giant crystals, sometimes including rare minerals and gems, even though their major element chemistry differs little from the standard haplogranitic melts, which are generally accepted as their parental magmas.

Therefore, it can be inferred that something in their origin favours extremely efficient partitioning, which would explain the high rare element concentrations (up to ore-grade). However, even in locations hosting pegmatite ore bodies, most pegmatites are barren. This leads to the conclusion that there are still many additional complexities to be unravelled through this research.

During the year, a paper was published in *Ore Geology Reviews* entitled 'Revisiting complete miscibility between silicate melts and hydrous fluids, and the extreme enrichment of some elements in the supercritical state'. A second paper, entitled 'Origin of miarolitic pegmatites in the Königshain granite; Lusatia', was published in *Lithos*. Both publications were authored by Rainer Thomas and Paul Davidson.

Researchers, including PhD student Jacob Mulder, rafting down the Colorado River, Grand Canyon, Arizona during a University of New Mexico geoscience research trip.

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

Leader: Khin Zaw

Team Members: Ross Large, Sebastien Meffre, Evan Orovan

Students: Joe Knight, Charles Makoundi

Collaborators: Cho Cho Aye, Tony Barber, Mohd Basril Iswadi Bin Basori, Pol Chaodumrong, Mike Crow, Azman Ghandi, Akira Imai, Somboon Khositantont, Mohd Shafeea Leman, Phisit Limtrakun, Robert Moritz, Tin Aung Myint, Grahame Oliver, Mega Rosana, Abhisit Salam, Kenzo Sanematsu, Sampan Singharajwarapan, Holly Stein, Andri Subandrio, Ye Myint Swe, Hai Thanh Tran, Ian Watkinson

This research builds 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 mainly at the tectonic, Cu-Au, and Au mineralisation of the Western Myanmar-Sumatra Terrane.

PhD student Joe Knight continued his research project entitled 'Geodynamic and metallogenic setting of Cu-Au mineralisation in Myanmar: Implications for mineral exploration', which is being funded by Anglo American. During the year, Joe completed his field work in Myanmar, which included revisiting areas of significant interest. While these field areas included aspects of the Western Myanmar Terrane, they also encompassed a number of other sites within the country. Preliminary laboratory work has been completed and the documentation of

the geological findings is underway. In 2017, Joe plans to undertake further laboratory work to gain a greater understanding of the mineralisation that has been located during the field work.

Project leader Khin Zaw is compiling a publication for the Geological Society of London and Myanmar Geosciences Society, which is based on his extensive geological experience in the country, dating back to 1968. The publication will be entitled 'Memoir on Myanmar: Geology, Resources and Tectonics'. In addition, Khin Zaw played a key role in the 3rd Myanmar Mining Summit, held in Yangon during October. His contribution included delivering the introduction to the pre-summit workshop, presenting three talks, chairing day three, and moderating a panel discussion. He also made a significant contribution to the organisation of the event.

ARCHITECTURE OF THE BIRIMIAN BELTS IN CÔTE D'IVOIRE

Leader: David Selley

Team Members: Sebastien Meffre, Sasha Stepanov

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

This Newcrest-sponsored project, initiated in August 2015, aimed 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, has been replicated in this project.

In 2016, work has been concentrated in the central and western parts of Côte d'Ivoire, in areas where the preserved Birimian sequence is both near-complete and relatively well-exposed. Results of field-based structural and stratigraphic analysis, coupled with geochronology, support existing models of a transition from ocean-floor and island-arc magmatism, through arc accretion, and ultimate collision and exhumation. The geochronology, in particular, has revealed some unexpected outcomes, with huge volumes of volcano-sedimentary strata having accumulated during only the youngest phases of basin growth.

Upsection transitions from subaqueous to subaerial depositional environments, evidence of intrabasinal cannibalisation, rapid exhumation and reworking of coeval plutonic rocks, and development of early stage, foliation-lacking recumbent folds within these younger sequences favour a syn-orogenic foreland basin environment. Gold mineralisation appears to have been multistage, bracketing the onset of collision and ultimate orogenic collapse.

With the successful progression of a robust chronostratigraphic framework for the development of the Birimian Belt in Côte d'Ivoire, this project has now concluded. However, CODES will continue to collaborate with Newcrest to expand the country's geochronological dataset.



LEFT: Bruce Gemmell (second from right) leading a post conference field trip in Alaska, which formed part of the GAC-MAC 2016 conference in Whitehorse, Yukon, Canada.

RIGHT: Field trip area close to Juneau, Alaska.

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

Leaders: Sebastien Meffre, David Cooke, Matt Cracknell, Joanne Whittaker (IMAS)

Team Member: Jeff Steadman

Students: Kyle Hughes, Corey Jago, Kathryn Job, Sitthithon Kultaksayos, Christopher Leslie, Sigmund Lloyd, Peerapong Sritangsirikul, Tristan Wells

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

This ARC Linkage project aims to improve economic mineral discoveries through an increased understanding of the geology and tectonic evolution of the Lachlan Orogen in southeastern Australia; and to integrate that knowledge with existing geological information to subsequently develop predictive and explanatory models.

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

A successful recruitment campaign has resulted in eight students being brought into the team – one PhD, four Masters and three Honours. The services of CODES' postdoctoral research fellow Jeff Steadman have been secured immediately, with a project manager, Irina Zhukova, expected to start in the new year. Both positions are on a part-time basis.

Although research is still in the early stages, all deadlines so far have been met or exceeded. Geochemical analyses and data compilation activities have begun and will continue throughout 2017.

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, neared completion in 2016. 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 trace element mapping, using synchrotron radiation XRF and LA-ICP-MS of Cu- and Zn-rich black smoker chimneys from the volcano, was prepared and will be submitted to *Economic Geology* in early 2017.

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. A manuscript in preparation for publication in *Economic Geology*.

VHMS RESEARCH – ANCIENT

Leader: Bruce Gemmell

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

Students: Jo Condon, Margy Hawke, Brian McNulty, Nathan Steeves

Collaborators: Mohd Basril Iswadi Bin Basori, Rosalind Coggon, Mark Hannington, Sajjad Maghfouri, Andrew

McNeill, Jim Mortensen, Fardin Mousivand, 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 2016, research was undertaken on deposits in the Mount Read Volcanic Belt (Tasmania), DeGrussa and Jaguar (Western Australia), Greens Creek (Alaska), Myra Falls (Canada), Tasik Chini (Malaysia), Nuduh (Iran) and Macquarie Island.

In collaboration with Mark Hannington from the University of Ottawa, Nathan Steeves continued his PhD investigation of the mineralogy, metal distribution and geomettallurgical characteristics of the complex ore bodies at the Greens Creek VHMS deposit in Southeast Alaska. Nathan presented his findings at the GAC-MAC conference in Whitehorse, Yukon, where he played a key role as co-leader, with Bruce Gemmell, of a post-conference field trip covering the orogenic gold and VHMS deposits in his research area. He also published a paper in *Economic Geology* entitled 'The Glacier Creek Cu-Zn VHMS deposit, Southeast Alaska: An addition to the Alexander Triassic Metallogenic Belt'. This 2016 publication was based on Nathan's Masters research at the University of Ottawa, which was undertaken in collaboration with CODES.

Brian McNulty continued his PhD research on the geologic and structural setting of the West Block area at the Myra Falls VHMS deposit on Vancouver Island, Canada. 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

PhD student Joe Knight discussing the geology and alteration of the Mahar San Cu-Au prospect in the Wuntho Massif, Upper Myanmar.

Participants in the post GAC-MAC Conference field trip at the Palmer Project in Alaska. Photograph taken from the ridgeline opposite the South Wall Zone, with Mount Henry Clay in the distance.



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. During the reporting period, Brian also presented his findings at the GAC-MAC conference, and was awarded a \$5,000 USD research grant from the Society of Economic Geologists (Canada Foundation) to complete TIMS zircon U-Pb analyses on the host rocks at Myra Falls.

Khin Zaw presented the results of his research on the VHMS deposits in mainland SE Asia at the IGC meeting in South Africa. Mohd Basril Iswadi Bin Basori published a paper in *International Geology Review* on the geochemistry, geochronology, and tectonic setting of early Permian VHMS deposits of the Tasik Chini district, Malaysia. He has also had a paper on the Pb isotopes of the Tasik Chini deposit accepted by the *Island Arc* journal. The geology, ore facies and sulfur isotope geochemistry of the Nudeh Besshi-type volcanogenic massive sulfide deposit, southwest Sabzevar basin, Iran, was published by Maghfouri et al. in the *Asian Journal of Earth Sciences*.

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 submitted her thesis in 2016, and a moderate number of corrections will be completed in early 2017. The second study was a Master of Economic Geology project by Jo Condon, which focussed on the ore and gangue mineralogy, textures, paragenesis, and mineral chemistry of two of the ore lenses at DeGrussa. Jo's thesis was passed and she graduated in 2016.

Susan Belford, a former PhD student of Garry Davidson, continued publication of her PhD results with co-authorship of a manuscript on the Jaguar-Teutonic Bore field for the AusIMM's *Australian Ore Deposits* monograph.

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

Garry Davidson made a significant contribution to the ocean crust hydrothermal activities through the publication in *Lithos* by Coggon et al. of the results on the Sr isotope perspective of fluid flow in the ~ 10 Ma mid-ocean ridge crust at Macquarie Island. This research outlines the hydrothermal contributions to global biogeochemical cycles based on insights from the Macquarie Island ophiolite.

VOLCANOLOGY RELATED TO ORE DEPOSITS

Leader: Rebecca Carey

Team Members: Jocelyn McPhie, Karin Orth, Robert Scott

Students: Eyob Andemeskel, David Douth, Pedro Fonseca

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

Pedro Fonseca's PhD thesis on the internal stratigraphy, volcanology and correlations in the Mount Read Volcanics in western Tasmania was submitted and approved. Pedro examined the complicated volcanic and sedimentary facies that occur between Hellyer in the north and White Spur in the south. He was able to characterise the stratigraphic levels where the known VHMS deposits occur, and demonstrate the critical importance of information on seafloor sulfide deposition versus subseafloor replacement, in exploration focussed on prospective stratigraphy.

Former CODES PhD student, Carlos Rosa, worked on the volcanology of the host succession to the Iberian Pyrite Belt VHMS deposits in Spain and Portugal. Carlos published a paper in the *Journal of Volcanology and Geothermal Research* on peperite, one of the most common, and widely misidentified, facies in VHMS successions.

Ray Cas and Robert Scott co-supervised David Douth's PhD research on the volcanology and ore prospectivity of the transition from the Late Archean submarine Black Flag Beds/Group to the subaerial Merougil Formation at the St Ives gold camp, Kambalda, Western Australia. This research is reported in greater detail in the final project within Theme 5 of this Module.

Research on the Rosebery Group, western Tasmania, by Master of Science student Eyob Andemeskel, made significant advances in 2016. Lithofacies, lithogeochemical, and structural analyses have underpinned local and regional correlation of the enigmatic sequence, and determined its position relative to strata prospective for VHMS mineralisation. A correlate of the Rosebery-Hercules host package is considered to be structurally repeated in the footwall of the Rosebery Fault, including a significant strike length.

THEME 3 – MAGMATIC-HYDROTHERMAL PROCESSES AND ORES

EXPLORING THE PORPHYRY ENVIRONMENT

Leaders: David Cooke, David Selley

Students: Erin Lawlis, Evan Orovan

Collaborators: Karyn Gardner, Anthony Harris, Marc Rinne

The team has worked in close collaboration with Newcrest Mining to obtain new knowledge and maximise opportunities for the discovery of porphyry and epithermal related gold resources in the South West Pacific region. The research advanced the conceptual models and exploration techniques at the relevant deposits and districts. This new knowledge was passed directly to Newcrest geologists through onsite training. The close working relationship with Newcrest throughout the life of this project was facilitated by the company's strong leadership in research, both logistically and financially.

Most aspects of this project have now been completed, with the following activities to be reported for the year:

- > Evan Orovan's PhD thesis on the Namosi porphyry deposits, Fiji, was examined and accepted early in the year. Evan is preparing manuscripts from his thesis for submission in 2017.
- > Marc Rinne is preparing manuscripts from his thesis on the Golpu porphyry Cu-Au deposit, PNG.
- > The geology chapter of Erin Lawlis's PhD study of the Kapit NE ore zone at the Lihir Au deposit, Papua New Guinea, was completed, with the remaining chapters to be finalised in 2017.

Stephanie Sykora's research project was transferred to the TMVC research hub at the end of 2015.

OLYMPIC DAM

Leader: Vadim Kamenetsky

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

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

Collaborators: Andrea Agangi, Chris Ballhaus, Elena Belousova, Isabelle Chambefort, Christiana Ciobanu, Nigel

Cook, Ken Cross, Kathy Ehrig, Karsten Goemann, Maria Kirchenbaur, Roland Maas

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

In particular, the team has quantitatively assessed the mineral, geochemical and stable and radiogenic isotope compositions of major ore-bearing assemblages (depositional events) and the relative timing of their formation. These studies were coupled with an evaluation of the geochemical specialisation of likely source rocks and magmas, positioned in space and time, including both ore-forming metals and non-metallic components.

Additionally, significant effort has been dedicated to establishing the age of regional metamorphic, magmatic and sedimentary rocks that were likely sources of mineral constituents and mineralising fluids for the deposit. A major outcome of the project has been the establishment of the relationships between the local, regional and continent-scale tectonic events and ore formation. These findings will be further used in deciphering the origin and evolution of Olympic Dam within time, space and a geodynamic context.

A number of major papers were published during the year, as follows:

- > A paper in *Precambrian Research* by McPhie et al., described the Mesoproterozoic bedded clastic facies (BCF) that occur in the Olympic Dam Breccia Complex (ODBC). The BCF comprise five main associations that have distinct textures and components and have not been mixed. Major sources of detritus were felsic and mafic volcanic units and granitoids of the ~1590 Ma Gawler Silicic Large Igneous Province (SLIP). Archean and Paleoproterozoic zircons in well-sorted quartz-rich sandstone indicate that older Gawler Craton basement successions also contributed sediment to the BCF. The depocenter in which BCF accumulated may have been bounded by a combination of NE-

and NW-striking faults. The BCF position at the top of the ODBC, and incorporation of BCF clasts into the ODBC, strongly indicate that the fault-controlled sedimentary basin was in place when the breccia complex and the Olympic Dam ore deposit were still forming.

- > A paper in *Precambrian Research* by Huang et al., focused on understanding the earliest magmatism of the ca. 1590 Ma Gawler SLIP. In addition to minor occurrences of olivine-phyric basalts at Kokatha and Mount Gunson, it describes rock lithologies intersected by drill holes at the Olympic Dam deposit and the Wirrda Well Cu-Au prospect. U-Pb dating of apatite confirmed temporal correlation of picrite lavas and dykes with the ca. 1590 Ma Gawler SLIP. The compositions of Cr-spinel correspond to those in island-arc volcanics and continental flood basalts, suggesting that the parental magmas originated in the rifted continental margin (supra-subduction zone). The team envisage that the heat flux from mantle-derived magmas caused large-scale partial melting of crustal rocks, which subsequently gave rise to silicic magmas of the Gawler SLIP and initiated the formation of Olympic Dam.

- > Papers in *Precambrian Research* by Huang et al., and *Contributions to Mineralogy and Petrology* by Apukhtina et al., focused on post-magmatic features (veins and alteration) of mafic dykes that intruded the Roxby Downs granite in the Mesoproterozoic (ca. 1590 Ma) and Neoproterozoic (ca. 830 Ma). The team aims to recognise the potential contribution of alteration processes of mafic rocks to the present-day metal endowment of the Olympic Dam deposit in terms of Fe, P and Cu contents.

A symposium entitled '40th Anniversary of Olympic Dam' was held as part of the Australian Earth Sciences Convention in Adelaide, in June, and featured eight invited presentations by the research team.

ORE DEPOSITS: CHARACTERISATION AND CONTEXT

PhD student Wei Hong collecting unidirectional solidification textures (USTs) and tourmaline orbicules from the Heemskirk Granite at Granville Harbour, western Tasmania.

MAGMATIC-HYDROTHERMAL VOLATILE EXSOLUTION AND MINERALISATION IN TASMANIAN Sn GRANITES

Leader: David Cooke

Team Members: Nathan Fox, Evan Orovan, Michael Roach, Lejun Zhang

Students: Wei Hong, Erin Lawlis, Stephanie Sykora

Collaborators: David Huston, Roland Maas

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

- > Develop a mineralogical paragenesis model and determine if the mineral chemistry of tourmaline could 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.

Large volumes of granites were emplaced across Tasmania in the mid-Palaeozoic. Many of these granites have distinctive magmatic –hydrothermal features, while others produced world class Sn-W deposits. Distinctive tourmaline-and quartz-rich magmatic –hydrothermal features characterise the Heemskirk and Pieman Heads granites of western Tasmania. They include tourmaline-rich patches, orbicules, miarolitic cavities, veins, and unidirectional solidification textures (USTs). Tourmaline cavities and USTs were observed in the Heemskirk Batholith, but not in the Pieman Heads Granite. These textural

features occur in discrete layers in the roof zone of granitic sills within the Heemskirk and Pieman Heads granites.

Isotopic and trace element variations in tourmaline and quartz from the different tourmaline-rich textures were caused by volatile exsolution and fluxing of aqueous boron-rich fluids that separated from the granitic melts during the emplacement of S-type magmas into the shallow crust. Volatile-rich hypersaline fluids separated from the crystallising aluminosilicate magmas due to liquid immiscibility, ascending and coalescing between grain boundaries of the crystallising melts via tube plumes and/or spanning clusters.

Rayleigh fractionation modelling indicates that approximately 60 % to 77 % of the boron was removed from the initial felsic melt to produce tourmaline patches, whereas higher degrees of fractional crystallisation of the initial granitic melt (up to 90 %) led to exsolution of boron-rich hypersaline fluids, from which the tourmaline orbicules and miarolitic cavities precipitated.

This project concluded at the end of the year, with the submission of Wei Hong's PhD thesis. The research results were delivered via a workshop and field trip in western Tasmania during December, which attracted 19 participants from universities, government and industry. Manuscripts have been reviewed and revised for *American Mineralogist* and *Gondwana Research*, and will be published in 2017.

THEME 4 – BASIN PROCESSES AND ORES

McARTHUR BASIN COPPER

Leader: Garry Davidson

Team Member: Stuart Bull

Collaborators: Barrie Bolton, Dorothy Close, Bruce Hooper, David Pascoe, Andrew Wygralak

This project, funded by the Northern Territory GS, with in-kind collaboration from Pacifico Minerals, and Sandfire Resources, aims to develop an improved understanding of copper ore formation processes in the central western McArthur Basin.

There are several Cu deposit 'camps' that show no clear relation to the major Zn-Pb mineralisation in the basin. One of these is being referred to as 'Amelia-style' in the project, due to a prevalence of occurrences in the Amelia Dolomite, part of the lowermost McArthur Group. The other is being termed the 'Stanton/Redbank' style, because Redbank is the most significant Cu mineralisation to date in the basin, and it is hosted by altered mafic volcanic rocks (Gold Creek Volcanics) in and around the Wollogorang Formation of the deeper Tawallah Group. In the reporting period, the most promising Amelia-style mineralisation, Coppermine Creek, was profiled for C-O isotopes and, to a lesser extent, S isotopes.

The results are being compared to major sediment-hosted copper deposit signatures, and the team plan to continue to evaluate other profiles at different distances from this mineralisation, as well as determining the background geochemical and isotopic signature of the host unit.

A decision regarding the future directions of this research is expected to be made in late July 2017.

KANSANSHI GOLD

Leader: Robert Scott

Team Member: Garry Davidson

Student: Jacob Heathcote

Collaborators: Tim Ireland, Louis van Heerden

This research project is funded by Kansanshi Mining (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 has an output of around 100,000 ounces of gold per year. Gold and copper principally reside in sheeted arrays of quartz – carbonate – sulfide veins, which range from a few centimetres to over 10 m wide. Mineralisation of the adjacent wall rocks also reach ore grade locally. The coarse grain-size of the veins, which often include crystals of gangue and sulfide minerals many centimetres across, coupled with the strong partitioning into near monomineralic domains, make the Kansanshi veins particularly challenging subjects for both representative sampling and analysis of mineral paragenesis. In addition, much of the recovered gold is relatively coarse grained (>100 microns) and has a nuggetty distribution.

The primary objectives of the project are to:

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

To achieve these objectives, PhD student Jacob Heathcote has undertaken detailed core logging, pit mapping, and sampling throughout the Kansanshi mine area. Whole rock

geochemistry, detailed petrography and micro-analytical studies have been completed on most of the samples collected.

In 2016, Jacob completed detailed petrographic analysis (optical microscopy $\pm$ SEM) on a suite of 230 primary ore and altered wall rock samples from the sulfide zone. For each sample in which gold was identified, Jacob documented the dimensions and habit of the gold grains, together with their immediate mineral associations. Although gold searches using intact rock samples are notoriously difficult, particularly for lower grade ores, Jacob's identification of gold in intact rock specimens now extends to over 800 grains across 54 samples. The gold grain-size distribution documented in these samples closely resembles that for gravity recovered gold from the deposit (KMP unpublished data), providing confidence that Jacob's observations of gold occurrence are statistically significant, and representative of the deposit as a whole. Through this painstaking work, Jacob has developed robust paragenesis for gold, sulfides and gangue minerals in the primary (sulfide zone) ores at the deposit.

In order to understand the role of weathering and near-surface chemical processes on gold distribution in the oxide zone, Jacob investigated the morphology, grain-size and composition of gravity-recovered gold from the oxide circuit at the deposit, and compared this to his data on gold in the primary ores.

The project has also involved detailed statistical analysis of KMP's geochemical database, augmented by 235 new fire assay gold analyses, and 58 whole rock XRF analyses obtained specifically for this study. This work was aimed at improving gold grade prediction at the mine through more rigorous geochemical characterisation of gold mineralised veins and wall rocks, and determining the extent to which chemical changes in the wall rocks (due to hydrothermal alteration) influenced the composition and mineralogy of the adjacent veins. A highlight of this aspect of the study has been the development of a robust geochemical proxy for predicting gold grade at the deposit.

URANIUM CONCENTRATIONS IN BASINS

Leader: Garry Davidson

Team Member: Sebastien Meffre

Collaborators: Karsten Goemann, Grant Osborne, Penny Sinclair, Ben Walsh

This project is focussed on researching the nature and causes of uranium concentration in sedimentary basins. Several basins were researched in 2016, and the team achieved the following outcomes:

- > Reviewers recommended that further analysis was required for a manuscript on epigenetic U-P mineralisation at the Northern Star Cu-Au ironstone mine, which is being conducted.
- > In the East Alligator Rivers Province, Northern Territory, the Angularli U unconformity-style mineralisation pilot project was approved for research by the JV partners Cameco (managing) and Rio Tinto Exploration. Working in close collaboration with Cameco geologists Ben Walsh and Penny Sinclair, preliminary petrological studies were carried out in the area, along with hyperspectral mineralogical determination of all samples. These results will be compared to whole core hyperspectral logging results attained by the Northern Territory Geological Survey to evaluate potential anomalies.

In the coming year, the team aims to undertake MLA-SEM-based detailed petrology, LA-ICP-MS analysis, and dating of appropriate phases that emerge. A major report is scheduled to be produced in July 2017.

ORE DEPOSIT CYCLES AND OCEAN/ATMOSPHERE CONDITIONS

Leader: Ross Large

Team Members: Leonid Danyushevsky, Sebastien Meffre, Jeff Steadman

Students: Sean Johnson, Charles Makoundi, Indrani Mukherjee

Collaborators: Dan Gregory, Valeriy Maslennikov

This project is investigating what ore deposits can reveal about upper crustal, ocean and atmosphere conditions. For example, why are sediment-hosted gold, banded iron formations and VHMS deposits

abundant in the period 3800 to 1800 Ma, whereas SEDEX Pb-Zn-Ag, sedimentary uranium and IOCG deposits are more prevalent in the period 1800 to 800 Ma? Most previous researchers ascribe this difference to a plate tectonic process, but there is increasing evidence, based on geochemical proxies derived from sedimentary pyrite, that atmosphere and upper crustal pO₂ and pCO₂ were the most important parameters. A manuscript on this topic has been reviewed for *Economic Geology* and will be published early in 2017.

A second focus of the research is on the genesis of highly metalliferous black shales containing Zn, Mo, Se, Ni, Cu and U. Sean Johnson successfully completed his PhD on this topic, with a focus on the Talvivaara deposit in Finland. The team's research has shown that metalliferous organic-rich shales occur at particular times through Earth history that correspond with pulses in the level of O₂ in the atmosphere. A manuscript on this aspect of the research has been submitted to *Mineralium Deposita*.

This project is being conducted in parallel with the Trace Elements in Past Oceans project in the Discipline of Earth Sciences. The combined research projects won the prestigious 2016 Eureka Award for Interdisciplinary Research.

SIGNIFICANCE AND EXTENT OF DEVONIAN GOLD MINERALISATION IN NE NEVADA, USA: A CRITICAL PRIMER TO A WORLD-CLASS GOLD DISTRICT?

Leaders: Robert Scott, Vadim Kamenetsky

Team Members: Ron Berry, Jacqueline Halpin, Sebastien Meffre

Student: Torsten Jensen

Collaborator: Poul Emsbo

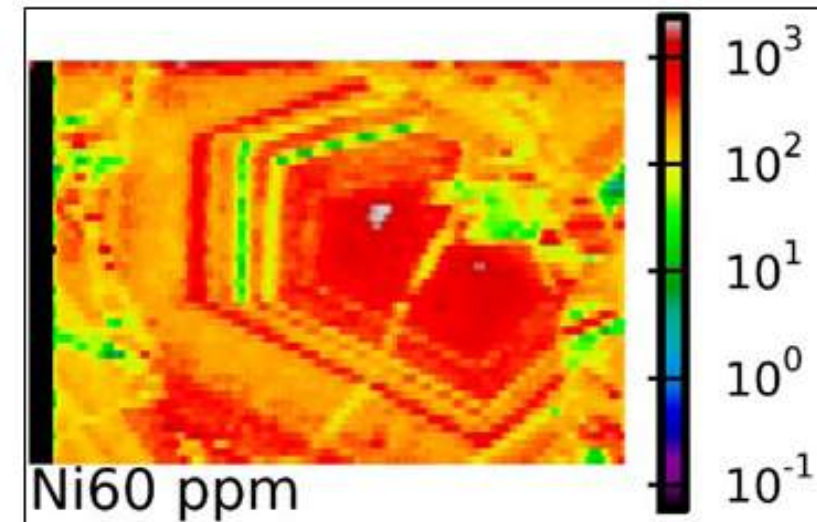
This project is investigating the primary compositional characteristics and diagenetic and hydrothermal alteration history of the sedimentary host rocks to one of the world's great gold provinces, the Carlin District in NE Nevada. In the project's first year, research has focused on characterising samples from the Wispy unit of the Devonian Popovich Formation. This unit forms the principal stratigraphic host to gold deposits on the northern Carlin Trend, and is the

source of well over 50 million ounces of gold.

Gold in Carlin deposits is principally contained in micron-sized grains and overgrowths of arsenian 'Carlin-type' pyrite (1000s ppm Au), disseminated throughout the mineralised rocks. Carlin-type pyrite formed during widespread Eocene hydrothermal activity in NE Nevada, ~38 million years ago. While the epigenetic nature of the Carlin deposits is well established (e.g. roughly 350 million years younger than the main stratigraphic host on the north Carlin Trend), the remarkable local stratigraphic confinement of so many Carlin deposits is largely unexplained.

This study investigates the extent to which primary compositional characteristics of the host rocks, and modifications during diagenesis and/or hydrothermal alteration history, may have influenced the subsequent distribution of gold. Of particular interest is the question of whether there is evidence for syngenetic gold in the Wispy unit, as has been previously identified at higher stratigraphic levels in the Popovich Formation. Although controversial, previous researchers have argued that widespread gold enrichment during deposition of the host rocks may have contributed significantly to the gold endowment of the Eocene deposits.

A major highlight of the research conducted by PhD student Torsten Jensen was the discovery of a single, ~5 mm wide, native gold-bearing sedimentary layer in a Wispy Unit sample from the Screamer deposit (north Carlin Trend). The layer contains numerous irregularly shaped to rounded gold grains, 5–10 microns in diameter. Some are embedded in, and apparently overgrown by (i.e. older than), Fe-bearing dolomite, which forms thin overgrowths on early diagenetic dolomite in most of the Wispy unit samples studied. Previous researchers have interpreted that similar Fe-bearing dolomite in the Wispy unit was also diagenetic in origin. Although the native-gold bearing sample was also affected by Eocene mineralisation, Carlin-type pyrite in the sample post-dates the Fe-dolomite overgrowths, and thus formed after the native gold. Work to constrain the age of the Fe-dolomite overgrowths is continuing, but if these are as old as suggested by previous



Hyphenate, as follows: LA-ICP-MS image of nickel content in pyrite from an IOCG deposit, showing an early Ni enrichment stage with coherent banding which has been partially obliterated by a second Ni enrichment stage. The pyrite thus preserves multiple stages of fluid evolution in this deposit.

researchers, the presence of syn-sedimentary or early diagenetic gold-bearing layers in the Wispy unit may have important implications for the genesis of the Eocene deposits hosted at this stratigraphic level.

THEME 5 – THE ORE AFFECTED CRUST

THE POWER OF PYRITE

Leaders: Jeff Steadman, Ross Large

Team Members: Matt Cracknell, Leonid Danyushevsky, Sebastien Meffre

Students: Sean Johnson, Charles Makoundi, Indrani Mukherjee

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

The 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.

The project team uses the vast database on hydrothermal and sedimentary pyrite developed at CODES to assist mining and exploration companies in the discovery of new resources. A number of exploration companies have added the pyrite chemistry fertility and vectoring technology developed at CODES to their exploration tool kit since the commencement of this initiative.

The research is split into the following sub-projects:

- > Pyrite and pyrrhotite as ore vectors and stratigraphic markers for orogenic gold, Carlin gold, VHMS, IOCG, sediment-hosted copper, and stratiform zinc targets.
- > South Australia pyrite, hematite, and magnetite fingerprint database.
- > McArthur River Basin pyrite research.
- > DeGrussa VHMS vectoring* (research is currently on hold, but expected to commence again in 2017).

Additional research on the chemistry of magnetite, hematite, titanite and chlorite was conducted during the year, with a focus on the following activities and sites:

- > Drilling in South Australia by joint GSSA-DSD and industry partners (Mineral Systems Drilling Program).
- > Using machine learning algorithms to assist with the discrimination of pyrite and magnetite from different mineral systems in South Australia (GSSA-DSD).
- > Kempfield VHMS mineralisation, NSW, with Argent Minerals.
- > Black Butte sedimentary copper deposit, Montana (USA) in collaboration with Sandfire and Tintina Resources.
- > Skellefte District VHMS deposits with Boliden (Sweden).
- > McArthur Basin SEDEX Zn-Pb-Ag style mineral systems.
- > Orogenic gold in collaboration with Pioneer Resources, Western Australia.

* The DeGrussa VHMS research was previously reported as a separate project.

INTEGRATING GEOLOGY AND GEOPHYSICS FOR RESOURCES TARGETING

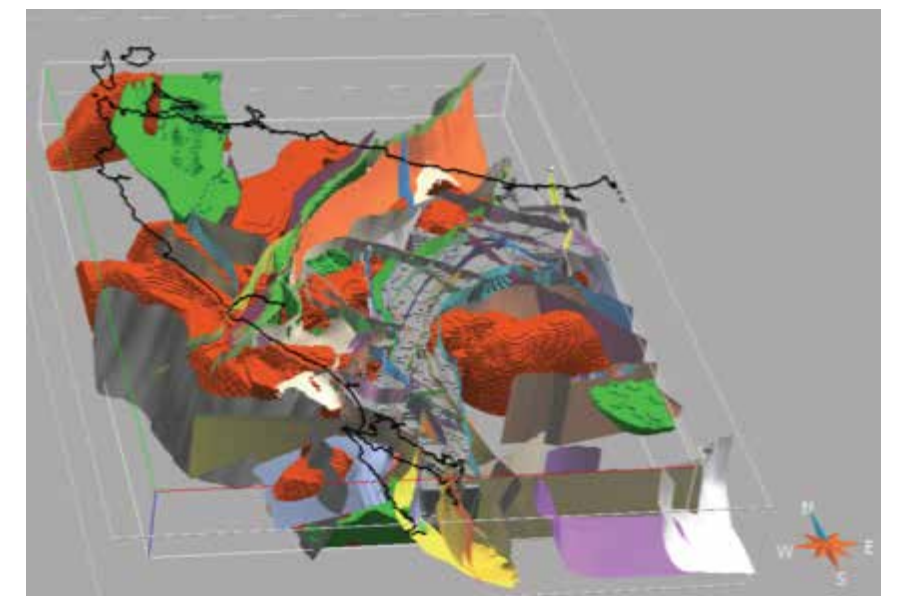
Leader: Anya Reading

Student: Esmaeil Eshaghi

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 changed to better reflect the evolving scope of the research.

In 2016, several geophysical inversion studies were carried out to better



Model displaying PhD student Esi Eshaghi's study area in northwest Tasmania, including a fault network (different surfaces), and three geological components (vertical exaggeration = 2).



constrain the 3D geological structure, using geological and geophysical constraints to provide improved pre-competitive information for the mineral explorer in Tasmania. A major finding during the reporting period was the refinement of the geometry of low density bodies in the northwest of Tasmania, which could be associated with movement of fluid through the crust and related mineralisation.

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

Leader: Garry Davidson

Team Members: Richelle Awid-Pascual, Ben Cave

Collaborators: Fraser Clark, Christian Dietz, Sue Finlayson, Wally Herrmann, Michael Nugus, Nick Oliver

The measurement and interpretation of stable isotopes in ore systems can provide information about ore genesis and proximity to ore. This continuing project, solely funded by AngloGold Ashanti, aims to explore the full potential of these methodologies, including their integration with other investigation techniques.

A major phase of study was concluded at the Sunrise Dam gold deposit in the Archean Yilgarn of Western Australia, evaluating C-O isotope variation as a means to both understand the genesis of the orogenic ores, and to expand the ore halo. The study shows that Sunrise Dam has 'missing link' characteristics within the range of isotopic variation of Archean orogenic gold systems.

Research will continue at this site, with the aims of evaluating detailed along-strike C-O isotope variation in some key lodes, and to better constrain the regional metamorphic fluid composition, and the composition of carbonate formed by non-ore-related processes in the rock mass.

This phase of work is employing sample sets that were obtained for other purposes by consultant Wally Herrmann.

IOCG AND RELATED DEPOSITS

Leader: Garry Davidson

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

Student: Subira Sharma

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

Iron oxide copper-gold (IOCG) research is being conducted on mineralisation in several Australian provinces outside of the Olympic Dam research project.

Prominent Hill and Vulcan South (Gawler Craton)

Work mainly focussed on the sulfur isotopes and mineral paragenesis of the Gap Zone ores west of the main Prominent Hill ore body, and included two presentations at the Australian Earth Sciences Convention, held in Adelaide during June. A geochronology paper on the Prominent Hill deposit was published in *Mineralium Deposita* (Bowden et al. 2016).

At Vulcan South (Tasman Resources), further geochronology was undertaken to augment Honours research work by former student Greg Clarke, with the aim of strengthening the overall case for publication.

Mt Dore-Merlin Re-Mo (Mt Isa Inlier)

Subira Sharma's PhD research on Chinova's Merlin ore body continued, and included a stint at ANU conducting SHRIMP oxygen isotope analyses on hydrothermal quartz, with the aim of constraining the nature and history of the Merlin fluids.

A dataset of Nd and Hf whole-rock isotopes from the Williams Batholith granites was also analysed, together with the reanalysis of a selection of related samples from Geoscience Australia.

A paper on the crystal-structure of Merlin molybdenite was published in *Vibrational Spectroscopy* (Sharma et al. 2016).

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

Leader: Garry Davidson

Student: Richelle Awid-Pascual

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

This project, which is evaluating the extraordinary occurrence and textures of a zinc-rich fossil peat deposit above a hardrock Zn-Pb 'Irish-style' deposit in wet temperate Tasmania, is the subject of PhD research by Richelle Awid-Pascual. Richelle took a break from her studies for a large part of 2016, but still managed to make significant progress in writing chapters for her thesis.

GEOLOGY AND GENESIS OF THE INVINCIBLE GOLD DEPOSIT, ST IVES

Leader: Robert Scott

Student: David Douth

Collaborator: Ray Cas

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

In the Kambalda area, the Black Flag Group consists of felsic to intermediate volcano-sedimentary rocks, locally capped by thick black shale, which is the primary host to ore at Invincible. These rocks are overlain by arkosic/lithic sandstone, polymict conglomerate and conglomeratic sandstone of the <2665 Ma Merougil Group, which forms the immediate hanging wall to the Invincible deposit. A key aspect of David's study has been to better define, and interpret, stratigraphic subdivisions in these rocks using a combination of lithofacies analysis, geochemistry, and detrital zircon U/Pb geochronology.

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

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

During 2016, David also made considerable progress towards characterising the geochemical footprint of the deposit. David used geochemical data acquired on a variety of scales to better understand patterns of element mobility and mass changes during hydrothermal alteration and ore formation.

Future studies will investigate spatial variations in mineral chemistry and paragenesis as a potential source of new, longer range, or more definitive vectors to ore. This work will also aid the interpretation of whole rock geochemical data, by providing additional paragenetic (i.e. relative temporal) constraints on observed patterns.

THEME 6 – DATES AND PLATES

BUILDING TASMANIA: THE CAMBRIAN AND BEYOND

Leaders: Sebastien Meffre, Robert Scott

Team Members: Ron Berry, Jacqueline Halpin

Student: Jacob Mulder

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

This project, driven by Jacob Mulder's ongoing PhD research, draws together many aspects of the Precambrian–Cambrian geological evolution of Tasmania; ranging from the age, affinity and significance of the cryptic Tasmanian basement and overlying Proterozoic successions, to the accretion of the Tasmanian micro-continent to the Gondwanan palaeo-Pacific margin.

Jacob spent most of 2016 at the University of New Mexico, where he made the most of his opportunity of working under the expert supervision of highly respected geologist Karl Karlstrom to further investigate the links between early Tasmania and SW Laurentia. These studies formed part of a prestigious Endeavour Postgraduate Scholarship, which he received from the Australian Government the previous year.

Jacob's collaboration with Professor Karlstrom has involved refining the depositional age of a series of Late Mesoproterozoic basins in Texas, New Mexico, Arizona, and California, which are potential correlates of Late Mesoproterozoic strata exposed in Tasmania.

Field work in the Grand Canyon, together with new data from Late Mesoproterozoic sequences exposed throughout southwest USA, has identified two distinct episodes of major basin formation at 1250–1230 Ma and 1140–100 Ma. These episodes coincide with convergence and continent-continent collision along the southern margin of the USA during the Grenville Orogeny. The sedimentary record of these basins provides new tectonic context for Late Mesoproterozoic basin formation in the southwestern USA and helps refine models for exhumation of the Grenville Orogeny.

During his stay in the US, Jacob delivered two oral presentations at the 2016 Geological Society of America conference in Denver, Colorado, including an invited talk in the session 'Tectonics of Mesoproterozoic basins'.

While in Tasmania, Jacob focused on refining the depositional age and better understanding the stratigraphic relationships of Mesoproterozoic sedimentary rocks. A major breakthrough has been refining the depositional age of turbidites comprising the Oonah Formation and their correlation with Mesoproterozoic turbidites exposed on King Island. Together, these turbidite sequences represent deep-water equivalents to

the shallow marine sequences of the Rocky Cape Group, and thus help to define the large-scale geometry of the Mesoproterozoic basin exposed in western Tasmania, confirming that it is compatible with an east-facing rifted margin. A publication arising from this work is being prepared for submission to the *Australian Journal of Earth Science*.

Stratigraphy, depositional age, and provenance of southwest Laurentia Late Mesoproterozoic basins are remarkably similar to Late Mesoproterozoic strata preserved in the upper Rocky Cape Group in western Tasmania and suggest Tasmania was a part of the extensive orogenic basin system. A publication arising from this work is being prepared for submission to *Geology*.

Ongoing work will involve new collaborations with researchers in Australia, Canada, and the USA, directed at understanding the global significance of Mesoproterozoic sedimentary sequences in Tasmania. This research aims to understand links between basin formation in Australia, Antarctica, and North America and the transition between supercontinents Nuna and Rodinia.

STRUCTURE OF SE AUSTRALIA USING MULTIPLE GEOPHYSICAL METHODS

Leader: Anya Reading

Collaborator: Mark Duffett

This research improved the understanding of the broad-scale structure of SE Australia, and was conducted in collaboration with Mineral Resources Tasmania (MRT). Research under this project title concluded with the completion of a study comparing Curie Point Depth from magnetic data to the depth of the Moho defined by seismic data. Nevertheless, as SE Australia remains a key area of tectonic and economic interest, this research will continue under the 'Ore deposits and tectonic evolution of the Lachlan orogen, SE Australia' project, in Theme One of this Module.

► LOOKING FORWARD

The cycle of completion and renewal, mentioned in the Highlights, is expected to continue in the coming year. A number of projects came to an end during the current reporting cycle, but those losses will be balanced by other studies that will either commence or gain momentum during 2017.

The ARC Linkage project investigating the ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia started very late in 2017 and is expected to gain considerable impetus in the months ahead.

In the Carlin District, Nevada, Robert Scott and Vadim Kamenetsky will build on the work started by PhD student Torsten Jensen, which found the presence of syn-sedimentary or early diagenetic gold-bearing layers in the Wispy unit. It is believed that this exciting discovery may have important implications for the genesis of the Eocene deposits hosted at this stratigraphic level. As a result, the researchers will be investigating the significance and extent of Devonian gold mineralisation in the area, and whether it is a critical primer to a world-class gold district.

Khin Zaw will continue negotiations with industry sponsors for new projects related to the Western Myanmar-Sumatra Terrane and Phanerozoic shales in mainland SE Asia. Zaw is also finalising a memoir covering his extensive geological experience in the region, dating back to 1968.

The Power of Pyrite project already has a number of 'runs on the board', and this success will continue with the development of a cobalt targeting technique that will have significant benefits for explorers.

PhD student Jacob Mulder is set to return from his Endeavor Postgraduate Scholarship at the University of New Mexico in March, and will no doubt be keen to use the experience and knowledge that he gained to good effect in his research into the links between early Tasmania and SW Laurentia.

The Uranium Concentrations in Basins project is expected to complete major phases of research, including the production of a significant report on the Angularli uranium deposit in mid-2017.

It also promises to be an excellent year for publications and theses completions, with a significant number of both outputs close to finalisation at the end of 2016.

Glacier National Park, Montana. Exposures of the Belt Group, a correlate of the Rocky Cape Group in Tasmania.

MODULE

GEOMETALLURGY

► 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.

Additional geometallurgical research is being carried out in the Quantifying Geometallurgical Characteristics and Predicting Geoenvironmental Behaviour themes within the ARC Industrial Transformation Research Hub – Transforming the Mining Value Chain (TMVC).

► HIGHLIGHTS

- > Inaugural CRC ORE Annual Assembly held in Perth, 30 November – under its second term of funding.
- > Nathan Fox accepted a postdoctoral research fellow position in December, for commencement early in 2017.
- > Technology transfer of GeM^{III} and CRC ORE research continued, including presentations at conferences in Belgium, Australia and the UK.
- > Acting Module Leader Anita Parbhakar-Fox organised and chaired a dedicated geoenvironmental session at the 3rd AusIMM GeoMet 16 Conference in Perth. Anita also chaired a session at Biohydrometallurgy '16 in Cornwall, UK.
- > An in-depth review of geometallurgical applications for sorting by surface analysis delivered to CRC ORE as part of its Program 1: Define – improving feed quality.

► 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.

The outcomes of the GeM^{III} project have provided a solid foundation for further research, particularly in relation to understanding mineralogical and textural controls over a range of scales, which dictate Grade Engineering™ and mineral processing responses. This research is largely being conducted as part of CRC ORE, of which CODES is an Essential Research Participant.

OPPOSITE PAGE FROM CENTRE, RIGHT: Boiler ash blended with mine waste in kinetic trials; Tailings mounted for SEM analysis.
ABOVE: Anita Parbhakar-Fox conducting acid mine drainage experiments for visitors during the UTAS Open Day.



ACTING LEADER
Anita Parbhakar-Fox

► THE MODULE TEAM

TEAM MEMBERS:

Ron Berry, Leonid Danyushevsky, Nathan Fox*, Bruce Gemmell, Sarah Gilbert, Sebastien Meffre

*Nathan was employed on a casual basis towards the end of the year, with his postdoctoral appointment to commence early in 2017.

COLLABORATORS:

ALS GLOBAL

John Glen, Donna Kemp

BRUKER

Jens Bergman, Gertruida Gloy

CRC ORE

Ben Adair, Steve Walters

CSIRO

Mark Pearce

GOLD MINES OF WALES, UK

Simon Dominy

GRANGE RESOURCES

Tony Ferguson, Roger Hill

JULIUS KRUTTSCHNITT MINERAL RESEARCH CENTRE/UNIVERSITY OF QUEENSLAND

Khoi Nguyen

MINERAL RESOURCES TASMANIA

David Green, Jake Moltzen

OLYMPUS

Dane Burkett

PETROLAB, UK

Christopher Brough

SCIAPS, USA

Andrew Somers

SPECIM

Rainer Bärts, Kati Laakso

UNIVERSITY OF CAPE TOWN, SOUTH AFRICA

Dee Bradshaw

UNIVERSITY OF LIEGE, BELGIUM

Julie Hunt

UNIVERSITY OF TASMANIA, CENTRAL SCIENCE LABORATORY

Sandrin Feig, Karsten Goemann, Thomas Rodemann

► THE YEAR IN REVIEW

CRC ORE

The major event of the year was the commencement of CODES collaboration with CRC ORE, as part of the Co-operative Research Centre's six-year extension. The key challenge for CRC ORE 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. As an Essential Research Participant, 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 during its extended tenure.

The research performed by CRC ORE 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.

Research collaborations with the CRC commenced late in the year, mainly via a project entitled 'Geometallurgical applications for sorting by surface analysis: review of status'. The project, led by Ron Berry, assessed the underlying advantages of using surface methods in measuring ore moving on a belt to control sorting opportunities. It also addressed the potential problems associated with rapid motion, irregular topography and dust distribution, and considered opportunities to attain size and sorting information from the data. This project has now concluded, with results submitted to the CRC.

The CRC held its inaugural Annual Assembly of its second term of funding on 30 November. Held at Curtin University in Perth, the meeting attracted a broad spectrum

of representatives from mining companies, the METS sector, and research organisations. The theme was 'Unlocking and fast-tracking new value for the minerals sector', which focussed on developing and deploying innovative world-class technology to effect a step change in value across the whole-of-mine system – one of the underlying objectives of CRC ORE's second funding term. Included amongst the invitees was Director Bruce Gemmell, who gave a presentation on CODES' role as an Essential Research Participant at a meeting of collaborators, held in parallel to the main proceedings. Earlier in the year, CRC ORE Director Ben Adair and Chief Technologist Steve Walters attended the CODES Science Planning Meeting, where Steve gave a presentation on the objectives of the CRC.

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 into 2016. Several of the outcomes are being applied in the new AMIRA P1183 Operational Geometallurgy project. This initiative is being run by the University of Cape Town where former GeM^{III} team member, and current CODES collaborator, Dee Bradshaw has taken the position of SARChI Chair in Mineral Beneficiation. The South African Research Chairs Initiative (SARChI) is a program designed to strengthen the ability of South Africa's universities to produce high quality research, innovation and students.

Ron Berry and JKTech collaborator Khoi Nguyen published a paper in *Economic Geology* on SStructure from photographs of ORiented Core (STORC), a tool developed in the GeM^{III} project.

SHORT COURSES

Ron Berry presented at a four-day geometallurgy short course held at the University of Liege, Belgium, in early October. The course was run under the auspices of 'The European Research and Education Hub in Geometallurgy', which is a group established to promote all of Europe's geometallurgy initiatives under a single umbrella. The course attracted approximately 20 participants, largely from the European mining industry (particularly Bulgaria and Turkey). Ron also gave a talk and a practical session at the University of Liege as part of the EMerald geometallurgy Masters program.

CONFERENCES

CODES had a strong presence at GeoMet 2016, held in Perth from 15 to 16 June, including an exhibition booth and four presentations from CODES/TMVC team members. Anita Parbhakar-Fox also played a key role as member of the organising committee. This was the third international geometallurgy conference run by the AusIMM.

CODES/TMVC team members also participated in the Sustainable Minerals '16 conference, held in Falmouth, Cornwall, UK, from 23 to 24 June. Contributions included a poster and an oral presentation. Anita Parbhakar-Fox also chaired a session and presented at Biohydrometallurgy '16, which was held in Falmouth immediately prior to Sustainable Minerals '16.



OPPOSITE PAGE: Analysis of tailings from King River, western Tasmania; Delegates at the CRC ORE Annual Assembly in Perth.

LEFT: Steve Walters, CRC ORE, addressing the CODES Science Planning Meeting.

▶ LOOKING FORWARD

There promises to be a busy year ahead for the Geometallurgy Module as the collaboration with CRC ORE gathers momentum, given added impetus by the appointment of experienced CODES researcher, Nathan Fox, who will be joining the team early in the new year. In a further boost to team resources, two PhD candidates will be appointed to work within the CRC ORE collaboration, examining textural and mineralogical controls on grade by size responses for two different ore deposit types. These appointments are expected to significantly enhance the research output of the module. Researcher forums are scheduled for March, which will help foster collaborations with the CRC, and consolidate planning for CODES' activities within the Define Program.

The Geometallurgy unit of the CODES Master of Economic Geology Program is scheduled to run from 23 October to 3 November. This popular biennial course has been updated to include additional topics, with a number of highly regarded geometallurgists being secured as presenters. These new topics include Grade Engineering™ (Steve Walters/Luke Keeney/Michael Scott – CRC ORE), and heap- and bio-leaching (Angus MacFarlane/Naomi Boxall – CSIRO). New practicals are also being introduced, which will be run with the assistance of CODES/TMVC staff and students.

The research on the geometallurgy characterisation of mine tailings at a western Tasmania site, which commenced within the TMVC Research Hub, will be continued exclusively within the Geometallurgy Module. Bioleaching trials on pyrite concentrates are planned to be conducted in mid-2017 at the ALS-Burnie metallurgy labs. Findings from this research will be reported to the Tasmanian State Government and published in a research paper.

ATSE seed funding will enable collaborative research to commence with SciAps Inc. and Petrolab UK Ltd. on projects exploring the applications for new mineralogical tools for enhancing geometallurgical and geoenvironmental characterisation.

Work will commence on a project entitled 'Predictive geometallurgy controls on grade by size'. Grade by size fractionation has been recognised in a number of deposits. The challenge is to recognise what aspects of ore mineralogy and texture lead to the development of significant grade by size fractionation. This project will aim to provide a predictive understanding of this process, which will significantly aid the recognition of suitable rock masses for Grade Engineering®.

A keynote presentation will be given by Anita Parbhakar-Fox at the 8th World Conference for Sampling and Blending (Perth, WA). Additional conference presentations will be delivered by CODES/TMVC team members at Process Mineralogy 17 (Cape Town, South Africa), SGA (Montreal, Canada), the 10th AusIMM Mining Geology Conference (Hobart, TAS) and the 9th Australian AMD conference (Burnie, TAS).

OPPOSITE PAGE: Magnetic separation.

MODULE

ENABLING TECHNOLOGIES

► 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 2016, 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, focusing 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

RESEARCH

One of the main highlights of the year was the awarding of a prestigious Australian Museum Eureka Prize to a team from CODES and the Discipline of Earth Sciences. While the core of this research resides in Earth Sciences, there is no doubt that this success was underpinned by analytical developments within this module. The prize was in the category of Excellence in Interdisciplinary Scientific Research, and was awarded for studies into the relationships between plate tectonics, past ocean chemistry and evolution and extinction cycles.

Other significant research highlights included:

- > CODES received funding from Laurin Technic for a two-year research project, which is focussed on the characterisation of laser ablation processes in silicate minerals. This important research will play a key role in the development of fundamental aspects of laser-ablation analysis applied to a range of geological problems.
- > U-Pb geochronology of accessory and hydrothermal minerals was further developed to improve accuracy and aid in directly dating mineralising events.

EQUIPMENT

The installation of the new generation TOFWERK Time-Of-Flight Inductively Coupled Mass spectrometry instrument was a significant addition to CODES Analytical Laboratories' suite of equipment. This state of the art installation, which is capable of simultaneous detection of virtually

OPPOSITE PAGE: PhD student Laura Jackson measuring laser energy before analysis.

ABOVE: Jay Thompson operating the new generation TOFWERK Time-Of-Flight inductively coupled mass spectrometry instrument.

ENABLING TECHNOLOGIES

the entire periodic table, substantially increases the range and speed of measurement processes, and greatly enhances the quality of data for mineral dating. This was the first time that this model had been installed in Australia.

An optical profiler by Bruker was installed mid-year, which allows routine crater depth measurements to be performed, leading to more accurate Pb/U dating applications.

SOFTWARE

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

STAFF

The Module team was sad to see the departure of Sarah Gilbert, who left to take up an appointment with the University of Adelaide. Sarah completed her Honours at UTAS, before joining the technical staff in 2002. She also completed her PhD at UTAS in 2015. While she will be sorely

missed, the team was pleased to welcome Sean Johnson to the group. Sean was appointed as a Research Fellow in LA-ICP-MS, after successfully finishing his PhD during the year.

CONFERENCES

Team members were involved in a number of major conferences and workshops in 2016, including AGU Fall (USA), Goldschmidt (Japan), Australian Earth Sciences Convention (Adelaide), European Workshop on Laser Ablation (Slovenia), Winter Conference of Plasma Spectrometry (USA), and the Australian Society of Exploration Geophysicists Conference (Adelaide). In total, team members produced over 20 conference abstracts.

Several conference presentations described the application of robust and intuitive workflows in open source software for supervised and unsupervised learning approaches to geological modelling in orogenic gold deposits.

LEADER

Leonid Danyushevsky

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
- > Geodata analytics, visualisation and decisions

[^]Research in the 'Technique development in computational knowledge discovery from High-D data' project, previously reported in this Module, is being continued within the TMVC Research Hub.

THE MODULE TEAM

TEAM MEMBERS:

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

PHD STUDENTS:

Nathan Chapman, Stephen Kuhn, Elena Lounejeva, Peter Morse, Jay Thompson

COLLABORATORS:

AGILENT TECHNOLOGIES

Fred Fryer

BUENAVENTURA

Billy Beas

FIRST QUANTUM MINERALS

Tim Ireland, Chris Wijns

GOLD FIELDS

Andrew Foley

IOWA STATE UNIVERSITY, USA

Sam Houk

LAURIN TECHNIC

Michael Shelley

MOSCOW STATE UNIVERSITY, RUSSIA

Alexey Ariskin, Pavel Plechov

NEWCREST MINING

Anthony Harris

NORRIS SOFTWARE

Ashley Norris

RIO TINTO

Paul Agnew, Alan Kobussen

TOFWERK

Olga Borovinskaya, Michael Cubison, Martin Tanner

UNIVERSITÉ GRENOBLE ALPES, FRANCE

Valentina Batanova, Alexander Sobolev

UNIVERSITY OF BRISTOL, UK

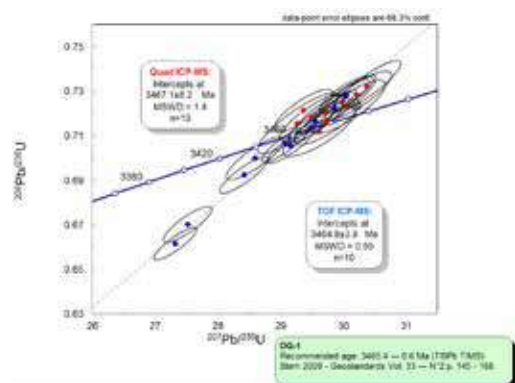
Jon Blundy

UNIVERSITY OF MELBOURNE

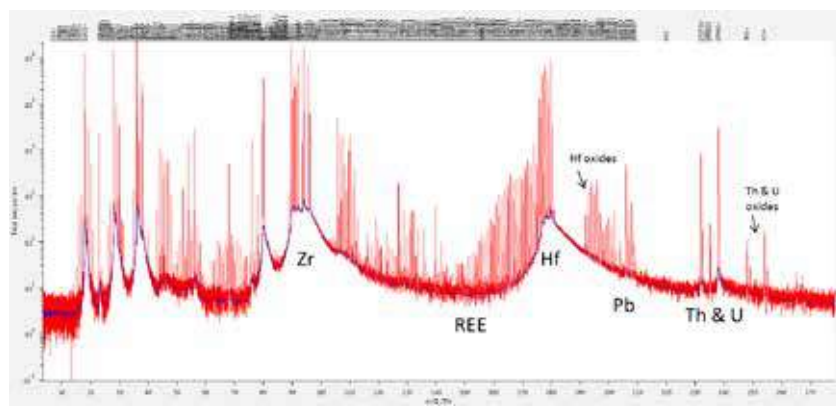
Roland Maas

UNIVERSITY OF TASMANIA

Karsten Goemann, Christopher Lueg



FROM LEFT: Example of results from the new TOF instrument, demonstrating the higher precision achieved in comparison to quadrupole instruments in the Analytical Laboratories; Typical mass spectrum from the TOF-ICP-MS instrument.



PROJECT SUMMARIES

THEME 1 – ANALYTICAL DEVELOPMENTS

FUNDAMENTALS OF ICP-MS

Leaders: Jay Thompson, Leonid Danyushevsky

Team Members: Sarah Gilbert, Paul Olin

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

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

The main focus in 2016 was on the testing of a new Time-of-Flight (TOF) ICP-MS, which was installed mid-year. This state of the art instrument has the capability of simultaneous detection of all masses, which can lead to increased precision and accuracy of LA-ICP-MS analyses. The applications are being developed in collaboration with the manufacturer, TOFWERK, to improve on the data acquisition and processing protocols for routine analysis for geological samples.

In addition, a manuscript covering an investigation into oxide and other interference formation in ICP-MS for laser ablation vs. solution ICP-MS was submitted to the *Journal of Analytical Atomic Spectrometry*. The results highlight the fundamental differences between aerosol characteristics between laser ablation and solution sample introduction.

FUNDAMENTALS OF LASER ABLATION

Leaders: Sarah Gilbert, Leonid Danyushevsky

Team Members: Sean Johnson, Sebastien Meffre, Paul Olin, Jay Thompson

Collaborator: Michael Shelley

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

In 2016, the project received funding from Laurin Technic for a two-year project focussed on the characterisation of ablation processes in silicate minerals. Key research activities focussed on:

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

ELEMENT MAPPING BY LA-ICP-MS

Leader: Sebastien Meffre

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

Student: Nathan Chapman

Collaborator: Michael Shelley

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

The main focus during the year has been on instrumentation developments

required for improved throughput and spatial resolution when using ICP-TOFMS. In particular, the impact of the lengths and configuration of interface tubing was assessed through a series of experiments that quantified the aerosol dispersion function. A manuscript is in preparation.

Other activities within this area form part of the technological developments within the TMVC Research Hub.

CALIBRATION STANDARDS FOR LA-ICP-MS

Leaders: Ivan Belousov, Leonid Danyushevsky

Team Members: Sarah Gilbert, Paul Olin, Jay Thompson

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

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

The development of the new calibration standard STDGL3 for sulfide analysis was completed during the year, and the standard has been distributed to several analytical laboratories, including facilities located in Asia, Europe and the USA. A manuscript describing this new reference material is in preparation.

The compositions of olivine reference material have been determined as part of an international collaboration involving five laboratories in the USA, Europe and Japan. A manuscript is also in preparation covering this research.

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

LA-ICP-MS INSTRUMENTATION DEVELOPMENT

Leader: Leonid Danyushevsky

Team Members: Sarah Gilbert, Paul Olin, Jay Thompson

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

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

In 2016, activities formed part of the technological developments within the TMVC Research Hub. The main focus was on developing operating conditions for ICP-TOFMS and modifications to the ablation cell designs.

U-PB DATING

Leader: Jay Thompson

Team Members: Leonid Danyushevsky, Sebastien Meffre

Collaborator: Roland Maas

This project investigates the causes of limitations to Pb/U dating of minerals by LA-ICP-MS, with the aim of enhancing laboratory practices and instrumentation parameters to lower systematic errors and improve precision. Zircon is the primary

mineral investigated, however ongoing investigations for apatite, uraninite, and monazite are currently underway.

This year the main focus was on:

- > Development of new reference materials for monazite U-Pb and rutile dating.
- > Investigation into the potential matrix effects during U-Pb dating of monazite and xenotime, and whether mineral specific reference materials are required for each.
- > Measurements of titanite reference materials for U-Pb, which have demonstrated that the current method is accurate relative to the precision quoted.

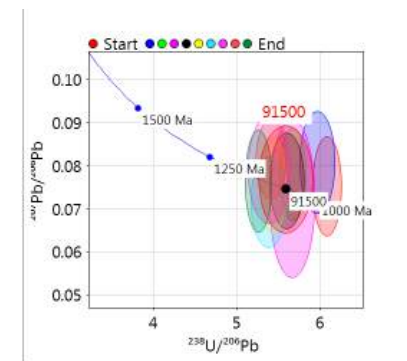
In addition, a paper was published in the *Journal of Analytical Atomic Spectrometry* on matrix effects in apatite U-Pb dating by LA-ICP-MS, which also characterised two new reference materials for U-Pb dating.

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



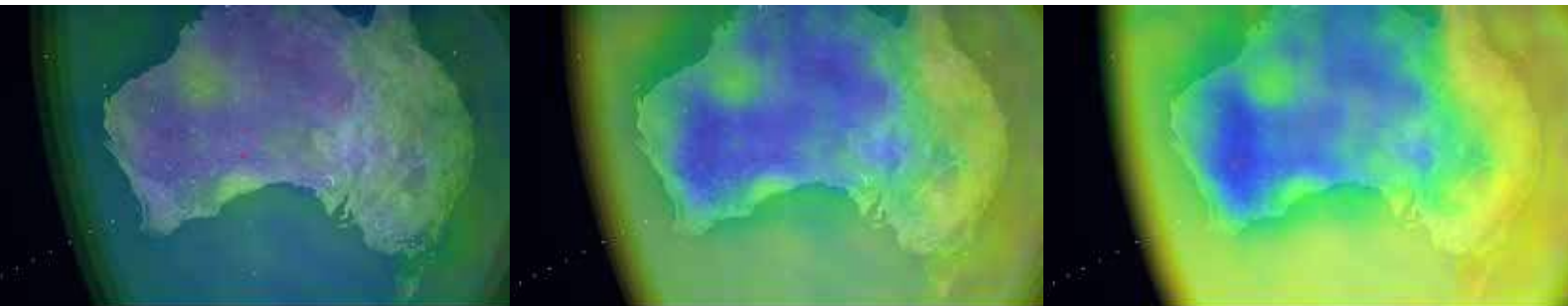
New LA-ICP-MS data reduction software developed by Leonid Danyushevsky and Ashley Norris. The software automates many of the steps involved in the calculation and produces much more accurate data, due to new algorithms.

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.





Screenshots from an interactive visualisation sequence from the prototype computer application (depth slices through the AusREM Australian seismic reference model for the mantle at 100, 175 and 250 km deep; blue colours indicate faster wave speeds and older lithosphere).

Activities in 2016 were directed towards developing algorithms for automated identification of ablation time intervals, U-Pb dating calculations, analysis of isotopic compositions, and interference corrections. A new, 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).

A temporary hold was placed on this project in 2016 to allow the team to focus its resources on the development of LA-ICP-MS data reduction software.

THEME 3 – COMPUTATIONAL KNOWLEDGE DISCOVERY FOR GEOSCIENCE

TARGET GENERATION AND GEOLOGY MAP REFINEMENT FROM DATA-DRIVEN COMPUTATION

Leader: Matt Cracknell

Team Member: Anya Reading

Student: Stephen Kuhn

Collaborators: Billy Beas, 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 2016, the focus was on a sedimentary copper deposit case study, using data from the Trident project in the Central African Copperbelt (First Quantum Minerals), ~ 100 km west of Kansanshi. This dataset includes 170,000 samples comprising approximately 40 geochemical and 17 geophysical input datasets. Experiments were conducted to identify optimal uncertainty outputs, given the

likelihood that a candidate lithology is predicted. Ongoing research with these data will investigate optimal sampling routines for input into lithology classification models.

Several conference presentations reporting on project outcomes were delivered at the ASEG-PESA-AIG 16th International Geophysical Convention and the Australian Earth Sciences Convention. Six manuscripts are in preparation for submission in 2017.

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 focuses on using the visualisation as part of the data inference process, rather than being simply a way of viewing the final output.

During the year, a prototype computer application for the visualisation of 3D seismic datasets was developed to progress the interpretation of seismic tomography images in an interactive framework, focussed on lithosphere-scale investigations. The software combines performance graphics technology with the ability to handle scientific data formats.

► LOOKING FORWARD

The team will further develop its analytical and computational research in 2017, working in close collaboration with the TMVC Research Hub. Developments are expected to include:

- > Researchers will build on their early work using the new ICP-TOFMS instrument, which enables simultaneous U-Pb dating and trace element analysis applications in various mineral geochronometers.
- > A potentially rewarding collaboration has commenced with the University of Bristol and Moscow State University on the characterisation of plagioclase reference material, and this research will gather momentum in the coming months.
- > The new calibration standard STDGL3 for sulfide analysis was completed in 2016 and has already been distributed to a number of laboratories around the world, with many more expected to take delivery in 2017.
- > Work will continue into establishing correction factors for pressed pellets of finely ground sulfide mixes (<5 micron), which are yet to be determined for different laser systems.
- > In South America, informative models will be constructed for Peru's La Zanja porphyry/epithermal field through the integration of soil geochemical and airborne geophysical data.

In addition, a number of papers will be submitted to international peer-reviewed journals, covering research on:

- > The development of the new calibration standard STDGL3 for sulfide analysis.
- > Instrumentation developments required for improved throughput and spatial resolution.
- > The compositions of olivine reference material.
- > Catchment-based gold prospectivity analysis combining geochemical, geophysical and geological data across northern Australia.
- > Development and testing of catchment-scale geoscience data integration and processing methods for gold prospectivity analysis via unsupervised clustering.
- > Random Forests for lithological mapping in the Eastern Goldfields, Australia, using geophysical and remote sensing data.
- > Supervised classification for lithology mapping in a regolith dominated terrain that identifies relevant data for efficient processing and uses uncertainty as a tool to indicate regions of correct classifications.
- > Machine learning for mapping in the Central African Copperbelt, using geophysical and geochemical data.
- > Development of supervised and unsupervised learning workflows for generating lithological maps in areas of limited geological observations.

MODULE

TRAINING

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.

HONOURS

Enrolments in the Honours Program were down compared to recent years. However, a suite of new workshops were introduced, covering a broad range of topics, from software expertise through to Machine Learning and presentation skills.

FIELD TRIPS, JOURNAL ARTICLES AND PRESENTATIONS

A highlight of the CODES SEG Student Chapter's professional development program was the 12-day field trip to Myanmar, which included visits to a number of ore deposits and mines.

In addition, postgraduate students had 23 refereed journal articles published, and produced 26 presentations for major international conferences in Australia, Indonesia, Japan, Malaysia, Switzerland and the USA.

► 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 63% of the projects involve collaborations with the minerals industry.

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, and the introduction of a suite of new courses at Honours level.

HDR

There were eight new enrolments for the HDR program, which included five Australian students, maintaining the strong local intake figures of recent years. The program also sustained its appeal in international markets, with over two thirds of the overall cohort emanating from overseas, representing 18 different countries.

MASTER OF ECONOMIC GEOLOGY

It was a milestone year for the Master of Economic Geology Program, which in August celebrated its 100th graduate in Maria Lourdes Faustino. While attendances at individual short courses were down, the program recruited 15 new students, which was close to a record.

► 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 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

OPPOSITE PAGE FROM TOP: A stop at the Baw Mar open pit ruby-sapphire mine during the CODES SEG Student Chapter trip to Myanmar; PhD student Jodi Fox on board RV Investigator during a research expedition to Heard and McDonald Islands; Master of Economic Geology student Anna Kutkiewicz (foreground) inspecting core samples at Waihi Gold, New Zealand.

CODES' success in attracting international HDR students is underpinned by its reputation for excellence as a research training centre. This success continued in 2016 with over two-thirds of the students enrolled in the program coming from overseas, representing a total of 18 nationalities. Notwithstanding the high ratio of international students, the trend of relatively healthy enrolment numbers for Australian students was maintained, with an intake of five new domestic candidates. 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 were 57 students enrolled in the HDR program during 2016 (54 PhD and 3 MSc), including eight new arrivals. The new enrolments were Australian students Adam Abersteiner, Ayesha Ahmed, Evan Draayers, Shawn Hood and Torsten Jensen, and international students Christopher Leslie (Canada), Peerapong Sritangsirikul (Thailand) and Tobias Staal (Sweden). Twelve PhD students had theses under examination, of which six graduated: Olga Apukhtina, Ben Cave, Pedro Fonseca, Qiuyue Huang, Charles Makoundi and Evan Orovan. One Master of Science candidate withdrew and several students had periods of suspension.

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

MASTER OF ECONOMIC GEOLOGY PROGRAM

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

It was a milestone year for the Master of Economic Geology Program, which in August celebrated its 100th graduate in Maria Lourdes Faustino. Maria, who hails from the Philippines, completed her research thesis on the Bayugo porphyry copper-gold deposit under the supervision of Professor David Cooke. She was also the first student to complete the degree with the support of an Australia Awards scholarship. In addition to Maria, a further five students graduated during the year: Joanna Condon, Richard Cotton, Danny Huisman, Imam Malik and Alan Riles.

Participant numbers at the year's three short courses were down in comparison with previous years, but were in line with expectations, based on current operating conditions in the minerals industry. The downturn has resulted in fewer geologists in full time employment, and those with jobs have much greater demands on their time. The proportion of students financially supported by their employers to complete the degree has also declined. For a program focussed primarily on the working geologist, these factors will naturally have an impact on participation. Nevertheless, there are signs that prospects are improving for the resources sector in the longer term, which is demonstrated by the enrolment of 15 new students – close to a record for the program.

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

VOLCANOLOGY AND MINERALISATION IN VOLCANIC TERRAINS

In March, Jocelyn McPhie and David Cooke led a group of six participants to New Zealand's North Island to examine modern volcanic systems for the Volcanology and Mineralisation in Volcanic Terrains short course. The second part of this field-based unit was led by Jocelyn and Bruce Gemmell, who took the group to the west coast of Tasmania to examine the well mineralised and altered Cambrian Mt Read Volcanics. This hands-on course provides an excellent introduction to the processes and products of different eruption styles, contrasts in scale and structure of volcanoes, identification of key volcanic facies associations, and interpretation of facies variations. Mineralisation and alteration processes related to hydrothermal systems in subaerial and submarine volcanic environments, and their implications for mineral exploration, are also addressed.

EXPLORATION IN BROWNFIELD TERRAINS

Matt Cracknell, Robert Scott and PhD student Steve Kuhn led the Exploration in Brownfield Terrains short course in June, which was attended by 16 participants. This unit is designed to bring students up-to-date with the latest exploration techniques and approaches to compiling and working with historical datasets. Exploration in data-rich environments, close to existing mines, has become a preferred method of enhancing company resources in recent years. This trend has led to strong interest in this course, which covers cutting-edge technologies in geophysics, geochemistry and 3D visualisation, and guides participants in the analysis of real data from world-class mineralised districts. In addition

to CODES teaching staff, minerals industry professionals and consultants involved in delivery of this unit were Patrick Smillie and Fionna Fraser (Leapfrog3d), David Green (Mineral Resources Tasmania) and Scott Halley (Consultant).

ORE DEPOSIT MODELS AND EXPLORATION STRATEGIES

Seventeen Masters students, and four other minerals industry participants, attended the final short course of the year, Ore Deposit Models and Exploration Strategies, held over the last two weeks in October.

This popular unit has an interactive format of lectures and practical exercises that provide an up-to-date synopsis for a range of key ore deposit types, addressing aspects such as location, characteristics, genesis and exploration strategies. Deposit types covered were porphyry Cu-Au-Mo; skarn; high-, intermediate- and low-sulfidation epithermal; iron-oxide-copper-gold (IOCG); volcanic-hosted massive sulfide and sea-floor hydrothermal; sediment-hosted Cu; sedimentary exhalative Pb-Zn; orogenic Au; Witwatersrand Au; Carlin Au; and Broken Hill-type Pb-Zn-Ag.

Highlights of this year's course were:

- > A dedicated session on one of the world's great ore deposits – the Olympic Dam IOCG deposit in South Australia – led by Dr Kathy Ehrig (BHP Billiton).
- > A full-day devoted to Tasmanian ore deposits, including a practical session at Mineral Resources Tasmania, during which participants inspected drill core from many of the state's major ore deposits.
- > A full-day excursion to the Freycinet Peninsula to examine spectacular exposures of features formed during granite emplacement and the magmatic–hydrothermal transition.

THE PROGRAM FOR 2017

- > 20 – 31 March: Ores in Magmatic Arcs (KEA706/KEA707)
- > 12 – 23 June: Ore Deposit Geochemistry, Hydrology and Geochronology (KEA704/KEA709)
- > 23 October – 3 November: Geometallurgy (KEA702/KEA711)

HONOURS PROGRAM

The Honours program was co-ordinated by Garry Davidson and David Selley, who administered ten students in the first half of the year and 11 thereafter, taking into account students that either enrolled or completed mid-year.

These figures are down on the previous year, resulting in a concomitant reduction in the spread of project subject areas, which covered geophysics (5), economic geology (3), igneous geochemistry, environmental geology, volcanology, and global tectonics. While the student intake is disappointing, it is believed that figures will improve when the mining industry rebounds and career opportunities improve.

Five projects were related to Tasmania, four to mainland Australia, and three had an international focus. None of the international projects involved overseas travel, as a result of the growing trend for students to work on previously collected materials. A highlight was research by Declan Radford, who employed Machine Learning techniques to gain new insights into radar maps of north-west Tasmania, which were produced by NASA almost two decades ago. The methods provide a cost effective and environmentally friendly pathway to greatly enhance the mapping of remote areas, with the potential for discovering mineralisation with economic potential. Declan worked closely with supervisor Matt Cracknell, and Mineral Resources Tasmania, who provided \$5,000 towards the field work as well as access to vital geological and remote sensing data.

Sponsoring companies and organisations in the Honours Program included the Australian Research Council, Forestry Tasmania, GHD, Heron Resources, the International Ocean Discovery Program, Mineral Resources Tasmania, MONA Heavy Metals Project (Tasmania), Northparkes Mines, Signature Gold, and the TMVC Research Hub. 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 - VIEPS

In 2016, CODES offered four short courses as part of the Victorian Institute of Earth and Planetary Sciences (VIEPS) Honours coursework program.

EXPLORATION FIELD SKILLS MAPPING CAMP

Course Leaders: Robert Scott and Martin Jutzeler

The Exploration Field Skills (EFS) mapping camp in February provided 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, which was conducted mainly in western Tasmania, the nine participants mapped, interpreted and 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.

This year, the camp began with a full day at Mineral Resources Tasmania's core library in Hobart, where the students logged three of the eight diamond drill holes previously drilled in the mapping area. One of these drill holes intersected a narrow low-grade Zn-Pb mineralised interval. The students were asked to assess textural, structural, mineralogical and geochemical features and the stratigraphic position of the mineralised interval, and decide whether it is more likely related to Cambrian VHMS or Devonian (structurally-controlled) mineralisation.

The next four days were spent in the field in western Tasmania. Data collected during the mapping and core logging exercises were used to unravel the stratigraphy and structure of the area, and interpret the nature and extent of hydrothermal alteration. This information provided the basis for maps, cross-sections and a report on the exploration potential of the area, which the students completed over the final days of the camp, before returning to Hobart.

FROM LEFT: PhD student Subira Sharma receiving the Peter W Smith Postgraduate Award from CSL Director Dr Evan Peacock; PhD graduates Charles Makoundi and Qiuyue Huang.



TRAINING

ORE DEPOSIT MODELS

Course Leader: David Selley

Course Presenters: Mike Baker, Garry Davidson, Bruce Gemmell, Margy Hawke, Ross Large, Brian McNulty, Robert Scott, David Selley, Jeff Steadman, Nathan Steeves

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

The deposits covered were:

- > Volcanic hosted massive sulfide.
- > Magmatic-hydrothermal: Epithermal, porphyry and skarn.
- > Iron-oxide copper gold.
- > Sediment hosted uranium, copper and lead-zinc.
- > Carlin-type and orogenic gold.

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

Course Presenter: Leonid Danyushevsky

Also in May, 17 students attended the Practical Igneous Petrology course presented by Leonid Danyushevsky. The five-day program is a mixture of lectures and practical exercises, aimed at postgraduate students at Honours level and above with an interest in the formation and evolution of basic and ultrabasic magmas and their relationship to magmatic ore deposits.

Topics covered included:

- > Key theoretical aspects of petrology, including units of concentration, solid solution and mineral formulas, activities and equilibrium, the phase rule, mass balance, phase diagrams, and equilibrium/fractional crystallisation.

- > Examination of a large layered intrusion (the Dovyren Magmatic Complex in Siberia), the affect 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.

ENVIRONMENTAL GEOLOGY FIELD TECHNIQUES

Course Leaders: David Cooke, Matt Cracknell, Garry Davidson, Anita Parbhakar-Fox

The Environmental Geology Field Techniques (EGF) course ran in late-August/September and provided participants with the opportunity to develop skills in practical hydrogeology, geoenvironmental sampling and in-field analyses, and geophysical surveying with an environmental focus.

The course ran for five days, starting with a day and a half of lectures at CODES, followed by field site studies conducted in western Tasmania. The eight participants joined KEA348 (Environmental Geology) students to examine historic mine waste associated with Mt. Lyell, courtesy of a site visit hosted by Copper Mines of Tasmania. They then conducted a survey along the Queen and King Rivers, including the collection of water and sediment samples for geochemical and mineralogical analyses. In-field measurements were taken by the students, which enabled them to hydrochemically characterise the river system.

The students then undertook a detailed geoenvironmental characterisation study of a bank of the King River, where they conducted several hydrogeological tests, took geochemical readings from water samples collected from piezometers, surveyed the surface morphology of the bank, conducted geophysical surveys and logged tailings sediments. Similar activities were also conducted at the King River Delta.

This year, the group was also able to visit the Renison Bell tin mine, where they examined fresh drill core, and

were given the choice of visiting either the processing plant or the tailings storage facilities.

The final day included a brief stop at the Zeehan slag/tailings site.

At the end of the course, the students were assessed based on group assignments related to the two mine visits, and the survey on the King River. The most significant of these assessments was the King River report, which required the students to be able to both interpret and integrate the data in order to understand the site's hydrochemistry and its role in the overall riverine system.

OTHER HONOURS COURSEWORK

HONOURS SKILLS WORKSHOPS

Workshops Leader: Anita Parbhakar-Fox

Course Presenters: Mike Baker, Matt Cracknell, Nathan Fox, Cassady Harraden, Anita Parbhakar-Fox, Lejun Zhang

From July to September, Honours and postgraduate students were invited to attend six day-long skills workshops, comprising of both lectures and practical sessions, where students were encouraged to bring their own

project data in order to get expert advice on how the data should be interrogated and presented. The workshops were organised by Anita Parbhakar-Fox, and led by various in-house presenters.

Skills and software covered during the sessions included:

- > **Introduction to ioGAS** (Mike Baker) covered importing data, constructing and using diagrams, and interrogating geochemical data. These topics were followed by an interactive practical session.
- > **ArcGIS for Geoscientists** (Cassady Harraden) covered a number of GIS-related topics including ArcGIS software basics, data querying, and data analysis and interrogation in the earth sciences. Students were able to work with existing GIS datasets, as well as creating their own from freely available raster and tabular data.
- > **Machine Learning with Orange** (Matt Cracknell) provided an introduction into the application of machine learning algorithms to data analysis and data inference. It covered the basic principles of supervised classification and unsupervised clustering, using the Orange data mining package.

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

- > **The Spectral Geologist** (Lejun Zhang). This interactive workshop covered the theory of shortwave infrared analyses in earth sciences, assembly and basic operation of the TerraSpec instrumentation, collecting spectra, and processing and identifying minerals using The Spectral Geologist (TSG) software package.
- > **Adobe Creative Suite** (Nathan Fox) included an introduction to Adobe platforms, figure drawing and drafting, and an introduction to InDesign for professional thesis design.
- > **Presentation Skills** (Anita Parbhakar-Fox). In the final workshop of the series, the student group was given several exercises to help with their public speaking skills, in an environment where self-analysis and group feedback were encouraged. This was followed by a detailed session showing the students how they can use PowerPoint effectively to get the most out of their newfound skills.



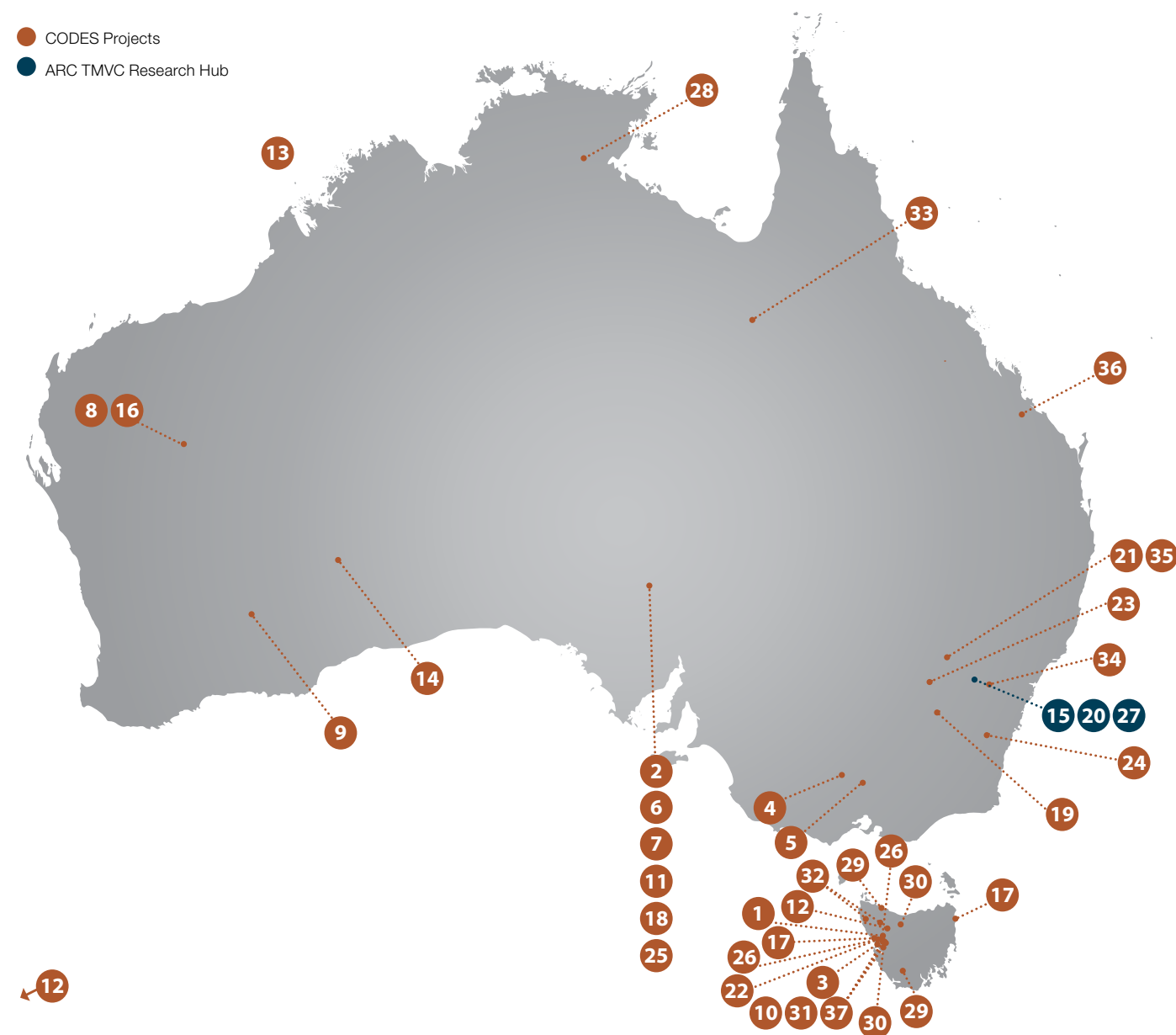
Group of undergraduate students on a field excursion to Broken Hill. PhD student Nathan Steeves (second from left) helped with the excursion, highlighting the co-operation and synergy between CODES and Earth Sciences.

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.

- CODES Projects
- ARC TMVC Research Hub



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

4. CAVE, BEN. VIC

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

5. CAVILL, CHLOE. VIC (MASTERS)

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

6. CHAPMAN, NATHAN. SA

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

7. CHERRY, ALEXANDER. SA

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

8. CONDON, JOANNA. WA (MASTERS)

Ore types of DeGrussa and Conductor 1 ore lenses of the DeGrussa VHMS deposit, Western Australia.

9. DOUTCH, DAVID. WA

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

10. ESHAGHI, ESMAEIL. TAS

Geophysical and petrophysical investigations of Tasmania at multiple scales.

11. FERGUSON, MATT. SA

Fe- and Ti-bearing minerals, apatite and zircon in the Olympic Dam district basement and Gawler Range Volcanics.

12. FOX, JODI. TAS

Submarine intraplate basaltic volcanism.

13. GOWER, BRADY. WA (HONS)

Structural and sedimentological analysis of the Adele Trend - Browse Basin.

14. HARDWICK, BRENDAN. WA (MASTERS)

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

15. HARRADEN, CASSADY. NSW*

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

16. HAWKE, MARGY. WA

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

17. HONG, WEI. TAS

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

18. HUANG, QIUYUE. SA

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

19. HUGHES, KYLE. NSW (MASTERS)

Paragenesis of the Dobroyde Deposit, central NSW.

20. JACKSON, LAURA. NSW*

Domaining of geoenvironmental properties in drill core.

21. JAGO, COREY. NSW (MASTERS)

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

22. KULTAKSAYOS, SITTHINON (GUN). NSW (MASTERS)

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

23. LESLIE, CHRISTOPHER. NSW

District scale ore deposit prospectivity of the Ordovician - Silurian Lachlan Fold Belt, southeastern Australia.

24. LLOYD, RICHARD (SIGMUN). NSW (HONS)

Alteration mineralogy and geochemistry of altered rocks in the Woodlawn VHMS belt, NSW.

25. LOWER, CHANTELE. SA (MASTERS)

An aspect of the geology of the Olympic Dam Cu-U-Au-Ag deposit.

26. McMAHON, CLAIRE. TAS

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

27. MORRISON, JOANNE. NSW (MASTERS)*

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

28. MUKHERJEE, INDRANI. NT

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

29. MULDER, JACOB. TAS

From Nuna to Gondwana: An evaluation of the early tectonic history of Tasmania.

30. OSTERSEN, THOMAS. TAS

Multi-scale geoelectric, and combined geophysical, investigations of Tasmania and Southeast Australia.

31. PEREIRA DA FONSECA, PEDRO. TAS

Facies analysis and correlations in complex mineralised submarine volcanic successions: Mount Read Volcanics, western Tasmania.

32. RADFORD, DECLAN. TAS (HONS)

Geological mapping from radar imagery with machine learning.

33. SHARMA, SUBIRA. QLD

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

34. SRITANGSIRIKUL, PEERAPONG. NSW (MASTERS)

Tectonic evolution and ore deposit prospectivity of the Rockley Volcanics, NSW Australia.

35. WELLS, TRISTAN. NSW (HONS)

Geology and genesis of the Two-Thirty prospect, Northparkes, NSW.

36. WHITNEY, BEN. QLD (HONS)

Geological framework and characteristics of the Specimen Hill high sulfidation epithermal system, southern Queensland, Australia.

37. WILLIAMS, TYLER. TAS (HONS)

Seismic evaluation of the integrity of the Henty tailings storage facility, Henty Tasmania.

OUTSIDE AUSTRALIA

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

1. ABERSTEINER, ADAM. CANADA, FINLAND, RUSSIA, SOUTH AFRICA

Kimberlites and diamonds:
Understanding their petrogenesis and
uncovering the identity of their source
composition.

2. AHMED, AYESHA. USA*

The effect of pressure/depth on
propylitic alteration mineral chemistry
in the porphyry environment.

3. BAKER, FABIAN. ARMENIA (MASTERS)

Amulsar HSE Au deposit, Armenia.

4. BENAVIDES, SEBASTIAN. ARGENTINA (MASTERS)

Characterisation of phyllic
assemblages at Taca Taca Bajo,
Argentina.

5. BERKENBOSCH, HEIDI. NEW ZEALAND

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

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

Chanca low sulfidation deposit, Peru.

7. CAVE, BEN. CANADA, NEW ZEALAND

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

8. CELIZ, DJOHANNE. PHILIPPINES (MASTERS)

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

9. CHEN, JING. CHINA*

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

10. CHIA, ZHENG (LEO). MARTINIQUE (HONS)

Sedimentological analysis of
Pleistocene pumice-rich turbidites
at Site U1398, IODP 340, offshore
Martinique.

11. DRAAYERS, EVAN. SW PACIFIC

The boninite magma genesis debate:
Assessing the role of mantle sources
associated with intra-plate magmatism
in the generation of boninitic magmas
above subduction zones.

12. ESCOLME, ANGELA. CHILE*

The geology, geochemistry and
geometallurgy of 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. FIRMANSYAH, ARGA. INDONESIA (MASTERS)

Geology and mineralisation of the
Trenggalek district, East Java,
Indonesia.

15. 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.

16. 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.

17. 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.

18. HOLT, SAM. USA

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

19. IKEGAMI, FUMIHIKO. NEW ZEALAND

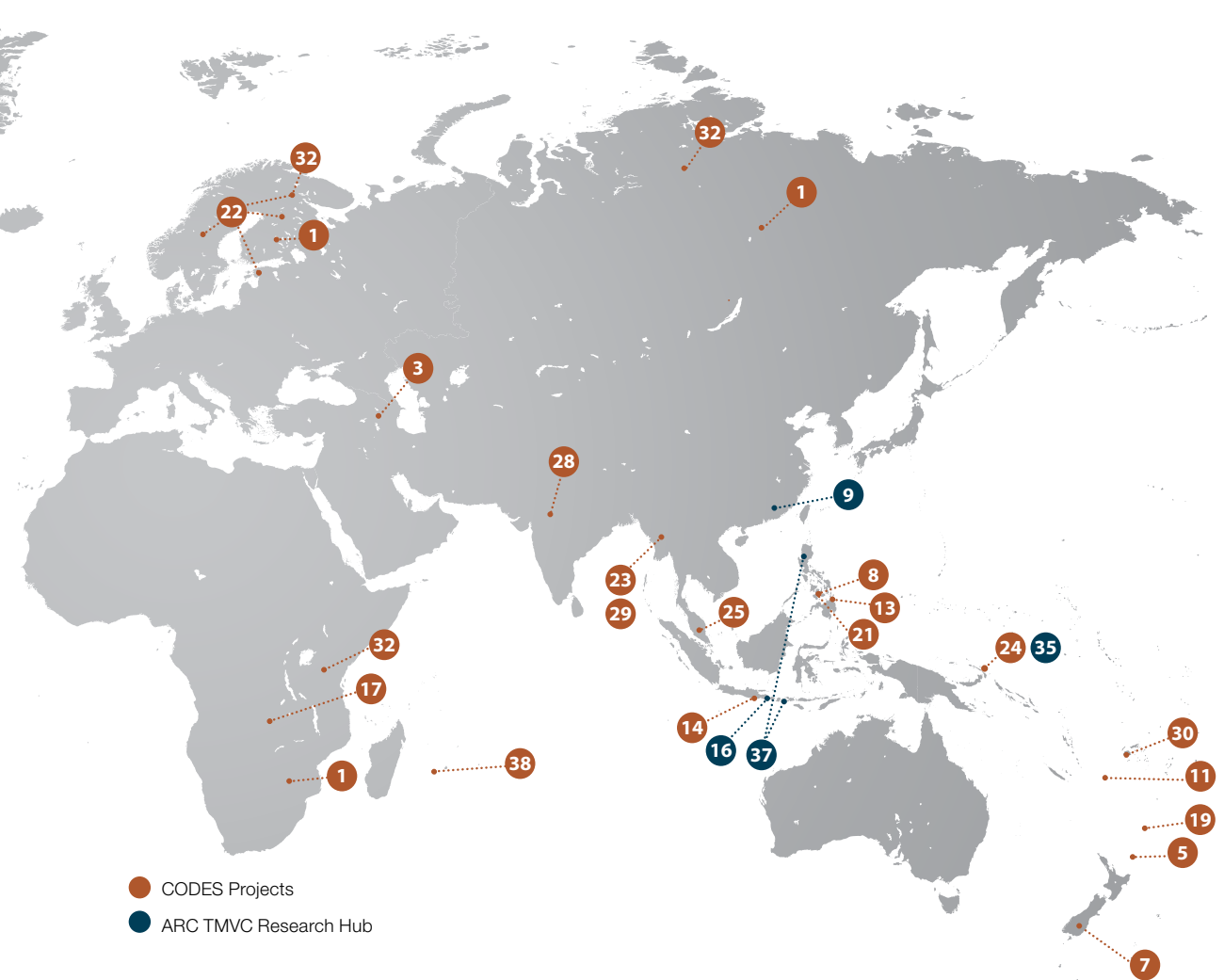
2012 submarine silicic eruption of
Havre volcano and implications for
ancient submarine successions in
Australia.

20. JENSEN, TORSTEN. USA

Devonian gold mineralisation in NE
Nevada, USA: Critical primer to a
world-class gold district?

21. JIMENEZ TORRES, CARLOS ANDRES. PHILIPPINES

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



● CODES Projects
● ARC TMVC Research Hub

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

The geochemistry of metalliferous
black shales: Understanding primary
enrichments, metamorphic processes
and the role of metal-rich black shales
in archiving earth evolution.

23. KNIGHT, JOSEPH. MYANMAR

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

24. LAWLIS, ERIN. PNG

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

25. MAKOUNDI, CHARLES. MALAYSIA

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

26. 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.

27. McNULTY, BRIAN. CANADA

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

28. MUKHERJEE, INDRANI. INDIA

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

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

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

30. OROVAN, EVAN. FIJI

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

31. PHILLIPS, JOSHUA. USA*

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

32. POTTER, NAOMI. TANZANIA, RUSSIA

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

33. STAAL, TOBIAS. ANTARCTICA

Seismic and geological constraints on
the lithospheric structure of Antarctica.

34. STEEVES, NATHAN. USA

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

35. SYKORA, STEPHANIE. PNG*

Origin, evolution and significance of
anhydrite-bearing vein arrays and
breccias, Lienetz orebody, Lihir gold
deposit, Papua New Guinea.

36. TESTA, FRANCISCO. ARGENTINA, CHILE

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

37. THOMPSON, JENNIFER. INDONESIA, PHILIPPINES*

Carbonate mineral chemistry in
epithermal and porphyry hydrothermal
systems.

38. VERGANI, DANIELE. REUNION

The 2007 explosive activity at Piton
de la Fournaise volcano (Reunion):
Constraints on the eruptive processes
by the volcanological study of the
erupted deposits.

LAB-BASED PROJECTS

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

BODINI, MATT. (HONS)

Evaluation of petrophysical and mineralogical proxies for rock strength with particular emphasis on civil engineering practice.

CESILE, STEPHANIE. (HONS)

An investigation into oceanic large igneous province plume swell.

CLIFTON, REBECCA. (HONS)*

Evaluating applications of boiler ash for controlling acid and metalliferous drainage-- examples from Tasmanian mine wastes.

GAL, MARTIN.

Seismic array analysis of ocean induced microseisms.

HOOD, SHAWN.*

Machine learning and automated geoscientific analyses for the spatial characterisation of metalliferous ore deposits.

JOB, KATHRYN. (HONS)

A palaeomagnetic study of the Palaeozoic Tasmanian Orocline Model.

KUHN, STEPHEN.*

The use of Machine Learning for lithological mapping and minerals targeting in various deposit styles and settings.

LOUNEJEVA, ELENA.

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

MORSE, PETER.

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

SANG, CALEB. (HONS)

Chasing the Kerguelen mantle plume 'tail': investigating the Miocene to Holocene record of volcanism using tephra glass in ODP Leg 183, Core 1138a.

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. From left: Ayesha Ahmed (Treasurer), Adam Abersteiner (Secretary), Joe Knight (Vice-President) and Shawn Hood (President).

► SOCIETY OF ECONOMIC GEOLOGISTS (SEG) STUDENT CHAPTER

The SEG Student Chapter plays an essential role in the activities of CODES, making significant contributions to the social and professional lives of students from a diverse range of backgrounds and cultures. Towards the end of each year, the students vote for a committee that plan and oversee a comprehensive social and professional development program that caters for everyone at the Centre, including students, researchers and professional staff.

PROFESSIONAL DEVELOPMENT

A high point of the professional development program is invariably the annual field trip, which this year was to Myanmar, where the group was afforded rare opportunities to view areas of the country that were off limits to geologists until recently. Highlights of the trip included visits to a number of mine sites, representing a diverse set of deposit styles and commodities, ranging from shear-hosted Au, epithermal Au, and skarn Au (Pb-Cu), through to primary and secondary ruby and sapphire, high-sulfidation epithermal Cu and orogenic/intrusion-related Cu-Ag-Au.

The 12-day excursion also covered features related to regional tectonics, taking in studies of the Sagaing Ridge, a surficial expression of the major Sagaing Fault system, and the

Palaeozoic stratigraphy of the western Sibumasu terrane.

The field trip was led by Professor Khin Zaw, together with Joe Knight and Jing Chen from the SEG Student Chapter, and was sponsored by CODES, First Quantum Minerals, Newcrest Mining, Rio Tinto, Savitar Exploration and the SEG. In addition to CODES students, the group included eight participants from four mining companies, and students from as far afield as Germany and Hong Kong.

Overall, it was a highly rewarding trip that not only exposed the participants to new and intriguing geological features, but also provided them with a once-in-a-lifetime opportunity to experience an enchanting country that is relatively poor, but so abundantly rich in history, culture and hospitality.

The Friday afternoon tradition of holding informal seminars, comprising a 20-minute technical talk, followed by a slide show and socialising was maintained in 2016, with the Chapter attracting an impressive array of first class speakers, who covered a diverse variety of (mostly) geological topics. The majority of speakers were from within UTAS, augmented by external speakers including Florent Sztikar (Geomar), Clive Calver (Mineral Resources Tasmania), Huanchun Qu (China University of Geosciences), and Grace Cumming (Mineral Resources Tasmania).

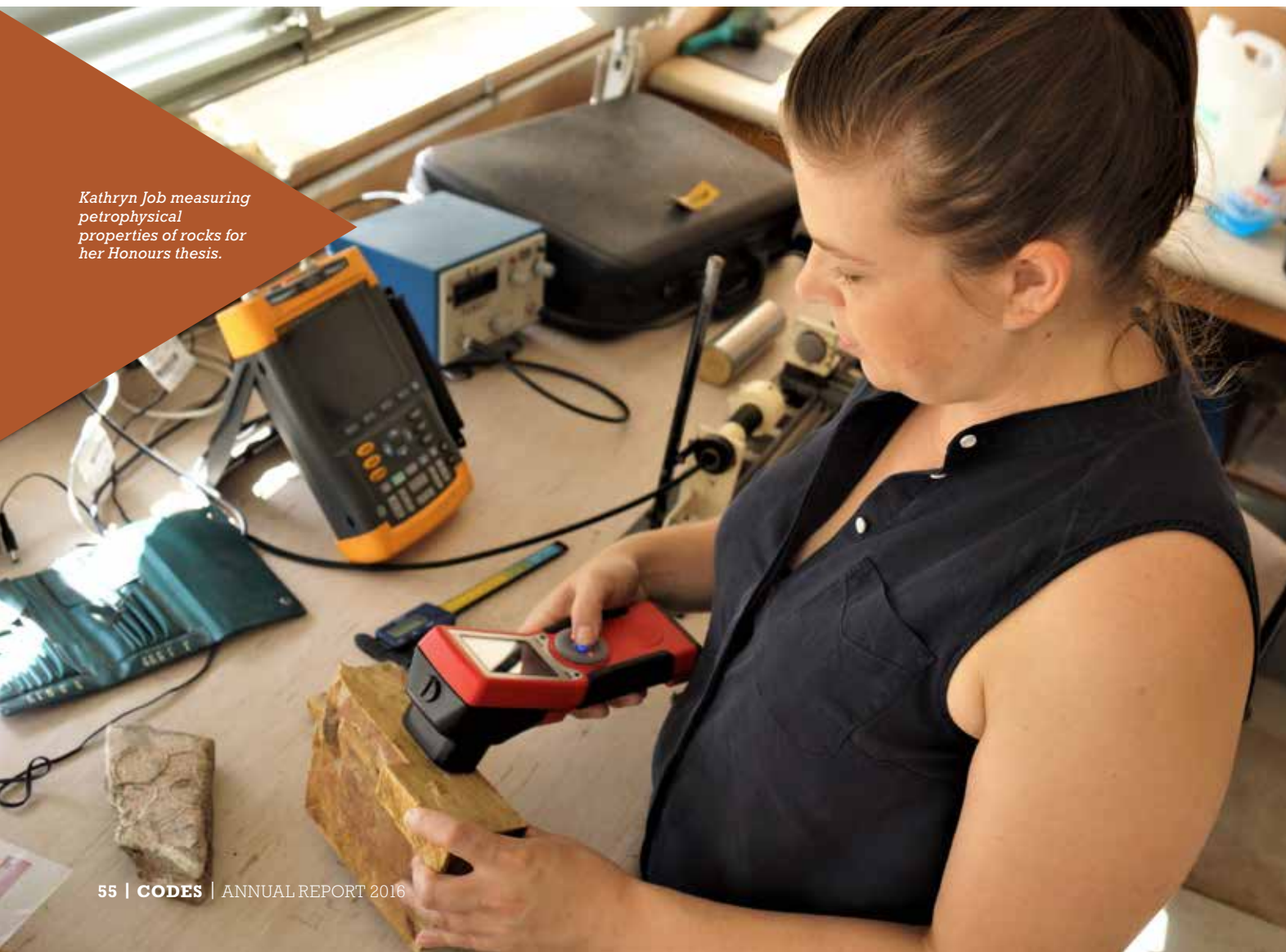
This year's Michael Solomon Memorial Lecture was delivered by Vic Wall. Vic has over 45 years' experience in mining, teaching and research, including formative interactions with Professor Solomon, as one of his PhD students, early in his career. This annual event is held in honour of the esteemed UTAS/CODES teacher and researcher, Professor Mike Solomon, who passed away in 2009. Speakers are chosen who have strong links with Mike. Vic's presentation, entitled 'Gold and granitoid plutonism', covered research that built on Mike's pioneering work in this area of study.

To finish the year, Professor Ross Large gave a retrospective on his varied career, having recently been awarded an Australian Museum Eureka Prize for Excellence in Interdisciplinary Scientific Research. Especially interesting were his thoughts on how academics can approach challenging long-held or dogmatic ore deposit models.

CONFERENCES AND EXHIBITIONS

One of the key areas where the students contribute to enhancing CODES' profile is by presenting papers at international conferences. Once again, it was a productive year in this regard, with students conducting 26 presentations at major international conferences in Australia, Indonesia, Japan, Malaysia, Switzerland and the USA.

Kathryn Job measuring petrophysical properties of rocks for her Honours thesis.



PUBLICATIONS

It was also another highly productive period for student outputs in terms of publications, with 23 refereed journal articles being produced throughout the year.

These included first author papers by Olga Apukhtina (*Contributions to Mineralogy and Petrology*), Ben Cave (*Mineralium Deposita*), Martin Gal (*Geophysical Journal International*), Laura Jackson (*Applied Geochemistry*), Indrani Mukherjee (*Precambrian Research*), Jacob Mulder (*Gondwana Research*), Subira Sharma (*Vibrational Spectroscopy*), Nathan Steeves (*Economic Geology*), and Jay Thompson (*Journal of Analytical Atomic Spectrometry*).

SOCIAL EVENTS

Social events organised by the committee act as a catalyst to foster friendships among students that come to CODES from all parts of the world, and widely different backgrounds. They also provide invaluable opportunities for researchers, supervisors and

professional staff to interact with the students in a relaxed environment, thereby enhancing understanding, communication and team spirit between all groups within CODES.

Events organised by the Student Chapter in 2016 included a wine tasting, 'fun bus' tour, welcome BBQ for Honours students, multiple social barbeques and icebreakers for visiting Master of Economic Geology students, and the 'winter warmer' series. In this novel winter innovation, students from different countries made a dish typical of their homeland. Given CODES multicultural cohort, there was plenty of fine winter fare on offer, from Aussie pumpkin soup through to Russian borsch, Burmese curry, Chinese duck soup, American southwestern chilli and corn bread, and Pakistani multani curry.

In addition, Student Chapter members assisted with the Christmas BBQ and participated in a host of other social events including weekly soccer games, dragon boat racing, ice hockey, indoor volleyball, badminton, squash, and a movie night.

AWARDS AND GRANTS

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

- > Cassady Harraden and Angela Escolme presented separate papers at the GeoMet 2016 conference in Perth, with the pair becoming co-recipients of the award for 'Best Paper by a Young Scientist'.
- > SEG Student Grants were received by Alex Cherry, Brian McNulty and Jennifer Thompson.
- > Subira Sharma received the Central Science Laboratory (CSL) Peter W Smith Postgraduate Award for the most outstanding peer-reviewed publication that made extensive use of CSL's facilities and expertise.

► LOOKING FORWARD

The healthy level of HDR enrolments will be maintained in 2017, with the number of graduations being balanced by a strong intake of new students, from both Australia and overseas.

The Master of Economic Geology Program is scheduled to have a full offering of three short courses, including the inaugural Ores in Magmatic Arcs. This unit builds on the success of Ore Deposits of South America by expanding the location options to include Indonesia, where participants will visit world-class porphyry and epithermal deposits over a two-week period. The unit will be held either in Indonesia or South America in future years.

The popular Geometallurgy short course returns in late October, and will include a comprehensive overview of the practical aspects of this field of the geosciences, from deposit characterisation and Grade Engineering through to improved management of mine waste. The course will include visits to Mineral Resources Tasmania's core storage facility, Hobart; ALS Minerals and Geochemistry Laboratories, Burnie; and mines at Savage River (iron ore) and Renison (tin).

After taking into account completions, graduations and other losses, the number of active continuing students in the overall program is expected to be maintained in 2017. It is anticipated that the average number of participants in individual courses will increase, partially bolstered by strong interest in the new course in Indonesia.

Honours enrolments will remain at a low level for the coming year in line with the relatively subdued career prospects in the mining industry, which have also had an impact on the lower numbers of undergraduate students feeding through to Honours. However, figures are expected to improve in future years. The series of Honours workshops introduced in 2016 will continue, as will the successful courses run in conjunction with the Victorian Institute of Earth and Planetary Sciences (VIEPS).

A highlight late in the year is the inaugural Geological Society of Australia Earth Sciences Student Symposium. This event will provide an excellent platform for students to showcase their research to their peers, plus stakeholders in government, industry and the broader academic community. The event is being held on 16 November at the Institute of Marine and Antarctic Studies on the Hobart waterfront. CODES is a main sponsor, and Dr Anita Parbhakar-Fox is an invited keynote speaker.

The SEG Student Chapter is planning to have another full schedule of social and professional development events throughout the year, the highlight of which will be a field trip to one of the most intriguing and geologically diverse places on the planet – Tasmania.

Will Clarke from Newcrest; one of the industry participants on the CODES SEG Student Chapter field trip to Myanmar.



PhD students Nathan Chapman, Adam Abersteiner and Alex Cherry helping and socialising at the Christmas barbeque.



TMVC:

THE ARC RESEARCH HUB FOR TRANSFORMING THE MINING VALUE CHAIN

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

► 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, HITLab Au, and RWTH Aachen University in Germany.

► HIGHLIGHTS

Activities gained considerable momentum during 2016, the first full year of the TMVC's operations. A key task was to further strengthen the UTAS-based element of the team, in order to establish a solid platform to tackle the challenges that lie ahead, and meet the Hub's KPIs. Successful outcomes in this regard were the appointments of Drs Evan Orován and Angela Escolme as Postdoctoral Research Fellows. Evan is working within Theme 1 – Detecting Proximity to Ore (footprints), while Angela's appointment commences in early 2017, when she will join the geometallurgical group in Theme 2.

In Theme 1, the AMIRA P1153 project initiated field campaigns at sites in Canada, Chile, Peru, USA and Serbia. A highlight of the year was the refinement of techniques for detecting proximity to mineralisation in lithocaps, which was achieved through an extensive analytical campaign, with technology transfer being facilitated through on-site meetings with the various stakeholders.

Cassady Harraden and Angela Escolme presented separate papers at the GeoMet 2016 conference in Perth, with the pair becoming co-recipients of the award for 'Best Paper by a Young Scientist'.

In early October, the team's pioneering geoenvironmental work in dealing with the legacy of mine waste contamination in western Tasmania was featured on ABC TV's *Australia Wide* program.

There were a number of exciting technological innovations during year. Highlights include the development of a novel approach for classifying ore domains geometallurgically using machine learning and geochemistry; and the establishment of a pilot algorithm that detects and extracts fractures in core samples from Corescan™ laser profiler data.

It was a fruitful year for student projects, with the submission of four theses spread across PhD (2), Master of Economic Geology and Honours. There was also a healthy output of various other publications, including nine refereed journal articles, 25 conference abstracts and 69 reports to industry.



DIRECTOR
David Cooke

► THE MODULE TEAM

DEPUTY DIRECTOR:
Leonid Danyushevsky

TEAM MEMBERS:

CODES

Mike Baker, Ivan Belousov, Ron Berry, Matt Cracknell, Nathan Fox, Bruce Gemmell, Sarah Gilbert, Ross Large, Sebastien Meffre, Paul Olin, Evan Orovan, Anita Parbhakar-Fox, Anya Reading, David Selley, Emily Smyk, Sasha Stepanov, Lejun Zhang

AMIRA International
Adele Seymon

BHP Billiton
Kathy Ehrig

Corescan
Neil Goodey

HITLab
Henry Duh

Laurin Technic
Michael Shelley

Newcrest Mining
Anthony Harris

RWTH Aachen University
Bernd Lottermoser

PHD STUDENTS: CODES

Ayesha Ahmed, Jing Chen, Angela Escolme, Amos Garay, Cassady Harraden, Rachel Harrison, Shawn Hood, Carlos Jimenez, Laura Jackson, Stephen Kuhn, Josh Phillips, Stephanie Sykora, Francisco Testa, Jennifer Thompson

IMPERIAL COLLEGE LONDON, UK
Adam Pacey

MASTERS STUDENTS:

CODES

Joanne Morrison

IMPERIAL COLLEGE LONDON, UK
Luke Neal

LAKEHEAD UNIVERSITY, CANADA

Ayat Baig, Nic Derome, Emily Gorner, Joseph Vrzovski

HONOURS STUDENTS:

CODES

Rebecca Clifton

LAKEHEAD UNIVERSITY, CANADA
Liam Fay

COLLABORATORS:

ALS METALLURGY
John Glen, Donna Kemp

BRUKER
Jens Bergmann

CHINA UNIVERSITY OF GEOSCIENCES
Zhanke Li

CONSULTANT
Noel White

CORESCAN

Ronell Carey, Ekaterina Savinova

CSIRO

Louise Fisher

GRANGE RESOURCES

Tony Ferguson, Roger Hill

GUANGZHOU INSTITUTE OF GEOCHEMISTRY, CHINA

Huayong Chen, Jinsheng Han

HEFEI UNIVERSITY OF TECHNOLOGY, CHINA

Shiwei Wang, Fan Yu, Taofa Zhou

HOT CHILI

Melanie Leighton

JUNIATA COLLEGE, USA

Richard Hark

LAKEHEAD UNIVERSITY, CANADA

Peter Hollings

MINERAL RESOURCES TASMANIA

Mike Reid

MONA HEAVY METALS PROJECT

Sarah Proud

NATURAL HISTORY MUSEUM, UNITED KINGDOM

Jamie Wilkinson

NEWCREST MINING

Karyn Gardner, Stephen Guy, Fiona Karaut, James Lett, Paul Napier

NORSKE SKOG

Peter Kearney

OLYMPUS

Dane Burkett

UNIVERSITY OF LIEGE, BELGIUM
Julie Hunt

UNIVERSITY OF TASMANIA, CENTRAL SCIENCE LABORATORY

Thomas Rodemann, Ashley Townsend

► 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. Underpinning Technologies and Knowledge Transfer and Training are essential parts of the TMVC, encompassing all research themes. The full scope of research activities gain considerably from the expertise, state-of-the-art facilities and technological developments within the Hub, and benefits to end-users are assured through extensive, hands-on technology transfer and training programs.

THEME 1: DETECTING PROXIMITY TO ORE (FOOTPRINTS)

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

THEME 2: OPTIMISING GEOMETALLURGICAL PREDICTION

- > General geometallurgy studies
- > Geotechnical and geometallurgical assessment of the Cadia East deposit using Corescan automated core logging technology
- > Ore characterisation and geometallurgical modelling at the Productora Cu-Au-Mo deposit, Chile
- > Cadia East multi-element lithogeochemistry: Evaluation of trace element deportment important to processing

THEME 3: MINIMISING GEOENVIRONMENTAL RISKS

- > Integrated waste classification for best practice AMD prediction
- > Development of effective short-term leach tests for water quality prediction
- > Mineralogical domaining of low grade and no grade zones using automated drill core logging at Cadia
- > Metal extraction from mine tailings using bioleaching: Environmental and economic benefits
- > Utilising industrial waste materials for AMD control

UNDERPINNING TECHNOLOGIES

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

KNOWLEDGE TRANSFER AND TRAINING

► PROJECT SUMMARIES

THEME 1 – DETECTING PROXIMITY TO ORE (FOOTPRINTS)

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

Leaders: David Cooke, Bruce Gemmell

Team Members: Mike Baker, Ivan Belousov, Matt Cracknell, Evan Orovan, Emily Smyk, Lejun Zhang

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

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

AMIRA P1153 is being conducted in collaboration with researchers from Lakehead University, the Natural History Museum, Guangzhou Institute of Geochemistry, and Hefei University of Technology. It is developing new methods for discovering porphyry and/or epithermal deposits through improved geochemical detection of ore deposit footprints. Analysis of the geochemical signals recorded in hydrothermal alteration halos will provide explorers with methods for assessing district fertility (how large?) and vectoring information (how far, and in what direction?), allowing the presence, location and significance of porphyry and/or epithermal copper, gold and molybdenum deposits in an



LEFT:
The AMIRA P1153 team at the project's November meeting.

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.

The research team initiated field campaigns at sites in Canada, Chile, Peru, USA and Serbia in 2016, several of which involve postgraduate students (Honours, MSc and PhD). Early in the year Ayesha Ahmed initiated her PhD study of the Yerington district, Nevada, while Emily Gorner and Joseph Vrzovski initiated their studies of the Hemlo gold deposit, Liam Fay commenced an honours study of Heron Bay, and Nic Derome began an MSc study of the Red Lake deposit, Ontario, mid-year. New screening methods for distinguishing porphyry-related alteration minerals from background metamorphic and calc-sodic alteration were developed through detailed studies of selected sites, and reanalysis of sample suites from previous analyses. New techniques for detecting proximity to mineralisation in lithocaps were refined through an extensive analytical campaign. Technology transfer was facilitated through on-site meetings with industry representatives at head offices and field sites.

José Piquer and Francisco Testa published manuscripts, reporting outcomes from their PhD work, in *Journal of Structural Geology*, *Lithos* and *Minerals*. Ayat Baig submitted and successfully defended his MSc thesis, and Adam Pacey submitted his PhD thesis and prepared a manuscript for *Economic Geology*. David Cooke gave a keynote presentation, and Lejun Zhang gave an invited presentation, at the MGEI conference in Bandung, Indonesia, in October.

PYRITE FOOTPRINTS

Leader: David Cooke

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

Student: Stephanie Sykora

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

Stephanie Sykora's PhD project at the Lihir gold deposit in Papua New Guinea (PNG) was incorporated into the TMVC early in 2016. Her research aims to resolve the genesis of an anhydrite-rich zone at the deposit, and was converted from an MSc to a PhD in 2015.

Stephanie analysed pyrite grains from structurally and paragenetically constrained vein samples that span from the early porphyry-style to late epithermal system at the Lihir gold deposit, PNG. Statistical analyses of LA-ICP-MS data from trace element images of pyrite grains has revealed the compositional signatures of various hydrothermal stages, and provides evidence for gold remobilisation. Her results have implications for ore genesis, mineral exploration and mineral processing at Lihir. A manuscript summarising the pyrite geochemistry results was submitted to a Special Issue of *Economic Geology* in late 2016. Stephanie delivered an invited oral presentation on her results at the MGEI conference in Bandung, Indonesia, in October, and submitted her PhD thesis in December.

David Cooke, Lejun Zhang and Leonid Danyushevsky co-authored an article on pyrite chemistry from the Haopinggou Au-Ag-Pb-Zn vein deposit in China, which was published online in *Contributions to Mineralogy and Petrology*. This study demonstrated that single veins formed by two temporally distinct mineralising events at Haopinggou, a Triassic metamorphic gold-forming event, and a Cretaceous magmatic-hydrothermal event that produced silver-lead-zinc mineralisation. The temporally distinct events produced pyrite grains with markedly different trace element compositions within composite veins.

THEME 2 – OPTIMISING GEOMETALLURGICAL PREDICTION

GENERAL GEOMETALLURGY STUDIES

Leader: Ron Berry

This research is focussed on advancing work that had been initiated in the previous GeMIII project, but had not yet reached a stage where it was ready for release to the mining industry. Major activities in 2016 were:

- > A paper was published in *Economic Geology* to accompany the STORC software program's public release.
- > Significant progress has been made on papers that review geological aspects of geometallurgy, as well as methods in calculated mineralogy. These are in preparation for a planned special issue.

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

Leaders: Sebastien Meffre, Ron Berry

Team Members: Matt Cracknell, Neil Goodey

Student: Cassady Harraden

Collaborators: James Lett

The goal of this PhD project by Cassady Harraden is to determine the correlation between Corescan™ 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 paper on the geotechnical methods previously developed in this project was presented at GeoMet 2016 in Perth, with Cassady being co-recipient of the award for 'Best Paper by a Young Scientist'.

Research has focussed on fine-tuning the protocols for extraction of geotechnical parameters, which was completed during the year. The integration of those parameters with alteration mineralogy will continue into 2017.

ORE CHARACTERISATION AND GEOMETALLURGICAL MODELLING AT THE PRODUCTORA CU-AU-MO DEPOSIT, CHILE

Leaders: David Cooke, Ron Berry

Student: Angela Escolme

Collaborators: Louise Fisher, Julie Hunt, Melanie Leighton

This project aims to determine relationships between ore textures, alteration and geochemical zonation patterns, and assess their impact on liberation behaviour and recovery response at the Productora Cu-Au-Mo deposit, Chile.

Major geometallurgy results of the project were completed during the year, drawing to a close the work program for this project. These results were presented at GeoMet 2016 in June, where Angela was co-recipient of the 'Best Paper by a Young Scientist' award.

Angela submitted her PhD thesis at the end of the year, and has secured a postdoctoral position within the Hub, starting early in 2017.

CADIA EAST MULTI-ELEMENT LITHOGEOCHEMISTRY: EVALUATION OF TRACE ELEMENT DEPORTMENT IMPORTANT TO PROCESSING

Leader: Ron Berry

Student: Joanne Morrison

The Cadia East ore body contains trace elements relevant to the value of ore. This Masters of Economic Geology project by Joanne Morrison identified the location and deportment of these trace elements, and the rate of recovery of the trace elements to concentrate. Four main domains in the ore were discovered to have different levels of relevant trace elements in situ, and to have different recovery behaviours when processed. These domains are monzonite/monzodiorite, alkali basalt, potassic-altered basalt and propylitic-altered basalt. Using these domains, it is possible to more accurately predict the trace element content of the concentrate. The identification of the domains with high critical trace element recovery to concentrate has enabled the optimisation of the draw schedule to manage the blend of material delivered to the mill for processing.

Joanne submitted her thesis at the end of the year.

THEME 3: MINIMISING GEOENVIRONMENTAL RISKS

INTEGRATED WASTE CLASSIFICATION FOR BEST PRACTICE AMD PREDICTION

Leader: Anita Parbhakar-Fox

Team Member: Nathan Fox

Collaborators: Dane Burkett, Tony Ferguson, Roger Hill

This project is looking at aspects of waste classification to better understand and manage current and planned sites.

During the year, Grange Resources proposed a study focused on determining the accuracy of the net acid generation (NAG) pH test. This test is used widely by the mining industry for rapid waste classification, and involves several stages, including length of reaction time, heating temperature, and cooling time before pH measurement. The study scrutinised each stage to determine the effect on the overall test results. Outcomes included the development of a site-specific NAG pH testing protocol (suitable for the waste types encountered at Grange Resources' Savage River operations), with a journal article also in preparation.

Another element of this project was a review of the Terra portable XRD instrument, manufactured by Olympus. This instrument has the ability to rapidly measure the mineralogy of a dried sample, with full phase identification and quantification capabilities. Testing of the instrument was conducted on various drill core and mine waste materials, with the results summarised in an internal TMVC report.

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

Leader: Anita Parbhakar-Fox

Team Member: Nathan Fox

Students: Rebecca Clifton, Laura Jackson

Collaborators: Jens Bergmann, Tony Ferguson, Roger Hill, Ashley Townsend

This project seeks to vary parameters (trial use of blends, reaction time, reagent concentration, quantity of solid/reagent) used in traditional static testing (e.g. net acid generation and paste pH testing) to determine if they can be optimised for more efficient use in the field.

During 2016, a static blended leach test (BLT) was developed to explore options for improved waste rock pile design at the Savage River mine (Grange Resources). Specifically, the project aimed to determine which waste blend ratios would produce the ‘cleanest’ leachate, and if a static test could be used to determine this prior to establishing kinetic cells. Findings of the Savage River case-study were reported to Grange Resources, with results to be presented at the Process Mineralogy ’17 conference. A journal publication is also in preparation.

In addition, a total reflectance XRD PICOFOX, manufactured by Bruker, was trialled in September to assist with the rapid and accurate collection of water quality data. An analytical method was developed enabling researchers and students across Theme 3 to analyse acid mine drainage (AMD) impacted river waters from western Tasmania, as well as NAG pH test samples and kinetic cell leachates generated in various projects.

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

Leader: Anita Parbhakar-Fox

Team Members: Ron Berry, David Cooke, Matt Cracknell, Nathan Fox, Neil Goodey, Anthony Harris, Bernd Lottermoser, Sebastien Meffre

Students: Laura Jackson

Collaborators: Ronell Carey, Stephen Guy, Ekaterina Savinova

Prediction of acid mine drainage (AMD) 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 AMD might evolve, or the role of secondary minerals in metal cycling in the surficial environment. This research is developing new protocols by which different mineralogical techniques can be effectively used and integrated to allow for geoenvironmental characterisation of intact-waste materials (i.e., drill core materials) to be efficiently performed, in terms of time and cost.

To date, method development has focussed on using Corescan™ data and drill core materials collected from the Cadia district, New South Wales. By undertaking a range of established static tests and conventional mineral identification (i.e., XRD), a geoenvironmental domaining index (GDI) tool has been developed using the hyperspectral data provided by Corescan™. GDI version 1 was fine-tuned to identify inherent primary neutralisers within low- or no-grade zones, so as to optimise their use when designing waste management strategies. A review of additional mineralogical tools to assist in refining estimates of sulfide abundance was also conducted, focussing on LA-ICP-MS, micro-XRF, laser Raman and laser induced breakdown spectroscopy. Data processing indicates that LA-ICP-MS is the most appropriate technology to enable development of GDI version 2.

METAL EXTRACTION FROM MINE TAILINGS USING BIOLEACHING: ENVIRONMENTAL AND ECONOMIC BENEFITS

Leader: Anita Parbhakar-Fox

Collaborators: Tony Ferguson, John Glen, Donna Kemp

This project aimed to determine the feasibility of reprocessing historic mine tailings at the Old Tailings Dam (OTD) in western Tasmania. The OTD contains 38 Mt of pyritic tailings, which are impacting the water quality of the adjacent Savage River. Other methods of tailings management have been evaluated but deemed unfeasible. However, as the pyrite within the tailings is cobalt-rich, the option of reprocessing is now being considered.

Two stages of testing at the ALS labs in Burnie were conducted during the year supported by funding from the UTAS Research Enhancement Grants Scheme. This testing has shown that the use of the BIOX™ bacterial consortia in the oxidation of pyritic tailings from the OTD resulted in liberation of 93% refractory cobalt. These research findings were presented at the Biohydrometallurgy ’16 conference (Cornwall, UK) with the publication of an associated conference paper.

Further work will need to be conducted in order to determine if there is real economic benefit in pursuing cobalt extraction from the tailings at this site.

UTILISING INDUSTRIAL WASTE MATERIALS FOR AMD CONTROL

Leader: Anita Parbhakar-Fox

Team Member: Nathan Fox

Students: Rebecca Clifton, Laura Jackson

Collaborators: Tony Ferguson, Peter Kearney, Sarah Proud, Mike Reid, Ashley Townsend

Cost-effective waste management of materials producing acid mine drainage (AMD) is essential for successful remediation. Considering this, using alkaline waste materials generated by other industrial processes represents a potential option for managing acid forming mine wastes, which this project aims to test.

In 2016, Honours student Rebecca Clifton assessed the use of boiler ash waste material from Norske Skog’s Boyer mill as an AMD ameliorant. Samples of waste rock and tailings from several sites around Tasmania, with very different mineralogical compositions, and therefore resulting water quality issues, were sourced for assessment of the effectiveness of utilising the paper mill waste in AMD control.

Results indicated that low-pyrite mine waste materials could be treated with boiler ash for limiting AMD, particularly if blended with commercial lime, as this encouraged the formation of a durable cement layer capping the tailings and retarding oxidation. Project results were presented to the Heavy Metals Project team at the Museum of Old and New Art (MONA) in December, with a journal article in preparation.

UNDERPINNING TECHNOLOGIES

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

Leaders: Leonid Danyushevsky, Michael Shelley

Team Members: Ivan Belousov, Paul Olin

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

During the year, the team focused on testing the importance of several variables, such as cell orifice diameter and the distance between the sample and the top of the cell. The impact of uneven sample surface on the detection limits, and quantification of LA-ICP-MS data were also tested. Together with performance testing of the first prototype of the fast response cell, these measurements helped to inform design of the second prototype cell.

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

Leader: Matt Cracknell

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

This project aims to extract and classify mineralogical and textural features from current Corescan™ output datasets. The project will primarily use Corescan™ visible and

hyperspectral imagery, and surface geometry imagery, as input data to extract and classify features, such as veins, fractures, grain boundaries, lithologies, alteration, textural fabrics and ARD domains. Output features will add value to the dense datasets currently generated by the Corescan™ system by making them more geologically interpretable, and thus accessible to users. Features will also be used to support quantitative analyses and qualitative interpretations across the TMVC’s three themes – covering footprints, geometallurgy and geoenvironment.

During the year, a prototype fracture detection algorithm was developed to identify and extract fractures from Corescan™ data. The outputs of this algorithm feed directly into workflows being developed for the extraction of geotechnical parameters.

LINE SCAN TECHNOLOGIES FOR DRILL CORE

Leader: Ron Berry

Team Member: Sebastien Meffre

Student: Cassady Harraden

Collaborators: Richard Hark, Thomas Rodemann

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

Initial scope of the technology assessment concentrated on 50 micron pixels, however this pixel size was not achievable with the available equipment. As a result, work during the year has been based on 100 to 300 micron pixels, and the application of sub-pixel analysis. This analysis aims to produce a grain size proxy reflecting the proportion of metals

present in sulfide grains larger than 50 microns.

Laser Raman, micro-XRF and LIBS technologies were tested on representative samples of drill core with the following outcomes:

- > The laser Raman technology was deemed to be unsuitable for analysis of sulfides in drill core.
- > Initial analysis of the LIBS data suggests that it may be suitable for line scan analysis within the life of the TMVC.
- > Early indicators suggest that micro-XRF should adequately assess grain size as well as being the only technology-ready option of those tested.

LIBS and micro-XRF data processing will continue into 2017, with the possibility of expanding the assessment to new technologies as they become available.

INTEGRATING CHEMICAL AND MINERALOGICAL DATA LAYERS FOR ELEMENT DEPARTMENT

Leaders: Sebastien Meffre, Matt Cracknell, Leonid Danyushevsky, Ron Berry

Team Members: Ivan Belousov, Nathan Fox, Sarah Gilbert, Paul Olin, Sasha Stepanov

Students: Cassady Harraden, Laura Jackson

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

During the year, various analytical instruments and methods were tested using 12 samples from two deposits. The results were compared using ArcGIS, which was identified to be the best package for this purpose, overlaying data layers for comparative analysis and evaluation.

Whole rock, modal mineralogy and trace element mineral chemistry were



acquired using LA-ICPMS rapid (0.3 mm s⁻¹) lines on large unpolished core samples (10-15 cm long). The results gained were very similar to whole rock XRF data, MLA and XRD mineralogical data, and data from conventional LA-ICP-MS spots. Further work on the quantification of uncertainties and resolution of conflicting data sets needs to be conducted before the techniques are validated on other ore deposit types.

INTERPRETING STRUCTURAL AND GEOCHEMICAL PATTERNS USING MACHINE LEARNING

Leaders: Anya Reading, Matt Cracknell

Student: Shawn Hood

This PhD project aims to develop and combine machine learning algorithms and automated workflows to process and interpret patterns found in 3D structural and geochemical data. Automated workflows are being developed using open source software that aim to rapidly generate repeatable and objective 3D models of geologically relevant features with input from domain experts. These workflows will fit seamlessly into existing industry methodology for defining ore bodies in brownfields environments. This research supports positive exploration and ore extraction outcomes in complex geological structural settings, such as those found in orogenic gold deposits.

During the year, workflows that implement both unsupervised clustering and supervised classification algorithms have been developed to identify protolith groups and their altered counterparts from whole rock geochemical analyses. Outputs are then used in automated mass balance calculations that calculate element relative enrichment or depletion during hydrothermal metasomatism. The results can be plotted in 3D space to visualise fluid flow networks, which provide the opportunity to model structural domains that control ore deposit formation.

GEOLOGICAL FEATURE DISCOVERY FROM QUANTITATIVE DATA INTEGRATION (ALGORITHM DEVELOPMENT)

Leader: Anya Reading

Team Member: Henry Duh

Student: Stephen Kuhn

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

During the year, robust methods for the selection of relevant variables, and predictive model uncertainty quantification, have been applied and tested on existing geological models from the Eastern Goldfields region of Western Australia and the Zambian Copperbelt in Central Africa.

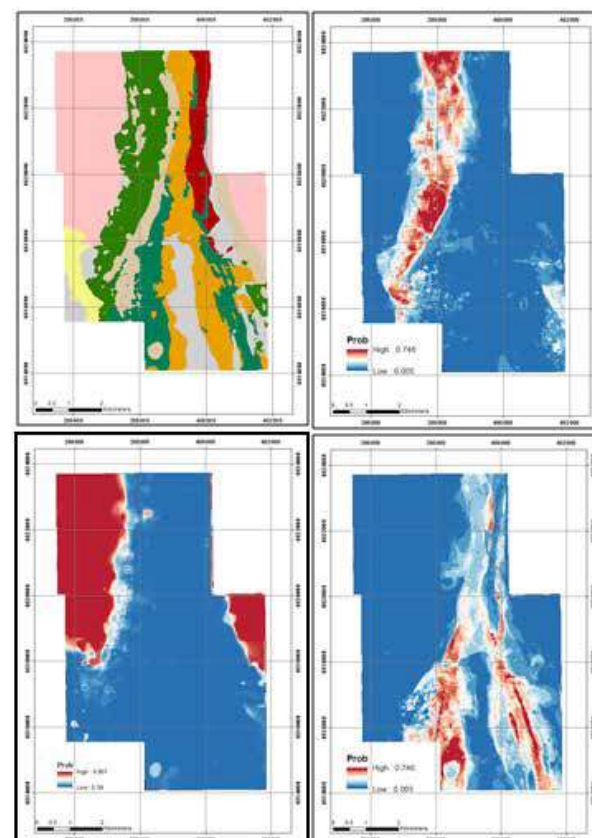
Results indicate that automatically defined relevant geochemical features align closely with features used by domain experts to interpret geological domains. Furthermore, uncertainty maps provide a quantitative means of streamlining data acquisition for increasing confidence in output geological models.

KNOWLEDGE TRANSFER AND TRAINING

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

During the year TMVC staff and students produced nine refereed journal articles, provided 69 reports and 19 on-site presentations to industry, delivered 25 conference presentations, and 12 workshops (both local and international). Several staff and students delivered a dedicated session on research highlights and the forward program at the annual CODES Science Planning Meeting (oral and poster presentations).

Team members also participated in public outreach opportunities including the University of Tasmania's Open Day, UTAS PhD video series, and radio and television interviews. A highlight of the TMVC's public outreach was a segment from the ABC's *Australia Wide* program on October 1st (<http://www.abc.net.au/news/2016-09-30/australia-wide-october-1/7893186>). The story highlighted the TMVC's geoenvironmental research, training and public outreach activities that deal with the legacy of historical mine waste contamination of the King-Queen River system and Macquarie Harbour in western Tasmania.



CLOCKWISE FROM TOP LEFT: Random Forests classified map, class membership probability of dolerite type 2, class membership probability of granite, class membership probability of dolerite type 2.

LOOKING FORWARD

The TMVC's activities will continue to build momentum in 2017, boosted by the commencement of geomettallurgy postdoctoral research fellow Angela Escolme in February; three long-term visiting PhD students, arriving in March; and two PhD recruits, who will begin their studies mid-year. The visiting students, from Guangzhou Institute of Geochemistry, Hefei University of Technology, and China University of Geosciences, will all be staying at the Hub for one year to work on various projects within Theme 1.

In other developments related to the 'footprints' theme, a project will be commencing in Western Australia, applying pyrite mineral chemistry in the search for sediment-hosted Cu-Co mineralisation.

In the geomettallurgy theme, Cassady Harraden's project at Cadia East is expected to conclude, after delivering invaluable results in determining the correlation between Corescan™ data and measured deportment data, plus processing parameters and geotechnical conditions at the deposit. Also in this theme, Ron Berry has made significant progress on papers reviewing the geological aspects of geomettallurgy, as well as methods in calculated mineralogy. These papers are in preparation for a planned special issue, which is just one of many publications in the pipeline throughout all areas of the TMVC.

A new project is set to commence at Boliden's Laver site in Sweden, with the aim of establishing effective mineralogical and geochemical techniques for deposit-wide geoenvironmental characterisation.

Underpinning Technologies will continue to play a key role throughout all TMVC activities. In just one of many initiatives in this area, the team is developing a new sample cell capable of high-throughput applications using laser ablation instruments. The instrumentation developed has the potential to have the capability of scanning large sections of drill half-core, providing significant benefits and efficiencies to the minerals industry.

It promises to be a very busy year for conference-related activities, with staff and students representing the TMVC at a host of international events, including the delivery of a number of talks and poster presentations. In addition, the TMVC (through CODES), is expected to have booths at three of these conferences, i.e. Roundup (Vancouver), SEG (Beijing) and FUTORES II (Townsville). In addition, there will be a booth sharing arrangement with Mineral Resources Tasmania at the PDAC Convention in Toronto.

THE DISCIPLINE OF EARTH SCIENCES

► 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. Close 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.

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 four 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.

► HIGHLIGHTS

EUREKA PRIZE

One of the main highlights of the year was unquestionably the Eureka Prize awarded to the team from the Trace Elements in Ancient Oceans project. Led by Emeritus Professor Ross Large, the researchers linked major evolution and extinction cycles with a drop in the concentration levels of trace elements in ancient oceans, particularly in respect to selenium. The research also linked these findings with a dramatic shift in the formation of ore bodies – changing from deposits rich in iron, gold and nickel to those containing zinc, silver, copper and uranium. This shift led to the formation of some of Australia's largest and richest ore deposits, including Broken Hill (Zn-Ag), Olympic Dam (Cu-U), Ranger (U), and Mt Isa (Cu-Zn-Pb-Ag). The discoveries deservedly attracted worldwide media coverage.

RESEARCH

Drs Karin Orth and Rebecca Carey initiated a new collaborative project with Mineral Resources Tasmania on volcanics exposed at Great Lake, in the central northern region of the state. Extraordinarily low water levels in the lake afforded the team a rare opportunity to investigate outcrops on

its shores, which were last examined in the mid-1960s.

In an intriguing mix of science, art and public outreach, research by Professor Anya Reading and PhD student Martin Gal formed part of a multidisciplinary Art-Science project, with a video presentation based on the outcomes also being included in the 'Dark Storm' exhibit at the 2016 Dark Mofo winter festival in Hobart. This novel research is applying algorithms from radio astronomy, newly implemented for seismic array processing, to understand ambient seismic energy generation around the Australian coast.

Staff and HDR students participated in two major research cruises during the year, both on board the CSIRO's state-of-the-art marine research vessel *RV Investigator*.

- > In early January, Jodi Fox and Evan Draayers embarked on a two-month voyage to the Heard and McDonald Islands region, Kerguelen Plateau, as part of their PhD projects.
- > In August, Dr Sean Johnson, Jodi Fox, and Rhiannon Mundana (undergraduate) took part in a voyage to the Cascade Seamount, East Tasman Rise, and collected volcanics and volcano-sedimentary rocks, which are now being analysed for Ar-Ar dating and geochemistry.

PUBLICATIONS

It was a productive year for publications. Highlights include:

- > PhD student Jodi Fox's collaboration with Professor Robert Duncan from Oregon State University led to a joint publication in the *Australian Journal of Earth Sciences* on the geological history of Heard Island.
- > Research by PhD student Naomi Potter on the liquid-liquid immiscibility in the Oldoinyo Lengai 1993 lava was published in *Chemical Geology*.
- > Large datasets on kimberlites and kimberlite-hosted mantle lithologies (peridotite and eclogite xenoliths) were presented in several papers published in *Chemical Geology* (Abersteiner et al.; Giuliani et al. and Kiseeva et al.), *Lithos* (Giuliani et al. and Soltys et al.) and in a review in *Earth and Planetary Science Letters* by Kamenetsky, V.
- > The 'Beneath Bass Strait: ambient seismic tomography' project came to a successful conclusion with the publication of a paper highlighting lithospheric fabric as identified by seismic anisotropy inferred from ambient seismic tomography.
- > Several papers by Professor Patrick Quilty were published, covering a wide range of topics including Pliocene molluscs from the Marine Plain, Antarctica; the volcanic history of Heard Island and Kerguelen Plateau (2 papers); and key sediments from the Coral Sea.

GRADUATIONS

It was also a productive year for PhD students associated with Earth Sciences, with the graduations or completions of Martin Gal, Qiuyue Huang, Sean Johnson and Charles Makoundi.

Ross Large and Jacqueline Halpin with the Eureka Prize in the category of Excellence in Interdisciplinary Research, awarded at a gala function in Sydney.

DISCIPLINE HEAD

Leonid Danyushevsky



► THE DISCIPLINE OF EARTH SCIENCES TEAM

STAFF MEMBERS:

CONTINUING APPOINTMENTS AT UTAS:

Academic: Rebecca Carey, David Cooke, Garry Davidson, Vadim Kamenetsky, Anya Reading, Michael Roach

Professional: Isabella von Lichten, Ian Little, Deborah Macklin

FIXED-TERM AND HONORARY APPOINTMENTS:

Academic: Sharon Allen, Ron Berry, Trevor Falloon, Nathan Fox, Bruce Gemmell, Jacqueline Halpin, Julie Hunt, Sean Johnson, Martin Jutzeler, Ross Large, Peter McGoldrick, Jocelyn McPhie, Sebastien Meffre, Karin Orth, Patrick Quilty, Robert Scott, David Selley, Jeff Steadman, Sasha Stepanov

Professional: Michelle Chapple-Smith, Alex Cuisson, Anika Husen, Irina Zhukova

PHD STUDENTS:

Adam Abersteiner, Evan Draayers, Jodi Fox, Martin Gal, Sam Holt, Qiuyue Huang, Fumihiko Ikegami, Sean Johnson, Elena Lounejeva, Charles Makoundi, Indrani Mukherjee, Thomas Ostensen, Naomi Potter, Daniele Vergani

HONOURS STUDENTS:

Leo Chia, Caleb Sang

COLLABORATORS:

ABERDEEN UNIVERSITY, UK
Nicholas Rawlinson

AUSTRALIAN NATIONAL UNIVERSITY

John Mavrogenes, Simone Pilia, Greg Yaxley

BHP BILLITON

Kathy Ehrig

BROWN UNIVERSITY, USA

Ryan Portner, Alberto Saal

DURHAM UNIVERSITY, UK

Peter Talling

FLINDERS UNIVERSITY

John Long

FROGTECH

Lynn Pryer

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Julie Hollis, Christopher Phillips

GEOSCIENCE AUSTRALIA

Jingming Duan, Tristan Kemp

GEOSCIENCE VICTORIA

Ross Cayley

GNS NEW ZEALAND

Fabio Caratori-Tontini, Michael Rosenberg

HAWAIIAN VOLCANO OBSERVATORY, USA

Tim Orr, Matthew Patrick

INGV OBSERVATORY, ITALY

Daniele Andronico

INSTITUTE OF EXPERIMENTAL MINERALOGY, RUSSIA

Michael Zelenski

INSTITUTE OF GEOLOGY AND MINERALOGY, RUSSIA

Alexander Golovin, Marina Gora, Dmitry Kuzmin, Victor Sharygin, Ella Sokol, Lyudmila Zhitova

INSTITUTE OF THE EARTH'S CRUST, RUSSIA

Yulia Danilova, Elena Demonterova, Alexei Ivanov, Valentina Savel'eva

JAPANESE NATIONAL MUSEUM OF NATURE AND SCIENCE

Kenichiro Tani

MACQUARIE UNIVERSITY

Leanne Armand, Nathan Daczko

MASSEY UNIVERSITY, NEW ZEALAND

Georg Zellmer

MELBOURNE MUSEUM

Thomas Darragh

MINERAL RESOURCES TASMANIA

Ralph Bottrill, Grace Cumming, Mark Duffett, John Everard, Andrew McNeill, Andrew Wakefield

NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH, NEW ZEALAND

Richard Wysoczanski

OREGON STATE UNIVERSITY, USA

Robert Duncan

REUNION ISLAND OBSERVATORY, FRANCE

Andrea DiMuro

SEOUL NATIONAL UNIVERSITY, SOUTH KOREA

Jung-Woo Park

SMITHSONIAN INSTITUTION, USA

Richard Fiske

THE DISCIPLINE OF EARTH SCIENCES

UNIVERSITÉ DE LORRAINE, FRANCE
Andrey Gurenko

UNIVERSITÉ GRENOBLE, FRANCE
Alexander Sobolev

UNIVERSITY OF ADELAIDE
Graham Heinson

UNIVERSITY OF BARCELONA, SPAIN
Marc Campeny

UNIVERSITY OF CALIFORNIA BERKELEY, USA
Michael Manga

UNIVERSITY OF CALIFORNIA RIVERSIDE, USA
Dan Gregory

UNIVERSITY OF GENEVA, SWITZERLAND
Constanza Bonadonna

UNIVERSITY OF HANNOVER, GERMANY
Lennart Fischer

UNIVERSITY OF HAWAII, USA
Bruce Houghton

UNIVERSITY OF ICELAND
Maria Janebo

UNIVERSITY OF MELBOURNE
Stephen Gallagher, Andrea Guiliiani, Roland Maas, Jon Woodhead

UNIVERSITY OF NEW HAMPSHIRE, USA
Alexander Proussevitch

UNIVERSITY OF NOTRE DAME, USA
Anthony Simonetti

UNIVERSITY OF OREGON, USA
Ilya Bindeman

UNIVERSITY OF OTAGO, NEW ZEALAND
Robert Fordyce, James White

UNIVERSITY OF OTTAWA, CANADA
Jeff Hedenquist

UNIVERSITY OF OXFORD, UK
Ekaterina Kiseeva

UNIVERSITY OF SOUTHAMPTON, UK
Maya Coussens, Rex Taylor

UNIVERSITY OF TASMANIA
Sandrin Feig, Karsten Goemann, Joanne Whittaker

UNIVERSITY OF UTAH, USA
Keith Koper

WOODS HOLE OCEANOGRAPHIC INSTITUTION, USA
Daniel Fornari, Adam Soule

► PROJECTS

- > Beneath Bass Strait: Ambient seismic tomography
- > Seismic array investigations of ocean storms
- > Magnetotelluric imaging of the Earth's crust and mantle
- > 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
- > Melt-fluid evolution, magmatic immiscibility and budget of chalcophile and noble metals in subduction-related magmas
- > Submarine volcanology
- > Subaerial volcanology
- > Geology and paleontology of southern hemisphere regions, particularly Antarctica and the Southern Ocean.
- > Geochemical and mineralogical characterisation of the abandoned Scotia mine, northern Tasmania
- > Kinetic trials of Scotia mine tailings: testing the application of lime cover
- > Tectonics of eastern Indonesia

N.B. Research related to the Kinetic testing of waste rock, Savage River, Tasmania project is now being conducted in the TMVC Research Hub.

► PROJECT SUMMARIES

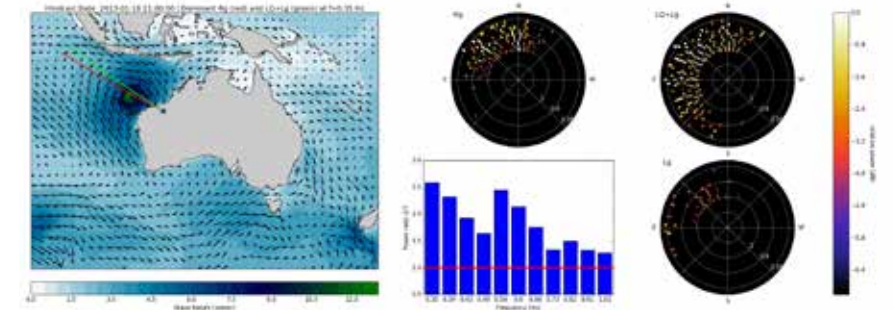
BENEATH BASS STRAIT: AMBIENT SEISMIC TOMOGRAPHY

Leader: Anya Reading

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

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

The project concluded with the publication of a paper highlighting lithospheric fabric as identified by seismic anisotropy inferred from ambient seismic tomography. The results were consistent with the orocline model for mainland southeast Australia and also showed distinct fabric within the island of Tasmania.



The map on the left displays the ocean wave height on the 18th January 2013 at 21pm UTC. To the north-west of the seismic array (blue star) a tropical storm can be seen, which produces elevated wave heights. The green and red lines in the figure display the direction of the strongest continuous seismic energy observed with the array during this time, which points towards the tropical cyclone, where red and green are vertically and transversely polarised seismic surface waves.

The diagrams on the right display the direction, frequency and energy distribution of differing seismic phases in more detail, and capture the complex nature of the seismic wavefield generated by ocean storms.

SEISMIC ARRAY INVESTIGATIONS OF OCEAN STORMS

Leader: Anya Reading

Student: Martin Gal

Collaborator: Keith Koper

The aims of the research are to gain a better understanding of the dynamics of ocean storms, using seismic array investigations.

During 2016, a major data analysis program was undertaken to apply algorithms from radio astronomy, newly implemented for seismic array processing, to understand ambient seismic energy generation around the Australian coast. The new analysis has provided insights into the generation of rarely observed seismic waves from Southern Ocean storms. The work also formed part of a multidisciplinary Art-Science project, and a video presentation based on the project outcomes was included in the 'Dark Storm' exhibit at the 2016 Dark Mofo winter festival in Hobart, run by the Museum of Old and New Art (MONA).

MAGNETOTELLURIC IMAGING OF THE EARTH'S CRUST AND MANTLE

Leader: Anya Reading

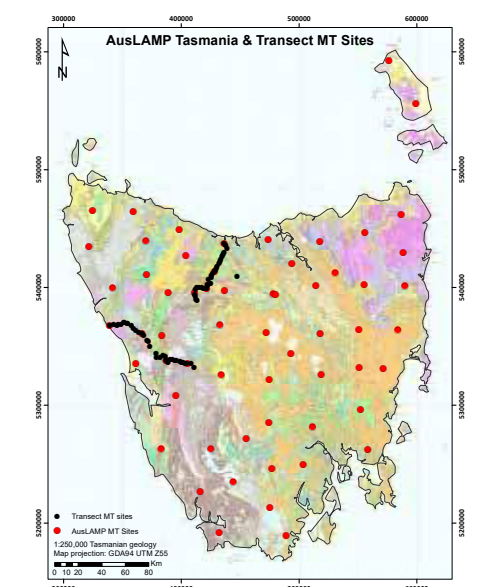
Team Member: Matt Cracknell

Student: Thomas Ostensen

Collaborators: Jingming Duan, Mark Duffett, Graham Heinson, Tristan Kemp

A major field geophysical program was undertaken during the year in collaboration with Mineral Resources

Tasmania, the University of Adelaide and Geoscience Australia. Long period magnetotelluric (MT) data recordings were made at locations across Tasmania and broadband MT transects completed in the west and north of the state. The aim is to produce a 3D map of the electrical resistivity of the lithosphere beneath Tasmania to inform understanding of Tasmania's tectonic evolution, and provide backbone information for mineral explorers. Field work was led by PhD student Thomas Ostensen, with staff and students from the participating institutes contributing many field-days to the effort – often working through severe conditions, including bushfires and snow storms.



Distribution of magnetotelluric instrument sites deployed by PhD student Thomas Ostensen as part of his research project into the geoelectric structure of the Tasmanian lithosphere.

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

Leader: Vadim Kamenetsky

Team Members: Anika Husen, Maya Kamenetsky, Sebastien Meffre, Jay Thompson

Students: Adam Abersteiner, Qiuyue Huang, Naomi Potter

Collaborators: Ilya Bindeman, Elena Demonerova, Kathy Ehrig, John Everard, Lennart Fischer, Alexander Golovin, Marina Gora, Andrea Guillani, Andrey Gurenko, Alexei Ivanov, Ekaterina Kiseeva, Dmitry Kuzmin, Roland Maas, Alberto Saal, Victor Sharygin, Alexander Sobolev, Ella Sokol, Jon Woodhead, Greg Yaxley, Georg Zellmer, Lyudmila Zhitova

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

Outcomes in 2016 included genetic constraints for a number of magmatic provinces on continents (Tasmania, Karoo, Arctic Siberia, Emeishan) and the ocean floor (South Atlantic and Gorgona Island).

The reconstruction of parental melts, their temperatures and the inventory of volatile elements was aided by studies of melt inclusions. Contributions from peridotitic and garnet pyroxenite mantle sources in the subcontinental lithosphere to the compositions of primary magmas were quantified using chemistry of olivine phenocrysts. It was shown that recent and modern magmas in the South Atlantic contain substantial contributions from the subcontinental lithospheric mantle that have been entrapped in the asthenosphere since the break-up of the Gondwana supercontinent. The outcomes, published in several high-profile publications, focused on the understanding of the origin and evolution of Large Igneous Provinces in time and space, and in particular their relationships to the so-called mantle plumes. Authors and journals include Ivanov et al. and Kamenetsky et al. in *Chemical Geology*, Husen et al. and Shimizu et al. in *Geochimica et*

Cosmochimica Acta, and Gurenko et al. in *Earth and Planetary Science Letters*

Large datasets on kimberlites and kimberlite-hosted mantle lithologies (peridotite and eclogite xenoliths) were presented in several papers published in *Chemical Geology* (Abersteiner et al.; Giuliani et al. and Kiseeva et al.), *Lithos* (Giuliani et al. and Soltys et al.) and in a review in *Earth and Planetary Science Letters* by Kamenetsky, V.

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

Leader: Vadim Kamenetsky

Team Member: Maya Kamenetsky

Student: Naomi Potter

Collaborators: Marc Campeny, Yulia Danilova, Elena Demonerova, Karsten Goemann, Marina Gora, Alexei Ivanov, Roland Maas, Valentina Savel'eva, Victor Sharygin, Anthony Simonetti, Greg Yaxley, Lyudmila Zhitova

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.

In 2016, research by PhD student Naomi Potter on the liquid-liquid immiscibility in the Oldoinyo Lengai 1993 lava was published in *Chemical Geology*. This paper presents petrographic evidence of liquid immiscibility between silicate, carbonate, chloride, and fluoride melt phases. Several textural features preserved in the silicate spheroids, melt inclusions, and carbonatite groundmass have been identified, which exhibit evidence of silicate-carbonate, carbonate-carbonate and carbonate-halide immiscibility. Rapid quenching of the lava facilitated fortuitous preservation of the end products of these multi-stage liquid immiscibility processes within the groundmass.

TRACE ELEMENTS IN ANCIENT OCEANS

Leader: Ross Large

Team Members: Leonid Danyushevsky, Sebastien Meffre, Jeff Steadman, Sasha Stepanov, Irina Zhukova

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

Collaborators: Dan Gregory, John Long

This research 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.

A highlight of the year was undoubtedly the team receiving an Australian Museum Eureka Prize in the category of Excellence in Interdisciplinary Scientific Research. The coveted prize was awarded for studies into the relationships between plate tectonics, past ocean chemistry (particularly the role of the trace element selenium) and evolution and extinction cycles.

A key factor in this research was an increase in the marine pyrite database to include over 5,000 analyses. This enabled the team to relate changes in ocean chemistry to atmosphere oxygenation and supercontinent cycles. It was found that many trace elements in the ocean dropped to very low concentrations during particular short time intervals over the past 500 million years.

Flinders University paleontologist John Long played an important role in helping the team understand this phenomena, and how it related to biological evolution. He brought together a team of international biologists and palaeontologists from the UK, USA and Australia to critically dissect the new data. Subsequently, it was found that the concentration of selenium, which is vital for life, dropped so low that life would be impossible to sustain through these short periods. Remarkably, this has happened three times, at 450, 375 and 200 million years ago, corresponding precisely to the timing of three of the five biggest mass extinction events on the Earth.

The pyrite data also enabled researchers to track the concentration of gold in the oceans, which revealed two significant features, i.e., gold in the Archean oceans was concentrated several times more than in the Proterozoic oceans; and

gold showed a cyclic pattern of concentration through the Phanerozoic corresponding to the cycles of gold ore deposits.

MELT-FLUID EVOLUTION, MAGMATIC IMMISCIBILITY AND BUDGET OF CHALCOPHILE AND NOBLE METALS IN SUBDUCTION-RELATED MAGMAS

Leader: Vadim Kamenetsky

Team Members: Leonid Danyushevsky, Maya Kamenetsky

Collaborators: Elena Demonerova, Sandrin Feig, Kathy Ehrig, Andrey Gurenko, Jeff Hedenquist, Alexei Ivanov, Roland Maas, John Mavrogenes, Jung-Woo Park, Michael Zelenski

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

Results in 2016 revealed that some lava flows and scoria cones of the historic basaltic eruptions of the Tolbachik volcano (Kamchatka arc) are unusually gold-rich. Based on whole rock analyses, Tolbachik basalts contain up to 11.6 ppb gold, nuggets of gold (electrum) up to 900µm in size, native gold droplets, and numerous vapour-deposited gold crystals within fumarolic incrustations and directly on surfaces of basaltic lapilli. The occurrence of native gold of magmatic origin is extremely rare, and only a few finds of micron-sized gold particles in unaltered basalts have been documented.

The results, published in *Earth and Planetary Science Letters*, demonstrate that the gold nuggets in the Tolbachik basalt are of hydrothermal origin, and were physically scavenged from epithermal veins hosted by country rocks during intrusion of mafic magmas. Depending on the melt temperature, and/or the time span of the melt-rock interaction, gold was either ejected by the erupting volcano in the form of abraded nuggets or liquid droplets, or fully assimilated into the shallow, long-lived magma chamber to provide a fourfold increase in gold content over the background

concentrations of 2.7 ppb Au. After the eruption, the continued discharge of volcanic gas enriched in gold led to the deposition of abundant crystals of gold on cooling lava and scoria.

SUBMARINE VOLCANOLOGY

Leader: Rebecca Carey

Team Members: Sharon Allen, Sean Johnson, Martin Jutzeler, Jocelyn McPhie, Karin Orth

Students: Leo Chia, Jodi Fox, Fumihiko Ikegami, Caleb Sang

Collaborators: Fabio Caratori-Tontini, Maya Coussens, Nathan Daczko, Robert Duncan, Richard Fiske, Daniel Fornari, Michael Manga, Alexander Proussevitch, Adam Soule, Peter Talling, Kenichiro Tani, Rex Taylor, James White, Joanne Whittaker, Richard Wysoczanski

The main aims of the Submarine Volcanology project are to:

- > Gain a better understanding of modern seafloor volcanic environments, and to apply that knowledge to ancient volcanic successions that host ore deposits.
- > Contribute to further development of fundamental knowledge on submarine volcanism.

In 2016, Joanne Whittaker, Sean Johnson, PhD student Jodi Fox, and undergraduate student Rhiannon Mundana participated in a CSIRO-led voyage on the RV *Investigator* to the Cascade Seamount, East Tasman Rise. Dredges collected tonnes of volcano and volcano-sedimentary rocks that are now being analysed for Ar-Ar dating and geochemistry. New geophysical bathymetric and backscatter data were also collected.

In a related initiative, Rebecca Carey received an IODP ANZIC grant to conduct research on IODP cores from the Cascade Seamount, with the goal of understanding the timing and development of the opening of the Tasman Basin. She received a further IODP ANZIC grant to study IODP cores from the Kerguelen Plateau, with the aim of understanding the timing of the volcanic activity of the plateau since the Miocene.

Jodi Fox participated in a research voyage on-board RV *Investigator* to the Heard and McDonald Islands region, Kerguelen Plateau, as part of her PhD project on intraplate basaltic

volcanism. Jodi's collaboration with Robert Duncan from Oregon State University led to a joint publication in the *Australian Journal of Earth Sciences* on the geological history of Heard Island.

Collaborator Kenichiro Tani and Rebecca Carey successfully applied for research ship time with the Japanese Agency for Marine-Earth Science and Technology (JAMSTEC) to visit three submarine volcanoes in the Izu-Bonin volcanic arc, south of Japan.

Martin Jutzeler published several papers in 2016 on the following subjects:

- > Explosion mechanisms underwater, with detailed analysis of vesiculation and fragmentation on mafic pyroclasts.
- > Pyroclastic flows travelling over water, based on IODP 340 cores offshore Montserrat.
- > Volcanic stratigraphy onshore and offshore Montserrat, with link to eruption periodicity and major debris avalanches in island arc context.
- > Detailed database of coring disturbances in cores of IODP 340.

Honours students Leo Chia and Caleb Sang conducted research on the volcanoclastic turbidites offshore of the island of Martinique in the Caribbean, and volcanic sediment from the submarine plateau of Kerguelen.

SUBAERIAL VOLCANOLOGY

Leader: Rebecca Carey

Team Members: Sharon Allen, Martin Jutzeler, Jocelyn McPhie, Karin Orth

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

Collaborators: Daniele Andronico, Costanza Bonadonna, Grace Cumming, Andrea DiMuro, John Everard, Julie Hollis, Bruce Houghton, Maria Janebo, Tim Orr, Matthew Patrick, Christopher Phillips, Ryan Portner, Michael Rosenberg

The Discipline's research in subaerial volcanology covers a wide range of magma types occurring in modern and ancient volcanic environments. Current research 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.

Jodi Fox completed fieldwork, analyses and geochronology on

the Stanley and Cape Grim areas of northwestern Tasmania during the early part of the year. The results have greatly advanced understanding of the character and setting of this Miocene submarine basaltic volcanism. Results were presented at the Australian Earth Sciences Convention (AESC), in Adelaide, at the end of June.

Sam Holt completed his research on eruption dynamics at Kilauea volcano, Hawaii, which focused on the active lava lake in Halema'uma'u crater; in particular, elucidating whether the surface features of the lava crust of the lake reflect shallow conduit geometry.

Daniele Vergani's research on the 2007 eruption on Reunion Island has focused on the connection between the caldera collapse event at the summit of the volcano and changing lava fountaining activity on the volcano's flank.

Third year undergraduate student Imbi Simpson received a Dean's summer scholarship and is working with Karin Orth, Jocelyn McPhie and Rebecca Carey on a Tertiary volcanic province on the Tasman Peninsula.

Karin Orth and Rebecca Carey have initiated a new project with Mineral Resources Tasmania on volcanics hosted at Great Lake. Low water levels in Great Lake afforded the opportunity to investigate outcrops on its shores that were last examined in the mid-1960s. The outcrops indicate the interaction of basalt lava with an ancient lacustrine environment. Basalt lava, pillow basalt breccia and a variety of volcanoclastic units were described, photographed and sampled during several field trips. Sample preparation for petrography and further analysis are underway. The photographs are being compiled to create 3D, geo-located photogrammetric images.

GEOLOGY AND PALEONTOLOGY OF SOUTHERN HEMISPHERE REGIONS, PARTICULARLY ANTARCTICA AND THE SOUTHERN OCEAN

Leader: Patrick Quilty

Student: Jodi Fox

Collaborators: Leanne Armand, Thomas Darragh, Robert Fordyce, Stephen Gallagher

Several papers were published during the year, covering a wide range of

topics including Pliocene molluscs from the Marine Plain, Antarctica; the volcanic history of Heard Island and Kerguelen Plateau (2 papers); and key sediments from the Coral Sea.

The year also saw the start of a major new initiative, focussed on producing a book on the history of Antarctic exploration. In addition, Project Leader Professor Patrick Quilty received the Phillip Law Medal from Australian National Antarctic Research Expeditions (ANARE) for his outstanding contribution to Antarctic affairs and the Antarctic community.

GEOCHEMICAL AND MINERALOGICAL CHARACTERISATION OF THE ABANDONED SCOTIA MINE, NORTHERN TASMANIA

Leader: Anita Parbhakar-Fox

Team Member: Nathan Fox

Collaborators: Ralph Bottrill, Andrew McNeill, Andrew Wakefield

This research project identified sources of acid rock drainage at the abandoned Scotia mine in Northern Tasmania, which is currently under the care of the State Government.

Prior to determining an appropriate mine waste management strategy, tailings material from the site were collected and characterised using mineralogical and geochemical methods. Investigations showed that, despite having a low content of sulfides, there was an absence of primary neutralising materials in the tailings, indicating a low acid forming potential. In addition, the oxidation front was predicted to be relatively shallow, with water quality risks posed primarily by aluminium.

This project has now concluded.

KINETIC TRIALS OF SCOTIA MINE TAILINGS: TESTING THE APPLICATION OF LIME COVER

Leader: Anita Parbhakar-Fox

Team Member: Nathan Fox

Collaborators: Ralph Bottrill, Andrew McNeill, Andrew Wakefield

Using kinetic testing, the research focussed on determining the long term effects of capping acid generating tailings at the abandoned Scotia

mine in northern Tasmania with lime, particularly in respect of its impact on controlling the formation of acid mine drainage.

Prior to determining an appropriate mine waste management strategy, tailings material from the site were collected and characterised during kinetic trials conducted over a 30-week period. Material from each tailings dam (1-3) and the main extraction pit were used in three experiments, one without a cover, and two with different thicknesses of a commercial lime cover. Investigations showed that, if left uncovered, tailings will be mildly acid forming almost immediately. The use of a commercial lime product will sufficiently raise the pH to an alkaline range and prevent continuous elution of several key metal contaminants above ANZECC (2000) and WHO (2006) guideline values, including for As, Cu, Cd, Pb and Zn.

Therefore, using this commercial material as a cover that is emplaced during engineering works will be effective in improving the site's geochemistry, providing the tailings are exposed directly to atmospheric oxygen, and the process forms part of a long-term rehabilitation program at the site.

This project has now concluded.

TECTONICS OF EASTERN INDONESIA

Leader: Ron Berry

Team Members: Sebastien Meffre, Jay Thompson

The aim of this research is to assess the tectonic significance of metamorphic rocks from Timor and South Sulawesi, which provide important constraints of the tectonic development of the collision between Australia and Indonesia.

Sample suites and detailed field data from the Aileu Formation in East Timor are being used to determine the age of metamorphism (results published in 2016) and produce a detailed P-T path for this complex.

Samples from the Miomaffo Complex in West Timor are part of an allochthonous terrain, which includes a range of accretionary complex rocks, ranging in the extent of metamorphism up to middle amphibolite facies. The samples are being used to establish the metamorphic petrology of the complex.

► LOOKING FORWARD

The staff and students in the Discipline of Earth Sciences have a lot to look forward to in 2017, including:

CHAPMAN CONFERENCE

Early in the year, the Discipline is set to play a major role in the international American Geophysical Union (AGU) Chapman Conference on Submarine Volcanism, which is being held in Hobart. Dr Rebecca Carey is one of the convenors and will be presenting an invited talk. Dr Karin Orth and Professor Jocelyn McPhie are part of the organising committee, with Jocelyn also presenting an invited talk.

RESEARCH CRUISE

In early March, Dr Martin Jutzeler will be joining a team of scientists aboard the RV *Sonne* for a six-week research voyage to the Kermadec Arc and the Havre Trough. The team will investigate processes that control the development of subduction zones, including subduction initiation, evolution of mature arc systems, and the transition from arc splitting to backarc basin generation.

RARE EARTH ELEMENTS

The Eureka award-winning Trace Elements in Ancient Oceans team will not be resting on its laurels, with a full program of analyses to extend the marine pyrite database scheduled throughout the year. The team will also be extending its research to encompass rare earth elements.

COLLABORATION WITH MINERAL RESOURCES TASMANIA (MRT)

In 2016, researchers took advantage of the exceptionally low water levels in Tasmania's Great Lake to investigate previously submerged outcrops on its shores. Working in collaboration with MRT, the team will progress this research by using the photographs taken during these low water levels to create 3D, geo-located photogrammetric images.

A HISTORY OF ANTARCTIC EXPLORATION

Professor Patrick Quilty's much anticipated book on the history of Antarctic exploration is expected to be near completion during the year. There is no better person to tackle such a major undertaking than Patrick, who has spent over half a century studying the icy continent, during which time he has published over 200 scientific papers, and had five species, a range of nunataks, and a bay named in his honour.



OUTREACH

Each year, CODES works with the Discipline of Earth Sciences to engage in a program of activities aimed at promoting the value of the geosciences to the broader community, and encouraging young people to consider a career in this field. The past year was another busy period for this program, which saw a further expansion of the range and breadth of outreach activities, both on campus and in the local community.

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 conducted with the help of Sebastien Meffre, Jacob Mulder, Karin Orth and Michael Roach, 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.

UTAS OPEN DAY

Staff and students played a major role in the University's annual Open Day in August. This year's expanded list of activities included practical gold panning exercises, volcanology video interpretations, 'pet' rock assessments, microscopic tours of the rocks of Tasmania, earthquake simulations, a presentation on mass extinctions, and acid mine drainage experiments in the geoenvironmental laboratory.

SCHOOL VISITS AND TRIPS

The year saw a number of visits by various pre-tertiary institutions, including Howrah Primary, New Town Primary, Waimea Heights Primary, Lenah Valley Primary, the Sorell School, and Taroona High.

In external activities, Sean Johnson took a group from Lenah Valley Primary on a geological trip along the Derwent River foreshore, and Jocelyn McPhie and Sharon Allen conducted practical exercises at the Sandy Bay Cubs Science Night.

TESEP

Support also continued for the Teacher Earth Science Education Program (TESEP). This national program operates under the auspices of the Australian Science Teachers Association, and provides a series of professional development workshops aimed at upper primary / lower secondary school teachers. The workshop provided a mix of interactive classroom and laboratory activities.

THE ROCK LIBRARY

Isabella (Izzy) von Lichtan is a regular contributor to the outreach program. The extensive rock library, which she curates, has proven to be an abundant source of inspiration for a wide variety of community projects for many years. Izzy's skills, enthusiasm and active engagement in a host of cultural activities ensure that the collection is both well utilised and at the forefront of promoting the value of the earth sciences to the local community.

Highlights of the year included hosting MONA curator, Delia Nicholls, who used the experience to help her write an article for *Island* magazine, which featured items from the collection.



CLOCKWISE FROM TOP LEFT: Teachers participating in a TESEP workshop; Vadim Kamenetsky (left) helping with a gold panning exercise at the UTAS Open day; a student from Taroona High conducting practical scientific exercises; Karin Orth talking to students about the geology of Tasmania during Science Experience; pupils from New Town Primary enjoy the tactile pleasures of the Gemnasium.

FROM LEFT: Aleksandr (Sasha) Stepanov with students from Waimea Heights Primary; Sean Johnson leading a group of students from Lenah Valley Primary on a geology excursion along the Bellerive foreshore.



Izzy also helped curate the Wunderkammer exhibition at The Plimsoll Gallery, which featured an eclectic array of specimens from the rock library. She also gave a lecture as part of the opening ceremony, followed by a two-hour question and answer session with a working group on her role as the curator of the rock library.

MEDIA

It was another prolific year for media coverage, with a number of stories making headlines, both locally and worldwide.

One of the major highlights was the extensive coverage received by Ross Large and his team, both when they were shortlisted for a prestigious

Australian Museum Eureka Prize, and even more so when they were awarded the prize in the category of Excellence in Interdisciplinary Scientific Research.

Other highlights included:

- > PhD student Nathan Chapman featured prominently in a feature entitled 'Young Tassie Scientists' in the *Mercury* newspaper.
- > Interview conducted by ABC Radio with Garry Davidson in relation to the extent of gold-bearing deposits in Tasmania.
- > A group of students, led by David Cooke, featured on ABC TV's *Australia Wide* program, showing how their studies are helping to mitigate environmental issues caused by old mining practices.

The story also featured across all of the ABC's main media platforms – website, radio and TV (news).

- > ABC TV's *Catalyst* program went to air, featuring research by Jacqueline Halpin and Jacob Mulder that has revealed links between Tasmania, Antarctica and the ancient Nuna supercontinent. Filming had taken place the previous year at CODES and on location in the Rocky Cape region in NW Tasmania.
- > Izzy von Lichtan had an article published in *Maritime Times of Tasmania* covering her insights into the techniques she used in moulding and casting the skull of a 23 million-year-old whale – *Prosqualodon* davidis.

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 2016, the group of CODES' industry partners comprised of four Australian and international mining companies: Anglo American, Newcrest Mining, Rio Tinto, and Teck Resources.

Partner companies have been providing 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.

► NEW INDUSTRY PARTNERSHIP OPPORTUNITIES

From 2017, CODES is offering a new and improved series of partnership opportunities, aligned to the evolving needs of mining companies. Management recognises that the minerals industry is cyclical by nature, and operating conditions can vary greatly from one year to the next, often through unforeseen circumstances. For this reason, the partnership opportunities are now being offered on an annual basis, giving partners the flexibility to adjust their involvement in line with their current operating conditions and research requirements.

Funding levels have also been adjusted, resulting in a range of cost effective options to suit all levels of operation, from junior explorers through to the large multi-nationals. Companies may sign-up at either the Silver (20K), Gold (40K) or Platinum (60K) level, depending on their planned level of involvement with the Centre.

Benefits of a partnership agreement vary depending on the level of investment, but include enhanced prospects of discoveries, optimisation of existing reserves, first call on geoscience graduates, and access to a world-class research team and state-of-the-art facilities. Further details can be found at: <http://www.utas.edu.au/codes/about-us/codes-industry-partners>

► 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 2016 it funded AMIRA P1153 Applying the explorers' toolbox to discover porphyry and epithermal Cu, Au and Mo deposits, which is being conducted within the ARC TMVC Research Hub.

► RESEARCH COLLABORATIONS

In 2016, CODES further cemented its reputation for cultivating research collaborations with other Australian and international research organisations. Throughout the year, collaborative research was conducted with 45 international and 14 national organisations.



Director Bruce Gemmell with Noel White and Yu Fan (Hefei University of Technology), during a trip to China.

TECHNOLOGY TRANSFER

OBJECTIVES

- > Involve end-users (exploration and mining companies) in research planning, research evaluation and research adoption.
- > Promote technology transfer so that innovative research outcomes are accessible to end-users.
- > Comply with the national principles of intellectual property management for publicly funded research.

TECHNOLOGY TRANSFER ACTIVITIES

CODES undertakes strategic and applied research into ore deposits (characterisation and context) and geometallurgy, and the development of innovative enabling technologies to support these research endeavours. These initiatives create knowledge, processes, methods and solutions for the minerals industry and ore deposit researchers – locally, nationally and internationally.

Research results and technical developments in the applied research modules are transferred to end-users via regular research meetings, research reports, monographs, books, digital presentations and software packages, where appropriate. In 2016, 134 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 2016.

- > Altered volcanic rocks: A guide to description and interpretation (2005). Authors: C Giffkins, W Herrmann and R Large (32 copies).
- > Basins, fluids and Zn-Pb ores. CODES Special Publication 2 (1999). Editors: O Holm, J Pongratz and P McGoldrick (2 copies).
- > Geophysical signatures of copper-gold porphyry and epithermal gold deposits, and implications for exploration (2011). Author: T Hoschke (11 copies).
- > Giant ore deposits: Characteristics, genesis and exploration. CODES Special Publication 4 (2002). Editors: D Cooke and J Pongratz (4 copies).
- > New developments in Broken Hill-type deposits. CODES Special Publication 1 (1996). Editors: J Pongratz and G Davidson (2 copies).
- > The geology and origin of Australia's mineral deposits (2000). Authors: M Solomon and D Groves (1 copy).
- > The geology of the Broken Hill Pb-Zn-Ag deposit, NSW, Australia (2006). Author: A Webster (4 copies).

- > 24ct Au workshop. CODES Special Publication 5 (2004). Editors: D Cooke, C Deyell and J Pongratz (3 copies).
- > Volcanic environments and massive sulfide deposits (2000). Editors: JB Gemmell and J Pongratz (2 copies).
- > Volcanic textures: A guide to the interpretation of textures in volcanic rocks (1993). Authors: J McPhie, M Doyle and R Allen (30 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 Belgium, Canada, China, India, Indonesia, Italy, Myanmar, New Zealand, Switzerland, and the USA.

Total attendance by industry geologists, academic researchers and postgraduate students was 767, with 32 different presenters from CODES involved in delivering the lectures or leading the conferences or field trips.

2016 SHORT COURSES, WORKSHOPS, CONFERENCES AND FIELD TRIPS LED BY CODES

TITLE	PRESENTERS [^]	NO. ^{^^}	LOCATION	DATE
VIEPS – Exploration Field Skills Mapping Camp	Martin Jutzeler, Robert Scott	9	western Tasmania	7 – 14 February
IoGAS Geochemistry Workshop – Part 1 *	Mike Baker	10	CODES, Hobart	3 March
Volcanology and Mineralisation in Volcanic Terrains	David Cooke, Bruce Gemmell, Jocelyn McPhie	6	New Zealand / western Tasmania	6 – 20 March
IoGAS Geochemistry Workshop – Part 2 *	Mike Baker	8	CODES, Hobart	17 March
VIEPS – Practical Igneous Petrology	Leonid Danyushevsky	17	CODES, Hobart	9 – 13 May
VIEPS – Ore Deposit Models	Mike Baker, Garry Davidson, Bruce Gemmell, Margo Hawke, Ross Large, Brian McNulty, Robert Scott, David Selley, Jeff Steadman, Nathan Steeves	10	CODES, Hobart	16 – 20 May
Ancient and Modern V(H)MS Deposits	Bruce Gemmell , Stephen Piercey	30	Whitehorse, Yukon, Canada	30 – 31 May
Exploration in Brownfields Terrains	Ron Berry, Matt Cracknell, Nathan Fox , Fiona Fraser, David Green, Scott Halley, Shawn Hood, Steve Kuhn, Robert Scott, David Selley , Patrick Smillie	16	CODES, Hobart	30 May – 10 June
Volcanogenic Massive Sulfide and Orogenic Gold Deposits in Northern Southeast Alaska (Field Trip)	Bruce Gemmell , Susan Karl, Patrick Sack, Nathan Steeves	20	Southeastern Alaska, USA	4 – 8 June
Gordon Research Conference - From Deep Earth to Surface: Metals for Society *	David Cooke , Robert Moritz, Francois Robert, (Conference chairs)	200	Les Diableret, Switzerland	19 – 24 June
Physical Volcanology of the Mesoproterozoic Gawler Range Volcanics (Field Trip)	Jocelyn McPhie	11	South Australia	21 – 25 June
Environmental Geology Field Techniques *	David Cooke, Matt Cracknell, Garry Davidson, Laura Jackson, Anita Parbhakar-Fox	20	CODES Hobart and western Tasmania	30 August – 2 September
Ancient and Modern VHMS Deposits	Bruce Gemmell	40	Hefei University of Technology, China	13 September
Low and Intermediate Sulfidation Deposits	Bruce Gemmell	40	Hefei University of Technology, China	14 September
GeMMe Masters Workshop (Emerald)	Ron Berry	22	University of Liege, Belgium	30 September
Breccias in Porphyry and Epithermal Environments – Working From Description to Interpretation *	Jing Chen, David Cooke, Rachel Harrison, Stephanie Sykora	50	Bandung, Indonesia	3 – 4 October
Geometallurgy Short Course	David Bastin, Ron Berry , Stoyan Gaydardzhiev, Julie Hunt, Simon Michaux, Eric Pirard	20	University of Liege, Belgium	4 – 7 October
Ore Deposit Models and Exploration Strategies	David Cooke, Garry Davidson, Kathy Ehrig, Bruce Gemmell, Ross Large, Erin Lawlis , Andrew McNeill, Brian McNulty, Sebastien Meffre, Evan Orovan, Robert Scott, David Selley, Nathan Steeves, Stephanie Sykora, Lejun Zhang	17	CODES, Hobart	17 – 28 October
Geological Workshop on Mineral Resources in Myanmar and Prospectivity	Kyin Htun, Than Htun, Ye Myint Swe, Aung Kyin, Tin, Aung Myint, Kyaw Thu, Khin Zaw	22	Yangon, Myanmar	18 October
Fluids in the Earth	Robert Bodnar, Leonid Danyushevsky , Maria Frezzotti, James Webster	30	Naples, Italy	19 – 24 October
SEG Student Chapter Field Trip to Myanmar	Jing Chen, Joe Knight, Khin Zaw	17	Myanmar	7 – 19 November
Porphyry Cu Deposits and Related Breccias *	David Cooke, Lejun Zhang	30	Hefei University of Technology, China	12 – 14 November
Melt and Fluid Inclusions in Minerals	Leonid Danyushevsky , Maria Frezzotti	50	Mumbai, India	22 – 24 November
Magmatic-Hydrothermal Textures of Bluestone Bay, Tasmania *	David Cooke, Evan Orovan	15	Freyrcinet, Tasmania	23 November
Workshop on SE Asia: Tectonics and Ore Deposits	Khin Zaw	21	Yangon University, Myanmar	5 December
Magmatic-Hydrothermal Features of the Heemskirk Granite, Trial Harbour *	David Cooke, Wei Hong, Stephanie Sykora, Lejun Zhang	20	Strahan, Tasmania	7 December
Ore Deposit Models	Stuart Bull, David Cooke, Garry Davidson	16	CODES, Hobart	15 December

[^] CODES presenters in bold. ^{^^} Number of attendees. * ARC TMVC Research Hub

FROM LEFT: Practical exercises during the Ore Deposit Models and Exploration Strategies short course – indoor (left) and outside in the Rock Garden (right).



PERFORMANCE INDICATORS

PERFORMANCE MEASURES IN 2014 – 2018 STRATEGIC PLAN

TITLE	TARGET	2016
Research Findings		
Publications in international journals	50pa	67
Percentage of publications in high quality international journals	70%	76%
Reports to industry collaborators	80pa	134
Special Issues and / or research monographs	1 per 2 years	0
Invitations to give keynote conference presentations	10pa	2
Papers at national / international meetings	70pa	61
Research Training and Professional Education		
Percentage of HDR students attracted from interstate	25%	29%
Percentage of HDR students attracted from overseas	65%	68%
Number of Honours students in CODES' modules	15	3
Number of HDR students in CODES' modules	50	33
Percentage of students in projects linked with industry	80%	63%
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 (2015)
Registrants at CODES' conferences / workshops	600pa	767 (2016)
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 28 years



FINANCES

► 2016 INCOME

Total CODES income was \$8.1 million (see Table 1). This was derived principally from UTAS (32%), the combined income sources of the ARC TMVC Research Hub (24%), and industry (16%) (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, and while there is a decrease compared to 2015, the portion of ARC funding to CODES projects (not including that portion received to the TMVC) has shown an increase.

Summary of the main income streams to CODES in 2016:

> **Host institution support:** Funding from UTAS in 2016 was \$2.6 million, down compared to the figure for 2015, mostly due to a decrease in operating grant support. UTAS funding relates primarily to research salaries, PhD scholarships and income earned by the Centre from research output.

> **ARC TMVC Research Hub:** The combined income sources for the TMVC amounted to \$1.9 million in

2016, comprising of funding from the ARC (\$861k), industry Partner Organisations (\$853k), Host Institution (\$145k), and other sources including Additional Funder Projects (\$90k).

> **Industry income:** Industry funding of \$1.3 million comprises funding related to Industry Partner support, industry funded student projects, and other research projects. This figure does not include industry-based support for the ARC TMVC Research Hub (see above).

► 2017 INCOME ESTIMATES

There is expected to be a small growth in funding into the TMVC due to several new Additional Funder Projects estimated to come online during 2017. Other funding into CODES is expected to remain similar to 2016.

TABLE 1
CASH INCOME FINANCIAL STATEMENT 2016

ARC TRANSFORMING THE MINING VALUE CHAIN RESEARCH HUB	
ARC Industrial Transformation Research Project	861,003
Partner Organisations	852,800
- AMIRA P1153	537,600
- BHP Billiton Olympic Dam	150,000
- Newcrest Mining	165,200
Host Institution	145,135
Additional Funder Projects	68,865
Miscellaneous	21,127
	1,948,929
ARC GRANTS	
Discovery Grants	80,343
Linkage Grants	166,773
Linkage Infrastructure, Equipment and Facilities Grants	600,000
	847,116
OTHER COMMONWEALTH GOVERNMENT	
Specific Projects	134,281
	134,281
STATE GOVERNMENT	
Specific Projects	5,000
	5,000
INDUSTRY/PRIVATE	
CODES Industry Partners	383,283
Cooperative Research Centre Projects	78,383
Directly Funded Research Projects	576,282
Directly Funded Student Projects	229,583
Miscellaneous	1,532
	1,269,063
CONTRACTS/CONSULTANCIES/REVENUE RAISING	
Short Courses	48,310
Book Sales	16,912
Miscellaneous (incl. Analytical Services)	1,184,864
	1,250,085
UNIVERSITY OF TASMANIA - HOST INSTITUTION SUPPORT	
Operating Grant	1,236,377
Scholarships and Tuition Fee Waivers	1,211,698
Strategic Projects	127,130
Miscellaneous	1,000
	2,576,205
OTHER INCOME SOURCES/INTEREST	
Overseas Governments	51,508
Society of Economic Geologists - Student Scholarships	9,740
Student Support	11,548
Miscellaneous	4,316
	77,112
TOTAL ANNUAL INCOME	8,107,790

FIGURE 1
TOTAL CASH INCOME 2016

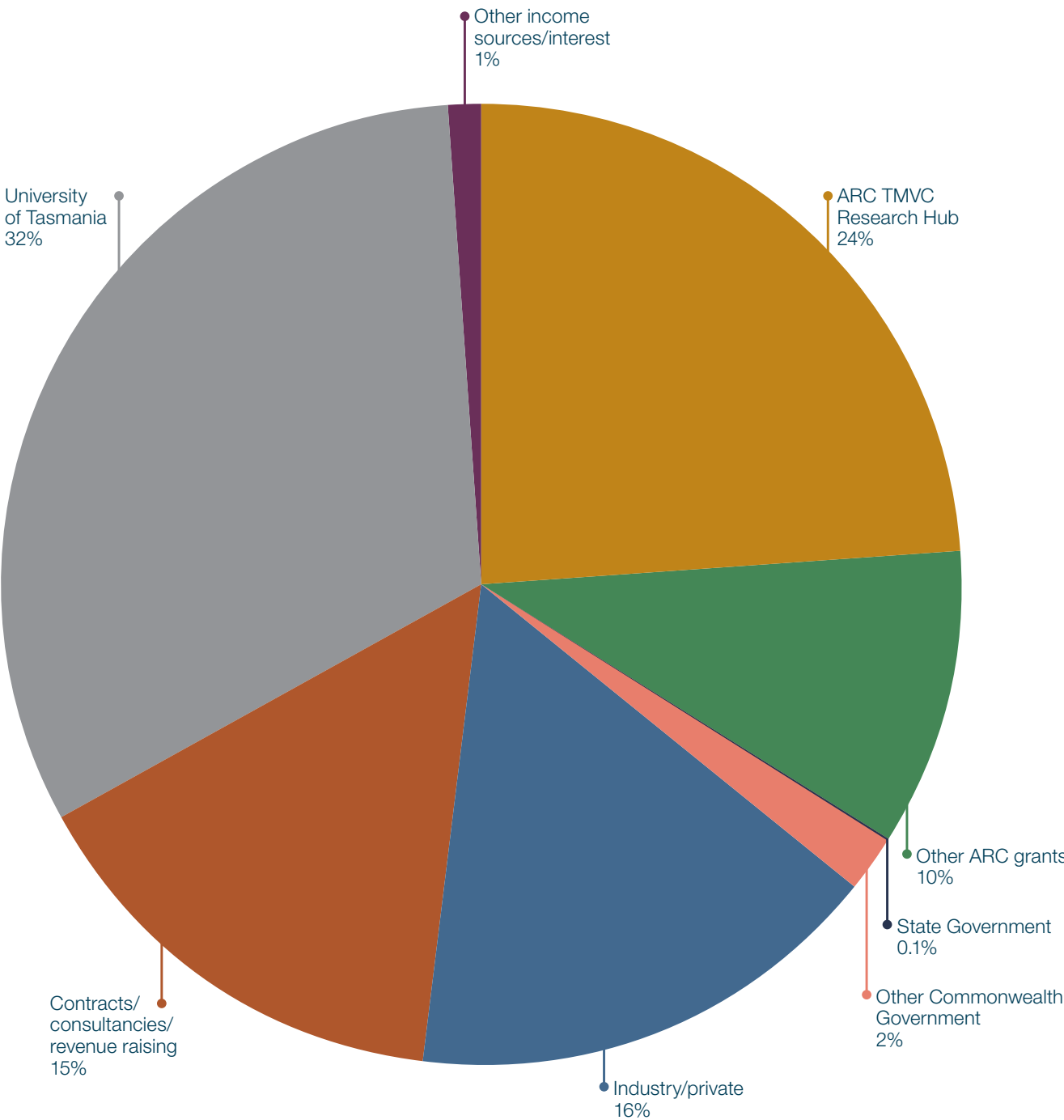
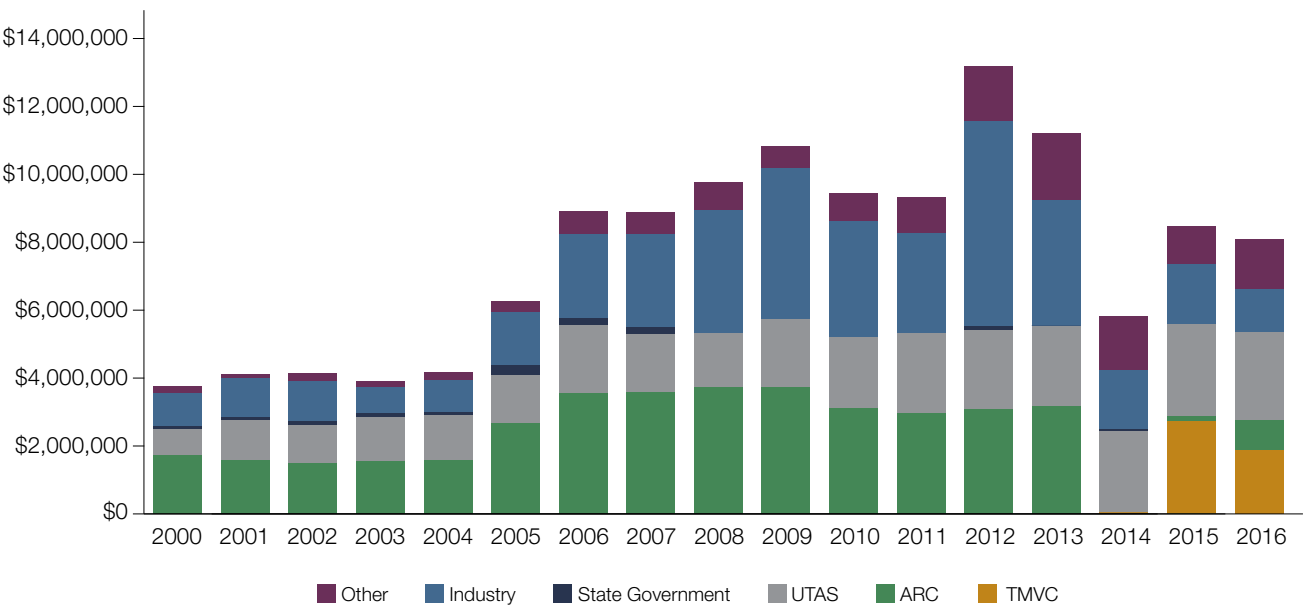


FIGURE 2
COMPARISON OF CODES
MAIN INCOME STREAMS 2000–2016



NOTES TO, AND FORMING
PART OF, THE FINANCIAL
STATEMENTS FOR 2016

The financial pages of this Annual Report were prepared by Helen Scott (ARC TMVC Research Hub Manager). Data for the financial statements was extracted from UTAS systems, particularly its Finance System.

INCOME STATEMENT
EXPLANATIONS

The income figures in Table 1 represent actual income recorded in the University's finance system, transferred internally from UTAS to CODES during 2016, or centrally administered for CODES HDR students (as in the case of scholarships and tuition fee waivers).

2016 PUBLICATIONS

CODES

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* Denotes TMVC Research Hub

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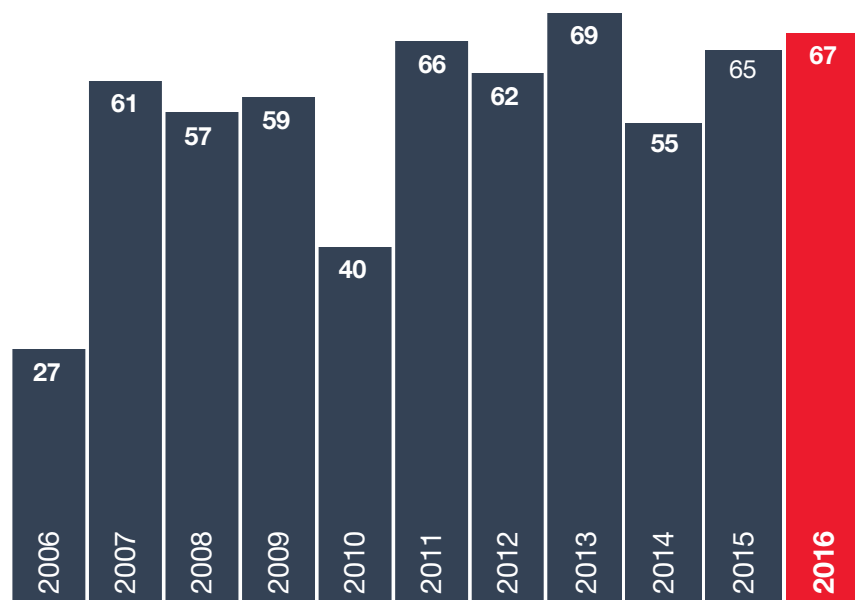
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Stepanov, A., and Meffre, S., 2016, Chlorite and epidote chemistry: Report to Quantum Pacific Exploration, February 2016, Hobart, Australia, 6 p.

Stepanov, A. and Meffre, S., 2016, Chlorite chemistry: Report to QP Exploration, May 2016, Hobart, Australia, 2 p.

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Stepanov, A., Thompson, J., and Meffre, S., 2016, U-Pb geochronology: Report to Anglo American, December 2016. 4 p.

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Thompson, J., Meffre, S., and Stepanov, A., 2016, U-Pb geochronology: Report to Antofagasta Minerals, September 2016, Hobart, Australia, 4 p.

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Sean Johnson (senior scientist), Harry West (PhD student Macquarie University) and Brian Duggan (University of South Carolina) categorising rocks from a dredge on board the RV Investigator, East Tasman Plateau.

APPENDICES

CODES POSTGRADUATE STUDENTS 2016

BACHELOR OF SCIENCE (HONOURS) (12)

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Matt Bodini	Roach, Tassell (GHD)	Evaluation of petrophysical and mineralogical proxies for rock strength with particular emphasis on civil engineering practice	GHD
Stephanie Cesile ^	Whittaker (IMAS), Carey	An investigation into oceanic large igneous province plume swell	IMAS
Zheng (Leo) Chia ^	Jutzeler, Orth	Sedimentological analysis of Pleistocene pumice-rich turbidites at Site U1398, IODP 340, offshore Martinique	IODP
Rebecca Clifton ^A	Parbhakar-Fox, Fox	Evaluating applications of boiler ash for controlling acid and metalliferous drainage-- examples from Tasmanian mine wastes	MONA Heavy Metals Project, ARC TMVC
Brady Gower ^	Roach	Structural and sedimentological analysis of the Adele Trend - Browse Basin	UTAS
Kathryn Job	Roach, Meffre, Musgrave (GSNSW)	A palaeomagnetic study of the Palaeozoic Tasmanian Orocline Model	MRT, ARC Linkage
Richard (Sigmun) Lloyd	Meffre, Steadman	Alteration mineralogy and geochemistry of altered rocks in the Woodlawn VHMS belt, NSW	ARC Linkage, Heron Resources
Declan Radford ^	Cracknell, Roach	Geological mapping from radar imagery with Machine Learning	MRT, Forestry Tasmania
Caleb Sang ^	Carey, Falloon	Chasing the Kerguelen mantle plume 'tail': investigating the Miocene to Holocene record of volcanism using tephra glass in ODP Leg 183, Site 1138a cores	IODP
Tristan Wells ^	Cooke, Baker, Zhang	Geology and genesis of the Two-Thirty prospect, Northparkes, NSW	Northparkes Mines
Ben Whitney ^	Zhang, G.Davidson	Evaluation of the Specimen Hill high-sulfidation epithermal prospect, Southern Queensland, Australia	Signature Gold
Tyler Williams ^	Roach, Tassell (GHD)	Seismic evaluation of the integrity of the Henty tailings storage facility, Henty Tasmania	GHD

MASTER OF ECONOMIC GEOLOGY (50)

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Michael Adams		coursework only	
Robert Ayres		coursework only	
Fabian Baker	Cooke	Amulsar HSE Au deposit, Armenia	Lydian International
Thomas Bartschi		coursework only	
Sebastian Benavides	Cooke	Characterisation of phyllic assemblages at Taca Taca Bajo, Argentina	First Quantum
Christopher Booth		coursework only	
Kim Boundy		coursework only	
Cesar Calderon-Tipiani	Gemmell	Chanca low sulfidation deposit, Peru	Buenaventura
Jimmy Carranza Meza		coursework only	
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	Ore types of DeGrussa and Conductor 1 ore lenses of the DeGrussa VHMS deposit, Western Australia	Sandfire Resources
Rachel Cooke		coursework only	

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Richard Cotton ^		coursework only	
Daniel Cronin		coursework only	
Christopher Crouchly		coursework only	
Roseanna Dale		coursework only	
Paul Edmonds		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	Cooke	TBA	
Arga Firmansyah	Cooke	Geology and mineralisation of the Trenggalek district, East Java, Indonesia	PT Pamapersada Nusantara
Daniel Foulds		coursework only	
David Groombridge		coursework only	
David Haddow		coursework only	
Brendan Hardwick	Meffre, Doyle (AngloGold Ashanti)	Ore mineral textures and their implication for gold genesis and deportment at the Tropicana Gold Mine, Western Australia	AngloGold Ashanti
Kyle Hodges		coursework only	
Kyle Hughes	Meffre	Paragenesis of the Dobroyde Deposit, central NSW	ARC Linkage
Danny Huisman ^		coursework only	
Corey Jago	Meffre, Cooke	Toward an understanding of the temporal, spatial and mineralogical characteristics of the Northparkes Alkalic Porphyry Deposits, New South Wales	ARC Linkage
Sitthinon (Gun) Kultaksayos	Meffre	Provenance of Early to Mid-Paleozoic sediments in western Tasmania	ARC Linkage
Anna Kutkiewicz		coursework only	
Thomas Langley		coursework only	
Esther Little		coursework only	
Chantelle Lower	Ehrig (BHPBilliton)	An aspect of the geology of the Olympic Dam Cu-U-Au-Ag deposit	BHP Billiton
Walter Lozano Garcia Naranjo		coursework only	
Imam Malik ^		coursework only	
Rebekah McLelland		coursework only	
Joanne Morrison *	Berry	Cadia East multi-element lithogeochemistry: Evaluation of trace element deportment important to processing	Newcrest Mining
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
Alister Orton		coursework only	
Chris Piggott		coursework only	
Thomas Ralston		coursework only	
Alan Riles ^		coursework only	
Philip Roger		coursework only	
Christopher Shanley		coursework only	
Markus Staubmann		coursework only	
Luke Timmermans		coursework only	

MASTER OF EXPLORATION GEOSCIENCE (1)

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Peerapong Sritangsirikul	Meffre	Tectonic evolution and ore deposit prospectivity of the Rockley Volcanics, NSW Australia	Thai Royal Government Scholarship

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

DOCTOR OF PHILOSOPHY (54)

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Adam Abersteiner	V.Kamenetsky, M.Kamenetsky, Goemann (CSL)	Kimberlites and diamonds: Understanding their petrogenesis and uncovering the identity of their source composition	UTAS
Ayesha Ahmed *	Cooke, Baker, Orovan	The effect of pressure/depth on propylitic alteration mineral chemistry in the porphyry environment	AMIRA P1153, ARC TMVC, UTAS
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	G.Davidson, V.Kamenetsky, Goemann, Noble	The evolution of Zn-Pb-Fe-bearing minerals in the Grieves Siding peat, western Tasmania	CoE, UTAS, CRC ORE
Heidi Berkenbosch	Gemmell, McNeill (MRT), Christie (GNS Science)	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, China Scholarship Council, ARC TMVC, 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
Evan Draayers	Danyushevsky	The boninite magma genesis debate: Assessing the role of mantle sources associated with intra-plate magmatism in the generation of boninitic magmas above subduction zones	UTAS
Angela Escolme *#	Cooke, Hunt, Berry	The geology, geochemistry and geometallurgy of Productora Cu-Au-Mo deposit, Chile	UTAS, Hot Chili, CSIRO, AusIMM, ARC TMVC
Esmael Eshaghi	Reading	Geophysical and petrophysical investigations of Tasmania at multiple scales	UTAS
Matt Ferguson	V.Kamenetsky, Ehrig (BHPBilliton), Meffre	Fe- and Ti-bearing minerals, apatite and zircon in the Olympic Dam district basement and Gawler Range Volcanics	UTAS, ARC Linkage, BHP Billiton
Jodi Fox	McPhie, Carey	Submarine intraplate basaltic volcanism	UTAS, CoE, ANZIS, Australian Antarctic Science Program, MRT, Linnean Society of NSW
Martin Gal #	Reading, Ellingsen (Physics)	Seismic array analysis of ocean induced microseisms	UTAS
Amos Garay *	Cooke, Baker, Zhang	Magnetite and epidote chemistry and textures at Las Bambas Cu-Au-Fe skarn, Peru: Assessing district and deposit-scale fertility - implications for ore genesis and exploration	AMIRA P1153, ARC TMVC, UTAS Foundation
Cassady Harraden *	Meffre, Berry, Cracknell	Geotechnical and geometallurgical assessment of the Cadia East deposit using Corescan automated logging technology	UTAS, ARC TMVC, Newcrest Mining, Corescan
Rachel Harrison *	Cooke, Zhang	Tumpangpitu porphyry Au-Cu-Mo and high-sulfidation epithermal Au-Ag deposit, Tujuh Bukit project, SE Java, Indonesia - geology, alteration and mineralisation	UTAS, SEG, ARC TMVC

STUDENT	SUPERVISORS	PROJECT	SUPPORT
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
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
Shawn Hood *	Cracknell, Reading	Machine learning and automated geoscientific analyses for the spatial characterisation of metalliferous ore deposits	UTAS, ARC TMVC, Gold Fields Australia, Saracen Mineral Holdings, Integra Gold Corp
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, Newcrest Mining
Torsten Jensen	Scott, Meffre, Selley	Devonian gold mineralisation in NE Nevada, USA: Critical primer to a world-class gold district?	CODES, 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 geochemistry of metalliferous black shales: Understanding primary enrichments, metamorphic processes and the role of metalrich black shales in archiving earth evolution	UTAS, CoE, Mining Institute of Scotland, ANZIC-IODP, ECORD, NERC, Talvivaara Mining, GTK, SEG
Joe Knight	Zaw, Large	The geodynamic and metallogenic setting of Cu-Au mineralisation in Myanmar: Implications for mineral exploration	Anglo American
Stephen Kuhn*	Reading, Cracknell	The use of Machine Learning for lithological mapping and minerals targeting in various deposit styles and settings	UTAS, CODES, ARC TMVC, First Quantum Minerals, Gold Fields, Buenaventura
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
Christopher Leslie	Meffre, Cooke	District scale ore deposit prospectivity of the Ordovician - Silurian Lachlan Fold Belt, southeastern Australia	ARC Linkage, UTAS
Elena Lounejeva	G.Davidson, 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, 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 (IMAS), Meffre	Pyrite trace element chemistry of black shales of the "boring billion" period	UTAS, SEG, AMIRA, CODES
Jacob Mulder	Meffre, Halpin (IMAS), Berry, Scott	From Nuna to Gondwana: An evaluation of the early tectonic history of Tasmania	UTAS, CODES

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Evan Orovan ^	Cooke, Harris (Newcrest)	Geology, geochemistry and genesis of the Namosi porphyry Cu-Au deposits, Fiji	CODES, Newcrest Mining, SEG , Namosi Joint Venture
Thomas Ostersen	Reading, Cracknell, Roach, Thiel (GSSA)	Multi-scale geoelectric, and combined geophysical, investigations of Tasmania and Southeast Australia	UTAS, CODES, MRT, U Adelaide, Geoscience Australia, GSSA
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, Scott, Baker	Geologic and geochemical vectors to mineralisation at the Resolution porphyry Cu-Mo deposit, Arizona	ARC TMVC, AMIRA P1153, Rio Tinto, Resolution Copper Ltd
Naomi Potter	V.Kamenetsky, Goemann, M.Kamenetsky	An investigation into the genesis of intrusive and extrusive carbonatitic melts	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
Tobias Staal	Reading, Whittaker (IMAS), Halpin (IMAS)	Seismic and geological constraints on the lithospheric structure of Antarctica	Antarctic Gateway Partnership
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	Origin, evolution and significance of anhydrite-bearing vein arrays and breccias, Lienetz orebody, Lihir gold deposit, Papua New Guinea	Newcrest Mining, CODES, TMVC, UTAS
Francisco Testa	Cooke, Baker	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	Carbonate mineral chemistry in epithermal and porphyry hydrothermal systems	UTAS, AMIRA P1153, ARC TMVC, SEG
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

MAJOR EXTERNALLY FUNDED RESEARCH PROJECTS^

ARC INDUSTRIAL TRANSFORMATION RESEARCH HUB GRANTS 2016

INVESTIGATORS	PROJECT	FUNDING BODY	PERIOD	ARC FUNDING FOR 2016	PARTNER FUNDING FOR 2016	UTAS FUNDING FOR 2016	MISC FUNDING FOR 2016
Cooke, Danyushevsky, Duh, Gemmell, Large, Meffre, Reading, Harris (Newcrest), Seymon (AMIRA), Ehrig (BHP Billiton), Goodey (Corescan), Lottermoser (Aachen), Shelley (Laurin Technic)	Transforming the mining value chain	ARC, AMIRA International, BHP Billiton Olympic Dam, Newcrest Mining, UTAS	2015 - 2020	\$861,003	\$852,800	\$145,135	\$21,127

ADDITIONAL FUNDER PROJECTS WITHIN THE ARC TMVC RESEARCH HUB 2016

INVESTIGATORS	PROJECT	FUNDING BODY	PERIOD	FUNDING FOR 2016
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	\$7,544
Cooke, Baker, Zhang, Garay (student)	Magnetite and epidote chemistry and textures at Las Bambas Cu-Au-Fe skarn, Peru: Assessing district and deposit-scale fertility - implications for ore genesis and exploration	UTAS Foundation	2015 - 2018	\$16,000
Parbhakar-Fox	Integrating mineralogical evaluations into kinetic testing protocols	Australian Academy of Technology and Engineering	2016 - 2017	\$7,000
Parbhakar-Fox	Evaluation of NAG pH testing: Tracking reaction pathways and products	Grange Resources	2016	\$5,396
Cooke, Danyushevsky, Meffre, Thompson (student)	Textural geochemical and C-O isotopic variations at Batu Hijau	Society of Economic Geologists Foundation	2016	\$4,067
Parbhakar-Fox, Fox, Clifton (student)	Evaluating applications of boiler ash for controlling acid and metalliferous drainage-- examples from Tasmanian mine wastes	MONA Heavy Metals Project	2016	\$3,000

ARC LINKAGE GRANTS 2016

INVESTIGATORS	PROJECT	FUNDING BODY	PERIOD	ARC FUNDING FOR 2016	PARTNER FUNDING FOR 2016
Meffre, Whittaker (IMAS), Norman (ANU), Cracknell, Belousova (Macquarie), Collins (UoN), Arundell (IMEx Consulting), Cooke	Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia	ARC, Rio Tinto, Alkane Exploration, Sandfire Resources, Evolution Mining, Geoscience Australia, Geological Survey of New South Wales, Heron Resources, Mineral Resources Tasmania, Northparkes Mines, New South Resources, AngloGold Ashanti, Geological Survey of Victoria, Emmerson Resources	2016 - 2019	\$80,343	\$145,000

ARC LIEF GRANTS 2016

INVESTIGATORS	PROJECT	PERIOD	ARC FUNDING FOR 2016	PARTNER FUNDING FOR 2016
Danyushevsky, V.Kamenetsky, Cooke, Large, Goemann (CSL)	A state-of-the-art field emission electron microprobe for Tasmania	2016	\$600,000	\$0

ARC DISCOVERY GRANTS 2016

INVESTIGATORS	PROJECT	PERIOD	ARC FUNDING FOR 2016
Large, Danyushevsky, Halpin (IMAS), Meffre	Pyrite: A deep-time capsule of ocean chemistry and atmosphere oxidation	2015 - 2017	\$166,773

CRC PROJECTS 2016

INVESTIGATORS	PROJECT	PERIOD	CRC FUNDING FOR 2016	UTAS FUNDING FOR 2016
Gemmell	CRC ORE II Participant funding	2015 - 2021	\$0	\$100,000
Gemmell	CRC ORE II- Predictive geometallurgy controls on grade by size	2016 - 2019	\$57,083	\$0
Berry, Danyushevsky, Thompson,Rodemann (CSL)	CRC ORE II- Geometallurgical applications for sorting by surface analysis: review of status	2016 - 2017	\$21,300	\$0

INDUSTRY AND OTHER EXTERNALLY FUNDED RESEARCH GRANTS 2016

INVESTIGATORS	PROJECT	FUNDING BODY	PERIOD	FUNDING FOR 2016
Large, Danyushevsky	Research and development in mineral deportment and exploration	Newcrest Mining Limited	2012 - 2016	\$235,000
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, Boliden Mineral, Argent Minerals, Intrepid Mines	2015 - 2017	\$153,000
Large, Meffre, Gregory, Steadman	South Australia pyrite, hematite and magnetite fingerprint database	Geological Survey of South Australia	2012 - 2016	\$83,000
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
Zhang	Exploration tools and genesis of the lithocaps in Eastern China	Hefei University of Technology	2016 - 2017	\$46,035
Danyushevsky	LAM data reduction software development	Rio Tinto	2014 - 2016	\$45,000
Gemmell, G.Davidson, McNulty (student)	Geology and genesis of the mineral deposits of the Myra Falls VHMS District, Canada	Nyrstar Myra Falls	2015 - 2017	\$40,000
Scott, G.Davidson, Heathcote (student)	Gold distribution and association at the Kansanshi copper-gold deposit Zambia	Kansanshi Mining	2014 - 2017	\$28,000
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
Johnson, Noble (IMAS), Olin, Meffre, Grice (Curtin), Large	The establishment of ocean anoxia and ocean acidification during the PETM: Understanding the biological and chemical response on a regional and global scale	IODP (via Australian National University)	2016 - 2018	\$20,000
Gemmell, Large, Hannington (UOttawa), Steeves (student)	Ore genesis of the Greens Creek VHMS Deposit, Alaska: Implications for mining, milling and exploration	Hecla Mining Company	2013 - 2016	\$19,000
G.Davidson, Bull, Selley	Controls on copper mineralising processes in the McArthur Basin, NT, and its implications for the metallogeny of extensional basins	Northern Territory Geological Survey	2016 - 2017	\$16,281
G.Davidson	Determination of the temporal relationship between the pyrite-silica-sericite alteration, and spatially associated uranium mineralisation, at Angularli Deposit, East Arnhem Land	Cameco	2015 - 2017	\$10,465
Cooke, Baker, Zhang, Wells (student)	Geology and genesis of the Two-Thirty prospect, Northparkes, NSW	Northparkes Mines	2016	\$10,000
G.Davidson	Carbonate formation and gold, Sunrise Dam: a stable isotope perspective	AngloGold Ashanti	2012 - 2016	\$7,817
Gemmell, G.Davidson, McNulty (student)	First application of high-resolution CA-ID-TIMS U-Pb zircon dating to resolve the timing of the H-W and L-M-P ore horizons of the Myra Falls VHMS district	Society of Economic Geologists Foundation	2016 - 2017	\$6,684

INVESTIGATORS	PROJECT	FUNDING BODY	PERIOD	FUNDING FOR 2016
Cracknell, Roach, Radford (student)	Geological mapping from radar imagery with Machine Learning	Mineral Resources Tasmania	2016	\$5,000
V.Kamenetsky, McPhie, Ehrig (BHPBilliton), Cherry (student)	Sedimentary units within the Olympic Dam deposit: Provenance and implications to metal sources	Society of Economic Geologists Foundation	2016	\$3,522
Cooke, Chen (student), Fan (visitor), Zhang, Zhou (visitor)	Porphyry and skarn mineralisation in China	Hefei University of Technology	2015 - 2017	**
Cooke, Jansen, Selley, Harris (Newcrest)	Exploring the porphyry environment	Newcrest Mining Limited	July 2009 - 2016	**
Danyushevsky, Johnson	Development of fundamental aspects of laser-ablation analysis applied to geological problems	Laurin Technic	2015 - 2018	**
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	**
Gemmell, Large, G.Davidson, Hawke (student)	Geological evolution of the DeGrussa Cu-Au VHMS deposit, Western Australia	Sandfire Resources	2012 - 2016	**
Large, Gregory, Steadman	DeGrussa vectoring project	Sandfire Resources	2015 - 2016	**
Zhang, G.Davidson, Whitney (student)	Geological framework and characteristics of the Specimen Hill high sulfidation epithermal system, southern Queensland, Australia	Signature Gold	2015 - 2016	**

^ projects with greater than \$2,000 external funding per year
** all project funding received, project still active

VISITORS 2016
INDUSTRY VISITORS

NAME	COMPANY
Ben Adair	CRC ORE
Paul Agnew	Rio Tinto
Debora Araujo	Rio Tinto
Phil Baker	Rio Tinto
Jens Bergmann	Bruker
John Bishop	Mitre Geophysics
Adam Black	Rio Tinto
Joel Blake	Rio Tinto
Bryan Bowden	Rio Tinto
Dane Burkett	Olympus
Erin Carswell	MMG
David Close	Origin Energy
Mawson Croaker	Rio Tinto
Paul Cromie	Anglo American
Andrew Davies	Teck
Gary DeSchutter	North American Palladium
Mark Doyle	AngloGold Ashanti
Jon Drew	Rio Tinto
Kathy Ehrig	BHP Billiton
David First	Freeport McMoRan
Fiona Fraser	Leapfrog3D
Fred Fryer	Agilent Technologies
Simon Gatehouse	BHP Billiton
Kathy George	Total Instrument Controls
Michael Gill	Rio Tinto
Bruce Godfrey	Australian Scientific Instruments
Jonathon Graham	Datamine
David Gray	Consultant
Scott Halley	Consultant
Anthony Harris	Newcrest
Nick Hayward	Teck
Roland Hill	QPX
Kate Hine	Mitre Geophysics
Tony Hope	GHD

NAME	COMPANY
Terry Hoschke	Newcrest
Tim Ireland	First Quantum Minerals
Andrew Jaunzems	Rio Tinto
Alan Kobussen	Rio Tinto
Jennifer Maguire	Rio Tinto
Martin Male	Mount Isa Mines
Dmitriy Malovichko	Institute of Mine Seismology
Stephen Meyer	Institute of Mine Seismology
Doreen Mikitiuk	Rio Tinto
Stephanie Mills	Rio Tinto
Brenda Mooney	Mooney and Reinhardt
Inna Mudrovska	Rio Tinto
Ashley Norris	Australian Scientific Instruments / Norris Software
Sasha Pontual	AusSpec
Cassie Porter	Rio Tinto
William Powell	Rio Tinto
Adele Seymon	AMIRA International
Trevor Shaw	Mount Isa Mines
Michael Shelley	Laurin Technic
Penny Sinclair	Cameco
Patrick Smillie	Leapfrog3D
Nick Smith	PassiveX
Andrew Somers	SciAps
Yi Sun	Myanmar Yangtze Copper
Steve Turner	Newmont
Vic Wall	Vic Wall and Associates
Steve Walters	CRC ORE
Shuo Wang	Rio Tinto
Tom Wesby	First Quantum Minerals
Mike Whitbread	MMG
Noel White	Consultant
Andy Wurst	Barrick

NATIONAL ACADEMIC AND GOVERNMENT VISITORS

NAME	INSTITUTION
Farah Ali	Latrobe University
Daniel Bombardieri	Mineral Resources Tasmania
Goran Boren	University of Adelaide
Ralph Bottrill	Mineral Resources Tasmania
Clive Calver	Mineral Resources Tasmania
Matthew Carey	Geoscience Australia
Ray Cas	Monash University
Yanbo Cheng	James Cook University
Richard Chopping	Geoscience Australia
Jingming Duan	Geoscience Australia
Mark Duffett	Mineral Resources Tasmania
Sinead Ferris	DFAT
Imogen Fielding	Curtin University
Tanya Fomin	Geoscience Australia
Geoff Fraser	Geoscience Australia
Andrea Giuliani	University of Melbourne
Brooke Goddard	DFAT
David Green	Mineral Resources Tasmania
William Griffin	Macquarie University
Nikhil Gulati	University of Melbourne
Martin Hand	University of Adelaide
Steve Hardy	Data61 / CSIRO
Jethro Hotbatahi Hasoloan	University of Melbourne

NAME	INSTITUTION
Derrick Hasterok	University of Adelaide
Robert Hough	CSIRO
Mark Kendrick	Australian National University
Craig Lindley	CSIRO
Roland Maas	University of Melbourne
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Andrew McNeill	Mineral Resources Tasmania
Jake Moltzen	Mineral Resources Tasmania
Rebecca Nelson	University of Melbourne
Jennifer Parnell	Mineral Resources Tasmania
Andrew Pitt	Launceston Cityprom
Rhys Pogonoski	DFAT
Aedan Puleston	DFAT
Ashfaqur Rahman	CSIRO
Phil Samson	Geoscience Education Tasmania
Michael Sephton	Latrobe University
Wendy Stanford	Latrobe University
Don Thomson	Cradle Coast Authority, Tasmania
Anthony Tran	University of Melbourne
Andrew Wakefield	Mineral Resources Tasmania
Rebecca White	University of Melbourne
Greg Yaxley	Australian National University

INTERNATIONAL ACADEMIC AND GOVERNMENT VISITORS

NAME	INSTITUTION
Huayong Chen	Guangzhou Institute of Geochemistry, China
Mi Chen	Geological Survey of Hubei Province, China
Tang Chun'an	Dalian University of Technology, China
Wendou Dong	Chinese Academy of Sciences
Patricia Durance	GNS Science, New Zealand
Yu Fan	Hefei University of Technology, China
Ty Ferre	University of Arizona, USA
Xue Gao^	China University of Geosciences
Dan Gregory	University of California, USA
Gwen Halemaku	Overseas Diplomat, Solomon Islands
Lisa Hart	Imperial College London, UK
Murray Hitzman^	Colorado School of Mines, USA
Xiaoye Jin^	China University of Geosciences.
Tobias Kampmann	Lulea University of Technology, Sweden
Vakaoca Kedrayate	Overseas Diplomat, Fiji
Wenbo Li	Peking University, China
Ping-Ping Liu	National Taiwan University
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Peter Michael	University of Tulsa, USA
Yaoling Niu	Durham University, UK

NAME	INSTITUTION
Graham Pearson	University of Alberta, Canada
Nilanthi Pelawaththage	Overseas Diplomat, Sri Lanka
Ryan Portner	Brown University, USA
Malcolm Reid	University of Otago, NZ
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Ping Shen^	Chinese Academy of Sciences
Robert Sievwright	Imperial College London, UK
Sifang Sun	Geological Survey of Hubei Province, China
Florient Sztikar	GEOMAR, Germany
Kenichiro Tani	National Museum of Nature and Science, Japan
Nasir Uddin	Overseas Diplomat, Bangladesh
Dongtian Wei	Chinese Academy of Sciences
Jamie Wilkinson	Natural History Museum, UK
Yuling Xie	University of Science and Technology of China
Feng Xiong^	Chinese Academy of Sciences
Georg Zellmer	Massey University, NZ
Taofa Zhou	Hefei University of Technology, China

^ Visitor for longer than three months.

OPPOSITE PAGE CLOCKWISE FROM TOP LEFT: John Bishop, Mitre Geophysics; Banxiao Ruan, China University of Geosciences; Vic Wall, Vic Wall and Associates; Yaoling Niu, Durham University, UK; Taofa Zhou, Hefei University of Technology, China; Xiaoye Jin, China University of Geosciences.





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TRANSFORMING THE MINING VALUE
CHAIN, AND THE UTAS DISCIPLINE
OF EARTH SCIENCES