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

CONTENTS
DIRECTOR’S REPORT 3
VALE KATIE McGOLDRICK AND GARRY DAVIDSON 6
PROFILE AND RESEARCH STRUCTURE 7
STAFF & MANAGEMENT 9
ORE DEPOSITS: CHARACTERISATION AND CONTEXT MODULE 13
GEOMETALLURGY MODULE 31
ENABLING TECHNOLOGIES MODULE 37
TRAINING MODULE 45
TMVC: THE ARC RESEARCH HUB FOR TRANSFORMING THE MINING VALUE CHAIN 59
THE DISCIPLINE OF EARTH SCIENCES 69
OUTREACH 79
INDUSTRY LINKS & RESEARCH COLLABORATIONS 81
TECHNOLOGY TRANSFER 83
PERFORMANCE INDICATORS 85
FINANCES 87
2016 PUBLICATIONS 91
APPENDICES 103

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.
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 round-up 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 distinguished researcher. David 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.

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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 development of techniques for detecting proximity to mineralisation in lithocaps, with the findings already convened 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 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 the 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 the module, and for the future of CODES.

One of these new initiatives is the ARC Linkage project, led by Sebastien Mefire, which is investigating the ore deposits and terminal evolution of the Lachlan Orogen, in SE Australia. This exciting new project is being conducted in collaboration with five universities, four geological surveys and 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.

**TRAINING**

It was another good year for the Training Module, which was marked by healthy enrolments in both the HDR and Master of Economic Geology programs, and the introduction of a suite of new courses at Honours level, covering a broad range of topics, from software expertise through to Machine Learning and presentation skills.

The HDR program continued to appeal to international markets, with over two-thirds of the overall cohort hailing from overseas, representing 18 different nationalities. While attendances at individual short courses in the Master of Economic Geology program were down, primarily due to the downturn in the minerals industry, it is pleasing that the program recruited 15 new students, which was close to a record, and celebrated its 100th graduate in Maria Lourdes Fuinola.

PhD student Jacob Mulder spent most of the year at the University of New Mexico, working under the supervision of renowned geologist Professor Karl Karstorn, on 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 in 2015. We look forward to this outstanding student’s return to CODES in 2017.

**CONFERENCES, EXHIBITIONS, WORKSHOPS AND FIELD TRIPS**

Our researchers always play 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, ASEG 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 Anila Parbhatkar-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, identifying opportunities for new investment, 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. Potential 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 analytical laboratories, with included services...
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 Awards; the airing on ABC TV's coverage of our success in the Eureka Awards; the publication in ECONOMIC GEOLOGY of 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 landslide 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 Carin 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 UTAS TMVC $1.3 million $2.6 million $1.9 million

WORLDWIDE COLLABORATIONS

Institute and Universities 59
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 industry and upskilling needs of the minerals industry, and supervisors that are exceptional links with industry, and supervisors that are international leaders in their field.

RESEARCH FACILITIES

CODES state-of-the-art facilities cover a wide range of applications encompassing the routine multi-element analysis of sulfide and oxide minerals, including the full range of platinum group elements; U/Pb dating of zircon and monazite; and multi-element analysis of silicates.

These facilities include four laser ablation ICP-MS laboratories specialising in ore deposit applications, an XRF laboratory, solution ICP-MS and clean room, fluid/melt inclusion laboratory, a lapidary department and sample preparation facilities. In addition, portable analytical techniques are provided, including shortwave infrared (SWIR) and portable XRF.

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

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

Awards

Six 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.

CODES in the community

- The training module provides a step-change in exploration techniques for metal discovery, new practices for sustainable mining, and 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 tools and to aid researchers with big data knowledge discovery, data reduction, modeling 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.
  - MSc – a two-year degree that will help you to develop knowledge and skills, and improve your career prospects. It is essential for those pursuing a research career or who require advanced knowledge.
  - PhD – four years of full-time study for a higher research degree.

Industry-focused 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, modeling 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.
  - MSc – a two-year degree that will help you to develop knowledge and skills, and improve your career prospects. It is essential for those pursuing a research career or who require advanced knowledge.
  - PhD – four years of full-time study for a higher research degree.
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.

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

PROFESSIONAL STAFF
Dr Ian Swan has left his position as Laser Ablation Technician at the TMVC Research Hub to take up an appointment at the University of Adelaide.

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 Ovran 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.

MOVEMENTS 2016

FROM LEFT: Delegates enjoying a break at presentations during the Science Planning Meeting; Sean Johnson aboard RV Investigator during a research cruise to the Cascade Seamount.

ACADEMIC/RESEARCH STAFF AT UTAS

SENIOR MANAGEMENT

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<tr>
<th>NAME</th>
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<tr>
<td>Director, Professor J Bruce Gemmell, BSc (UBC), MA, PhD (Dartmouth)</td>
<td>VH-MS deposits and epithermal Au-Ag</td>
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<tr>
<td>Deputy Director, Professor David Cooke, BSc Hon (Latrobe), PhD (Monash)</td>
<td>Porphyry Cu-Au, fluid-rock geochemistry</td>
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<td>Dr Sharon Allen, BSc (Massey), MSc (Auckland), PhD (Monash)</td>
<td>Volcanic facies analysis</td>
<td>Hon</td>
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<td>Dr Mike Baker, BSc Hons (Sydney), PhD (UTAS)</td>
<td>Igneous petrology, mineral chemistry</td>
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<tr>
<td>Associate Professor Ron Berry, BSc, PhD (Finders)</td>
<td>Structure of mineralised provinces, CHIME dating, geotectonics</td>
<td>Hon</td>
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<tr>
<td>Dr Stuart Bull, BSc Hons, PhD (Monash)</td>
<td>Clastic and carbonate sedimentology and volcanology</td>
<td>Hon</td>
</tr>
<tr>
<td>Dr Rebecca Carey, BSc Hons (UTAS), PhD (U Hawaii)</td>
<td>Volcanology</td>
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<tr>
<td>Dr Matt Craik, BSc Hons, PhD (UTAS)</td>
<td>Geophysics, machine learning and data mining</td>
<td>Hon</td>
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<tr>
<td>Professor Tony Crawford, BSc Hons, PhD (Melbourne)</td>
<td>Petrology, geochemistry and tectonics of volcanic arcs</td>
<td>Hon</td>
</tr>
<tr>
<td>Professor Leonid Danyushevsky, PhD (Vernadsky Inst.)</td>
<td>Petrology, geochemistry, LA-ICP-MS analysis</td>
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<tr>
<td>Dr Garry Davidson, BSc Hons (ANU), PhD (UTAS)</td>
<td>Sulfur isotope geochemistry and Cu-Au ores</td>
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<tr>
<td>Dr Paul Davidson, BSc Hons, PhD (UTAS)</td>
<td>Metall and fluid inclusions</td>
<td>Hon</td>
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<tr>
<td>Professor David Green, BSc Hons, MSc, DSc, DLitt Hon (UTAS), PhD (Cambridge)</td>
<td>Experimental petrology</td>
<td>Hon</td>
</tr>
<tr>
<td>Dr Jacqui Haplin, BSc Hons (Melbourne), PhD (Sydney)</td>
<td>Metamorphic petrology, geochemistry</td>
<td>Hon</td>
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<tr>
<td>Dr Sean Johnson, BSc Hons (St. Andrew), PhD (UTAS)</td>
<td>Geochemistry, LA-ICP-MS, sedimentology, marine geoscience</td>
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<tr>
<td>Dr Martin Jutzeler, MSc (U Lausanne), PhD (UTAS)</td>
<td>Volcanology and clastic sedimentology</td>
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<tr>
<td>Dr Maya Kamenetskaya, PhD (UTAS)</td>
<td>MLA-BSE, geotectonics, petrology</td>
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<td>Professor Vadim Kamenetskaya, BSc Hons (Moscow), PhD (Vernadsky Inst.)</td>
<td>Petrology and geochemistry of melt inclusions</td>
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<tr>
<td>Professor Khin Zaw, BSc (Bangong), MSc (Queen’s) PhD (UTAS)</td>
<td>Fluid inclusions, SE Asian metallogenosis</td>
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<td>Dr Chun-kit Lai, BSc, MPhil (HKU), PhD (UTAS)</td>
<td>Volcanology</td>
<td>Hon</td>
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<tr>
<td>Professor Ross Large, BSc Hons (UTAS), PhD (UNE)</td>
<td>Volcanic-hosted and sediment-hosted base metal and gold ores</td>
<td>Hon</td>
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<tr>
<td>Dr Peter McGuirk, BSc Hons, PhD (Melbourne)</td>
<td>Ore deposits and their halos</td>
<td>Hon</td>
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<td>Professor Joselyn McNie, BA Hons (Queensland), PhD (UNE)</td>
<td>Volcanic-facies architecture and volcanic textures</td>
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<td>Associate Professor Sebastian Metffe, BSc Hons, PhD (Sydney)</td>
<td>Petrology and tectonics of the SW Pacific</td>
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<tr>
<td>Dr Evan Ovran, BSc Hons (Carleton), PhD (UTAS)</td>
<td>Porphyry environment, mineral chemistry and hydrothermal geochemistry</td>
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<tr>
<td>Dr Karin Orth, BSc Hons (Monash), PhD (UTAS)</td>
<td>Structural geology, gold deposits / MTEC Senior Lecturer and Masters Program Coordinator</td>
<td>70</td>
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<td>Dr Anit Parbatkhar-Fox, MSc Hons (London), PhD (UTAS)</td>
<td>Geophysical responses of ore deposits</td>
<td>Hon</td>
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<tr>
<td>Dr Michael Ross, BSc Hons (Newcastle), PhD (UTAS)</td>
<td>Ore and sedimentary pyrite geochemistry; seawater composition through geologic time</td>
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<td>Dr Aleksandar (Sasha) Stepanov, MSc (Novosibirsk), PhD (ANU)</td>
<td>Geochemistry of rare metals</td>
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<td>Dr Lian Zhang, BSc, PhD (HFUT)</td>
<td>Porphyry Cu-Au and HS epithermal</td>
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ACADEMIC/RESEARCH STAFF BASED AT COLLABORATIVE INSTITUTIONS/INDUSTRY

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<td>Dr John Bishop</td>
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<tr>
<td>Dr Daniel Bombardieri</td>
<td>Mineral Resources Tasmania</td>
<td>Hon</td>
</tr>
<tr>
<td>Professor Ray Cas</td>
<td>Monash University</td>
<td>Hon</td>
</tr>
<tr>
<td>Kathy Ehrig</td>
<td>BHP Billiton</td>
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<tr>
<td>Associate Professor Jeff Foster</td>
<td>S2 Resources</td>
<td>Hon</td>
</tr>
<tr>
<td>Neil Goodley</td>
<td>Corescan</td>
<td>Hon</td>
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<tr>
<td>Professor Mark Hannington</td>
<td>University of Ottawa</td>
<td>Hon</td>
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<tr>
<td>Dr Anthony Harris</td>
<td>Newcrest Mining</td>
<td>Hon</td>
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<tr>
<td>Professor Peter Hollings</td>
<td>Lakerock University</td>
<td>Hon</td>
</tr>
<tr>
<td>Dr Julie Hunt</td>
<td>University of Liege</td>
<td>Hon</td>
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<tr>
<td>Professor Bernd Lottermoser</td>
<td>RWTH Aachen University</td>
<td>Hon</td>
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<tr>
<td>Dr Andrew McNell</td>
<td>Mineral Resources Tasmania</td>
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<tr>
<td>Adela Seymon</td>
<td>AMERA International</td>
<td>Hon</td>
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<tr>
<td>Michael Shelley</td>
<td>Laburn Technic</td>
<td>Hon</td>
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<td>Dr Tony Webster</td>
<td>University of Queensland</td>
<td>Hon</td>
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<tr>
<td>Dr Neil White</td>
<td>Consultant</td>
<td>Hon</td>
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<tr>
<td>Dr Jamie Wilkinson</td>
<td>Natural History Museum / Imperial College London</td>
<td>Hon</td>
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TECHNICAL/ADMINISTRATIVE STAFF

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<tr>
<td>Dr Ivan Belousov, BSc, MSc (Moscow), PhD (Vernadsky)</td>
<td>Research Associate - ARC TMVC Research Hub</td>
<td>100</td>
</tr>
<tr>
<td>Mr Steve Calladine</td>
<td>Communications Manager</td>
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<tr>
<td>Mrs Michele Chapple-Smith</td>
<td>Lapidary Technician</td>
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<tr>
<td>Mr Alex Cuison</td>
<td>Lapidary Manager</td>
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<tr>
<td>Dr Jane Higgins, BSc, BEd (UTAS)</td>
<td>Personal Assistant to the Director</td>
<td>90</td>
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<tr>
<td>Mr Ian Little, BSc, BEd (UTAS)</td>
<td>Maintenance, Field Equipment, and Safety Officer</td>
<td>50</td>
</tr>
<tr>
<td>Ms Elena Lounejeva</td>
<td>Laboratory Analyst</td>
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<tr>
<td>Mrs Michelle Makoudi</td>
<td>Laboratory Assistant</td>
<td>40</td>
</tr>
<tr>
<td>Mrs Kadee McGodrick</td>
<td>Laboratory Assistant</td>
<td>20</td>
</tr>
<tr>
<td>Dr Paul Oli, BA [SOE], MSc, PhD (WSU)</td>
<td>Laser Ablation Technician - ARC TMVC Research Hub</td>
<td>100</td>
</tr>
<tr>
<td>Ms June Pongratz</td>
<td>Publications</td>
<td>5</td>
</tr>
<tr>
<td>Mrs Claire Rutherford</td>
<td>Administrative Assistant</td>
<td>60</td>
</tr>
<tr>
<td>Ms Helen Scott, BSc Hons (UTAS), BEd (QUT)</td>
<td>Hub Manager - ARC TMVC Research Hub</td>
<td>100</td>
</tr>
<tr>
<td>Mr Jay Thompson, BSc Hons, BSc (U Iowa)</td>
<td>Laboratory Analyst</td>
<td>100</td>
</tr>
<tr>
<td>Ms Isabella von Lichtan, BSc Hons (UTAS)</td>
<td>Curator / Administrative Assistant</td>
<td>25</td>
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ADVISORY BOARD

<table>
<thead>
<tr>
<th>NAME</th>
<th>Department of State Development, South Australia</th>
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<tbody>
<tr>
<td>Chair: Paul Heithersay</td>
<td>(Could not attend 2016 meeting)</td>
</tr>
<tr>
<td>Deputy Chair: Paul Agnew</td>
<td>Chair of 2016 meeting</td>
</tr>
<tr>
<td>Richard Coleman</td>
<td>Pro Vice-Chancellor, Research Infrastructure, UTAS</td>
</tr>
<tr>
<td>David Cooke</td>
<td>CODES, UTAS</td>
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<tr>
<td>Paul Cromie</td>
<td>Anglo American</td>
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<td>Leonid Danyushhevsky</td>
<td>CODES, UTAS</td>
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EXECUTIVE COMMITTEE

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<thead>
<tr>
<th>NAME</th>
<th>Chair: Bruce Gammell, Director, CODES</th>
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<tr>
<td>Steve Caladine</td>
<td>Communications Manager</td>
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<tr>
<td>David Cooke</td>
<td>Deputy Director, CODES / ARC TMVC Research Hub Director</td>
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<tr>
<td>Leonid Danyushhevsky</td>
<td>Enabling Technologies Module Leader / Head of the Discipline of Earth Sciences</td>
</tr>
<tr>
<td>Garry Davidson</td>
<td>Ore Deposits: Characterisation and Context Module Leader</td>
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SCIENCE PLANNING PANEL

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<thead>
<tr>
<th>NAME</th>
<th>Chair: Bruce Gammell, Director, CODES, UTAS</th>
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<tbody>
<tr>
<td>Ben Adair</td>
<td>CRC ORE</td>
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<tr>
<td>Paul Agnew</td>
<td>Rio Tinto Exploration</td>
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<td>Daniel Bombardieri</td>
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<td>Andrew Davies</td>
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<td>John Dickey</td>
<td>Head, School of Physical Sciences, UTAS</td>
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<td>Mark Doyle</td>
<td>AngloGold Ashanti</td>
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<td>Mark Duffett</td>
<td>Mineral Resources Tasmania</td>
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<tr>
<td>Kathy Ehrig</td>
<td>BHP Billiton</td>
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<tr>
<td>David First</td>
<td>Freeport McMoRan</td>
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<td>Geoff Fraser</td>
<td>Geoscience Australia</td>
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<tr>
<td>David Green</td>
<td>Mineral Resources Tasmania</td>
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<tr>
<td>Dan Gregory</td>
<td>University of California</td>
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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.
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.

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

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

HIGHLIGHTS
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.

> 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 Gymmett 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.

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 Doutch’s PhD project.
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.

ORE DEPOSITS: CHARACTERISATION AND CONTEXT

THE MODULE TEAM

TEAM MEMBERS: Ron Berry, Stuart Buli, 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 McPhee, Sebastien Meffre, Evan Orovan, Karen Orth, Anya Reading, Michael Roach, Robert Scott, David Selley, Jeff Sheathman, Sasha Stepanov, Jay Thompson, Khin Zaw, Lujun Zhang

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

MASTERS STUDENTS: Eyob Andemeskel, Jo Condon, Kyle Hughes, Corey Jago, Sithmony Kultakayos, Peeraopong Sritangsiriuk

HONOURS STUDENTS: Kathryn Job, Sigmun Lloyd, Tristan Wells

COLLABORATORS:
AKITA UNIVERSITY, JAPAN
Akiro Imar

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

CAMERO RESOURCES
Penny Sinclair, Ben Walsh

CHIANG MAI UNIVERSITY, THAILAND
Phsai Limtrakun, Sampan Singharaarapan

CHINOA RESOURCES
Mark McGeogh

CHULALOKORN UNIVERSITY, THAILAND
Abhisit Salam

LEADER

Garry Davidson

CLUMP MOUNTAIN GEOSCIENCE
Pat Williams

COLORADO STATE UNIVERSITY, USA
Holly Stein

CONSULTANTS
Neil Allen, Wally Hermann

CURTIN UNIVERSITY
Andrea Agangi, William Collins

DEPARTMENT OF MINERAL RESOURCES, THAILAND
Pol Chaodumrong, Somboon Khositanont

DIRECTORATE OF GEOLOGICAL SURVEY AND EXPLORATION, MYANMAR
Ye Myint Sae

DRUMMOND GOLD
Ed Eshuys

EAST YANGON UNIVERSITY, MYANMAR
Cho Cho Aye

EMMISON RESOURCES
Grant Osborne

ENTERPRISE METALS
Frank Doeders, Dermot Ryan

FIRST QUANTUM MINERALS
Tim Ireland, Louis van Heerden

GEOFORSCHUNGSZENTRUM POTSDAM, GERMANY
Rainer Thomas

GEOLOGICAL SURVEY OF JAPAN
Kenzo Sanematsu

GEOLOGICAL SURVEY OF THAILAND
Phal Limtrakun, Sampan Singharaarapan

GEOLOGICAL SURVEY OF SOUTH AUSTRALIA
Adrian Fabris, Steve Hill

GEOMAR, GERMANY
Sven Petersen
AND CONTEXT
CHARACTERISATION
ORE DEPOSITS: PROJECTS
THEME 1 – ORE FERTILITY OF THE CRUST AND MANTEL
New project
THEME 2 – VOLCANISM, AND ITS EFFECT ON ORE FORMING PROCESSES
New project
THEME 3 – MAGMATIC-HYDROTHERMAL PROCESSES AND ORES
New project
THEME 4 – BASIN PROCESSES AND ORES
New project
THEME 5 – THE ORE AFFECTED CRUST
New project
THEME 6 – DATES AND PLATES
New project

PROJECT SUMMARIES
THEME 1 – ORE FERTILITY OF THE CRUST AND MANTEL
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 Megatone-Apatite Deposits project, which has now come to a conclusion.
Pegmatites are noted for the presence of giant crystals, sometimes including rare minerals and gem, even through 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 ‘Reviving 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 magmatic pegmatites in the Kongshain granite; Lusatia’, was published in Lithos. Both publications were authored by Rainer Thomas and Paul Davidson.

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 to 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 had two main components to 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 1969. 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 BIRMMAN BELTS IN CÔTE D’IVOIRE

Leader: David Selley

Team Members: Sebastien Meffe, Sasha Stepianov

Collaborators: Mathieu Agneau, Anthony Harris, Paul Kitti, Dominic Murphy, Charlotte Seabrook

This Newcest-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 project builds on major multidisciplinary research by the WAXI consortium, led by the University of Western Australia and the University of the Witwatersrand, which has focussed on areas 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, geochemical, and geochronological 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 Birrmian sequence is both near-complete and relatively well-exposed. Results of field-based structural and stratigraphic analysis, coupled with geochemistry, 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 intrastratal canibalisation, rapid exhumation and reworking of coeval plutonic rocks, and development of early stage, foliation-lacking reworked units within these younger sequences favour a syn- orogenic foreland basin environment.

Gold mineralisation appears to have originated from younger sub-aqueous to subaerial depositional environments, evidence of intrabasinal reworking of coeval plutonic rocks, and development of early stage, foliation-lacking reworked units within these younger sequences favours a syn- orogenic foreland basin environment.

Gold mineralisation appears to have originated from younger subaqueous to subaerial depositional environments. Evidence of intrabasinal reworking of coeval plutonic rocks, and development of early stage, foliation-lacking reworked units within these younger sequences favours a syn- orogenic foreland basin environment.

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 and the coalition of 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, Ira Zhukova, expected to start in the new year. Both positions are on a part-time basis.

Although the project has 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.

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

Leaders: Sebastien Meffe, David Cooke, Matt Cracknell, Joanna Whiteman, Nathan Stevens

Team Member: Jeff Steadman

Students: Kyle Hughes, Corey Jago, Kathryn Job, Sittinon Kultakosay, Christopher Leslie, Sigmun Lloyd, Peerangon Sritangsirikul, Tristan Wels

Collaborators: Mark Arundell, Elena Belousova, William Collins, John Greenfield, David Hudson, Roland Maas, Robert Muirgray, 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.

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

VHMS RESEARCH – MODERN

Leader: Bruce Gemmell

Student: Heidi Benkerbochs

Collaborators: Cornel de Rondel, Andrew McNulty, Sven Petersen

Heidi Benkerbochs’ PhD project at Brothers volcano, in the Tonga-Kermadec arc, reached completion in 2016. This collaborative project with GNS, New Zealand (Cornel de Rondel is investigating the ore and gangue mineralogy, textures, paragenesis, mineral chemistry and copper isotope analyses of the sulphide-chlorine systems. A paper detailing the trace element mapping, using synchrotron radiation XRF and LA-ICP-MS of Cu- and Zn-rich black smoker chimney from the volcano, was prepared and will be submitted to Economic Geology in early 2017.

Bruce Gemmell is continuing research on the Palau seafloor mineralisation system in the Tyrrhenian Sea, Italy, which is an evolving intermediate to high sulfilation massive sulphide. Bruce is using LA-ICP-MS analysis of the different paragenetic generations of pyrite to elucidate the evolving hydrothermal fluids responsible for the Palau seafloor mineralisation. This research is being conducted in collaboration with Sven Petersen at GEOMAR, Germany. A manuscript is 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 Coggan, Mark Hannington, Sajjad Magnhiart, Andrew McNeil, Jim Mortensen, Ford Brown, Sven Petersen, Mike Vicary

The genesis of volcanic-hosted Cu-Pb-Zn-Au massive sulphide deposits is being investigated across the spectrum of massive sulphide deposit types, from typical seafloor VHMS (Zn-Pb-Cu-Au-Ag) 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 Jaguard (Alaska), Greens Creek (Alaska), Myra Falls (Canada), Tasar Chini (Malaysia), Naiish (Iran) and Marquette Island.

In collaboration with Mark Hannington from the University of Ottawa, Nathan Stevens continued his PhD investigation of the mineralogy, metal distribution and geometallurgical characteristics of the complex ore bodies at the Greens Creek VHMS deposit in Southeast Alaska. Nathan presented his findings at the GAC-MAC conference in Whitehorse, Yukon, where he played a key role in collaboration with Bruce Gemmell, of a post-conference field trip covering the ore and gangue mineralogy, textures, paragenesis, mineral chemistry and copper isotope analyses of the sulphide-chlorine systems. 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...
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 $5,000 US$ research grant from the Society of Economic Geologists (Canada Foundation) to complete TIMS-U-Pb analyses on the host rocks at Myra Falls.

Khin Zaw presented the results of his research on the VHMS deposits in New Guinean SE Asia at the ICG meeting in South Africa. Mohd Basri 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 Nudun Basotho-type volcanogenic massive sulfide deposit, southwest Sabzevar basin, Iran, was published by Maghroui et al. in the Asian Journal of Earth Sciences.

Two student projects continued at Sanfire Resources’ VHMS deposit at DeGrussa, WA. The first, a PhD project by Mary Hammond, is investigating the geologic, structural and geochronological setting of the deposits. Mary 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 Condron, 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, has continued publication of her PhD results with co-authorship of a manuscript on the Jugaue-Teutonic Bore field for the AusMIM’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 VHMS DEPOSITS**

**LEADER:** Rebecca Carey

**TEAM:** Jocelyn McPhie, Karin Orth, Robert Scott

**STUDENTS:** Ebyd Andemanselke, David Doucet, Pedro Fonseca, Ray Cas, 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 demonstrated the critical importance of information on seafloor sulfide deposition versus sub-seafloor 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 pristine, one of the most common, and widely misidentified, facies in VHMS successions.

Ray Cas and Robert Scott co-supervised David Doucet’s PhD research on the volcanology and ore prospectivity of the transition from the Late Archean to the Early Proterozoic of Australia by McPhie et al., described 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-defined quartz-rich sandstone indicate that older Gawler Craton basement successions also contributed sediment to the BCF. The depocenter in which BCF accumulation 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.

**THEME 3 – MAGMATISM, HYDROTHERMAL PROCESSES AND ORES EXPLORING THE PORPHRY ENVIRONMENT**

**LEADER:** David Cooke, David Selley

**STUDENTS:** Erin Lawlis, Evan Croran

**COLLABORATORS:** Karyn Gardner, Anthony Harris, Marc Rine

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 ongoing support and 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 become competitors and opportunities for the team have been generated by increased mining activities to be reported for the year:

> Evan Croran’s PhD thesis on the Namosi porphyry deposits, Fiji, was examined and accepted in December of the year. Evan is preparing manuscripts from his thesis for submission in 2017.

> Marc Rine is preparing manuscripts from his thesis on the Golpu porphyry Cu-Au deposit, PNG.

> A geology chapter of Erin Lawlis’s PhD study of the Kapi 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 TMRC research hub at the end of 2015.

**OLYMPIC DAM**

**LEADER:** Vadim Kamenetsky

**TEAM:** Maya Kamenetsky, Jocelyn McPhie, Sebastian Mehtre, Karin Orth, Jay Thompson

**STUDENTS:** Olga Apukhtina, Nathan Griffin, Maya Kamenetsky, Carlos Lamarr, John Yee, Rebecca Carey, Matthew Fargnoli

**COLLABORATORS:** Andrea Asch, Chris Bathurst, Elena Belousova, Isabelle Chambert, Christiana Ciobanu, Nigel Cook, Ken Gross, Kathy Ehrig, Karsten Goemann, Maria Kirchenbauer, Roland Maas

This project is building on existing knowledge related to economic geology at Olympic Dam through a combination of petrogeochemical, geochronological and geochemical 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 pre-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 between 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 banded 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-defined quartz-rich sandstone indicate that older Gawler Craton basement successions also contributed sediment to the BCF. The depocenter in which BCF accumulation 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-phryic basalts at Kokatha and Mount Gunson, it describes rock lithologies intersected by drill holes at the Olympic Dam deposit and the Winda Welti Cu-Au prospect. U-Pb dating ofapatite confirmed temporal restriction of porphyry and dykes with the ca. 1590 Ma Gawler SLIP. The compositions of Co-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, while the upper crust 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 intrude the Middle Proterozoic Gawler megasuite in the Mesoproterozoic (ca. 1590 Ma) and Neoproterozoic (ca. 830 Ma) of the Gawler Craton. The team aims to characterise 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.
Collaborators: Stephanie Sykora

Pieman Heads Granite. These textural and USTs were observed in the Tasmania. They include tourmaline-rich magmatic –hydrothermal features. Distinctive tourmaline-and quartz-rich granites have distinctive magmatic mid-Palaeozoic. Many of these > Resolve the sources of volatile NW Tasmania were to: The key objectives of this project in Wei Hong, Erin Lawlis, Orovan, Michael Roach, Lejun Zhang Team Members: Nathan Fox, Evan Students: Wei Hong, Erin Lawlis, Stephanie Sykora Collaborators: David Huston, Roland Maas

The project, funded by the Northern Territory GIS, 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 tovomost 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 Wollongorang 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, 5 isotypes. 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 zones) 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 ± SEM) on a suite of 230 primary ore and altered wall rock specimens 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 detailed and geologically characteristic 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 Members: Sebastien Meffre
Collaborators: Karsten Goemann, Grant Osborne, Penny Sinclair, Ben Walsh

This project is focused on researching the nature and causes of uranium concentration in sedimentary basins. Several basins were visited in 2016, and the team achieved the following outcomes:
- Further analysis was required for a manuscript on epigenetic U-P mineralisation in the Northern Star Cu-Au ironstone mine, which is being continued.
- In the East Alligator Rivers Province, Northern Territory, the Angulali 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 compiled 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 Danyszhevsky, Sebastien Meffre, Jeff Steadman
Students: Sean Johnson, Charles Makoundi, Indrani Mukherjee
Collaborators: Dan Gregory, Valeriy Maslennikov

This project is investigating the primary compositional characteristics and diagenetic and hydrothermal alteration history of sedimentary rocks to one of the world’s most important mineral 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 (1000 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 whether there is evidence for syngenetic gold in the Wispy unit, as this 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 arsenian pyrite Unit sample from the Snaker 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 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 formation of the native gold. Work to constrain the age of the Fe-dolomite overgrowths is continuing, but these are as old as suggested by previous 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 at this stratigraphic level.

THE POWER OF PYRITE
Leaders: Jeff Steadman, Ross Large
Team Members: Matt Cracknell, Leonid Danyszhevsky, 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, Georgin Manuc, Todd McGilvray, Roger Nordin, Dermot Ryan, Torsten Jensen

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 tool 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, titane and chloride was conducted during the year, with a focus on the following activities and sites:
  - Drilling in South Australia by joint GSSA OGD 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-GD).
  - Kemptfield VHMS mineralisation, NSW, with Argent Minerals.
  - Black Butte sedimentary copper deposit, Montana (USA) in collaboration with Sandfire and Tintina Resources.
  - Skelefteå 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
Students: Emnaai Eshaghi
Collaborators: Daniel Bombardi, 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).
This phase of work is employing key lodes, and to better constrain the aims of evaluating detailed along-gold systems. 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 explore indications of future deposits. This phase showed that Sunrise Dam has ‘missing link’ characteristics within the range of isotopic values of Archean orogenic gold systems.

Research will continue at this site, with the aims of evaluating detailed along-strike C-O isotope variation, and to explore indications of future deposits. Research is ongoing at the Arrow Project, which is a part of the extensive collaborations with researchers in Australia, Canada, and the USA, directed at understanding the global significance of Mesoproterozoic sedimentary sequences preserved in the southwestern USA and helps refine models for exhumation of the Grenville Orogen. The sedimentary record of these basins provides new tectonic context for Late Mesoproterozoic basin formation in the southwestern USA and improves understanding of the broad-scale tectonic evolution of the Lachlan orogen, SE Australia. This research aims to understand links between basin formation in Australia, Antarctica, and the transition between supercontinents Nuna and Rodinia.

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

**Leader:** Garry Davidson

**Team Members:** Stuart Bull, David Crook, Hamish Freeman, Mark Duffett, Thomas Rodemann

**Collaborators:** Sebastien Meffre, Richelle Awid-Pascal, Ben Cave, Jacob Mulder

**Collaborator:** Sebastien Meffre

**Collaborator:** Ben Cave

**Collaborator:** David Crook

**Collaborator:** Hamish Freeman

**Collaborator:** Mark Duffett

**Collaborator:** Thomas Rodemann

**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 focused on the sulphur 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 Honour’s research work by another 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 H whole-rock isotopes from the Williams Batholith granites was also analysed, together with the reanalysis of a selection of related samples from Gosses Bluff. A paper on the crystal-structure of Merlin molybdenite was published in Vibrationl Spectroscopy (Sharma et al. 2016).

**The CHARACTERISTICS AND ROLE OF COGDOIDILIA FLUIDS IN THE FORMATION OF THE GIEVES SIDDIO Pb-Zn PROSPECT, WESTERN TASMANIA**

**Leader:** Garry Davidson

**Student:** Subira Sharma

**Collaborators:** Bryan Bowden, Greg Clarke, Mawson Croaker, Geoff Fraser, Hamish Freeman, Josh Greene, Mark McGeogh, Thomas Rodemann, 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.**

This project, which is evaluating the occurrence of anomalies and textures of a zinc-rich fossil peat deposit above a hardrock Zn-Pb “thick-style” deposit in western Tasmania, is the subject of PhD research by Richelle Awid-Pascal. Richelle took a break from her studies for a portion 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:** David Doucet

**Collaborator:** Ray Cas

David Doucet’s PhD study, funded by Gold Fields, is investigating the geology and genesis of the >1 Moz Au Invincible deposit in the St Ives goldfield, Kambalda, WA. This deposit differs from most in the >1 Moz Au St Ives goldfield, as it is hosted by sedimentary rocks at the top of the Black Flag Group (2680 – 2656 Ma), rather than by mafic rocks. A major finding from this study is that the change in palaeoenvironmental setting may have been due to uplift associated with the local emplacement and unroofing of granitoid 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 aid the interpretation of new geochronological data, by providing additional paragenetic (i.e. relative temporal) constraints on observed patterns.

**THEME 6 – DATES AND PLATES BUILDING TASMANIA: THE CAMBIAN AND BEYOND Leaders:** Sebastien Mettre, Robert Scott

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

**Student:** Jacob Mulder

**Collaborators:** Clive Calver, Grace Cumming, Nathan Daczko, John Evamy, Paul Godfrey, Stewart Heaps, Kevin Sharp

**Collaborator:** Sebastien Mettre

**Collaborator:** Robert Scott

**Collaborator:** Ron Berry

**Collaborator:** Jacqueline Halpin

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 cystic Taobhach turbidite, through to Mesoproterozoic Proterozoic successions, to the accretion of the Tasmanian micro-continent to the Gondwanan paleo-Pacific margin.

Despite this major change, available geochronological data, and similarly of bedrock orientations, suggest the two sequences are conformable. David has first interpreted the appearance of granite clasts in basal conglomerates of the group to suggest that the change in palaeoenvironmental setting may have been due to uplift associated with the local emplacement and unroofing of granitoid 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 aid the interpretation of new geochronological data, by providing additional paragenetic (i.e. relative temporal) constraints on observed patterns.

**Mineral Resources Tasmania (MRT).**

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 for Late Mesoproterozoic basin formation in the southwestern USA and helps refine models for exhumation of the Grenville Orogen.’

While in Tasmania, Jacob focused on refining the depositional age and better understanding the structural relationships of Mesoproterozoic sedimentary rocks. A major breakthrough has been refining the depositional age of turbidites comprising the Onahin Formation and their correlation with Mesoproterozoic turbidites exposed on King Island. Together, these turbine sequences represent deep-water equivalents to the shallow marine sequences of the Rocky Cape Group, and thus help to define the broad-scale geometry of the Mesoproterozoic basin formed in western Tasmania, confirming that it is compatible with an east-facing rifted margin.

This research is ongoing for the project titled ‘Mesoproterozoic basin evolution in the southwestern USA and western Tasmania with potential correlates of Late Mesoproterozoic strata exposed in eastern Australia’. Field work in the Grand Canyon, together with new data from Late Mesoproterozoic sequences exposed throughout southwestern USA, has identified two distinct episodes of major basin formation at 1250 – 1300 Ma and 1400 – 1450 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 forLate Mesoproterozoic basin formation in the southwestern USA and helps refine models for exhumation of the Grenville Orogeny.

In addition to his ongoing research, Jacob was invited to present his work at the 2016 Geological Society of America conference in Denver, Colorado, including an invited talk in the session ‘Tectonics of Mesoproterozoic basins in the southwestern USA’.
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 Kamsnetsky 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 signficance 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.
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 (GeMIII) 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 GeMIII 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.

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).

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.

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 GeMIII 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.
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 topography and dust distribution, and associated with rapid motion, irregular belt to control sorting opportunities. It also addressed the potential problems 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 focused 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 Gennell, 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 GeM3 project ended in mid-2013, the process of transcending the knowledge and expertise developed during the project’s long life cycle continued into 2016. Several of the outcomes are being applied in life cycle continued into 2016. Several developed during the project’s long life cycle continued into 2016. Several of the outcomes are being applied in the mining and resources sector.

Included amongst the invitees was Director Bruce Gennell, 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.

TEAM MEMBERS:

Ron Berry, Leonid Danyushevsky, Nathan Fox*, Bruce Gennell, 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

THE MODULE TEAM

ACTING LEADER
Anita Parbhakar-Fox

JULIUS KRUTTSCHNITT
MINERAL RESEARCH CENTRE/UNIVERSITY OF QUEENSLAND
Khoo Nguyen

MINERAL RESOURCES
TASMANIA
David Green, Jake Molten

OLYMPUS
Dane Burkett

PETROLAB, UK
Christopher Brough

SCIAPS, USA
Andrew Somers

SPECIM
Rainer Bärs, 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

Sandrin Feig, Karsten Goemann, Thomas Rodemann

Khoi Nguyen

Published a paper in Economic Geology on STuRicture from photographs of Oriental Core (STOPC), a tool developed in the GeM3 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 30 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 Sustainable Minerals ’16, which was held in Falmouth immediately prior to Sustainable Minerals ’16.
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 EngineeringTM (Steve Walters/Luke Keeneey/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).
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.

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.

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.

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 processes in silicate minerals.
- 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
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.

CONFERENCE
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.

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

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
> Geo-data analytics, visualisation and decision making
> 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.
FUNDAMENTALS OF LASER ABLATION

Leaders: Sarah Gilbert, Leonid Danyushevsky
Team Members: Martin Tanner, Fred Fryer, Sam Houk, Martin Tanner

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

This project aims to improve understanding of laser ablation processes, leading to improved analysis of geological materials, especially sulfides.

In 2016, the project received funding from Labor Technich for a two-year project focussed on characterising 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

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 Blandy, Karsten Goemann, Pavel Pechov, 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 Cubisron, 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.
- Development of the new calibration standard STDGL3 for sulfide analysis.

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 Trace 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

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

This project, partially co-funded by Newcrest Mining (until April 2014) and Rio Tinto (from December 2014) as part of their support for the R&D program of the CODES Analytical Laboratories, aims to develop comprehensive, user-friendly LA-ICP-MS data processing software, capable of:

- Quantification of data acquired using multiple calibration standards and a range of internal standard elements.
- Quantification of images depicting distribution of major and trace element concentrations in fine-grained multi-mineral aggregates of sulfides, silicates, phosphates and carbonates.
- Identification of mineral phases in, and sizes of, micro inclusions in minerals.
Activities in 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 Danyushhevsky
**Collaborators:** Alexey Aniskin, 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 Bass, Andrew Foley, Tim Ireland, Chris Wynn

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 geological 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 processing tools, rather than being simply a way of viewing the final output.

During the year, a prototype computer application for the visualisation of 3D geochemical and geological data across northern Australia 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.

**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 mix (<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/pothermal 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 geochemo, 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.
PROGRAMS, through to a variety of short courses and workshops, most of which are aimed at re- and up-skilling its work force.

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.

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.
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 McBrie 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 popular unit has an interactive format of lectures and practical exercises that provide an up-to-date synopsis of a range of key ore deposit types, addressing aspects such as location, characteristics, genesis and exploration strategies. Deposit types covered were porphyry Cu-Au; skarn; high-, intermediate- and low-sulphidation epithermal; iron-oxide copper-gold (IOC)-volcanic-hosted massive sulphide and sea-floor hydrothermal deposits; sediment-hosted Cu; seafloor massive sulphide; Zn; aggressive Au; W/titanniferous Au; Carlin Au; and Broken Hill-type Pb-Zn-Ag.

**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 exploration in brownfield terrains. 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 Smith and Fiona Fraser (Leighton Geoscience), Simon 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 of a range of key ore deposit types, addressing aspects such as location, characteristics, genesis and exploration strategies. Deposit types covered were porphyry Cu-Au; skarn; high-, intermediate- and low-sulphidation epithermal; iron-oxide copper-gold (IOC)-volcanic-hosted massive sulphide and sea-floor hydrothermal deposits; sediment-hosted Cu; seafloor massive sulphide; Zn; aggressive Au; W/titanniferous 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 IOC deposit in South Australia – led by Dr Kathy Ehig (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: Ore’s in Magmatic Arcs (KEA706/KEA707)
- 12 – 23 June: Ore Deposit Geochemistry, Hydrology and Geophysics (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 data. 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 funders 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 Economic Policy (VIEPS) Honours coursework program.

**EXPLORATION FIELD SKILLS MAPPING CAMP**

Course Leaders: Robert Scott and Martin Radford

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 quadrat area of Cambrian Mt Read Volcanics. The rock sequence exposed in the mapping area is similar to those that host the Rosebery and Hercules volcanic-hosted massive sulphide (VMS) deposits, located 150 km to the south 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 the potential of the core, using geological and geochemical features and the stratigraphic position of the mineralised interval, and decide whether it is more likely to be an epithermal 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.
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 Steves
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.
- Carbonatite 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. 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.

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 the Environmental Geology Field Techniques (EGF) course, which covered the basic principles of machine learning algorithms and the exploration of model uncertainty. The course focused heavily on 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 Parthakar-Fox, and led by various in-house presenters. Skills and software covered during the sessions included:
- Introduction to InQGIS (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.

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- Introduction to InQGIS (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 Parthakar-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.
## 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.

<table>
<thead>
<tr>
<th>CODES Projects</th>
<th>ARC TMVC Research Hub</th>
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1. **ANDEMESKEL, EYOB. TAS** (MASTERS)  
Litho- and chemo-stratigraphic, structural and mineral prospection aspects of the Rosebery Group, an emigmatic Cambrian volcano-sedimentary succession on Tasmania’s west coast.

2. **APUKHTINA, OLGA. SA** (MASTERS)  
Stable isotopes (C, S and O) and halogens (Cl, F) in gnangue and ore minerals at Olympic Dam: Evaluation of mantle and crustal contributions to mineralisation.

3. **AWID-PASCUAL, RICHELLE. TAS** (MASTERS)  
The evolution of Zn-Pb-Fe-bearing minerals in the Grieses Siding deposit, western Tasmania.

4. **CAVE, BEN. VIC** (MASTERS)  
A metamorphic course for tungsten in metasedimentary-hosted orogenic gold deposits.

5. **CAVILL, CHLOE. VIC** (MASTERS)  
Geochemical classification of ore-bearing metafelsic fluids of the Cotterfield region, Victoria.

6. **CHAPMAN, NATHAN. SA** (MASTERS)  
Pb-isotopic insights into the crustal evolution and metallogenesis of the Gawler Craton.

7. **CHERRY, ALEXANDER. SA** (MASTERS)  
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. **DOUTH, DAVID. WA** (MASTERS)  
The geology and geological controls on gold mineralisation at the Inivincible deposit, St Ives Gold Mine, Kambalda, WA.

10. **ESHAGHI, ESMAIEL. TAS** (MASTERS)  
Geophysical and petrophysical investigations of Tasmania at multiple scales.

11. **FERGUSON, MATT. SA** (MASTERS)  
Fe- and Ti-bearing minerals, apatite and zircon in the Olympic Dam district basement and Gawler Range Volcanics.

12. **FOX, JODI. TAS** (MASTERS)  
Submarine intraplate basaltic volcanism.

13. **GOWER, BRADY. WA** (HONS)  
Structural and sedimentological analysis of the Adile Trend - Browse Basin.

14. **HARDWICK, BRENDAN. WA** (MASTERS)  
Ore mineral textures and their implication for gold genesis and deformation at the Tropicana Gold Mine, Western Australia.

15. **HARRADEN, CASSADY. NSW** (MASTERS)  
Geochemical and geochronological assessment of the Cadia East deposit using Corescan automated logging technology.

16. **HAWKE, MARGOT. WA** (MASTERS)  
Geological evolution of the DeGrussa Cu-Au VHMS deposit, Western Australia.

17. **HONG, WEL. TAS** (MASTERS)  
Magnetic-hydrothermal volatile exsolution and mineralisation in Tasmanian Sn granites.

18. **HUANG, QUIYUE. SA** (MASTERS)  
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** (MASTERS)  
Dominating of geoenvironmental properties in drill core.

21. **JAGO, COREY. NSW** (MASTERS)  
Toward an understanding of the temporal, spatial and mineralogical characteristics of the Northparkes Alkalic Porphyry Deposits, New South Wales.

22. **KULTAKOSAYOS, SITHINON (GUN). NSW** (MASTERS)  
Provenance of Early to Mid-Paleozoic sediments in western Tasmania.

23. **LESJIE, CHRISTOPHER. NSW** (MASTERS)  
District scale ore deposit prospectivity of the Ordovician - Silurian Lachlan Fold Belt, southern Australia.

24. **LLOYD, RICHARD (GUN). NSW** (MASTERS)  
Alteration mineralogy and geochemistry of altered rocks in the Woodlawn VHMS belt, NSW.

25. **LOWER, CHANTELLE. SA** (MASTERS)  
An aspect of the geology of the Olympic Dam Cu-U-Au-Ag deposit.

26. **McMAHON, CLAIRE. TAS** (MASTERS)  
Distribution of, and controls upon, pyrite trace element content of hydrothermal alteration zones at Hercules VHMS ore deposit, Tasmania and NCO IOCG ore deposit, Northwest Territories, Canada.

27. **MORRISON, JOANNE. NSW** (MASTERS)  
Geochemical classification of bedded sedimentary successions on Tasmania’s west coast.

28. **MUKHERJEE, INDRANI. NT** (MASTERS)  
Pyrite trace element deportment important to lithogeochemistry: Evaluation of trace element deportment in drill core.

29. **MULDER, JACOB. TAS** (MASTERS)  
From Nuna to Gondwana: An evaluation of the early tectonic history of Tasmania.

30. **OSTERSEN, THOMAS. TAS** (MASTERS)  
Multi-scale geotectonic, and combined geophysical, investigations of Tasmania and Southeast Australia.

31. **PEREIRA DA FONSECA, PEDRO. TAS** (HONS)  
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** (MASTERS)  
Evaluation of links between Merlin-style Mo-Re mineralisation and magmatism in the Cloncurry fold belt, Queensland: Implications for exploration.

34. **SRIANGIRIKUL, 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. **WILLIAMS, TYLER. TAS** (HONS)  
Geomagnetic and geoelectric, and combined Multi-scale geoelectric, investigations of the Henty tailings storage facility, southern Queensland, Australia.

37. **WILLIAMS, TYLER. TAS** (HONS)  
Seismic evaluation of the integrity of the Henty tailings storage facility, Henty, Tasmania.
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. ARMENIA
Gold deposits in metasedimentary-hosted orogenic settings at Taca Taca Bajo, Argentina.

5. BERKENBOSCH, HEIDI. NEW ZEALAND
Geochemistry of hydrothermal mineral chimneys from Brothers volcano, Kermadec Arc.

6. CALDERON-TIPIAN, 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, alteration, and mineralisation of the Sagay deposit in northern Negros, Philippines.

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, Sgreg 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-Feskam, Peru: Assessing district and deposit-scale fertility - implications for ore genesis and exploration.

16. HARRISON, RACHEL. INDONESIA*
Tumipangotu porphyry Cu-Au-Mo and high-sulphidation 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
Dynamics and mechanisms: Effusive volcanism and explosive eruptions in Hawaii.

20. JENSEN, TORSTEN. USA
The 2007 explosive activity at Piton de la Fournaise volcano (Réunion): Constraints on the eruptive processes by the volcanological study of the erupted deposits.

21. JIMENEZ TORRES, CARLOS ANDRES. PHILIPPINES
Pyrite trace element chemistry of black shales: Understanding primary enrichments, metamorphic processes and the role of metallic black shales in archiving earth evolution.

22. JOHNSON, SEAN. FINLAND, ESTONIA, SWEDEN, RUSSIA
The geochemistry of metalloceniferous black shales: Understanding primary enrichments, metamorphic processes and the role of metallic black shales in archiving earth evolution.

23. KNIGHT, JOSEPH. MYANMAR
Geochemistry of carbonaceous black shale, sandstone, and chert in Myanmar: Insights into gold source rock potential.

24. LAWLIS, ERIN. PNG
Anhydrite-bearing vein arrays and paragenesis, pyrite geochemistry and ore fluids at Htongyi gold veins, Myanmar.

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

26. MAKOUNDI, CHARLES. MALAYSIA
Geology and genesis of the mineral deposits of the Myra Falls VHMS District, Canada.

27. McNULTY, BRIAN. CANADA
Ore genesis and genesis of the mineral deposits of the Myra Falls VHMS District, Canada.

28. MUKHERJEE, INDRANI. INDIA
Origin, evolution and significance of anhydrite-bearing vein arrays and breccias, Lierit orebody, Liher gold deposit, Papua New Guinea.

29. NUANLA-ONG, SARANYA. THAILAND
Paragenesis, pyrite geochemistry and ore fluids at Htongyi gold veins, Myanmar.

30. OROVAN, EVAN. FIJI
Gold distribution and association at the Kansanshi copper-gold deposit Zambia: Processes responsible for gold precipitation and implications for ore zone delineation and recovery.

31. PHILLIPS, JOSHUA. USA*
Geochemical and geochemical vectors to mineralisation at the Resolution porphyry Cu-Mo deposit, Arizona.

32. POTTER, NAOI. TANZANIA, RUSSIA
An investigation into the genesis of intrusive and explosive carbonatic melts.

33. STAAL, TOBIAS. ESTONIA, SWEDEN, RUSSIA
Seismic and geological constraints on the lithospheric structure of Antarctica.

34. STEEVES, NATHAN. USA
One genesis of the Greens Creek VHMS Deposit, Alaska: Implications for mining, milling and exploration.

35. STYKA, STEPHANIE. PNG*
Origin, evolution and significance of anhydrite-bearing vein arrays and breccias, Lierit orebody, Liher gold deposit, Papua New Guinea.

36. TESTA, FRANCISCO. ARGENTINA, CHILE
Tourmaline breccia pipes: San Francisco de los Andes, Argentina and Rio Blanco-Los Broncos, Chile.

37. THOMPSON, JENNIFER. INDONESIA, PHILIPPINES*
Carbonate mineral chemistry in epithermal and porphyry hydrothermal systems.

38. VERGANI, DANIELE. USA
Geology, geochemistry and genesis of the Namosi porphyry Cu-Au deposits, Fiji.

39. VERGANI, DANIELE. USA
Geology, geochemistry and genesis of the Namosi porphyry Cu-Au deposits, Fiji.

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

41. STALL, TOBIAS. ANTARCTICA
Seismic and geological constraints on the lithospheric structure of Antarctica.
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 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 Darcie Model.

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

LOUJEEVA, 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 Midocene 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.

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 (Pt-Cu), through to primary and secondary ruby and sapphires, high-sulfaclition 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 Sikumasu 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, Savater 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 Floris Stijak (Geomar), Clive Calver (Mineral Resources Tasmania), Huanchun Gu (China University of Geosciences), and Grace Cuming (Mineral Resources Tasmania).

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.
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 Gai (Geophysical Journal International), Laura Jackson (Applied Geochemistry), Indrani Mukherjee (Precambrian Research), Jacob Mulder (Geodynamic 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 barbecues 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:
- Cassidy 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 Geomaterials 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 Reunion (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.
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 Technik, HTL Lab 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 Orovan 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 is pioneering geoenvironmental work in dealing with the legacy of mine waste contamination in western Tasmania.

There were a number of exciting technological innovations during the 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 11 refereed journal articles, 25 conference abstracts and 69 reports to industry.
CORESCAN
Ronel Carey, Ekaterina Savinova

CSIRO
Louise Fisher

GRANGE RESOURCES
Tony Ferguson, Roger Hill

GUANGZHOU INSTITUTE OF GEOCHEMISTRY, CHINA
Huayong Chen, Jinsheing Han

HEFEI UNIVERSITY OF TECHNOLOGY, CHINA
Shiwei Wang, Fan Yu, Taofa Zhou

HOT CHILI
Melanie Lightton

JUNIATA COLLEGE, USA
Richard Hark

LAKEHEAD UNIVERSITY, CANADA
Peter Hollings

MINERAL RESOURCES TASMANIA
Mike Reid

MOKA 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 Kearnley

OLYMPUS
Dane Burkett

UNIVERSITY OF LIEGE, BELGIUM
Jens Bergmann

UNIVERSITY OF SOUTH AUCKLAND, NEW ZEALAND
Richard Hark

UNIVERSITY OF TASMANIA, CENTRAL SCIENCE LABORATORY
Thomas Rodemann, Ashley Townsend

THE MODULE TEAM
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TEAM MEMBERS:

CODES
Mike Baker, Ivan Beloussov, Ron Berry, Matt Cracknell, Nathan Fox, Bruce Gemmell, Sarah Gilbert, Ross Large, Sebastien Mefere, Paul Olin, Evan Oronov, Anja Pantheker-Fox, Anja Reading, David Selley, Emily Smyk, Sasha Stepanov, Lejun Zhang

AMIRA International
Adèle Seymon

BHP Billiton
Kathy Ehrg

Corescan
Neil Goodey

HITlab
Henry Duh

Laurin Technic
Michael Shelley

Newcrest Mining
Anthony Harris

RWTH Aachen University
Bernd Lottermoser

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Ayasha Ahmed, Jing Chen, Angela Escolme, Amos Ganay, Cassidy Hornaday, Rachel Harrison, Shawn Hood, Carlos Jimenez, Laura Jackson, Stephen Kuhn, Josie Phillips, Stephanie Sylvara, 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 Gerner, 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
Zhanki Li

CONSULTANT
Noel White

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
> Linscan technologies for drill core
> Integrating chemical and mineralogical data layers for element deportment
> Interpreting structural and geometallurgical patterns using machine learning
> Geological feature discovery from quantitative data integration (algorithm development)

KNOWLEDGE TRANSFER AND TRAINING
> Metal extraction from mine tailings
> Mineralogical domaining of low grade and no grade zones
> 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

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 Beloussov, Matt Cracknell, Evan Oronov, Emily Smyk, Lejun Zhang

Students: Ayasha Ahmed, Ayat Baig, Jing Chen, Nic Derome, Liam Fay, Amos Ganay, Emily Gerner, Rachel Harrison, Carlos Jimenez, Adam Pacey, Josie 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?), vectoring information (how far, and in what direction?), allowing the presence, location and significance of porphyry and/or epithermal copper, gold and molybdenum deposits in an...
exploration tenement to be determined during the early stages of exploration. This approach has particular relevance to exploration involving drilling under post-mineralisation cover 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 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, Ayasha 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 Deem 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-silicate alteration were developed through detailed studies of selected sites, and reanalysis of sample suites from previous analyses. New techniques for detecting mobility 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.

Jose Piquer and Francisco Testa published manuscripts, reporting outcomes from their PhD work, in Journal of Structural Geology, Lithos and Minerals. Ayat Biai submitted and successfully defended his MSc thesis, and Adriano 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 MGEE conference in Bandung, Indonesia, in October.

PYRITE FOOTPRINTS
Leader: David Cooke
Team Members: Leonid Danyushhevsky, Anthony Harris, Sebastien Mefere, David Sykes, Sasha Stepanov, Lejun Zhang
Student: Stephanie Sykora
Collaborators: Karyn Gardner, Fiona Karatau, Zhanhe Li, Paul Napier
Stephanie Sykora's PhD project at the Lihir gold deposit in Papua New Guinea (PNG) was incorporated into the TMV/2 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 pyrophyllite-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 have 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 MSB conference in Bandung, Indonesia, in October, and submitted her PhD thesis in December.

David Cooke, Lejun Zhang and Leonid Danyushhevsky co-authored an article on pyrite chemistry from the Haopinggou Au-Ag-Pb-Zn 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 focused on advancing work that had been initiated in the previous GeoMR 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 announce the STORGe 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 Mefere, Ron Berry
Team Members: Matt Cracknell, Neil Goodey
Student: Cassidy Harraden
Collaborators: James Leit
The goal of this PhD project by Cassidy Harraden is to determine the correlation between CoreScann™ data and measured deformation data, processing parameters and geological conditions. Hyperspectral data will be used to determine functional proxies that will ultimately be built into 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 Cassidy Harraden as co-recipient of the award for ‘Best Paper by a Young Scientist’. Research has focussed on fine-tuning the protocol for extraction of geometallurgical parameters, which was completed during the year. The integration of those parameters with alteration mineralogy will continue in 2017.

ORE CHARACTERISATION AND GEOMETALLURGICAL MODELLING AT THE PRODUTORCA 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 assay information for liberation behaviour and recovery response at the Produtorca 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 DEPARTMENT 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 depletion 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 element in situ, and to have different processing behaviours when processed. These domains are monzonite/monzodiorite, alkali basalt, potassic-alter basalt and propylictic-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 AND PRODUCTION
Leader: Anita Patharkar-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 projects.

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 assessed each stage to determine the effect on the overall test results. Outcomes included the development of a site-specific 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 XRF 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 TMV report.

DEVELOPMENT OF EFFECTIVE SHORT-TERM LEACH TESTS FOR WATER QUALITY IMPACT ASSESSMENT
Leader: Anita Patharkar-Fox
Collaborators: Rebecca Clifton, Laura Jackson
Students: Angela Escolme on a field trip in Yerington, Nevada.

This project seeks to vary parameters final use of blends, reaction time, reagent concentration, quantity of solids/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 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 Blaxcell study were reported to Grange Resources, with results to be presented at the Process Mineralogy conference. A journal publication is also in preparation.

In addition, a total reflectance XRD PICOFX, 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 DOMINATING 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 Cooke, Matt Cracknell, Nathan Fox, Neil Goodey, Anthony Harris, Bernd Lottermoser, Sebastien Meffre
Students: Laura Jackson
Collaborators: Ronell Carey, Stephen Carey, Antony Holmes, Tom Rodemann

Prediction of acid mine drainage (AMD) at the earliest life of mine stages is critical for designing the most 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 ecogeochemical characterisation of inactive 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 geological-domaining index (GDI) tool has been developed using the hyperspectral data provided by Corescan™. GDI version 1 was fine-tuned to identify inherent primary neutralisations within low- to 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 repressurizing historic mine tailings at the Old Tailing 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 repressuring 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 90% refractory cobalt. These research findings were presented at the Biotreatment/Pyromet '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 Members: 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 presents a potential option for managing acid forming mine waters, 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.

UNDERGRINDING TECHNOLOGIES
DEVELOPMENT OF THE FAST-THROUGHPUT SAMPLE CELL FOR LASER ABLATION APPLICATIONS
Leader: Leonid Danyushkevich, 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, Leon Danyushkevich, 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, geomaterials and geoservice.

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 Members: Sebastian Meffre, Ryan Danyushkevich

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. The project 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 be used for 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 DEPORTMENT
Leaders: Sebastien Meffre, Matt Cracknell, Leonid Danyushkevich, Ron Berry
Team Members: Ivan Belousov, Nathan Fox, Sarah Gilbert, Paul Olin, Sasha Stepanov
Students: Cassidy Harraden, Laura Jackson

This project aims to integrate mineralogical and chemical data from various spectral and analytical technologies in order to extract information on element deportment, mineral chemistry, mineral association and other mineralogical characteristics, such as the ability to automatically recognise gold in solid solution, and gold in inclusions. 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, xRF 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, overlaid data layers for comparative analysis and evaluation.

Whole rock, modal mineralogy and trace element mineral chemistry were tested...
acquired using LA-ICP-MS 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 XPE 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 to rapidly generate repeatable and objective 3D models of geochemically 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 protholith 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 metamatism. 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 lithologies from large volumes of 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 introduced 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 unusual 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-1-7988186). 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.

**LOOKING FORWARD**

The TMVC’s activities will continue to build momentum in 2017, boosted by the commencement of geometallurgy postdoctoral research fellow Angela Escoffier 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, Hebei 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 ‘footprint’ theme, a project will be commencing in Western Australia, applying pyrite mineral chemistry in the search for sediment-hosted Cu-Co mineralisation.

In the geometallurgy theme, Cascadia 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 geometallurgy, 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.
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 intrinsically 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 GEO SCIENCE
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:

- Paleoeceanography/paleoontology.
- Geochronology.
- Sedimentary and mineral chemistry.
- Ocean chemistry modelling.
- The origin of life.
- Biogeochemistry.
- Seismology.
- Volcanism and magnetism

COMPUTATIONAL AND ANALYTICAL GEO SCIENCE
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:

- 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.
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 Rhiammon Mundana (undergraduate) took part in a voyage to the Cascade Seamount, East Tasmian Rise, and collected volcanics and volcano-sedimentary rocks, which are now being analysed for Ar-Ar dating and geochemistry.

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.

Staf 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 Rhiammon Mundana (undergraduate) took part in a voyage to the Cascade Seamount, East Tasmian 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 Sytby 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 ambient seismic tomography.

- Several papers by Professor Patrick Quilty were published, covering a wide range of topics including Placene moluscs 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.

HONOURS STUDENTS:
Leo Chia, Caleb Sang

COLLABORATORS:
ABERDEEN UNIVERSITY, UK
Nicholas Rawlinson

AUSTRALIAN NATIONAL UNIVERSITY
John Mainvogenes, Simone Pika, 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

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INSTITUTE OF THE EARTH’S CRUST, RUSSIA
Yula Daniolova, Elena Demonterova Alexei Ivanov, Valentina Savel’eva

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OREGON STATE UNIVERSITY, USA
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REUNION ISLAND OBSERVATORY, FRANCE
Andrea DiMuro

SEOUL NATIONAL UNIVERSITY, SOUTH KOREA
Jung-Woo Park

SMITHSONIAN INSTITUTION, USA
Richard Fiske

THE DISCIPLINE OF EARTH SCIENCES TEAM

STAFF MEMBERS:
CONTINUING APPOINTMENTS AT UTAS
Academic: Rebecca Carey, David Cooke, Garry Davidson, Valdim Kamenetsky, Anya Reading, Michael Roach

Professional: Isabella von Lichtan, Ian Little, Deborah MacKlin

FIXED-TERM AND HONORARY APPOINTMENTS:
Academic: Sharon Allen, Ron Berry, Trevor Fallon, Nathan Fox, Bruce Gemmell, Jacqueline Halpin, Julie Hunt, Sean Johnson, Martin Jutzieler, Ross Large, Peter McClelland, Jocelyn McPhee, Sebstain Meffre, Kariin Orth, Patrick Quilty, Robert Scott, David Selley, Jeff Steadman, Sasha Stepanov

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

PHD STUDENTS:
Adam Abersteiner, Evan Draayers, Jodi Fox, Martin Gal, Sam Holt, Qiuyue Huang, Fumihiko Ikegami, Rhiannon Mundana, Sean Johnson, Elena Lounjeva, Charles Makoundi, Indrani Mukherjee, Thomas Osterens, Naomi Potter, Daniele Vergani

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Andrey Gurenko

UNIVERSITÉ GRENOBLE, FRANCE
Alexander Sobolev

UNIVERSITY OF ADELAIDE
Graham Heinson

UNIVERSITY OF BARCELONA, SPAIN
Marc Campany

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 Janeko

UNIVERSITY OF MELBOURNE
Stephen Gallagher, Andrea Guillian, 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, Res Taylor

UNIVERSITY OF TASMANIA
Sandrin Feig, Karsten Gromann, Joanne Whitaker

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 volcanocology
> Subaerial volcanocology
> Geology and paleoentology 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

The map on the left displays the ocean wave height on the 10th 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 Gál
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 Ostersen
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 Ostersen, 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.

Map projection: GDA94 UTM Z55

Distribution of magnetotelluric instrument sites deployed by PhD student Thomas Ostersen as part of his research project into the geoelectric structure of the Tasmanian lithosphere.
KIMBERLITES AND FLOOD BASALTUS: LINKING PRIMARY MELTS WITH MANTLE AND CRUSTAL SOURCES

Lead Investigator: Vadim Kamenetsky

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

Students: Adam Absteiner, Gluysse Huang, Naomi Potter


This project is aimed at understanding the relationship between kimberlites and diamonds, flood basalts and magmatic sulfides, and chromium- and platinum-group elements (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 (Tasmania, Karoo, Arctic Siberia, Ernirshan) and the ocean floor (South Atlantic and Caribbean).

The reconstruction of parental melts, their temperatures and the inventory of volatile elements was aided by studies of melt inclusions. Contributions from periodic and geyser pyrovents mantle sources in the subcontinental lithosphere (Tasmania, Karoo, Arctic Siberia, Ernirshan) and the ocean floor (South Atlantic and Caribbean) were included.

Results in 2016 revealed that some lava flows and volcano 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, and numerous vapour-deposited gold crystals within fumarolic nusculations and directly on surfaces of basaltic lava. The occurrence of native gold of magmatic origin is extremely rare, and only a few finds of magmatic gold are known. 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 that the gold was deposited from epithermal veins hosted by country rocks during intrusion of magmatic lavas. Deposition on the melt temperature, and/or the time span of the melt-rock interaction, gold was either expelled by the erupting volcano in the form of abraded nuggets or liquid droplets, or fully assimilated into the 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 the precious metal enriched gold led to the deposition of abundant crystals of gold on cooling lava and accretia.

SUBMARINE VOLCANOLOGY

Lead Investigator: Rebecca Carey

Team Members: Sharon Allen, Sean Johnson, Martin Jutziier, Jocelyn Mchge, Sarah Vigny

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


The main aims of the Submarine Volcanology project are to:

- Gain a better understanding of modern seafloor volcanic environments, and how 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 Rhian Mundaca 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 bathygraphic and backscatter data were also collected.

In a related initiative, Rebecca Carey received an IODP ANZC 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 Rise and the timing of 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 intrusive 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 funding from the Japanese Agency for Marine-Earth Science and Technology (JAMSTEC) to visit three submarine volcanic provinces in the Izu-Bonin volcanic arc, south of Japan. Martin Jutziier published several papers in 2016 on the following projects:

- Explosion mechanisms under water, 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 analogous processes on emergent, and ancient volcanic terrains in island arc context.
- Detailed databasing of discontinuities in cores of IODP 340.

Howard Zorn and Caleb Sang continued research on the volcaniclastic turbidites offshore of the islands of Hawaii, Kerguelen, and volcanic sediment from the submarine plateau of Kerguelen.

SUBAERIAL VOLCANOLOGY

Lead Investigator: Rebecca Carey

Team Members: Sharon Allen, Martin Jutziier, Jocelyn Mchge, Karin Ort

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

Collaborators: Daniele Andronico, Costanza Bonadonna, Grace Cumming, Andrea DiMuro, John Everard, Juliet Hollis, Bruce Houghton, Maria Janeiro, Tim On, Matthew Patrick, Christopher Phillips, Ryan Portier, Michael Rosenberg

The Discipline’s research in subaerial volcanology covers a wide range of magma types and settings, including both modern and ancient volcanic environments. Current research includes projects in various subaerial locations where active or dormant volcanism is taking place. This includes Hawai’i, Reunion Island, Kerguelen Plateau and the Etna volcano 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 characteristics and history 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’umā’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 volcano’s flank, lava fountaining activity on the summit of the volcano and changing lava plumbing 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 which had not been 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 volcaniclastic units were described, lava, pillow basalt breccia and a variety of ancient lacustrine environment. Basalt lava, pillow basalt breccia and a variety of volcaniclastic units were described, lava, pillow basalt breccia and a variety of ancient lacustrine environment.

Professors Patrick Quilty and John Aalders and PhD student Laura Jackson at the abandoned Scotia Mine, NE Tasmania.

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 Philip 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.

**TECTONICS OF EASTERN INDONESIA**

**Leader:** Ron Berry

**Team Members:** Sebastien Meffre, John 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 Aluei 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 Moomaff Complex in West Timor are part of an allochthonous terrain, which includes a range of accretionary complex rocks, ranging in the extent of metamorphism from low grade to middle amphibolite facies. The samples are being used to establish the metamorphic petrology of the complex.

**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.

**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 spiliting to backarc basin generation.

**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 Metre, 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.

SCHOOL VISITS AND TRIPS

The year saw a number of visits by various pre-tertiary institutions, including Howrah Primary, New Town Primary, Waimua 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 theDerwent 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. 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 featured items from the collection. Izzy also helped curate the Wunderkamer 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 – Protorhadin dawidii.
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.

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: https://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.
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 contextual geology, geology and ore deposit geology, 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, 154 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.
> The geology and origin of Australia’s mineral deposits (2003). Authors: M. Solomon and D. Groves (1 copy).

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, 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.

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

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

<table>
<thead>
<tr>
<th>TITLE</th>
<th>PRESENTERS*</th>
<th>NO.**</th>
<th>LOCATION</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>VEPS – Exploration Field Skills Mapping Camp</td>
<td>Martin Jutzieler, Robert Scott</td>
<td>9</td>
<td>western Tasmania</td>
<td>7 – 14 February</td>
</tr>
<tr>
<td>IoGAS Geochronology Workshop – Part 1 *</td>
<td>Mike Baker</td>
<td>10</td>
<td>CODES, Hobart</td>
<td>3 March</td>
</tr>
<tr>
<td>IoGAS Geochronology Workshop – Part 2 *</td>
<td>Mike Baker</td>
<td>8</td>
<td>CODES, Hobart</td>
<td>17 March</td>
</tr>
<tr>
<td>VEPS – Practical Igneous Petrology</td>
<td>Leonid Danyushevsky</td>
<td>17</td>
<td>CODES, Hobart</td>
<td>9 – 13 May</td>
</tr>
<tr>
<td>VEPS – Ore Deposit Models</td>
<td>Mike Baker, Garry Davidson, Bruce Gemmell, Margy Hawke, Ross Large, Brian McNulty, Robert Scott, David Selley, Jeff Steadman, Nathan Stevens</td>
<td>10</td>
<td>CODES, Hobart</td>
<td>16 – 20 May</td>
</tr>
<tr>
<td>Ancient and Modern VH-MIO Deposits</td>
<td>Bruce Gemmell, Stephen Penney</td>
<td>30</td>
<td>Whitehorse, Yukon</td>
<td>30 – 31 May</td>
</tr>
<tr>
<td>Exploration in Brownfields Tarns</td>
<td>Ron Berry, Matt Cracknell, Nathan Fox, Fiona Fraser, David Siners, Scott Halley, Shawn Hood, Steve Kuhn, Robert Scott, David Selley, Patrick Smillie</td>
<td>16</td>
<td>CODES, Hobart</td>
<td>30 May – 10 June</td>
</tr>
<tr>
<td>Volcanogenic Massive Sulfide and Dioritic Gold Deposits in Northern Southeast Asia (Field Trip)</td>
<td>Bruce Gemmell, Susan Karl, Patrick Saich, Nathan Stevens</td>
<td>20</td>
<td>Southeastern USA, Alaska</td>
<td>4 – 8 June</td>
</tr>
<tr>
<td>Physical Volcanology of the Mesopelagitic Galilee Range Volcanics (Field Trip)</td>
<td>Jocelyn McPhie</td>
<td>11</td>
<td>South Australia</td>
<td>21 – 25 June</td>
</tr>
<tr>
<td>Environmental Geology Field Techniques</td>
<td>David Cooke, Matt Cracknell, Garry Davidson, Laura Jackson, Anita Partnaker-Fox</td>
<td>20</td>
<td>CODES Hobart and western Tasmania</td>
<td>30 August – 2 September</td>
</tr>
<tr>
<td>Ancient and Modern VH-MIO Deposits</td>
<td>Bruce Gemmell</td>
<td>40</td>
<td>Hobart University of Technology, China</td>
<td>13 September</td>
</tr>
<tr>
<td>Low and Intermediate Sulfidation Deposits</td>
<td>Bruce Gemmell</td>
<td>40</td>
<td>Hobart University of Technology, China</td>
<td>14 September</td>
</tr>
<tr>
<td>GeWSo Masters Workshop (Emerald)</td>
<td>Ron Berry</td>
<td>22</td>
<td>University of Liege, Belgium</td>
<td>14 September</td>
</tr>
<tr>
<td>Broecia in Porphyry and Epithermal Environments – Working From Description to Interpretation</td>
<td>Jing Chen, David Cooke, Rachel Harrison, Stephanie Sykora</td>
<td>50</td>
<td>Bandung, Indonesia</td>
<td>3 – 4 October</td>
</tr>
<tr>
<td>Gaometalurgy: Short Course</td>
<td>David Baslin, Ron Berry, Stoyan Gaydardzhiev, Julie Hunt, Simon Michaux, Eric Phelan</td>
<td>20</td>
<td>University of Liege, Belgium</td>
<td>4 – 7 October</td>
</tr>
<tr>
<td>Geological Workshop: On Mineral Resources in Myanmar and Prospectivity</td>
<td>Kyin Htun, Than Htun, Ye Myint Swe, Aung Kyaw, Tin, Aung Myint, Kyaw Thu, Khin Zaw</td>
<td>22</td>
<td>Yangon, Myanmar</td>
<td>18 October</td>
</tr>
<tr>
<td>Fluids in the Earth</td>
<td>Robert Bodnar, Leonid Danyushevsky, Maria Frezzotti, James Webster</td>
<td>30</td>
<td>Naples, Italy</td>
<td>19 – 24 October</td>
</tr>
<tr>
<td>SBS Student Chapter Field Trip to Myanmar</td>
<td>Jing Chen, Joe Knight, Khuin Zaw</td>
<td>17</td>
<td>Myanmar</td>
<td>7 – 19 November</td>
</tr>
<tr>
<td>Porphyry Cu Deposits and Related Broecia</td>
<td>David Cooke, Lejun Zhang</td>
<td>30</td>
<td>Hobart University, Technology, China</td>
<td>12 – 14 November</td>
</tr>
<tr>
<td>Molybdenum Deposits in Minerals</td>
<td>Leonid Danyushevsky, Maria Frezzotti</td>
<td>50</td>
<td>Hefei University of Technology, China</td>
<td>22 – 24 November</td>
</tr>
<tr>
<td>Magmatic-Hydrothermal Textures of Bluestone Bay, Tasmania</td>
<td>David Cooke, Evan Oravan</td>
<td>15</td>
<td>Freycinet, Tasmania</td>
<td>23 November</td>
</tr>
<tr>
<td>Workshop on ENS Asia: Tectonics and Ore Deposits</td>
<td>Khiin Zaw</td>
<td>21</td>
<td>Yangon University, Myanmar</td>
<td>5 December</td>
</tr>
<tr>
<td>Magmatic-Metasedimentary Features of the Haematite Granite, Trial Harbour</td>
<td>David Cooke, Wei Hong, Stephanie Sykora, Lejun Zhang</td>
<td>20</td>
<td>Strahan, Tasmania</td>
<td>7 December</td>
</tr>
<tr>
<td>Ore Deposit Models</td>
<td>Stuart Bell, David Cooke, Garry Davidson</td>
<td>16</td>
<td>CODES, Hobart</td>
<td>15 December</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>TITLE</th>
<th>TARGET</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Findings</td>
<td>50pa</td>
<td>67</td>
</tr>
<tr>
<td>Publications in international journals</td>
<td>70%</td>
<td>76%</td>
</tr>
<tr>
<td>Percentage of publications in high quality international journals</td>
<td>10pa</td>
<td>134</td>
</tr>
<tr>
<td>Reports to industry collaborators</td>
<td>1 per 2 years</td>
<td>0</td>
</tr>
<tr>
<td>Special issues and / or research monographs</td>
<td>10pa</td>
<td>2</td>
</tr>
<tr>
<td>Invitations to give keynote conference presentations</td>
<td>70pa</td>
<td>61</td>
</tr>
<tr>
<td>Papers at national / international meetings</td>
<td>25%</td>
<td>29%</td>
</tr>
<tr>
<td>Research Training and Professional Education</td>
<td>65%</td>
<td>68%</td>
</tr>
<tr>
<td>Percentage of HDR students attracted from interstate</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Percentage of HDR students attracted from overseas</td>
<td>50</td>
<td>33</td>
</tr>
<tr>
<td>Number of Honours students in CODES’ modules</td>
<td>15%</td>
<td>63%</td>
</tr>
<tr>
<td>Number of HDR students in CODES’ modules</td>
<td>20pa</td>
<td>27</td>
</tr>
<tr>
<td>Percentage of students in projects linked with industry</td>
<td>1 per 2 years</td>
<td>2 (2016)</td>
</tr>
<tr>
<td>Professional short courses/workshops for industry</td>
<td>600pa</td>
<td>767 (2016)</td>
</tr>
<tr>
<td>International, National and Regional Links and Networks</td>
<td>1 per 2 years</td>
<td>2 (2016)</td>
</tr>
<tr>
<td>CODES’ national or international conferences / workshops</td>
<td>15pa</td>
<td>20+</td>
</tr>
<tr>
<td>Registrants at CODES’ conferences / workshops</td>
<td>1 per 5 years</td>
<td>9 in 28 years</td>
</tr>
<tr>
<td>End-user Links</td>
<td>15pa</td>
<td>20+</td>
</tr>
<tr>
<td>National Benefit</td>
<td>1 per 5 years</td>
<td>9 in 28 years</td>
</tr>
</tbody>
</table>

Juan Burlando (First Quantum) and Anthony Cook (Gold Fields) at the underground operations of the Bagr Mar ruby-sapphire mine, Myanmar. Juan and Anthony were industry participants in the CODES SEG Student Chapter field trip to the SE Asian country.
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.

ARC TRANSFORMING THE MINING VALUE CHAIN RESEARCH HUB

<table>
<thead>
<tr>
<th>Project</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC Industrial Transformation Research Project</td>
<td>861,033</td>
</tr>
<tr>
<td>Partner Organisations</td>
<td>852,800</td>
</tr>
<tr>
<td>- AMIRA P1153</td>
<td>537,600</td>
</tr>
<tr>
<td>- BHP Balcatta Olympic Dam</td>
<td>150,000</td>
</tr>
<tr>
<td>- Newcrest Mining</td>
<td>165,200</td>
</tr>
<tr>
<td>Host Institution</td>
<td>145,135</td>
</tr>
<tr>
<td>Additional Funder Projects</td>
<td>68,865</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>21,127</td>
</tr>
<tr>
<td>Total</td>
<td>1,948,929</td>
</tr>
</tbody>
</table>

ARC GRANTS

<table>
<thead>
<tr>
<th>Grants</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discovery Grants</td>
<td>80,343</td>
</tr>
<tr>
<td>Linkage Grants</td>
<td>166,773</td>
</tr>
<tr>
<td>Linkage Infrastructure, Equipment and Facilities Grants</td>
<td>600,000</td>
</tr>
<tr>
<td>Total</td>
<td>847,116</td>
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</table>

OTHER COMMONWEALTH GOVERNMENT

<table>
<thead>
<tr>
<th>Specific Projects</th>
<th>Funding</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>134,281</td>
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<tr>
<td>Total</td>
<td>134,281</td>
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</table>

STATE GOVERNMENT

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<tr>
<th>Specific Projects</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5,000</td>
</tr>
<tr>
<td>Total</td>
<td>5,000</td>
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</table>

INDUSTRY/PRIVATE

<table>
<thead>
<tr>
<th>Project</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>CODES Industry Partners</td>
<td>383,283</td>
</tr>
<tr>
<td>Cooperative Research Centre Projects</td>
<td>78,383</td>
</tr>
<tr>
<td>Directly Funded Research Projects</td>
<td>576,282</td>
</tr>
<tr>
<td>Directly Funded Student Projects</td>
<td>229,582</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1,532</td>
</tr>
<tr>
<td>Total</td>
<td>1,269,063</td>
</tr>
</tbody>
</table>

CONTRACTS/CONSULTANCIES/REVENUE RAISING

<table>
<thead>
<tr>
<th>Activity</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Courses</td>
<td>48,310</td>
</tr>
<tr>
<td>Book Sales</td>
<td>16,912</td>
</tr>
<tr>
<td>Miscellaneous (incl. Analytical Services)</td>
<td>1,184,864</td>
</tr>
<tr>
<td>Total</td>
<td>1,250,085</td>
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</tbody>
</table>

UNIVERSITY OF TASMANIA - HOST INSTITUTION SUPPORT

<table>
<thead>
<tr>
<th>Activity</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Grant</td>
<td>1,236,377</td>
</tr>
<tr>
<td>Scholarships and Tuition Fee Waivers</td>
<td>1,211,688</td>
</tr>
<tr>
<td>Strategic Projects</td>
<td>127,130</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1,000</td>
</tr>
<tr>
<td>Total</td>
<td>2,576,205</td>
</tr>
</tbody>
</table>

OTHER INCOME SOURCES/INTEREST

<table>
<thead>
<tr>
<th>Activity</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overseas Governments</td>
<td>51,508</td>
</tr>
<tr>
<td>Society of Economic Geologists - Student Scholarships</td>
<td>9,740</td>
</tr>
<tr>
<td>Student Support</td>
<td>11,548</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>4,316</td>
</tr>
<tr>
<td>Total</td>
<td>77,112</td>
</tr>
</tbody>
</table>

TOTAL ANNUAL INCOME

|                      | $8,107,790 |
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).
**2018 PUBLICATIONS**

**CODES**

**REFEREED JOURNAL ARTICLES (67)**

- 2018, Geology Reviews, v. 78, p. 166-175.


Gregory, D.D., Large, R.R., and Stepanov, A.S., Comparison of detailed whole rock and pyrite chemistry as geochemical proxies for paleo-ocean and atmospheric chemistry: An example from the Late Proterozoic Doushantuo Formation, China, American Geophysical Union Fall Meeting 2016, San Francisco, USA.


Kyna, P., Berry, R., and Borrmann, J.B., Genesis and structural architecture of the CSA Cu-Ag Mine, Cobar, NSW, Australia.

Large, R.R., A multi-proxy approach tracking ocean chemistry over the last 1500 Ma: Goldschmidt 2016, Yokohama, Japan, p. 1676.


Mifsud, S., Thompson, J., and Danyushevsky, L.V., Minimising U-Pb fractionation effects for LA-ICPMS zircon geochronology: American Geophysical Union Fall Meeting 2016, San Francisco, USA.


Thompson, J.A., Baker, M., Cooke, D.R., and Chen, J. Potential for calcic vein fluorine to provide indicators for prophyte for mineralization hosted porphyry-related deposits: an example from Orasberg, Papua, Indonesia: Australian Research Council 2016, Lausanne, Switzerland.

Tsukiyama, M.S., Makismov, Y.V., Avakyan, N.R., Makismov, B.P., Large, R.R., and Danyushevsky, L.V. Rar minerals and trace elements in sulphide turbidites from Yabukovsky deposit, South Siberia: Russian Goldschmidt 2016, Yokosuka, Japan, p. 316.


Zak, K. Volcanic-hosted massive sulphide deposits in mainland SE Asia: Their potential and prospectivity: 33th Australian Geology and Geophysics Conference, Cape Town, South Africa. CD-ROM.


## APPENDICES

### CODES POSTGRADUATE STUDENTS 2016

**BACHELOR OF SCIENCE (HONOURS) (12)**

<table>
<thead>
<tr>
<th>STUDENT</th>
<th>SUPERVISORS</th>
<th>PROJECT</th>
<th>SUPPORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matt Bodri</td>
<td>Roach, Tassell (GHD)</td>
<td>Evaluation of petrophysical and mineralogical proxies for rock strength with particular emphasis on civil engineering practice</td>
<td>GHD</td>
</tr>
<tr>
<td>Stephanie Casile ^</td>
<td>Whittaker (MASS), Caray</td>
<td>An investigation into oceanic large igneous province plume swell</td>
<td>IMAS</td>
</tr>
<tr>
<td>Zheng (Leo) Chia ^</td>
<td>Jutzieler, Orth</td>
<td>Sedimentological analysis of Plaistocene pumice-rich turbidites at Site U1398, IODP 340, offshores Martinique</td>
<td>IODP</td>
</tr>
<tr>
<td>Rebecca Clifton ^</td>
<td>Panhikar-Fox, Fox</td>
<td>Evaluating applications of boiler ash for controlling acid and metaliferous drainage-- examples from Tasmanian mine wastes</td>
<td>MONA Heavy Metals Project, ARC TMVC</td>
</tr>
<tr>
<td>Brady Gower ^</td>
<td>Roach</td>
<td>Structural and sedimentological analysis of the Adela Trend - Browse Basin</td>
<td>UTAS</td>
</tr>
<tr>
<td>Kathryn Job</td>
<td>Roach, Martha, Musgrave (KSINSW)</td>
<td>A palaeomagnetic study of the Palaeozoic Tasmanian Orogenic Model</td>
<td>MRT, ARC Linkage</td>
</tr>
<tr>
<td>Richard (Sigmun) Lloyd</td>
<td>Mattie, Stadman</td>
<td>Alteration mineralogy and geochemistry of altered rocks in the Woodtown VHMS belt, NSW</td>
<td>ARC Linkage, Heron Resources</td>
</tr>
<tr>
<td>Declan Radford ^</td>
<td>Cracknell, Roach</td>
<td>Geological mapping from radar imagery with Machine Learning</td>
<td>MRT, Forestry Tasmania</td>
</tr>
<tr>
<td>Calib Sang ^</td>
<td>Carey, Fallon</td>
<td>Chasing the Kerguelen mantle plume 'tail': Investigating the Micanore to Holocene record of volcanism using tephra glass in ODP Leg 183, Site 1138ka cones</td>
<td>IODP</td>
</tr>
<tr>
<td>Tristan Walls ^</td>
<td>Cooke, Baker, Zhang</td>
<td>Geology and genesis of the Two-Thirty prospect, Northpaines, NSW</td>
<td>Northpaines Mines</td>
</tr>
<tr>
<td>Ben Whitney ^</td>
<td>Zhang, O'Davidson</td>
<td>Evaluation of the Spitzmum Hill high-sulfidation epithermal prospect, Southern Queensland, Australia</td>
<td>Signature Gold</td>
</tr>
<tr>
<td>Tylar Williams ^</td>
<td>Roach, Tassell (GHD)</td>
<td>Seismic evaluation of the integrity of the Henty tailings storage facility, Henty Tasmania</td>
<td>GHD</td>
</tr>
</tbody>
</table>

### MASTER OF ECONOMIC GEOLOGY (50)

<table>
<thead>
<tr>
<th>STUDENT</th>
<th>SUPERVISORS</th>
<th>PROJECT</th>
<th>SUPPORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michael Adams</td>
<td>coursework only</td>
<td>coursework only</td>
<td></td>
</tr>
<tr>
<td>Robert Ayres</td>
<td>coursework only</td>
<td>coursework only</td>
<td></td>
</tr>
<tr>
<td>Fabian Baker</td>
<td>Cooke</td>
<td>Amulsar HSE Au deposit, Armenia</td>
<td>Lydian International</td>
</tr>
<tr>
<td>Thomas Bartschi</td>
<td>Cooke</td>
<td>Characterisation of phyllic assemblages at Taca Taca Bajo, Argentina</td>
<td>First Quantum</td>
</tr>
<tr>
<td>Sebastian Benavides</td>
<td>Cooke</td>
<td>coursework only</td>
<td>coursework only</td>
</tr>
<tr>
<td>Christopher Booth</td>
<td>Cooke</td>
<td>coursework only</td>
<td>coursework only</td>
</tr>
<tr>
<td>Kim Boudry</td>
<td>coursework only</td>
<td>coursework only</td>
<td></td>
</tr>
<tr>
<td>Caesar Calderon-Tipiani</td>
<td>Gammall</td>
<td>Chacra low sulfidation deposit, Peru</td>
<td>Buenaventura</td>
</tr>
<tr>
<td>Jimmy Carranza Meza</td>
<td>coursework only</td>
<td>coursework only</td>
<td></td>
</tr>
<tr>
<td>Wayne Carter</td>
<td>coursework only</td>
<td>coursework only</td>
<td></td>
</tr>
<tr>
<td>Glen Cathers</td>
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<td>Chioa Cavil</td>
<td>G. Davidsson</td>
<td>Geochemical classification of metatelluriferous deposits of the Costerfield Region, Victoria</td>
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<td>Djohanne Celiz</td>
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<td>The geology, alteration, and mineralisation of the Sagay deposit in northern Negros, Philippines</td>
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<td>Joanna Condon ^</td>
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<td>Ore types of DaGruissa and Conductor 1 ore lenses of the DaGruissa VHMS deposit, Western Australia</td>
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<td>Rachel Cooke</td>
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### MASTER OF EXPLORATION GEOSCIENCE (1)

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<td>Richard Cotton ^</td>
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<td>Daniel Cronin</td>
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<td>Maria Lourdes M.</td>
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<td>Intrusive history and genesis of Basuqporphry copper-gold deposit, Surigao Del Norte, Philippines</td>
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<td>Franco Farnetra</td>
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<td>Arga Firmansyah</td>
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<td>Geology and mineralisation of the Trenggalek district, East Java, Indonesia</td>
<td>PT Pamarapersada Nusantara</td>
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<td>Daniel Foulds</td>
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<td>Brandon Hardwick</td>
<td>Mathis, Doyle (AngloGold Ashanti)</td>
<td>Ore mineral textures and their implication for gold genesis and deposit formation at the Tropicana Gold Mine, Western Australia</td>
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<td>Paragenesis of the Dodroyd deposit, central NSW</td>
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<td>Corey Jago</td>
<td>Mathis, Cooke</td>
<td>Toward an understanding of the temporal, spatial and mineralogical characteristics of the Northpaines Alkaline Porphyry Deposits, New South Wales</td>
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<td>Shih Bin (Gary) Kulkasayos</td>
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<td>Provenance of Early to Mid-Paleozoic sediments in western Tasmania</td>
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<td>An aspect of the geology of the Olympic Dam Cu-U-Au-Ag deposit</td>
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<td>Joanne Morrison ^</td>
<td>Berry</td>
<td>Cadia East multi-element lithogeochemistry: Evaluation of trace element deportment important to processing</td>
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<td>Saranya Nuanla-Ong</td>
<td>Zaw</td>
<td>Paragenesis, pyro geochemistry and ore fluids at Htuongy gold veins, Myanmar</td>
<td>Ore Deposits of SE Asia Project, National Prosperity Company</td>
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<td>Alastar Orton</td>
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<td>Alan Riles ^</td>
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<td>Philip Roger</td>
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<td>Luke Timmermans</td>
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### MASTER OF GEOLOGY (Master of Science) (1)

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<tr>
<td>Peapasong Srittsarkkiul</td>
<td>Mathis</td>
<td>Tectonic evolution and ore deposit prospectivity of the Rockley Volcanics, NSW Australia</td>
<td>Thai Royal Government Scholarship</td>
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**STUDENT SUPERVISORS PROJECT SUPPORT**

Eyob Andrikaskeal Bailey Litho- and chemo-stratigraphic, structural and mineral paragenesis, and understanding the implications of these in the source composition UTAS

Irmu Vejajlo \( \bar{s} \) V.Kamenetsky, McPhie, Ehrig (BHP/Billiton) Geological evolution of the Winda K Well Prospect, Gawler Craton, South Australia UTAS, CoE, BHP Billiton, ARC

**DOCTOR OF PHILOSOPHY (54)**

**STUDENT SUPERVISORS PROJECT SUPPORT**

Adam Albrechtsen V.Kamenetsky, J.M.Kamenetsky, Christie (JOMS Science) Kimberlites and diamonds: Understanding their paragenesis and uncovering the identity of their source composition UTAS

Ayasha Ahmad \( ^* \) Cooke, Baker, Orphan The effect of pressure/depth on propylitic alteration mineral chemistry in the porphyry environment AMIRA P1153, ARC TMVC, UTAS

Olg Aplukhtina \( ^v \) V.Kamenetsky, McPhie, Masu \( ^i \) (IMAS) Stable isotopes (C, S and O) and halogens (F, Cl) in gangue and ore minerals at Olympic Dam: Evaluation of mantle and crustal contributions to mineralisation BHP Billiton Olympic Dam, UTAS

Richella Awd-Piscual G.Davidson, V.Kamenetsky, Goermann, Noble The evolution of Zn-Pb-Zn-Pb seawater minerals in the Grieses mining district, Western Tasmania COE, UTAS, CRC ARC

Heldi Berkeloob \( ^b \) Gammel, McNeil (VR, UTAS, CODES) Gaschemistry of hydrothermal mineral chimneys from Brothers volcano, Kermadec Arc COE, GNS Science, UTAS, SEG, AustIMM, Australian Synchrotron

Ben Cave \( ^v \) Larga, Danyushovskiy A metamorphic course for tungsten in metasedimentary-hosted orogenic gold deposits UTAS, CoE

Nathan Chapman Metfies, V.Kamenetsky Pb-Isotopic Insights into the Crustal Evolution and Mafic Metallogeny of the Gawler Craton ARC, BHP Billiton

Jing Chen \( ^* \) Cooke, Zhang The geology, mineralisation, alteration and fluid evolution of Zijinshan main deposit, Fujian Province, China UTAS, China Scholarship Council, ARC TMVC, SEG, Zijin Mining

Alexander Cherry V.Kamenetsky, McPhie, Ehrig (BHP/Billiton) Petrology, provenance and composition of banded sedimentary facies in the Olympic Dam deposit UTAS, CoE, BHP Billiton

David Douth Scott, Cas The geology and geochronological controls on gold mineralisation in the Hinchinbrook deposit, St Ives Gold Mine, Kambalda, WA St Ives Gold

Evan Drayers Danyushovskiy 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 Escotra \( ^* \) Cooke, Hunt, Barry The geology, geochemistry and geometallurgy of Productora Cu-Au-Mo deposit, Chile UTAS, Hot CNR, CSIRO, AustIMM, ARC TMVC

Esmaeil Esfahali \( ^* \) Reading Geophysical and petrophysical investigations of Tasmania at multiple scales UTAS

Matt Ferguson V.Kamenetsky, Ehrig (BHP/Billiton) Mafic and Fe- and Ti-bearing minerals, apatite and zircon in the Olympic Dam deposit: Distribution, nature and implications for ancient submarine successions in Australia UTAS, CoE, BHP Billiton

Jodi Fox McPhie, Carey Submarine intraplate basaltic volcanism UTAS, CoE, ANZE, Australian Antarctic Science Program, MRT, Linnaean Society of NSW

Shawn Hood \( ^* \) Cooke, Zhang T chemist analysis at the Cadia East deposit using CoreScan automated logging technology UTAS, CoE, BHP Billiton, Newcrest Mining, CoreScan

Rachel Harrison \( ^* \) Cooke, Zhang Tungsten ore deposit porphyry Au-Cu-Mo with high-sulphidation epithermal Au-Ag deposit, Tujah Bult project, SE Java, Indonesia - geology, alteration and mineralisation UTAS, SEG, ARC TMVC

**STUDENT SUPERVISORS PROJECT SUPPORT**

Mangi Hakwe \( ^d \) Gammel, Large, G.Davidson Geologic evolution of the DeGrussa Cu-Au VHMS deposit, Western Australia UTAS, SEG, National Science Foundation

Jacob Heathcote Scott, G.Davidson Gold distribution and association at the Kambanshi copper-gold deposit Zambian: 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, CSIRO

Wei Hong \( ^d \) Cooke, Zhang T 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 metallogenic ore deposits UTAS, ARC TMVC, Gold Fields Australia, Sarakan Mineral Holdings, Integra Gold Corp

Glycy Hue \( ^v \) V.Kamenetsky, McPhie, Allen Mafic magma in the Gawler Ranges: Distribution, composition, timings, sources and tectonic setting UTAS, SEG, BHP Billiton, ARC

Sumiko Ikagi 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 \( ^* \) Pathikhar-Fox, Cooke, Fox Domaining of geoenvironmental properties in drill core ARC TMVC, UTAS, Newcrest Mining

Torsten Jansen Scott, Metfies, Bailey Devonian gold mineralisation in NE Nevada, USA: Critical primer to world-class gold deposit? CODES, UTAS

Carlos Andres Jimenez Torres Cooke, White, Baker Banting International, Negros Island, Philippines: Mineralogy, textures, and chemistry UTAS Foundation, AMIRA P1060

Sean Johnson \( ^d \) Large, McPhie, McGoldrick The geochemistry of metaffluidal black shales: Understanding primary enrichments, metamorphic processes and the role of silicate black shales in researching earth evolution UTAS, CoE, Mining Institute of Scotland, ANZ-ODP, ECOORD, NIBRC, Talvivaara Mining, GTK, SEG

Joe Knight Zaw, Large The geodynamic and magmatic 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 mineral targeting in various deposit styles and settings UTAS, CODES, ARC TMVC, First Quantum Minerals, Gold Fields. BHP Billiton, ARC

Lawrence Kuse \( ^b \) Cooke, Zhang T Pyrite trace element chemistry of black shales of the “boring billion” period UTAS, SEG, National Science Foundation

Erl Linawis Cooke Au-bearing pyritic ore of Lihir, Papua New Guinea: Its mineralogy and ore potential Newcrest Mining, UTAS, SEG

Christopher Leslie Metfies, Cooke Diatreme scale on 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 Makound \( ^d \) Zaw, Large Geochemistry of carbonaceous black shale, sandstone, and shale in Malaysia: Insights into gold source rock potential IPR, 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 IOCO ore deposit, Northwest Territories, Canada ARC, CODES

Brian McNulty Gammel, G.Davidson Geology and genesis of the mineral deposits of the Myra Falls VHMS District, Canada Nyxstar, 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), Metfies Pyrite trace element chemistry of black shales of the “boring billion” period UTAS, SEG, AMIRA, CODES

Jacob Mulder Metfies, Halpin (IMAS), Carey, Scott From Nuna to Gondwan: An evaluation of the early tectonic history of Tasmania UTAS, CODES
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<tr>
<td>Evan Orobian ^</td>
<td>Cooke, Harris (Newcrest)</td>
<td>Geology, geochemistry and genesis of the Namosi porphyry Cu-Au deposits, Fiji</td>
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<td>Thomas Ostasen</td>
<td>Reading, Cracknell, Roach, Thal (GISSA)</td>
<td>Multi-scale geoelectric, and combined geophysical, investigations of Tasmania and Southeast Australia</td>
<td>UTAS, CODES, MRT, U Adelaide, Geoscience Australia, GISSA</td>
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<td>Pedro Pereira da Fonseca ↴</td>
<td>McPhie, McNall (MRT), Reivas (GeoCU)</td>
<td>Face analysis and correlations in complex mineralised submarine volcanic successions: Mount Read Volcanics, western Tasmania</td>
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<td>Joshua Phillips ^</td>
<td>Cooke, Scott, Baker</td>
<td>Geologic and geochemical vectors to mineralisation at the Resolution porphyry Cu-Mo deposit, Arizona</td>
<td>ARC TMVC, AMIRA P1153, Rio Tinto, Resolution Copper Ltd</td>
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<td>Naomi Potter</td>
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<td>An investigation into the genesis of intrusive and extrusive carbonatitic melts</td>
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<td>Subira Sharma</td>
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<td>Evaluation of links between Merlin-style Mo-Re mineralisation and magmatism in the Otscorrey feldspar, Queensland: Implications for exploration</td>
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<td>Tobias Staal</td>
<td>Reading, Whittaker (MAS), Haipin (MAS)</td>
<td>Seismic and geological constraints on the lithospheric structure of Antarctica</td>
<td>Antarctic Gateway Partnership</td>
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<td>Nathan Stevens</td>
<td>Gammell, Large, Hannington, J.Ottawa</td>
<td>One genesis of the Greens Creek VHMS Deposit, Alaska: Implications for mining, milling and exploration</td>
<td>Hecila Mining, UTAS</td>
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<td>Stephanie Sykora ^</td>
<td>Cooke, Salley</td>
<td>Origin, evolution and significance of anhydrite-bearing vein arrays and breccias, Lisanz arzobey, LiFe gold deposit, Papua New Guinea</td>
<td>Newcrest Mining, CODES, TMVC, UTAS</td>
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<td>Francisco Tosta</td>
<td>Cooke, Baker</td>
<td>Tournaille breccia pipes: San Francisco de los Andes, Argentina and Rio Blanco Los Bronces, Chile</td>
<td>UTAS, AMIRA P1060</td>
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<td>Jay Thompson</td>
<td>Danyushievski, Mattie</td>
<td>Understanding the specifics of H2O-free aerosol behaviour in the inductively-coupled plasma in geochemical LA-ICPMS applications involving IPQ dating and accurate trace element analysis in silicate minerals and glasses</td>
<td>UTAS, AMIRA P1153, ARC TMVC, SEG</td>
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MAJOR EXTERNALLY FUNDED RESEARCH PROJECTS^ ARC INDUSTRIAL TRANSFORMATION RESEARCH HUB GRANTS 2016

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<td>Cooke, Danyushievski, DuB, Gammell, Large, Moffie, Reading, Harris, Newcrest, Staal, (AMIRA), Bing (BHP Billiton), Gosseley (Corecien), Lottermoser (Aachen), Shelley (Lauren Technic)</td>
<td>Transforming the mining value chain</td>
<td>AMIRA, AMIRA, International, BH Billiton, Olympic Dam, Newcrest Mining, UTAS</td>
<td>2015 - 2020</td>
<td>$861,000</td>
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ADDITIONAL FUNDER PROJECTS WITHIN THE ARC TMVC RESEARCH HUB 2016

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<td>Cooke, Hunt, Berry, Escolme (student)</td>
<td>Ore characterisation and geometallurgical modelling at the Productora Cu-Au-AO deposit, Chile</td>
<td>Hot Chili</td>
<td>2013 - 2016</td>
<td>$25,858</td>
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<td>Cooke, Baker, Zhang, Guyar (student)</td>
<td>Magnetite and pyrite chemistry and textures at Las Bambas Cu-Au-Fs skarn, Peru: Assessing district and deposit-scale fertility - implications for ore genesis and exploration</td>
<td>UTAS Foundation</td>
<td>2015 - 2018</td>
<td>$16,000</td>
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<td>Parthiban-Fox</td>
<td>Integrating mineralogical evaluations into kinetic testing protocols</td>
<td>Australian Academy of Technology and Engineering</td>
<td>2016 - 2017</td>
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<td>Parthiban-Fox</td>
<td>Evaluation of NAG pH tasting. Tracking reaction pathways and products</td>
<td>Grange Resources</td>
<td>2016</td>
<td>$5,396</td>
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<td>Cooke, Danyushievski, Moffie, Thompson (student)</td>
<td>Textural geochemical and C-D isotopic variations at Batu Hijau</td>
<td>Society of Economic Geologists Foundation</td>
<td>2016</td>
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<td>Parthiban-Fox, Fox, Clifton (student)</td>
<td>Evaluating applications of boiler ash for controlling acid and metalliferous drainage--examples from Tasmanian mine wastes</td>
<td>MONA Heavy Metals Project</td>
<td>2016</td>
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ARC LINKAGE GRANTS 2016

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ARC LIEF GRANTS 2016

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<tr>
<td>Danyushievski, V.Kamenetsky, Cooke, Large, Goemann (CSL)</td>
<td>A stable of the art field emission electron microscope for Tasmania</td>
<td>2016</td>
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ARC DISCOVERY GRANTS 2016

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<tr>
<td>Large, Danyushievski, Haipin (MAS), Moffie</td>
<td>Pyrite: A deep-time capsule of ocean chemistry and atmosphere oxidation</td>
<td>2015 - 2017</td>
<td>$166,773</td>
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### INDUSTRY AND OTHER EXTERNALLY FUNDED RESEARCH GRANTS 2016

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<td>Large, Danyushkevich</td>
<td>Research and development in mineral deposition and exploration</td>
<td>Newcrest Mining Limited</td>
<td>2012 - 2016</td>
<td>$235,000</td>
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<td>Largo, Moffre, Gregory, Steadman</td>
<td>South Australia pyrita, hematite and magnetite fingerprint database</td>
<td>Geological Survey of South Australia</td>
<td>2012 - 2016</td>
<td>$83,000</td>
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<td>Scott, Gas, Douthit (student)</td>
<td>The geology and geological controls on gold mineralisation at the Inovible deposit, St Ives Gold Mine, Kambalda, WA</td>
<td>St Ives Gold</td>
<td>2015 - 2018</td>
<td>$55,000</td>
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<td>Zhang</td>
<td>Exploration tools and genetics of the lithocaps in Eastern China</td>
<td>Hefei University of Technology</td>
<td>2016 - 2017</td>
<td>$46,035</td>
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<td>Danyushkevich</td>
<td>LAM data reduction software development</td>
<td>Rio Tinto</td>
<td>2014 - 2016</td>
<td>$45,000</td>
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<tr>
<td>G.Davidson, McNulty (student)</td>
<td>Geology and genesis of the mineral deposits of the Myra Falls VHMS District, Canada</td>
<td>Nystar Myra Falls</td>
<td>2015 - 2017</td>
<td>$40,000</td>
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<tr>
<td>Scott, G.Davidson, Heathcote (student)</td>
<td>Gold distribution and association at the Kansanshi copper-gold deposit, Zambia</td>
<td>Kansanshi Mining</td>
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<td>Zai, Large, Krigt (student)</td>
<td>The geodynamic and metallogenic setting of Cu-Au mineralisation in Myanmar: Implications for mineral exploration</td>
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<td>Johnson, Noble (AMAS), Orl, Moffre, Grice Kurkin, Large</td>
<td>The establishment of ocean anoxia and ocean acidification during the PETM: Understanding the biological and chemical response on a regional and global scale</td>
<td>IODP (via Australian National University)</td>
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<td>G.Davidson, Large, Harvington (student), Stevenos (student)</td>
<td>Ore genesis of the Greens Creek VHMS deposit, Alaska: Implications for mining, milling and exploration</td>
<td>Hieda Mining Company</td>
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<td>G.Davidson</td>
<td>Determination of the temporal relationship between this pyrite-silica-sericite alteration, and spatially associated uranium mineralisation, at Angolardt deposit, East Arnhem Land</td>
<td>Cameco</td>
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<td>Cooke, Baker, Zhang, Walls (student)</td>
<td>Geology and genesis of the Two-Thirty prospect, Northparkes, NW</td>
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<td>AngloGold Ashanti</td>
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<td>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</td>
<td>Society of Economic Geologists Foundation</td>
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### VISITORS 2016

**INDUSTRY VISITORS**

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**NATIONAL ACADEMIC AND GOVERNMENT VISITORS**

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<tr>
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<tbody>
<tr>
<td>Farah Al</td>
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* Visitor for longer than three months.
THIS REPORT INCLUDES SECTIONS ON THE ARC RESEARCH HUB – TRANSFORMING THE MINING VALUE CHAIN, AND THE UTAS DISCIPLINE OF EARTH SCIENCES.