

CODES

ARC CENTRE OF EXCELLENCE IN ORE DEPOSITS

ANNUAL REPORT **2014**







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PLEASE NOTE: IN VARIOUS PLACES THROUGHOUT THIS PUBLICATION, IMAGERY HAS BEEN USED FOR GRAPHIC PURPOSES ONLY. CAPTIONS HAVE NOT BEEN PROVIDED IN THESE INSTANCES.

DIRECTOR'S REPORT



This has been a very special year in the history of CODES, during which, for the first time since our inception in 1989, we operated without the support of funding as an Australian Research Council (ARC) Centre. Despite this significant loss of income, I am pleased to report that life not only went on, but we had one of the most successful years on record.

THE HUB

The highlight of the year was undoubtedly the announcement in June that CODES, together with its industry partners, had been awarded one of the ARC's Industrial Transformation Research Hubs. The ARC has allocated nearly \$4 million over the five-year life of the Hub, with a further \$8 million of matching funds, in cash and in-kind, being pledged by participants within the minerals industry. While a lot more work still needs to be done to reach the level of funding we had as a Centre of Excellence, this announcement is a major step forward, and testament that CODES is held in high regard by both the ARC and our

partners in industry. The new Hub is entitled Transforming the Mining Value Chain (TMVC) and is expected to come on stream mid-2015. See pages 8–9 for further details.

SEG-CODES 2015 CONFERENCE

Another major highlight was when the Society of Economic Geologists (SEG) confirmed that it had appointed CODES as its partner for its annual conference and exhibition in 2015. The event is the biggest conference in the world for economic geology, and is expected to attract at least 600 national and international delegates. The SEG-CODES Conference will be held at Wrest Point from 27 to 30 September, 2015. This is the first time that this major international event has been held in Tasmania, and as co-hosts it provides an exceptional opportunity to showcase our research.

RESEARCH MODULES

Key objectives when establishing the new research modules were to ensure that CODES retained its core research strengths, while establishing a platform that was conducive to growth and development. I believe that this has been achieved. If you look through this report, you will see that much of the research from the Programs has been continued and developed in the Modules, with a number of new projects commencing, all related to our core strengths.

Two major projects came to an end during the year. The team from the AMIRA P1060 project (Enhanced geochemical targeting in magmatic-hydrothermal systems) held its final meeting in June. This initiative had the support of 20 industry sponsors, making it the largest exploration-based research project in AMIRA's history. This important research has been ongoing for a number of years under various project titles. It is expected that it will be developed even further in 2015 through the advent of AMIRA P1153 (Applying the explorers' toolbox to discover porphyry and epithermal Cu, Au and Mo deposits).

Ore Deposits of SE Asia was completed via a final project meeting in November. This extensive project greatly enhanced the geological knowledge of mainland SE Asia,

and more recently of Sumatra, and did a considerable amount to extend our research footprint within Asia. Negotiations are in progress with sponsors to extend this research via a new initiative to investigate the tectonics and origin of copper-gold mineralisation of the Western Myanmar-Sumatra Terrane.

It has been a relatively quiet year for the Geometallurgy Module, as it transitions to life after the conclusion of the highly successful GeM^{III} project. Nevertheless, significant technology transfer from GeM^{III} continued throughout the year, and this will pick up pace in late 2015 as confidentiality agreements expire. CODES has been named as an Essential Research Participant in the CRC ORE II bid, which, if approved by Government, will considerably increase our collaboration with the Centre in this field. Geometallurgy is also included as a dedicated Theme in the TMVC Hub, which will further add to the activities in the year ahead.

The Enabling Technologies Module has retained all the key elements of the research from the Technology Program, which have been augmented by new projects in areas such as big data knowledge discovery.

Technology is the backbone of the research activities within all our modules and we are proud of the innovations that have come from this area over the years. In 2014, the team continued to excel with novel work in a number of areas. An example of this is the development of innovative techniques for manufacturing a new calibration standard for sulfide analysis characterised by better homogeneity of selenium, titanium, gold, and platinum. They also developed a new technique for incorporating spatial context into data driven lithology prediction. This innovative technique enables disparate geological parameters relating to areas such as geochemical assay data, geophysical signals, and field observations to be integrated, allowing lithology prediction to be conducted in a holistic manner.

TRAINING

One of the cornerstones of our success has always been the strength of our postgraduate training programs. They play a crucial role in supplying world class geoscientists to industry, and are integral to our research activities. In recognition of the importance that we place on this aspect of our operations, we have created a module within our new research structure that is specifically dedicated to training. It has been a very good year for this new Module, which included a number of highlights.

Despite losing MTEC funding a couple of years ago, the Master of Economic Geology program has continued to go from strength to strength. In 2014, it had 52 people enrolled at UTAS, which is the highest number in the history of the program. It also had strong attendances at all three of its short courses held throughout the year.



CODES has been named co-host of the SEG's annual conference, which is to be held at Wrest Point in Hobart, from 27 to 30 September, 2015.

The Higher Degree by Research (HDR) Program is known for the high number of students it attracts from all parts of the globe. While that trend continued in 2014, with 37 international students from 18 countries, it was also pleasing to note that the cohort included seven Australian students. This was a record for the program, although the figure could partly be a reflection of the current downturn in the minerals industry.

Re- and up-skilling training for industry professionals is another important part of the Training Module. CODES has increased its focus on this important service in recent years, and this trend continued in 2014 with the inaugural running of the Advances in Geo-logging course, held in collaboration with GHD and Mineral Resources Tasmania (MRT). The course was held at MRT's facilities in Hobart, which includes an extensive drill-core library. This was just one of a number of collaborations that strengthened our ties with MRT, which we plan to foster further in 2015.

PUBLICATIONS AND INDUSTRY REPORTS

While the number of publications was down on the record high of the previous year, the output matched the average achieved during our tenure as a funded Centre of Excellence, which was consistently above the ARC target. A highlight of the output was the Special Issue of *Economic Geology* devoted to Alkaline Porphyry Copper-Gold and Epithermal Gold deposits. The publication includes contributions from 15 authors affiliated to CODES. Professor David Cooke was guest editor of the publication, along with Dr Thomas Bissig from UBC. CODES remains the leading university-based group to publish in *Economic Geology*, the world's leading journal in this field of research.

Research from the SE Asia project was featured in the print version of a special issue of *Gondwana Research* entitled *Tectonics and Metallogeny of Mainland SE Asia*. The publication included 12 authors affiliated to CODES. Professor Khin Zaw was one of the guest editors.

In addition to our publications, CODES produces a substantial number of reports to industry each year, which are vital to our sponsors in terms of technology transfer. CODES has consistently exceeded the performance indicator of 80 for this output, and that trend continued in 2014.

AWARDS AND ACCOLADES

It has been a particularly prolific year in terms of awards and accolades. Professor Leonid Danyushevsky was elected as a Fellow of the Mineralogical Society of America (MSA). Less than 3% of past Fellows have been from Australia, and Leonid is the first Tasmanian to receive the honour.

One of our brightest young researchers, Rebecca Carey, received the UTAS Vice Chancellor's Award for Research Excellence. Rebecca also won a National Science Foundation Research Grant (USA) that will fund a research cruise in 2015 to study the aftermath of the 2012 explosive submarine eruption of Havre volcano.

It was also a good year for our students. Sam Holt received the GSA's David Grove's Medal for the 'best paper in the *Australian Journal of Sciences* by a young Australian'. Stephanie Sykora achieved first place in the student poster presentation category at the SEG's annual conference in Keystone, Colorado. Martin Gal was awarded an American Geophysical Union (AGU) 'Outstanding Student Paper Award' at the 2014 AGU Fall Meeting in San Francisco. A number of students also received various grants towards their research.

In addition to the individual awards, a team led by David Cooke and I won the Measurement in Action category at the prestigious UK-based Institute of Engineering Technology's Innovation Awards in London. The award was for research related to the AMIRA P765/765A/1060 projects.

RETIREMENTS

Two more of CODES' most valued and long serving staff members retired during the year. Professional staff member Peter Cornish left us after many years of service for the University, dating back to 1972. In recent years, Peter was our Laboratory Manager, providing exceptional and wide ranging support for the day-to-day activities of CODES and Earth Sciences.

One of our finest researchers, Jocelyn McPhie, retired at the end of the year. Jocelyn joined CODES soon after its inception and has been one of the main drivers behind our success. She has done a sterling job in various roles for CODES, including Graduate Research Co-ordinator, Program Leader and more recently Co-Leader of the

Training Module. She was also Head of the Discipline of Earth Sciences. She is one of the world's most highly respected volcanologists, and her co-authored book, *Volcanic Textures*, has been one of our most sought-after publications for many years.

Both Peter and Jocelyn will be sorely missed, but I am pleased to say that they haven't been lost to us entirely, as both have been retained by UTAS in honorary capacities.

2015 AND BEYOND

I would like to thank all our stakeholders, particularly those in the minerals industry who continued to support us despite the current difficult operating conditions. I would also like to thank all the academic, technical and professional staff, as well as the students, for all their hard work and dedication.

There is a lot to look forward to in the year ahead, including the start of the new Hub, the AMIRA P1153 project, a potential CRC ORE II, and last, but not least, the SEG 2015 Conference co-hosted by CODES. I look forward to seeing many of you there.



Professor J Bruce Gemmell,
Director and Chief Operations Officer

STATISTICS AT A GLANCE 2014

Academic Research Staff	45
Postgraduate Students	127
Major Research Projects	36
Countries Involved	31
Publications in Refereed Journals	55
Research Reports to Industry	82
Workshops and Short Courses:	
Number	16
Countries	6
Attendees	918
Funding:	
Industry	\$1.77 million
UTAS	\$2.42 million
Worldwide Collaborations:	
Industry	54
Institutes and Universities	81

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.

PROFILE AND RESEARCH MODEL

CODES – A BRIEF OVERVIEW

CODES was formed in 1989, and has been the Australian Research Council (ARC) Centre of Excellence in Ore Deposits since 2005. Based at the University of Tasmania, the Centre has grown substantially over the years and is now widely regarded as a global leader in ore deposit research and postgraduate training. It is home to 45 highly qualified research staff and 127 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 50 industry companies, plus a host of joint research initiatives with 81 institutions and universities – 25 in Australia and 56 overseas. It currently has 36 major research projects spanning 31 countries, and is the leading academic group to publish in *Economic Geology*. In the past year, it maintained its reputation for delivering excellence in technology transfer by producing 82 reports to industry and conducting 16 workshops and short courses in six countries.

In mid-2014, it was announced that CODES, together with a group of its research partners, had been awarded one of the ARC's Industrial Transformation Research Hubs, entitled Transforming the Mining Value Chain. The Hub is covered in more detail later in this section.

RESEARCH FRAMEWORK

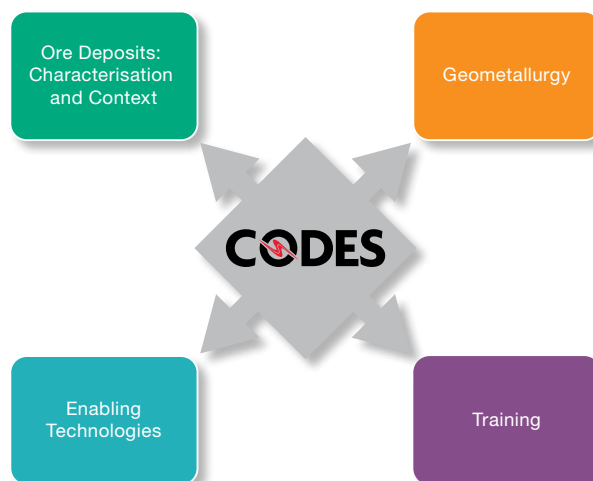
As foreshadowed in last year's annual report, CODES introduced a new four module research model early in 2014, which replaced the five Programs in place previously.

Key objectives in developing this model were to ensure all the well established and valued research capabilities were maintained, while enhancing the structure to better reflect the Centre's strengths. It is believed that this model also better positions the Centre to adapt to the evolving needs of the minerals industry and other stakeholder groups.

The new integrated research modules provide 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 up-skilling needs of the minerals industry.

THE NEW MODULES

- **Ore Deposits: Characterisation and Context**, led by Dr Garry Davidson, 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).
- **Geometallurgy**, led by Dr Julie Hunt, builds on the success of the AMIRA P843/A GeM^{III} projects and the collaborative involvement with CRC ORE. This module aims 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, rather than during feasibility assessment.
- **Enabling Technologies**, led by Professor Leonid Danyushevsky, continues the work carried out under the old Technology Program by producing innovative analytical and computational tools, and facilitating technology transfer to the minerals exploration and geoscientific industries.





- **Training**, jointly led by Professor Jocelyn McPhie (graduate research) and Dr Robert Scott (Master of Economic Geology Program), builds on CODES' ability to produce highly-skilled Honours, Masters and PhD graduates, and provide professional development short courses and workshops for re- and up-skilling of the minerals industry workforce. Associate Professor Anya Reading will be taking over from Professor McPhie as joint leader early in 2015.

While some of the projects under the Programs were timed to come to a natural conclusion with the expiry of the Centre of Excellence funding, a large majority of the research work is continuing under the new structure, and these are included in the Module sections of this annual report. In addition, a number of new projects have been included in these sections, with more to be introduced as the Modules evolve.

TRANSFORMING THE MINING VALUE CHAIN

AN ARC INDUSTRIAL TRANSFORMATION RESEARCH HUB

CODES, together with its research partners, was awarded one of the Australian Research Council's (ARC) Industrial Transformation Research Hubs in the organisation's latest funding round, announced in June. The ARC has allocated nearly \$4 million over the five-year life of the Hub, with a further \$4 million of matching funds being pledged by participants within the minerals industry. Professor David Cooke has been appointed as Hub Director, and will be supported by a team of world class researchers from within CODES, plus industry partners.



TMVC Hub Director
David Cooke.

In addition to a consortium of global companies co-ordinated by AMIRA International, the Australian partner organisations are Newcrest Mining, BHP Billiton – Olympic Dam, and the service company Corescan. Other organisations affiliated with the initiative include Laurin Technic, National Information Communications Technology Australia (NICTA) and the University of Exeter in the UK.

Two planning meetings with Hub participants were held (Hobart and Melbourne) in 2014.

THE ROLE OF THE HUB

The Hub is entitled Transforming the Mining Value Chain (TMVC) and encompasses a wide array of activities from exploration, discovery, ore deposit characterisation, and environmental assessment, through to mining, ore processing and waste rock disposal. The main objective is to improve efficiencies within this value chain, focussing on areas that will have a marked impact on the value of Australia's mineral resources, thereby benefiting the nation's economy.

The minerals industry will benefit greatly through advanced mineral characterisation methods, and innovative technologies for their implementation, which will be able to be applied much earlier in the mining value chain. This will enhance decision making and maximise productivity and profitability at Australian mine sites.

RESEARCH THEMES

The Hub will focus 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 will tackle through three principal research themes:

Theme 1: Detecting proximity to ore (footprints).

Theme 2: Quantifying geometallurgical characteristics.

Theme 3: Predicting geoenvironmental behaviour.

AIMS

The Hub is set to resolve some of the greatest challenges currently facing the minerals industry. The aims are to:

- Achieve real-time automated acquisition and interpretation of detailed mineralogical, textural and geochemical data in mine site cores that can be used immediately for 3D-modelling of geometallurgical and geoenvironmental parameters and ore zone footprints.
- Move the mining industry from the data-rich, but comparatively knowledge-poor, environment that they currently work in to a data-rich, knowledge-rich environment that allows for rapid decision making during the exploration and development phases of mining operations.

- Develop tools and protocols that allow near-instantaneous identification of proximity to ore zones, together with geometallurgical and geoenvironmental characterisation of ores and waste through automated core logging and spectral analyses of drill core. This will enable 3-D exploration, mining and geometallurgy models to be developed that are continually updated as the exploration or resource drilling program continues.

By helping to develop more efficient and environmentally sustainable practices throughout the mining value chain, it is anticipated that the Hub will extend the lives of mines and create employment opportunities across Australia's regional mining centres.

LOOKING FORWARD

The agreement between the University of Tasmania and the Australian Research Council has been signed and agreements between the financial partners of the Hub are being negotiated. Anticipated start-up of the Hub will be mid-2015.

CENTRE OF EXCELLENCE STATUS

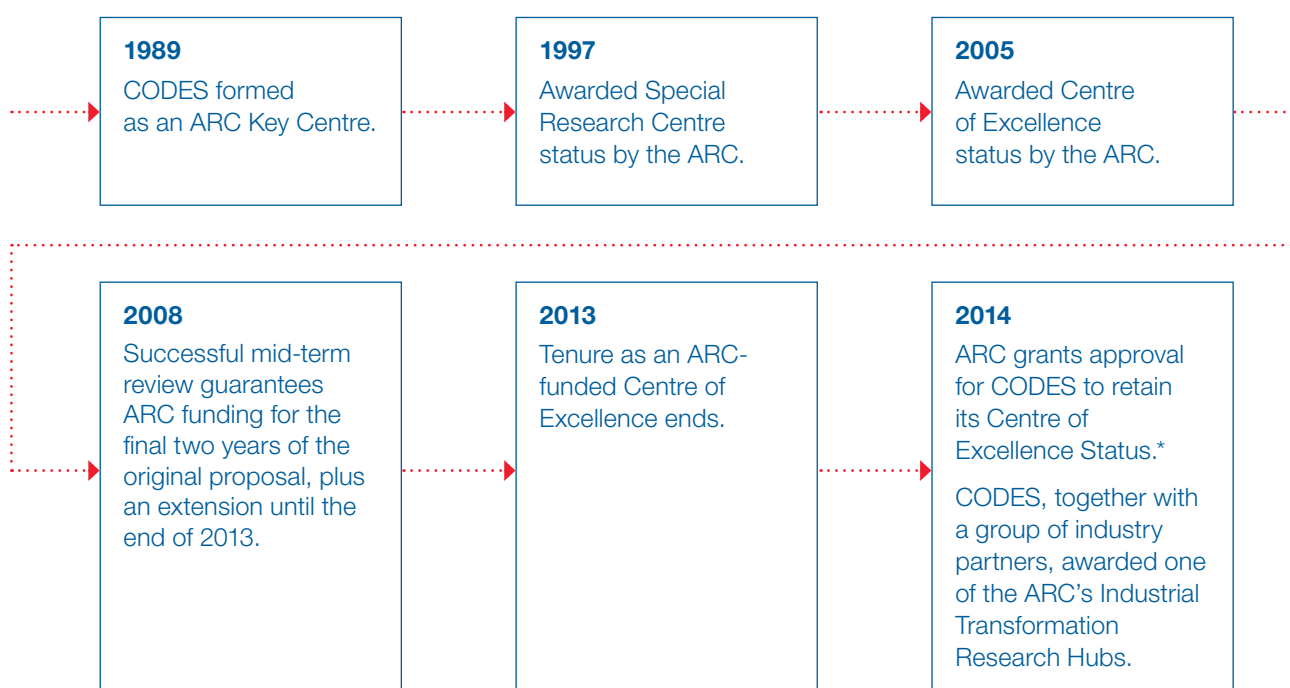
CODES has obtained approval from the Australian Research Council (ARC) to retain its Centre of Excellence (CoE) status, despite its tenure as a funded Centre coming to a conclusion at the end of 2013.

THE NEW RESEARCH MODEL HAS BEEN DESIGNED TO ENABLE US TO MAINTAIN AND BUILD ON OUR CORE STRENGTHS, WHILE ENSURING THAT WE HAVE THE STRUCTURES AND CAPABILITIES TO ADAPT TO THE EVOLVING NEEDS OF THE MINERALS INDUSTRY.

Director, Bruce Gemmell

Provision is made in the ARC rules for Centres to apply to retain their CoE status, providing they meet certain criteria. One of the key requirements is that there must be no substantive changes to the Centre's research program. Although CODES has transitioned to a new four-Module research model, its primary strategy remains to build on the research strengths that industry partners have valued during its tenure as a funded CoE. Therefore, the case for meeting this criterion was relatively straightforward to make. Nevertheless, a detailed application had to be submitted to the ARC, which was executed via the University of Tasmania. Confirmation of the successful outcome was received in May.

TIMELINE



**Note that no further extensions of funding were allowed under the ARC's rules for this type of Centre.*

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.

HUB DIRECTOR

Professor David Cooke is Director of the Transforming the Mining Value Chain Hub.

ADVISORY BOARD

The Advisory Board meets at least once a year to review the progress of the Centre and to advise on future directions. The Board is composed of representatives from major industry partners, University of Tasmania senior management, and key national geoscience organisations. It is chaired by Dr Paul Heithersay, from the Department of State Development, South Australia, who has extensive experience in the minerals industry and the public service. Paul Agnew from Rio Tinto is Deputy Chair.

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 a representative from UTAS Financial Services. It meets approximately six times a year, working closely with the Director to develop the Centre's goals, strategies and research directions.



STAFF MOVEMENTS 2014

APPOINTMENTS

Dr Matt Cracknell was appointed as a Research Fellow working in geophysics, with a focus on machine learning and data mining.

Dr Dan Gregory was appointed as a Research Fellow, specialising in paleo-oceanography and ore deposit vectoring techniques.

Jeff Steadman was appointed as a Research Fellow, specialising in ore and sedimentary pyrite geochemistry.

DEPARTURES

A total of nine academic and professional staff left their positions during the year, but just over half of these people have been retained in honorary capacities.

ACADEMIC STAFF

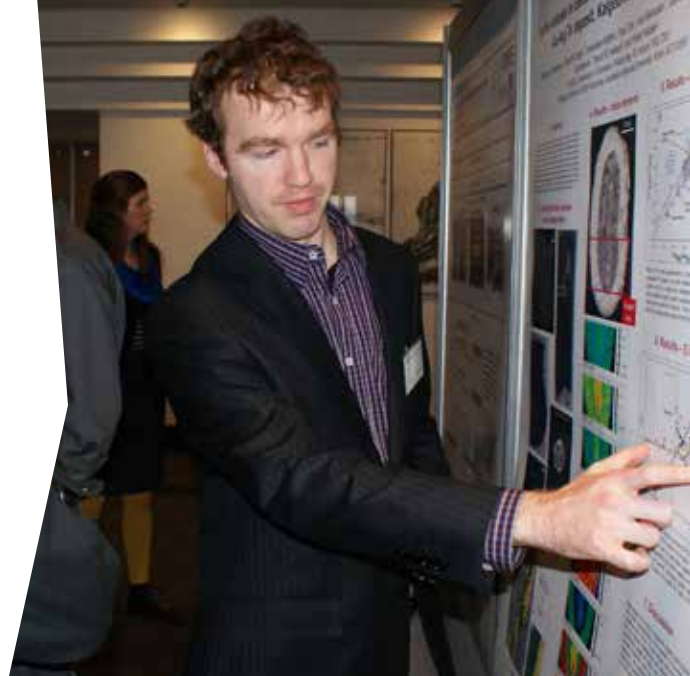
Drs Sharon Allen, Daniel Bombardieri and Chun-kit Lai left their research positions at CODES, but have been retained in honorary roles.

Professor Jocelyn McPhie retired at the end of the year, and has also been retained in an honorary position.

Drs Nic Jansen, Lyudmyla Koziy, Takayuki Manaka and Nathan Fox left the Centre during the period, the latter to take up a position with CRC ORE, via the Discipline of Earth Sciences.

PROFESSIONAL STAFF

Laboratory Manager Peter Cornish retired, but has been retained as a University Associate.



Left: Delegates enjoy a break at the Science Planning Meeting.

Top: Newly appointed Research Fellow Jeff Steadman.

Centre: Jocelyn McPhie, who retired at the end of 2014, with Garry Davidson (L) and Bruce Gemmell. **Bottom:** Peter Cornish inspects one of his retirement gifts, bookends made from trachyte, watched by David Selley and Jacqui Halpin.

STAFF AND MANAGEMENT

Name	%
Director, Professor J Bruce Gemmell, BSc (UBC), MA, PhD (Dartmouth)	VHMS deposits and epithermal Au-Ag 100

Name	%
Deputy Director, Professor David Cooke, BSc Hons (Latrobe), PhD (Monash)	Porphyry Cu-Au, fluid-rock geochemistry 50

ACADEMIC/RESEARCH STAFF AT UTAS

Name	%
Dr Sharon Allen, BSc (Massey), MSc (Auckland), PhD (Monash)	Volcanic facies analysis Hon
Dr Mike Baker, BSc Hons (Sydney), PhD (UTAS)	Igneous petrology, mineral chemistry 100
Dr Ivan Belousov, BSc, MSc (Moscow), PhD (Vernadsky)	Igneous petrology, geochemistry, volcanology, LA-ICP-MS analysis 100
Associate Professor Ron Berry, BSc, PhD (Flinders)	Structure of mineralised provinces, CHIME dating, geometallurgy Hon
Dr Stuart Bull, BSc Hons, PhD (Monash)	Clastic and carbonate sedimentology and volcanology Hon
Dr Rebecca Carey, BSc Hons (UTAS), PhD (U Hawaii)	Volcanology 50
Dr Matt Cracknell, BSc Hons, PhD (UTAS)	Geophysics, machine learning and data mining 30
Professor Tony Crawford, BSc Hons, PhD (Melbourne)	Petrology, geochemistry and tectonics of volcanic arcs Hon
Professor Leonid Danyushevsky, PhD (Vernadsky Inst.)	Petrology, geochemistry, LA-ICP-MS analysis 50
Dr Garry Davidson, BSc Hons (ANU), PhD (UTAS)	Sulfur isotope geochemistry and Cu-Au ores 50
Dr Paul Davidson, BSc Hons, PhD (UTAS)	Melt and fluid inclusions Hon
Dr Trevor Falloon, BSc Hons (Canterbury), BTeaching, PhD (UTAS)	Marine geoscience, petrology Hon
Professor David Green, BSc Hons, MSc, DSc, DLitt Hon (UTAS), PhD (Cambridge)	Experimental petrology Hon
Dr Dan Gregory, BSc Chem, BSc Hons Geol (UBC), PhD (UTAS)	Paleo-oceanography and ore deposit vectoring techniques 100
Dr Jacqui Halpin, BSc Hons (Melbourne), PhD (Sydney)	Metamorphic petrology, geochronology 100
Dr Julie Hunt, MSc (UBC), PhD (JCU)	Geometallurgy, IOCG deposits 100
Dr Maya Kamenetsky, PhD (UTAS)	MLA-SEM, geometallurgy, petrology 100

Name	%
Professor Vadim Kamenetsky, BSc Hons (Moscow), PhD (Vernadsky Inst.)	Petrology and geochemistry of melt inclusions 50
Professor Khin Zaw, BSc (Rangoon), MSc (Queen's), PhD (UTAS)	Fluid inclusions, SE Asian metallogenesis 100
Dr Chun-kit Lai, BSc, MPhil (HKU), PhD (UTAS)	Petrology, geochemistry and tectonics of SE Asia Hon
Professor Ross Large, BSc Hons (UTAS), PhD (UNE)	Volcanic-hosted and sediment-hosted base metal and gold ores 100
Dr Peter McGoldrick, BSc Hons, PhD (Melbourne)	Ore deposits and their halos Hon
Professor Jocelyn McPhie, BA Hons (Macquarie), PhD (UNE)	Volcanic facies architecture and volcanic textures 50
Dr Sebastien Meffre, BSc Hons, PhD (Sydney)	Petrology and tectonics of the SW Pacific 100
Dr Karin Orth, BSc Hons (Monash), PhD (UTAS)	Volcanology 100
Associate Professor Anya Reading, BSc Hons (Edinburgh), PhD (Leeds)	Geophysics, seismology, computational methods 50
Dr Michael Roach, BSc Hons (Newcastle), PhD (UTAS)	Geophysical responses of ore deposits 20
Dr Robert Scott, BSc Hons, PhD (Monash)	Structural geology, gold deposits / MTEC Senior Lecturer and Masters Program Coordinator 70
Dr David Selley, BSc Hons (Adelaide), PhD (UTAS)	Structural geology, basin analysis, ore deposit modelling 80
Jeff Steadman, BSc (Central Missouri), MSc (Iowa)	Ore and sedimentary pyrite geochemistry; seawater composition through geologic time 100
Dr Aleksandr (Sasha) Stepanov, MSc (Novosibirsk), PhD (ANU)	Geochemistry of rare metals 100
Dr Lejun Zhang, BSc, PhD (HFUT)	Porphyry Cu-Au and HS epithermal 100



Staff in the Tea Room.

ACADEMIC/RESEARCH STAFF BASED AT COLLABORATIVE INSTITUTIONS/INDUSTRY

Name		%
Dr Daniel Bombardieri	Mineral Resources Tasmania	Hon
Professor Ray Cas	Monash University	Hon
Kathy Ehrig	BHP Billiton	Hon
Associate Professor Jeff Foster	Sirius Resources	Hon
Professor Mark Hannington	University of Ottawa	Hon
Dr Anthony Harris	Newcrest Mining	Hon

Name		%
Professor Peter Hollings	Lakehead University	Hon
Professor Bernd Lottermoser	University of Exeter	Hon
Dr Tony Webster	University of Queensland	Hon
Dr Noel White	Consultant	Hon
Dr Jamie Wilkinson	Imperial College London	Hon

TECHNICAL/ADMINISTRATIVE STAFF

Name		%
Mr Steve Calladine	Communications Manager	100
Mrs Michele Chapple-Smith	Lapidary Technician	40
Mr Alex Cuison	Lapidary Technician	80
Ms Sarah Gilbert, BSc Hons (UTAS)	Laboratory Manager ICP-MS	100
Dr Jane Higgins, BIS, BAntSt Hons, PhD (UTAS)	Personal Assistant to the Director	80
Mr Ian Little, BSc Hons (UTAS)	Maintenance, Field Equipment, and Safety Officer	50
Ms Elena Lounejeva	Laboratory Analyst	100
Mrs Katie McGoldrick	Laboratory Assistant	20

Name		%
Ms Caroline Mordaunt, BA Hons (King's College London)	Administrative Assistant	20
Dr Paul Olin, BA (SOU), MSc, PhD (WSU)	Laboratory Analyst	100
Ms June Pongratz	Publications	5
Mrs Claire Rutherford	Administrative Assistant	40
Mr Jay Thompson, BSc Hons, MSc (U Iowa)	Laboratory Analyst	100
Mrs Jennifer Thompson, BSc (OSU), MSc (U Iowa)	Laboratory Analyst	50
Ms Isabella von Lichten, BSc Hons (UTAS)	Curator	15

ADVISORY BOARD

Name	
Chair: Paul Heithersay	Department of State Development, South Australia
Deputy Chair: Paul Agnew	Rio Tinto Exploration
Margaret Britz	Dean, Faculty of Science, Engineering and Technology, UTAS
David Cooke	CODES, UTAS
Paul Cromie	Anglo American
Joe Cucuzza	AMIRA International
Leonid Danyushevsky	CODES, UTAS
Andrew Davies	Teck Resources

Name	
John Dickey	Head, School of Physical Sciences, UTAS
Kathy Ehrig	BHP Billiton
Bruce Gemmell	CODES, UTAS
John Holliday	Consultant
Andrew McNeill	Mineral Resources Tasmania
Colin Moorhead	Newcrest Mining
Paddy Nixon	DVC Research, UTAS
Aubrey Paverd	Buenaventura
Noel White	Consultant

EXECUTIVE COMMITTEE

Name	
Chair: Bruce Gemmell	Director
Steve Calladine	Communications Manager
David Cooke	Deputy Director, and Transforming the Mining Value Chain Hub Director
Leonid Danyushevsky	Enabling Technologies Module Leader
Garry Davidson	Ore Deposits: Characterisation and Context Module Leader

Name	
Julie Hunt	Geometallurgy Module Leader
Jocelyn McPhie	Training Module Co-Leader/Head of the Discipline of Earth Sciences
Helen Scott	UTAS Financial Services
Robert Scott	Training Module Co-Leader

SCIENCE PLANNING PANEL

(also includes the Executive Committee and all CODES Research Staff and Students)

Name	
Chair: Bruce Gemmell	Director, CODES
Paul Agnew	Rio Tinto Exploration
Edwin Bonilla	NICTA
John Dickey	Head, School of Physical Sciences, UTAS
Kathy Ehrig	BHP Billiton
John Everard	Mineral Resources Tasmania
Bruce Godfrey	Australian Scientific Instruments
Will Goodall	University of Queensland
Anthony Harris	Newcrest Mining
Paul Heithersay	Department of State Development, South Australia
Tony Hope	GHD

Name	
Andrew McNeill	Mineral Resources Tasmania
Colin Moorhead	Newcrest Mining
Javier Ortuzar	Anglo American
Aubrey Paverd	Buenaventura
Michael Perfit	University of Florida
Leon Rawson	GHD
Adele Seymon	AMIRA International
Daniel Steinberg	NICTA
Brett Stewart	Mineral Resources Tasmania
Steve Turner	Newmont Asia Pacific
Steve Walters	CRC ORE
Noel White	Consultant



QUALITY STAFF, OPERATING
IN A TEAM ENVIRONMENT,
HAVE BEEN KEY FACTORS
IN CODES' SUCCESS

*Rebecca Carey inspecting pumice from the 2012
Havre submarine volcanic eruption that found its
way to Tasmanian shores during the year.*

MODULE

ORE DEPOSITS: CHARACTERISATION AND CONTEXT

OBJECTIVE

To describe the geological 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 is the result of the amalgamation of the Location, Formation and Discovery Programs, which were in operation until the end of 2013, when CODES' tenure as a funded ARC Centre of Excellence (CoE) came to an end. Key objectives in the amalgamation were to ensure that all the well established and valued research capabilities were maintained within an expanded framework that better caters for the needs of key stakeholders, particularly those in the minerals industry.

As a result, many of the projects under the CoE structure have been maintained, alongside new initiatives that ensure that the Centre's fundamental and applied research continues to expand and evolve.

As a reflection of CODES' diversity in the field of hard-rock geology, the new Module has six themes, with a current total of 25 projects.

HIGHLIGHTS

Despite being in its inaugural year, the Module enjoyed a relatively smooth transition from the Program structure in place in 2013. Many of the older projects evolved and adjustments were made, where appropriate, to ensure that they were well positioned to build on their achievements. These studies were augmented by a number of exciting new projects that came on stream during the period.

FINAL REPORTS AND MEETINGS

The year also saw the conclusion of some of CODES most successful and long running projects. The final meeting of the 'Enhanced geochemical targeting in magmatic-hydrothermal systems' project, AMIRA P1060, was held in June. This initiative had the support of 20 industry sponsors, making it the largest exploration-based research project in AMIRA's history. In November, the final report was delivered to sponsors of the Ore Deposits of SE Asia project, which greatly enhanced the geological knowledge of mainland SE Asia, and more recently of Sumatra. Both projects built on earlier CODES research, and negotiations are in progress for them to continue to evolve via new initiatives (see Looking Forward section).

PUBLICATIONS

It was an excellent year for publications, with 50 refereed journal articles being published that were directly related to the Module. Highlights included:

- Special Issue of *Economic Geology* devoted to 'Alkalic Porphyry Cu-Au and Epithermal Au Deposits'. The publication includes contributions from 15 authors affiliated to CODES.
- Research from the SE Asia project was featured in the print version of a special issue of *Gondwana Research* entitled *Tectonics and Metallogeny of Mainland SE Asia*. The publication included 12 authors affiliated to CODES.





RESEARCH OUTCOMES

For such a large Module, space restrictions do not allow inclusion of research activities from all the projects. However, here is a selection of some of the major highlights from the Module as a whole.

- Jacqui Halpin and Peter McGoldrick were the focus of intense media attention when they announced that they had established a strong prehistoric connection between Tasmania and western North America. The research findings, associated with the Rock Cape Group in NW Tasmania, were published in *Precambrian Research*.
- Master of Economic Geology student Billy Beas' research accurately defined the setting and age of gold deposits in northern Peru.
- A geophysics team, led by Anya Reading, obtained new 3D images of the seismic structure beneath Bass Strait.
- PhD student Jodi Fox produced a new geological map of Heard Island using satellite imagery.
- A team led by Ross Large produced a database that provides the basis for using pyrite as a prospective fertility and vectoring tool.
- PhD student Selina Wu completed her study of the mineralogical and geochemical characteristics of district-scale alteration in the Que Hellyer District in the Mount Read Volcanics.

AWARDS

In addition to the awards listed below, a number of students associated with the Module received recognition during the year. These achievements are covered in the SEG Student Chapter's report in the Training Module section of this document.

- Rebecca Carey received the UTAS Vice Chancellor's Award for Research Excellence.
- David Cooke was presented with the SEG Silver Medal, and collaborator Noel White with the SEG Penrose Gold Medal, at SEG 2014, held in Keystone, Colorado, USA.
- Research related to the AMIRA P765/P765A and P1060 projects won the 'Measurement in Action' category at the prestigious UK-based Institute of Engineering and Technology's Innovation Awards in London.
- Sam Holt received the GSA's David Groves Medal for 'the best paper in the *Australian Journal of Earth Sciences* by a young Australia'.
- Stephanie Sykora achieved first place in the student poster presentation category at the SEG's annual conference in Keystone, Colorado, USA.

Top: Rebecca Carey (centre) with Jocelyn McPhie and Bruce Gemmell after she received the UTAS Vice Chancellor's Award for Research Excellence. *Centre:* David Cooke receiving the SEG Silver Medal from Judith A. Kinnaird, who was President of the SEG at that time. *Bottom:* All the winners at the UK-based Institute of Engineering and Technology's Innovation Awards in London. Collaborator Jamie Wilkinson (middle row, centre) accepted the award on behalf of CODES.

MEET THE TEAM



LEADER:

Garry
Davidson

TEAM MEMBERS:

Mike Baker, Ivan Belousov, Daniel Bombardieri, Stuart Bull, Rebecca Carey, David Cooke, Matt Cracknell, Leonid Danyushevsky, Paul Davidson, Nathan Fox, Bruce Gemmell, Dan Gregory, Jacqui Halpin, Nic Jansen, Maya Kamenetsky, Vadim Kamenetsky, Joe Knight, Chun-kit Lai, Ross Large, Elena Lounejeva, Takayuki Manaka, Peter McGoldrick, Jocelyn McPhie, Sebastien Meffre, Karin Orth, Anya Reading, Michael Roach, Robert Scott, David Selley, Jeff Steadman, Sasha Stepanov, Jay Thompson, Jennifer Thompson, Craig Winter, Khin Zaw, Lejun Zhang

PHD STUDENTS:

Olga Apukhtina, Mohd Basril Iswadi Bin Basori, Heidi Berkenbosch, Alexander Cherry, Esmaeil Eshaghi, Pedro Fonseca, Jodi Fox, Hugo Galván, Margy Hawke, Jacob Heathcote, Sam Holt, Qiuyue Huang, Carlos Jimenez, Sean Johnson, Erin Lawlis, Charles Makoundi, Larriana Morgan, Indrani Mukherjee, Jacob Mulder, Evan Orovan, Adam Pacey (Imperial College London), Simone Pilia (ANU), Jose Piquer, Marc Rinne, Subira Sharma, Nathan Steeves, Francisco Testa, Irma Vejelyte, Daniele Vergani, Sally Watson (IMAS), Selina Wu

MASTERS STUDENTS:

Ayat Baig (Lakehead University), Billy Beas, Djohanne Celiz, Jo Condon, Glen Deimar, Pablo Farias, Xuan Troung Le, Wes Lueck (Lakehead University), Neil Macaladad, Saranya Nuanla-Ong, Emily Smyk (Lakehead University), Stephanie Sykora

HONOURS STUDENTS:

Wayne Baker, Ashby Cooper, Tobias Erskine, Supitchaya Paipana, Naomi Potter, Jonathan Traynor, Toban Wild (Monash), Jie Yu

COLLABORATORS:

ANGLO AMERICAN

Paul Cromie

ANGLOGOLD ASHANTI

Michael Nugus

BHP BILLITON, OLYMPIC DAM

Kathy Ehrig

BRITISH GEOLOGICAL SURVEY

Mike Crow

CAMECO

Penny Large

CHIANG MAI UNIVERSITY, THAILAND

Phisit Limtrakun,
Sampan Singharajwarapan,
Weerapan Srichan

CLUMP MOUNTAIN GEOSCIENCE

Pat Williams

COLORADO STATE UNIVERSITY, USA

Holly Stein

CONSULTANT

Noel White

CSIRO

James Cleverley, June Hill

CURTIN UNIVERSITY

Fred Jourdan

DEPARTMENT OF MINERAL RESOURCES, THAILAND

Pol Chaodumrong,
Somboon Khositanont

EMMERSON RESOURCES

Hamish Johns, Grant Osborne

EXXON MOBIL

Nick Direen

FIRST QUANTUM MINERALS

David Wood

FLINDERS UNIVERSITY

John Long

GEOFORSCHUNGSZENTRUM POTSDAM, GERMANY

Rainer Thomas

GEOLOGICAL SURVEY OF FINLAND

Peter Sorjonen-Ward

GEOLOGICAL SURVEY OF JAPAN

Kenzo Sanematsu

GEOLOGICAL SURVEY OF SOUTH AUSTRALIA

Rian Dutch, Anthony Reid

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Trevor Beardsmore, Julie
Hollis, Christopher Phillips

GEOSCIENCE AUSTRALIA

Geoff Fraser, David Huston,
Terry Mernagh, Roger Skirrow

GEOSCIENCE VICTORIA

Ross Cayley

GNS NEW ZEALAND

Jannine Cooper,
Cornel de Ronde

GUANGZHOU INSTITUTE OF GEOCHEMISTRY, CHINA

Huayong Chen, Jinsheng Han

HANOI UNIVERSITY OF MINING AND GEOLOGY, VIETNAM

Hai Thanh Tran

HAWAII VOLCANO OBSERVATORY, USA

Tim Orr, Matthew Patrick,
Michael Poland

HEFEI UNIVERSITY OF TECHNOLOGY, CHINA

Shiwei Wang, Dayu Zhang,
Taofa Zhou

HOLCOMBE COUGHLIN OLIVER

Nick Oliver

IMPERIAL COLLEGE LONDON, UK

Clara Wilkinson,
Jamie Wilkinson

INSTITUTE OF TECHNOLOGY, INDONESIA

Andri Subandrio

IGLOBAL

Heidi Pass

JAMSTEC, JAPAN

Kenichiro Tani

KING ABDULAZIZ UNIVERSITY, SAUDI ARABIA

Hesham Harbi

LAKEHEAD UNIVERSITY, CANADA

Peter Hollings

MACQUARIE UNIVERSITY

Nathan Daczko,
Robyn Gardner

MINERAL RESOURCES TASMANIA

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

MIRA GEOSCIENCE

Tim Chalke

MONASH UNIVERSITY

Ray Cas, Chris Mays,
Jeff Stilwell

MURORAN INSTITUTE OF TECHNOLOGY, JAPAN

Yoshihiko Goto

NANYANG TECHNOLOGY UNIVERSITY, SINGAPORE

Alexander Belousova, Marina
Belousova, Chris Newall

NATIONAL OCEANOGRAPHY CENTRE, UK

Martin Jutzeler

NATIONAL UNIVERSITY OF SINGAPORE

Grahame Oliver

NEWCREST MINING

Benjamin Ackerman,
Antonius Bambang, Nicholas
Fitzpatrick, Anthony Harris,
Fiona Karaut, Colin McMillan,
Paul Napier, Rendy Nurdianto,
John Rutter, Daud Silitonga,
Dadan Wardiman

**NORTHERN TERRITORY
GEOLOGICAL SURVEY**

Dorothy Close,
Andrew Wygralak

OZ MINERALS

Hamish Freeman

**PITON DE LA FOURNAISE
OBSERVATORY,
REUNION ISLAND**

Andrea Di Muro

RIO TINTO EXPLORATION

Bryan Bowden

**ROYAL HOLLOWAY
UNIVERSITY OF
LONDON, UK**

Ian Watkinson

**RUSSIAN ACADEMY
OF SCIENCES**

Valeriy Maslennikov

**SMITHSONIAN
INSTITUTION, USA**

Richard Fiske

**TARBIAT MODARES
UNIVERSITY, IRAN**

Ali Sholeh

TERRAMIN AUSTRALIA

Ken Cross

UNIVERSITY OF ADELAIDE

Cristiana Ciobanu, Nigel Cook

**UNIVERSITY OF ALBERTA,
CANADA**

Robert Creaser

UNIVERSITY OF BALLARAT

Stafford McKnight

**UNIVERSITY OF BRITISH
COLUMBIA, CANADA**

Richard Friedman,
Jim Mortensen

**UNIVERSITY OF CALIFORNIA
RIVERSIDE, USA**

Tim Lyons

**UNIVERSITY OF CENTRAL
MISSOURI, USA**

Mark Dudley, John L. Nold

**UNIVERSITY COLLEGE OF
SCIENCE, TEHRAN, IRAN**

Mirsaleh Mirmohammadi

**UNIVERSITY OF
COLOGNE, GERMANY**

Maria Kirchenbaur

**UNIVERSITY
OF HAWAII, USA**

Bruce Houghton

**UNIVERSITY OF
JOHANNESBURG,
SOUTH AFRICA**

Bradley Guy

**UNIVERSITI KEBANGSAAN,
MALAYSIA**

Mohd Rozi Umor, Wan Fuad
Wan Hassan

**UNIVERSITY OF MALAYA,
MALAYSIA**

Azman Ghandi, Teh Guan Hoe

**UNIVERSITY OF
MELBOURNE**

Andy Gleadow, Barry Kohn,
Roland Maas

**UNIVERSITY OF
NEW ENGLAND**

Luke Milan

**UNIVERSITY OF
NEW SOUTH WALES**

Ian Graham

**UNIVERSITY OF
OTAGO, NEW ZEALAND**

James White

**UNIVERSITY OF
OTTOWA, CANADA**

Mark Hannington

**UNIVERSITY OF
PADJAJARAN,
BANDUNG, INDONESIA**

Mega Rosana

**UNIVERSITY
OF QUEENSLAND**

Sue Golding,
Paulo Vasconcelos

**UNIVERSITY OF SCIENCE
AND TECHNOLOGY, CHINA**

Yuling Xie

UNIVERSITY OF SYDNEY

Simon Williams

UNIVERSITY OF TASMANIA

Mike Coffin, Karsten
Goemann, Pat Quilty,
Thomas Rodemann,
Donna Satterthwait,
Joanne Whittaker

**UNIVERSITY OF WAIKATO,
NEW ZEALAND**

Alan Hogg

**UNIVERSITY OF
WESTERN AUSTRALIA**

Mark Barley

**UNIVERSITY OF
WESTERN SYDNEY**

Lin Sutherland

**WOODS HOLE
OCEANOGRAPHIC
INSTITUTION, USA**

Adam Soule

YALE UNIVERSITY, USA

Noah Planavsky

**YUKON GEOLOGICAL
SURVEY, CANADA**

Patrick Sack

CORE PROJECTS

THEME 1 – ORE FERTILITY OF THE CRUST AND MANTLE

- Melt-melt immiscibility and the origin of magnetite-apatite deposits
- Ore deposits of SE Asia

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

- VHMS research – modern
- VHMS research – ancient
- Submarine volcanology and VHMS research
- Rhyolitic caldera successions
- Basaltic volcanoes
- Carson Volcanic-Hart Dolerite LIP and Paleoproterozoic, mafic magmatism of the Kimberley Basin, Western Australia

THEME 3 – MAGMATIC-HYDROTHERMAL PROCESSES AND ORES

- Exploring the porphyry environment
- Olympic Dam
- Epithermal deposits
- Enhanced geochemical targeting in magmatic-hydrothermal systems (AMIRA P1060)

THEME 4 – BASIN PROCESSES, OCEAN CHEMISTRY, AND ORES

- McArthur Basin copper project
- Kansanshi gold project
- Global ocean chemistry, marine basins and mineralisation
- Uranium concentration in basins
- Trace elements in the ocean (TEO)

THEME 5 – THE ORE AFFECTED CRUST

- The power of pyrite
- Integrated geology and geophysical modelling and exploration targeting in the Lyell-Rosebery region
- Metamorphic architecture of the western Gawler Craton
- Application of carbonate C-O isotopes to ore genesis and exploration
- Australian hydrothermal IOCG and related deposits

THEME 6 – DATES AND PLATES

- Age, affinity and provenance of Tasmanian Proterozoic metasedimentary successions
- Tectonic reconstruction of East Gondwana
- Structure of SE Australia using multiple geophysical methods

PROJECT SUMMARIES

THEME 1 – ORE FERTILITY OF THE CRUST AND MANTLE

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

Leader: Paul Davidson

Team Member: Vadim Kamenetsky

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

Over the past few decades, melt-melt immiscibility has gone from being a laboratory curiosity to a process that may rank with fractionation as a significant, if subordinate, driver of magma evolution, and thus crustal evolution. In this group of related processes, melts spontaneously split into two or more mutually immiscible phases at specific TPX conditions. In contrast to fractionation, melt-melt immiscibility is a sudden, intense, stepwise change in magma composition.

This project is studying various forms of melt-melt immiscibility, particularly Fe-Ti oxide melt-silicate melt immiscibility (Kiruna-type magnetite-apatite deposits) and silicate melt-silicate melt immiscibility (pegmatites), with a view to understanding the generation of economically valuable ore-deposits. Extensive melt inclusion studies on samples from these types of deposits have provided considerable evidence of melt-melt immiscibility, with silicate, carbonate, sulfide, and Fe-Ti oxide components observed in a number of combinations in various melt inclusions.

A major review paper on Fe-Ti oxide ore bodies has been published in *Ore Geology Reviews* via collaborators, and a further paper is in progress related to pegmatite studies. The latter research has also resulted in two keynote presentations at international conferences during the year by the team.

ORE DEPOSITS OF SE ASIA

Leader: Khin Zaw

Team Members: Joe Knight, Chun- kit Lai, Ross Large, Takayuki Manaka,

Students: Mohd Basril Iswadi Bin Basori, Tobias Erskine, Xuan Truong Le, Charles Makoundi, Saranya Nuanla-Ong, Supitchaya Paipana, Jonathan Traynor

Collaborators: Mark Barley, Alexander Belousova, Marina Belousova, Pol Chaodumrong, Paul Cromie, Mike Crow, Azman Ghandi, Sue Golding, Ian Graham, Wan Fuad Wan Hassan, Teh Guan Hoe, David Huston, Somboon Khositantont, Phisit Limtrakun, Terry Mernagh, Chris Newall, Grahame Oliver, Mega Rosana, Kenzo Sanematsu,



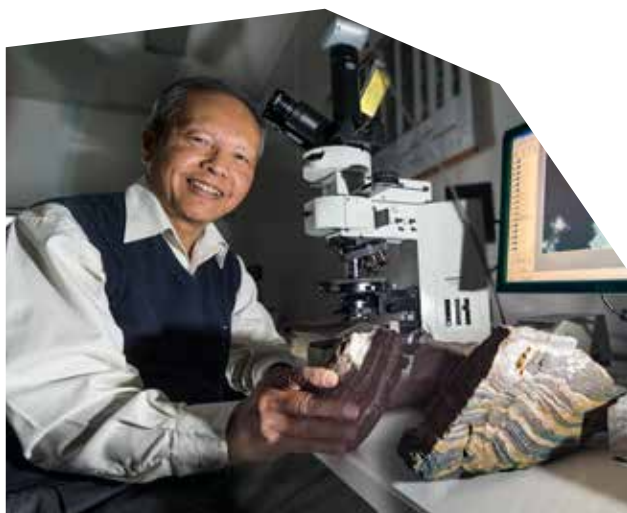
PhD student Charles Makoundi examining deformed quartz-carbonate veins in bedded, carbon-rich sandstones belonging to the Early Silurian Setul Formation, Langkawi Island, Malaysia.

Sampan Singharajwarapan, Weerapan Srichan, Holly Stein, Andri Subandrio, Lin Sutherland, Hai Thanh Tran, Mohd Rozi Umor, Paulo Vasconcelos, Ian Watkinson

This highly successful project came to a conclusion during the year, with a final report being delivered to the sponsors in November. Commencing in 2011, it built on the fruitful outcomes of two previous projects that examined the age, style and origin of key ore deposits in SE Asia in the context of regional tectonic and magmatic cycles. In recent times, the scope of research was expanded to encompass the whole of mainland SE Asia and Sumatra.

In line with its aims, the following major outcomes were achieved over the life of the project:

- A regional tectonic and metallogenic analysis of the mineralised fold belts in mainland SE Asia.
- Deposit-scale studies were conducted to characterise many of the important ore deposits.



Ore Deposits of SE Asia project leader Khin Zaw.

- Sponsor companies were provided with an increased understanding of ore deposit location, formation and evolution.
- A new understanding was developed of the geological and tectonic events that formed ore deposits in SE Asia.
- A new, well-constrained, dated, and documented geological framework was provided that enables better exploration targeting within the region.

New findings and activities in the final year of the project included:

- Using field, geochemical and geochronological data from the project combined with published information, entirely new tectonic and terrane elements from within mainland SE Asia were documented.
- The western part of Sibumasu Terrane has a highly complex Mesozoic-Recent geological history, driven by the interactions of the oblique subduction of the Mesotethys and Neotethys beneath West Myanmar-Sumatra, the tectonic coupling of West Myanmar with India during the India-Asia collision, and the extrusional tectonics of mainland SE Asia.
- Geochemistry of Palaeozoic black shale in Malaysia indicates that higher concentrations of gold are predominately found in diagenetic pyrites. Gold and silver have a strong correlation in framboidal ($R=0.901$) and hydrothermal ($R=0.711$) pyrites. The genesis of existing orogenic gold deposits in East Malaya may be related to early gold enrichment in diagenetic pyrites hosted in black shales, which was later remobilised during deformation. These results provide key criteria for the two-stage metallogenic model for gold mineralisation within the Bentong-Raub Suture, which is part of the Palaeo-Tethys Suture Zone.

- Overall, mainland SE Asia has a unique tectonic evolution of continental microplates, subduction events and collisions, and a unique set of ore deposits formed at specific times and locations.
- Studies show that the existence of epithermal- and sediment-hosted ore deposits in many SE Asian countries imply immense exploration potential for deeper-level porphyry- and porphyry-related skarn deposits in these regions.

Although the project has come to an end, it is anticipated that negotiations will be held with industry sponsors to support a new project related to the tectonics and origin of the copper-gold mineralisation of the western Myanmar-Sumatra Terrane.

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

VHMS RESEARCH – MODERN

Leader: Bruce Gemmell

Student: Heidi Berkenbosch

Collaborators: Cornel de Ronde, Andrew McNeill

Heidi Berkenbosch's PhD project at Brothers volcano, in the Tonga-Kermadec arc, continued in 2014. This collaborative project with GNS, New Zealand (Cornel de Ronde) is investigating the ore and gangue mineralogy, textures, paragenesis, mineral chemistry and copper isotopes of the sulfide-sulfate chimneys.



PhD student Nathan Steeves underground at the Greens Creek mine.

A paper on the Cu isotopes of the chimneys has been accepted by *Mineralium Deposita* and will be published in early 2015. Two papers were co-authored in *Economic Geology* in 2014, on the S-Su Knolls hydrothermal field (PNG), and the Palinuro Volcanic Complex (offshore Italy).

VHMS RESEARCH – ANCIENT

Leader: Bruce Gemmell

Team Members: Ross Large, Khin Zaw

Students: Mohd Basril Iswadi Bin Basori, Jo Condon, Margy Hawke, Nathan Steeves, Selina Wu

Collaborators: Mark Hannington, Andrew McNeill, Jim Mortensen

The genesis of volcanic-hosted Cu-Pb-Zn-Ag-Au massive sulfide deposits is being investigated across the spectrum of massive sulfide deposit types, from typical seafloor VHMS (Zn-Pb-Cu-Ag-Au) deposits, through sub-seafloor shallow-water, replacement Au-rich epithermal styles, to deep sub-volcanic intrusion-related Cu-Au-rich styles. In 2014, research was undertaken on deposits at Fossey-Hellyer-Que-River-Mt Charter (Tasmania), DeGrussa (Western Australia), Greens Creek (Alaska) and Tasik Chini (Malaysia).

Selina Wu completed her PhD study on the VHMS deposits in the Que-Hellyer Volcanics, western Tasmania. Selina has been investigating the geologic setting and genetic relationships of the Fossey-Hellyer-Que-River-Mt Charter deposits and the distribution of hydrothermal alteration throughout the district.

Nathan Steeves continued his PhD investigation of the Greens Creek VHMS deposit in southeast Alaska. Nathan is studying the mineralogy, metal distribution and geometallurgical characteristics of the complex ore bodies. The study is being conducted in collaboration with Mark Hannington from the University of Ottawa.

Mohd Basril Iswadi Bin Basori completed his PhD thesis on the geochemical, isotopic and genetic aspects of the Tasik Chini and related VHMS hydrothermal systems in Malaysia. Three styles of massive sulfide mineralisation are distinguished in the Bukit Botol deposit area: a) stratiform sulfide lenses; b) disseminated sulfide; and c) stringer sulfide mineralisation. At Bukit Ketaya, massive sulfide forms as stratiform sheets, overlain by a layer of Mn-Fe-rich exhalites and barite.

Two student projects continued at Sandfire Resources' VHMS deposit at DeGrussa, WA. The first, a PhD project by Margy Hawke, is investigating the geologic, structural and geochronological setting of the deposits. The second is a project by Jo Condon, which is concentrating on the ore and gangue mineralogy, textures, paragenesis, and mineral chemistry of two of the ore lenses.



Jodi Fox (L) and Jocelyn McPhie on top of a mega-pillow, Stanley, Tasmania.

The final project in this summary is aimed at improving the age, and geochronological, constraints on the development of the Mount Read Volcanic Belt (MRV) in collaboration with Jim Mortensen (UBC) and Andrew McNeill (MRT). Work included U-Pb dating of zircons, which produced many new dates that have helped to constrain the timing of the development of the MRV and associated VHMS mineralisation. A manuscript was accepted for publication, and will appear in *Economic Geology* in early 2015. A second phase of age dating throughout the MRV is being completed and a second publication is being prepared.

SUBMARINE VOLCANOLOGY AND VHMS RESEARCH

Leader: Jocelyn McPhie

Team Member: Rebecca Carey

Students: Wayne Baker, Pedro Fonseca

Collaborators: Ray Cas, Richard Fiske, Martin Jutzeler, Adam Soule

Pedro Fonseca's PhD project on the internal stratigraphy and architecture of the Mount Read Volcanics in western Tasmania has achieved correlation between the host sequences to two very important VHMS deposits, Hellyer in the north and Rosebery in the south. Pedro has also produced detailed reconstructions of the volcanic setting and volcano types for the periods before, during and after the VHMS mineralising events at these locations. Pedro's project is due for completion in early 2015.

Honours student Wayne Baker began a project mid-year at the Archaean DeGrussa VHMS deposit, Western Australia, supervised by Visiting Professor Ray Cas, and sponsored

by Sandfire Resources. The project is concentrating on the volcanology and stratigraphy of the host succession in order to improve the exploration model and to refine current ideas on the deposit genesis.

Former CODES' PhD student, Martin Jutzeler, published two papers based on his PhD project. The project focussed on submarine pyroclastic successions in the USA, New Zealand and Japan. In a *Bulletin of Volcanology* paper, Martin argued for a new interpretation of the Dogashima Formation, Japan, challenging entrenched models for submarine explosive eruption plumes. The Ohanapecosh Formation in Washington has also been important in submarine volcanology, being one of the first submarine pyroclastic successions to be recognised. Martin provided new field and textural data in a paper in the *Bulletin of the Geological Society of America*, demonstrating that most of the formation was deposited from subaqueous density currents sourced from subaerial pyroclastic flows that crossed the coast.

Rebecca Carey won a National Science Foundation Research Grant (USA) that will fund a research cruise to study the aftermath of the 2012 explosive submarine eruption of Havre volcano. This eruption took place in at least 900 m of water and produced a large, long-lived pumice raft and weak subaerial plume. Rebecca and co-authors published a paper outlining the setting and style of the eruption in *EOS*, and another paper in *Nature Communications* with Martin Jutzeler, describing the pumice raft and comparing its path with predictions of numerical models. The 2015 Havre research cruise will map and sample the submarine products of the 2012 eruption, and will provide an unprecedented sample and data set for further volcanological research.



Jocelyn McPhie observing pillow lava at Cape Grim, Tasmania.

Jocelyn McPhie was invited to join an international team in writing a proposal to the Continental Scientific Drilling Project for the drilling of Surtsey, a famous Icelandic volcanic island created by offshore basaltic eruptions in 1963-67. The proposed drilling will recover core that can be used to answer numerous volcanological questions relating to the submarine part of the island, and also the active hydrothermal system in the core of the volcano.

RHYOLITIC CALDERA SUCCESSIONS

Leader: Jocelyn McPhie

Team Member: Bruce Gemmell

Student: Billy Beas

Collaborators: Yoshihiko Goto, Kenichiro Tani

Jocelyn McPhie and Associate Professor Yoshihiko Goto undertook fieldwork in Hokkaido, Japan, investigating the architecture of a Quaternary rhyolitic caldera volcano that has been the source of at least ten large explosive eruptions in the past 340 ka. Yoshihiko Goto visited CODES in September, working with Jocelyn analysing the results and preparing a manuscript that has been submitted for publication in *Geology*.

Master of Economic Geology student Billy Beas is working on a volcanology and geochronology project sponsored by Minera La Zanja in northern Peru. His study area includes several high-sulfidation gold deposits, three of which are currently being mined. The district comprises diverse, subaerial, caldera-related rhyolitic ignimbrites, as well as dacitic and andesitic domes and high-level intrusions. In 2014, Billy produced a new map and stratigraphy of the region, and used U-Pb zircon dates to clarify the ages and duration of the main volcanic and mineralising episodes. Billy's thesis is due for completion in early 2015.

BASALTIC VOLCANOES

Leader: Jocelyn McPhie

Team Members: Rebecca Carey, Vadim Kamenetsky

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

Collaborators: Andrea Di Muro, John Everard, Bruce Houghton, Andrew McNeill, Tim Orr, Matthew Patrick, Michael Poland, Lin Sutherland, James White

Research on basaltic eruptions and their products is underway at five locations: Hawaii (USA), Piton de la Fournaise (Reunion Island), Cape Grim (Tasmania), Heard Island, and Etna (Italy).

Sam Holt's PhD project is focussing on explosive basaltic eruptions, using samples and other data from recent events on Kilauea, and historic and pre-historic 'rootless' littoral eruptions on the flanks of Mauna Loa. Detailed microtextural analyses are being integrated with field and geophysical data in order to understand the primary controls on eruption intensity. This project is being conducted in collaboration with the Hawaii Volcano Observatory.

Daniele Vergani is working on the 2007 eruption of Piton de la Fournaise volcano. The 2007 eruption contrasted markedly from the typical Piton de la Fournaise eruptions in being long-lived (32 days), consisting of both effusive and explosive phases from multiple vents, generating a large volume of deposits, and featuring a rare caldera collapse event. This eruption was very well documented by collaborators at the Piton de la Fournaise Volcano Observatory. Daniele is combining photographic records, geophysics, and data from samples (grainsize, componentry, microtextural analyses) to explore the controls on the summit, flank and littoral explosive activity.

Jodi Fox is studying basaltic intraplate volcanism at Cape Grim, northwestern Tasmania, and on Heard Island. Jodi has produced a new geological map of Heard Island using high-resolution satellite imagery and samples available from several expeditions. Selected samples have been submitted for Ar/Ar dating, the results from which will clarify the age of onset and duration of subaerial eruptions from Heard Island vents. Jodi has also mapped and sampled a very well exposed, mainly submarine Tertiary basaltic succession at Cape Grim. She has discovered new field exposures that suggest the current stratigraphy requires revision. This succession will also be dated to clarify both the order and duration of the eruptions.

Honours student Naomi Potter undertook a project on the products of basaltic high fountaining events on Etna, during an eruption in 2013, using a sample set collected by Rebecca Carey. Naomi generated new data on the vesicularity and microtextures that, together with geochemical information from melt inclusion analyses, allowed detailed reconstruction of the degassing history and its links to the eruption dynamics.

CARSON VOLCANIC-HART DOLERITE LIP AND PALEOPROTEROZOIC, MAFIC MAGMATISM OF THE KIMBERLEY BASIN, WESTERN AUSTRALIA

Leader: Karin Orth

Collaborators: Julie Hollis, Christopher Phillips

The Carson Volcanic-Hart Dolerite Large Igneous Province (LIP) project ended in June 2014. Project findings were reported via a poster, a presentation at the Geological Society of Western Australia (GSWA) Open Day, and PICO Presentations at the European Geoscience Union Congress

in Vienna, and at the AESC in Newcastle. An annual report, summarising the findings of the project between 2013 and 2014, was lodged with the GSWA in April.

Fieldwork was completed in June and August on a new year-long collaborative research project with GSWA, entitled 'Paleoproterozoic, mafic magmatism of the Kimberley Basin, Western Australia'. Results from this work, combined with the earlier project, were reported at the GSWA Annual Lectures and at a special one day Kimberley Workshop in Perth in November.

THEME 3 – MAGMATIC-HYDROTHERMAL PROCESSES AND ORES

EXPLORING THE PORPHYRY ENVIRONMENT

Leaders: David Cooke, David Selley

Team Members: Nic Jansen, Sasha Stepanov

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

Collaborators: Benjamin Ackerman, Antonius Bambang, Jannine Cooper, Robert Creaser, Nicholas Fitzpatrick, Richard Friedman, Anthony Harris, Alan Hogg, Fred Jourdan, Fiona Karaut, Roland Maas, Stafford McKnight, Colin McMillan, Paul Napier, Rendy Nurdianto, John Rutter, Daud Silitonga, Dadan Wardiman

The team is working in close collaboration with Newcrest Mining in order to obtain new knowledge and maximise opportunities for the discovery of porphyry and epithermal related gold resources in the South West Pacific region. The team is conducting research that is advancing the conceptual models and exploration techniques at the



Black rocks of Hart Dolerite amongst upended sandstone, Kimberley, WA.

relevant deposits and districts. This new knowledge is then passed directly to Newcrest geologists with onsite training. The close working relationship with Newcrest is facilitated by the company's strong leadership in research, both logistically and financially.

Multidisciplinary research in the Gosowong epithermal district was undertaken by David Selley and Nic Jansen. This work has led to significant advances in the understanding of the stratigraphic and structural evolution of the mineral field, its influence on magma emplacement, hydrological architecture, and ore localisation. Integration of multi-layer datasets within a newly developed 3-D geological model reveals transient magmatic-hydrothermal input to the meteoric-dominant system, and robust geochemical and mineralogical vectors of fluid inflow and outflow. A parallel study of quartz chemistry, led by Sasha Stepanov, provided further evidence for the hybrid character of the mineral system, and chemical fingerprints of fluid outflow.

Student research activities at the Lihir gold mine included Stephanie Sykora's structural analysis of the so-called 'anhydrite seal', and Erin Lawlis's studies of the Kapit NE ore body. The detailed and systematic methods applied to these studies have provided robust geometric and temporal constraints on the deposit's complex evolution of volcano-magmatic assembly, and subsequent mechanically- and chemically-induced collapse. This insight has the potential to greatly enhance our understanding of the porphyry-epithermal transition.

Marc Rinne completed his PhD study of the Wafi-Golpu deposit in Papua New Guinea, demonstrating unequivocal genetic links between porphyry Cu, high-sulfidation and intermediate-sulfidation state epithermal gold mineralisation.

Evan Orovan's PhD study of the Waisoi porphyry Cu-Au deposits in Fiji neared completion. New high-precision geochronology established the absolute ages of mineralisation at each deposit, and allowed for the evolution of mineralisation in the district to be related to the Late Miocene tectonic evolution of Fiji.

OLYMPIC DAM

Leaders: Jocelyn McPhie, Vadim Kamenetsky

Team Members: Maya Kamenetsky, Sebastien Meffre, Jay Thompson

Students: Olga Apukhtina, Alexander Cherry, Glen Deimar, Qiuyue Huang, Irma Vejelyte

Collaborators: Cristiana Ciobanu, Nigel Cook, Ken Cross, Kathy Ehrig, Karsten Goemann, Maria Kirchenbaur, Roland Maas

Research at Olympic Dam seeks to clarify the setting, age and origin of this supergiant Cu-U-Au-Ag deposit. The project was initiated in 2008 with funding from BHP Billiton, which concluded in 2014. Studies so far have generated four papers (three in *Geology*, one in *Economic Geology*) and nine confidential reports. Additional manuscripts are in preparation.

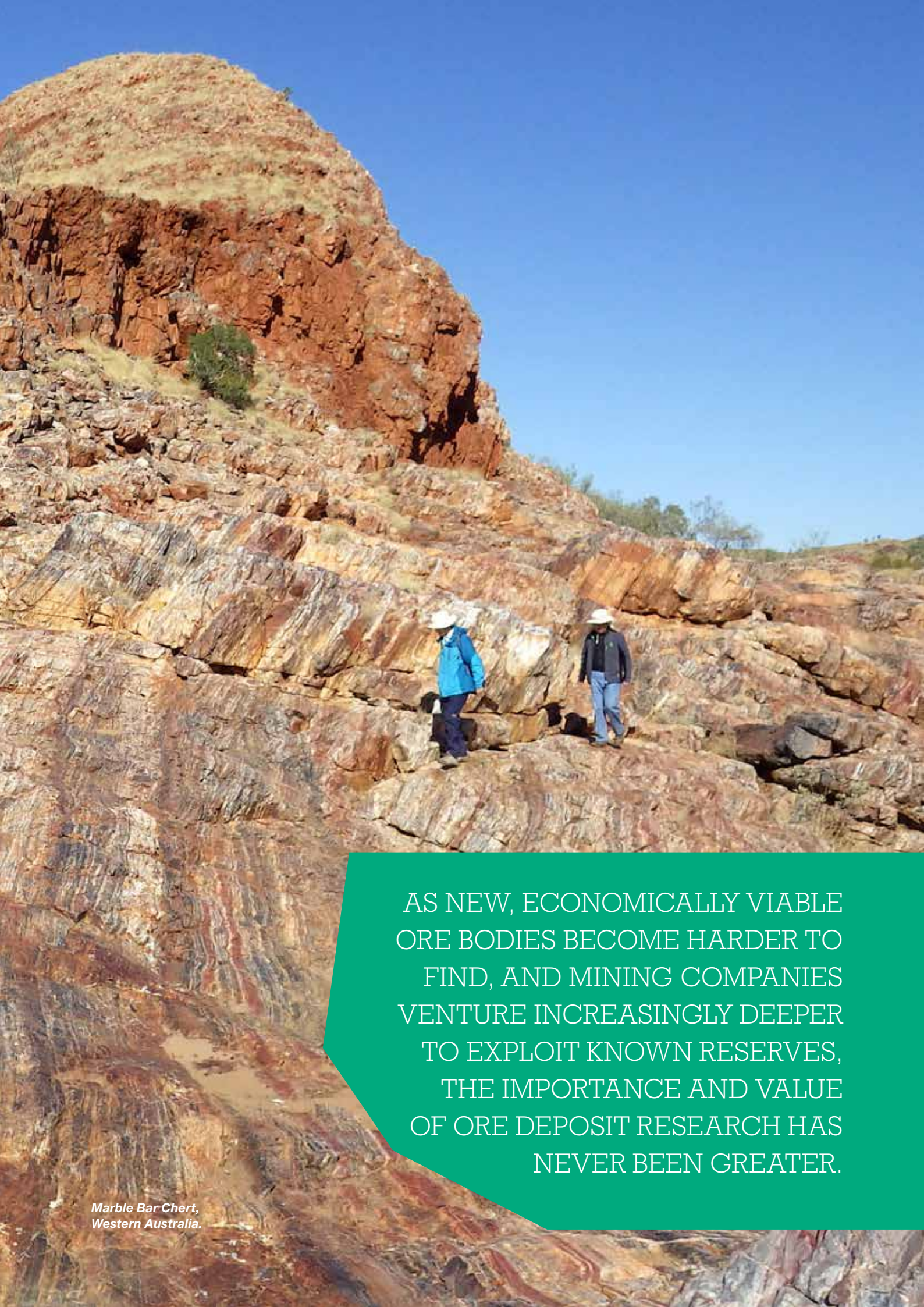
Highlights of the year included:

- PhD student Olga Apukhtina completed collection of textural and compositional data on the carbonates, and is preparing a manuscript presenting her findings.
- PhD student Qiuyue Huang completed geochemical and geochronological analyses of picritic and basaltic rocks and dolerite dykes that predate and postdate, respectively, the Olympic Dam Breccia Complex. His results demonstrate a clear correlation with the ~820 Ma Gairdner Dyke Swarm, which is part of the Gairdner Large Igneous Province.
- PhD student Irma Vejelyte is studying the setting of IOCG mineralisation at Wirrda Well, 20 km southwest of Olympic Dam. Irma finished collection of field and analytical data, and began writing her thesis.
- PhD student Alexander Cherry joined the project and began research concentrating on the bedded clastic facies at Olympic Dam.
- The team continued to generate petrographic, mineralogical and geochronological data on all types of rocks present at the site, which should eventually result in a new view on the age and duration of ore-forming events at the deposit.
- A new collaboration was initiated with Cristiana Ciobanu and Nigel Cook from the University of Adelaide.

Ongoing research at Olympic Dam falls under the umbrella of the ARC Linkage Project won by the team and supported by BHP Billiton as the Partner Organisation (2013-2016).



Members of the Olympic Dam project team during a meeting at CODES.



AS NEW, ECONOMICALLY VIABLE
ORE BODIES BECOME HARDER TO
FIND, AND MINING COMPANIES
VENTURE INCREASINGLY DEEPER
TO EXPLOIT KNOWN RESERVES,
THE IMPORTANCE AND VALUE
OF ORE DEPOSIT RESEARCH HAS
NEVER BEEN GREATER.

*Marble Bar Chert,
Western Australia.*



Quartz and bladed anhydrite,
Lihir gold deposit, PNG.

EPITHERMAL DEPOSITS

Leader: Bruce Gemmell

Team Member: Nic Jansen

Students: Hugo Galván, Erin Lawlis, Stephanie Sykora

Collaborators: Anthony Harris, David Huston, Ali Sholeh

The geology and genesis of low- and high-sulfidation epithermal deposits are being investigated in Australia and in the southwest Pacific region. Research has concentrated on determining the geological and geochemical constraints on the formation of these deposits, which will lead to improved genetic and exploration models.

PhD student Erin Lawlis continued her thesis on the modern geothermal system associated with the low-sulfidation Ladolam Au deposit in PNG. This research is supported by Newcrest.

MSc student Stephanie Sykora continued her research into the structural evolution from porphyry to epithermal conditions recorded by anhydrite veins and cemented breccias at the Lihir Au deposit, PNG. Stephanie won the best student poster award at the Society of Economic Geologists' conference in Keystone, Colorado. This research is also supported by Newcrest.

A manuscript was submitted to *Economic Geology* based on the PhD research of Ali Sholeh (Tarbiat Modares University, Iran), who visited CODES in 2012 to undertake petrologic, mineralogical and LA-ICP-MS analyses. Working with Bruce Gemmell and David Huston (Geoscience Australia), Ali investigated the low sulfidation epithermal gold deposits associated with the Bazman Volcano in the western Makran Volcanic Arc, southeast Iran.

PhD student Hugo Galván graduated. Hugo's thesis was on the epithermal silver-gold-bearing veins at Palmarejo, Guadalupe and La Patria, Chihuahua, Mexico. Hugo's research was supported by Coeur d'Alene Mines Corporation.

ENHANCED GEOCHEMICAL TARGETING IN MAGMATIC-HYDROTHERMAL SYSTEMS (AMIRA P1060)

Leaders: David Cooke, Bruce Gemmell, Mike Baker

Team Members: Nathan Fox, Elena Lounejeva, Jennifer Thompson, Lejun Zhang

Students: Ayat Baig, Djohanne Celiz, Carlos Jimenez, Wes Lueck, Neil Macaladad, Adam Pacey, Jose Piquer, Emily Smyk, Francisco Testa

Collaborators: Huayong Chen, Peter Hollings, Noel White, Clara Wilkinson, Jamie Wilkinson

This initiative commenced in June 2011, building on research carried out within AMIRA P765A, which concluded in late 2010. The project was conducted in collaboration with Lakehead University and Imperial College London, and had the support of 20 industry sponsors, making it the largest exploration-based research project in AMIRA's history. The project concluded in June 2014, with the final sponsors meeting held at CODES.

The aims of the project were to develop and refine new geochemical and geological tools that will help explorers to determine the locations of porphyry and epithermal deposits, discriminate between different styles of mineralisation, and assess the fertility of individual districts. These techniques will assist explorers to detect the subtle hypogene geochemical dispersion halos that extend for kilometres away from the intrusive centre; thereby enhancing their ability to discover new deposits more quickly and at less cost. An additional aim was to develop cost-effective, field-based methods that can be applied by explorers who do not have access to suitable laboratory facilities for LA-ICP-MS geochemical analysis.

The two main environments (lithocap and green rock) that are being explored in porphyry-epithermal districts were further investigated, with the objective of developing new tools for exploration in these areas through the analyses of pre-existing and new sample suites. Blind site testing on one lithocap site and seven green rock sites were used to validate the findings.

Tools developed by the P765A team have proven to work effectively in volcanic terrains, but have not been tested effectively in other environments. Therefore, an important component of the research was to investigate the effects on various protoliths (limestones, sandstones, granite, etc.), as well as on mineralised and un-mineralised regionally metamorphosed terranes. Since project commencement, field campaigns have been conducted in Australia, USA, Canada, Indonesia, Chile, Peru, Panama, Colombia, Scotland, the Philippines and Argentina.

In November 2014, the P1060 research team was awarded the UK-based 2014 Institution of Engineering and Technology (IET) Innovation Award in the 'Measurement in

Action' category, for 'Laser ablation analysis for enhanced discovery of buried mineral resources', based on research from the AMIRA P765, P765A and P1060 research projects.

A new project that builds on the success of P1060 and its predecessors is scheduled to commence in June 2015. The overall aim of this new initiative is to help project sponsors discover porphyry and/or epithermal deposits. This will be achieved through the development of new geochemical and geological tools and the application of previously developed tools that can help to:

- Determine the locations of porphyry and epithermal deposits.
- Discriminate between different styles of mineralisation.
- Assess the fertility of individual districts.

THEME 4 – BASIN PROCESSES, OCEAN CHEMISTRY, AND ORES

McARTHUR BASIN COPPER PROJECT

Leader: Garry Davidson

Team Members: Stuart Bull, David Selley

Student: Larriana Morgan

Collaborators: Dorothy Close, Andrew Wygralak

This project began in mid-late 2014, sponsored wholly by the Northern Territory Geological Survey (NTGS), with the aim of developing an understanding of a number of clusters of copper mineralisation in the central western McArthur Basin. Initially, the research will exclude the Redbanks deposits, because they have been the focus of previous academic studies.

The hypothesis to be tested is that these sites originated as part of a separate basinal fluid event to that which formed the giant HYC Zn-Pb-Ag deposit in the McArthur Group. The copper sites largely sit lower in the stratigraphy in the Tawallah Group, and the lowermost McArthur Group, with a particular concentration in the Amelia Dolomite and Mallapunyah Formation.

Fieldwork commenced with core logging by Larriana Morgan and Stuart Bull at the NTGS facilities in Darwin, focussing on samples from the Coppermine Creek area.

KANSANSHI GOLD PROJECT

Leader: Robert Scott

Team Member: Garry Davidson

Student: Jacob Heathcote

Collaborator: David Wood

This project began in early 2014, sponsored wholly by Kansanshi Mining Plc (KMP), a subsidiary of First Quantum Minerals. The aim of the research is to better understand the origins, distribution, mineral associations and paragenesis of gold at the Kansanshi Cu-Au deposit, northwestern Zambia. The Kansanshi Mine, situated in the Domes region of the Lufilian fold belt, currently produces over 100,000 oz of gold per year as a by-product of the copper mining operation. The high gold content of the Kansanshi ores is atypical of sediment-hosted copper deposits of the Central African Copperbelt (CACB). The post-peak metamorphic timing of mineralisation at Kansanshi also differs from classical copper deposits of the CACB.



Large anhydrite, calcite and quartz breccia vein, Lihir gold deposit, PNG.

This research is investigating the timing and distribution of gold (relative to copper) and deposit-scale controls, and processes and mineralogical associations of both primary and secondary (i.e. oxide-zone) gold mineralisation at Kansanshi. A key objective is to identify pit-scale criteria (alteration mineral assemblages, structures, vein stages/compositions, etc) or trends that aid delineation of gold mineralised zones. These characteristics will underpin development of a set of parameters that can be used by KMP resource and production geologists to better recognise and predict the distribution of gold mineralised zones at Kansanshi.

Jacob Heathcote commenced fieldwork in late April, which involved detailed mapping and sampling in the Main and Northwest pits, and sampling of selected drill cores. Jacob's subsequent work has included detailed petrography (optical microscopy) on over 50 samples with follow-up SEM MLA, EMPA and laser Raman studies, as required. Initial findings include identification of a previously unrecognised paragenetic/mineralogical association of gold at the deposit, which appears to represent the main (primary) influx of gold in some of the higher grade (Au) samples studied to date.

GLOBAL OCEAN CHEMISTRY, MARINE BASINS AND MINERALISATION

Leader: Peter McGoldrick

Collaborators: Tim Lyons, Noah Planavsky, Donna Satterthwait

The project aims are to:

- Decipher processes that controlled the sulfur chemistry and redox state of oceans that existed in northern Australia approximately 1.65 billion years ago.
- Understand how coeval ocean water interacted with hydrothermal fluids responsible for forming the giant northern Australian Proterozoic SEDEX Zn-Pb-Ag deposits.
- Understand the role played by (micro-)organisms during seafloor venting of fluids responsible for forming Proterozoic sedimentary Zn mineralisation.

The main activity in 2014 was the preparation, submission and acceptance of a paper in *Science* (Low Mid-Proterozoic atmospheric oxygen levels and the delayed rise of animals). The study used Cr isotope data from mid-Proterozoic ironstones to place a robust upper limit on atmospheric O₂ during the mid-Proterozoic.

This project has come to a conclusion in its current form, but some elements of the research will continue as smaller projects within this Module, such as the extraction and documentation of fossils from the Century Zn deposit.

URANIUM CONCENTRATION IN BASINS

Leader: Garry Davidson

Team Members: Sebastien Meffre, Karin Orth

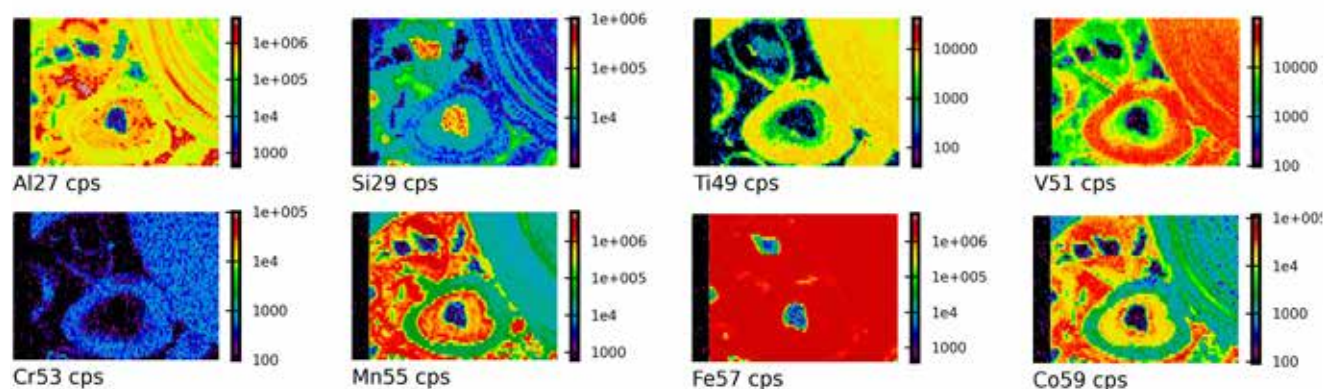
Student: Pablo Farias

Collaborators: Karsten Goemann, Hamish Johns, Penny Large, Grant Osborne, Andrew Wygralak

This project is researching the special occurrence of uranium in particular sedimentary basins, and encompasses studies that began within the previous Program structure at CODES.

Highlights of the year included:

- A paper was published in *Mineralium Deposita*, lead-authored by Karin Orth, on the timing of ore formation in the U-PGE-Au Coronation Hill deposit, South Alligator Rivers Province, Northern Territory (NT).
- A paper featuring U mobility along faults within the Paleoproterozoic Tennant Creek Inlier, NT, was submitted by former Honours student Hamish Johns, and co-authors.
- Pablo Farias commenced a Master of Economic Geology project focussed on the Angularli U mineralisation in the East Alligator Rivers Province. This is an unmined zone of mineralisation, with diverse geology, that appears to be a new variant of U-forming activity in the McArthur Basin, NT.



LA-ICP-MS images of trace elements (0.5mm across), including chromium, for Sherwin Formation oolitic ironstones.



PhD student Indrani Mukherjee, analysing sedimentary pyrite in black shales for sulfur isotopes at the SHRIMP laboratory at ANU.

TRACE ELEMENTS IN THE OCEAN (TEO)

Leader: Ross Large

Team Members: Leonid Danyushevsky, Dan Gregory, Jacqui Halpin, Elena Lounejeva, Sebastien Meffre, Jeff Steadman

Students: Sean Johnson, Charles Makoundi, Indrani Mukherjee

Collaborators: Clive Calver, Bradley Guy, John Long, Tim Lyons, Valeriy Maslennikov, Patrick Sack, Peter Sorjonen-Ward

LA-ICP-MS studies of hydrothermal pyrite chemistry, focussed on ore genesis and exploration applications, has enabled a whole new line of research on some of the more fundamental issues relating to ocean chemistry through time.

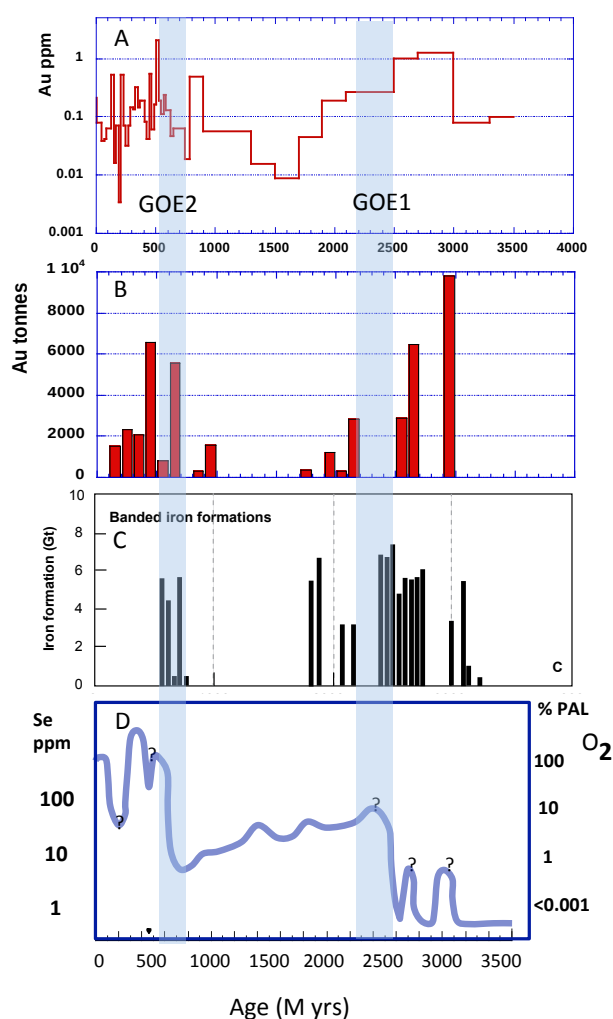
Sedimentary pyrite formed in the water column, or during diagenesis in organic muds, provides an accessible proxy for seawater chemistry in the marine rock record. Except for Mo, U, Ni and Cr, surprisingly little is known about trace element trends in the deep time oceans; even though they are critical to developing better models for the evolution of the Earth's atmosphere and evolutionary pathways of life.

In this project, the team has developed a novel approach to simultaneously quantify a suite of trace elements in sedimentary pyrite from marine black shales. These trace element concentrations, at least in a first-order sense, track the primary elemental abundances in coeval seawater. This has never been achieved before.

In general, the trace element patterns show significant variation of several orders of magnitude in the Archaean and Phanerozoic, but less variation on longer wavelengths

in the Proterozoic. Certain trace elements (e.g., Ni, Co, As, Cr) have generally decreased in the oceans through the Precambrian, while other elements (e.g., Mo, Zn, Mn) have generally increased, and a further group initially increased and then decreased (e.g., Se and U). These changes appear to be controlled by many factors.

This research demonstrates that Ni and Co content of seawater is affected by global Large Igneous Province events, whereas redox sensitive trace elements, such as Se and Mo, are affected by atmosphere oxygenation. A flat to declining pattern of many biologically important nutrient elements through the mid to late Proterozoic may relate to declining atmosphere O_2 , and supports previous models of nutrient deficiency inhibiting marine evolution during this period. These trace elements (Mo, Se, U, Cu and Ni) reach a minimum in the mid Cryogenian and rise abruptly toward the end of the Cryogenian, marking the position of a second great oxidation event (GOE2).



Gold content of marine pyrite as a proxy for gold content of the oceans through time (A). Note how gold drops by two orders of magnitude from the Neoproterozoic through to the start of the Mesoproterozoic. Comparison with temporal distribution of sediment-hosted gold deposits (B), banded iron formations (C) and oxygen in the atmosphere (D) from Large et al. (2014)



*PhD student Indrani Mukherjee
conducting field work in NW Tasmania.*

A paper providing the first phase results of the project was published in *Earth and Planetary Science Letters*. Two further manuscripts were submitted on the second phase results.

THEME 5 – THE ORE AFFECTED CRUST

THE POWER OF PYRITE

Leader: Ross Large

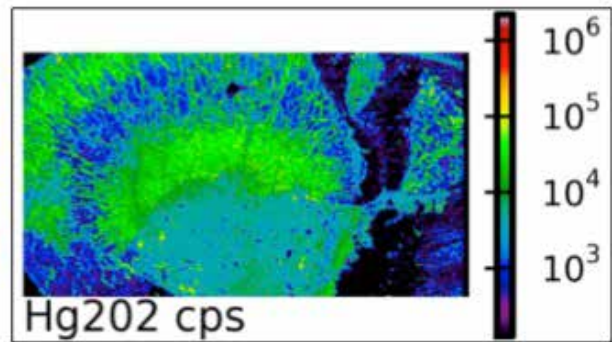
Team Members: Ivan Belousov, Leonid Danyushevsky, Dan Gregory, Jeff Steadman

Collaborator: Trevor Beardsmore

Several projects developing the use of LA-ICP-MS chemistry of pyrite as a fertility and vectoring tool are currently being pursued.

A major collaboration with the Geological Survey of Western Australia has analysed over 1,500 pyrites from 30 orogenic gold deposits and five VHMS deposits, plus barren rocks, to develop protocols and parameters for pyrite use in both fertility discrimination and vectoring to ore centres. The resulting database provides the basis for using pyrite as a prospective fertility and vectoring tool, and enables a better understanding of the geochemical associations of different orogenic Au and VHMS deposits.

The data indicates that pyrites from orogenic gold deposits commonly have higher levels of Ni, As, Au, W, V and Cr, compared with pyrites from VHMS deposits, which generally have higher levels of Cu, Co, Pb, Se, Zn, Sn and Bi. The differences may relate to source rocks and differences in salinity, temperature and pH of the ore fluids. These differences in pyrite chemistry are used as the basis

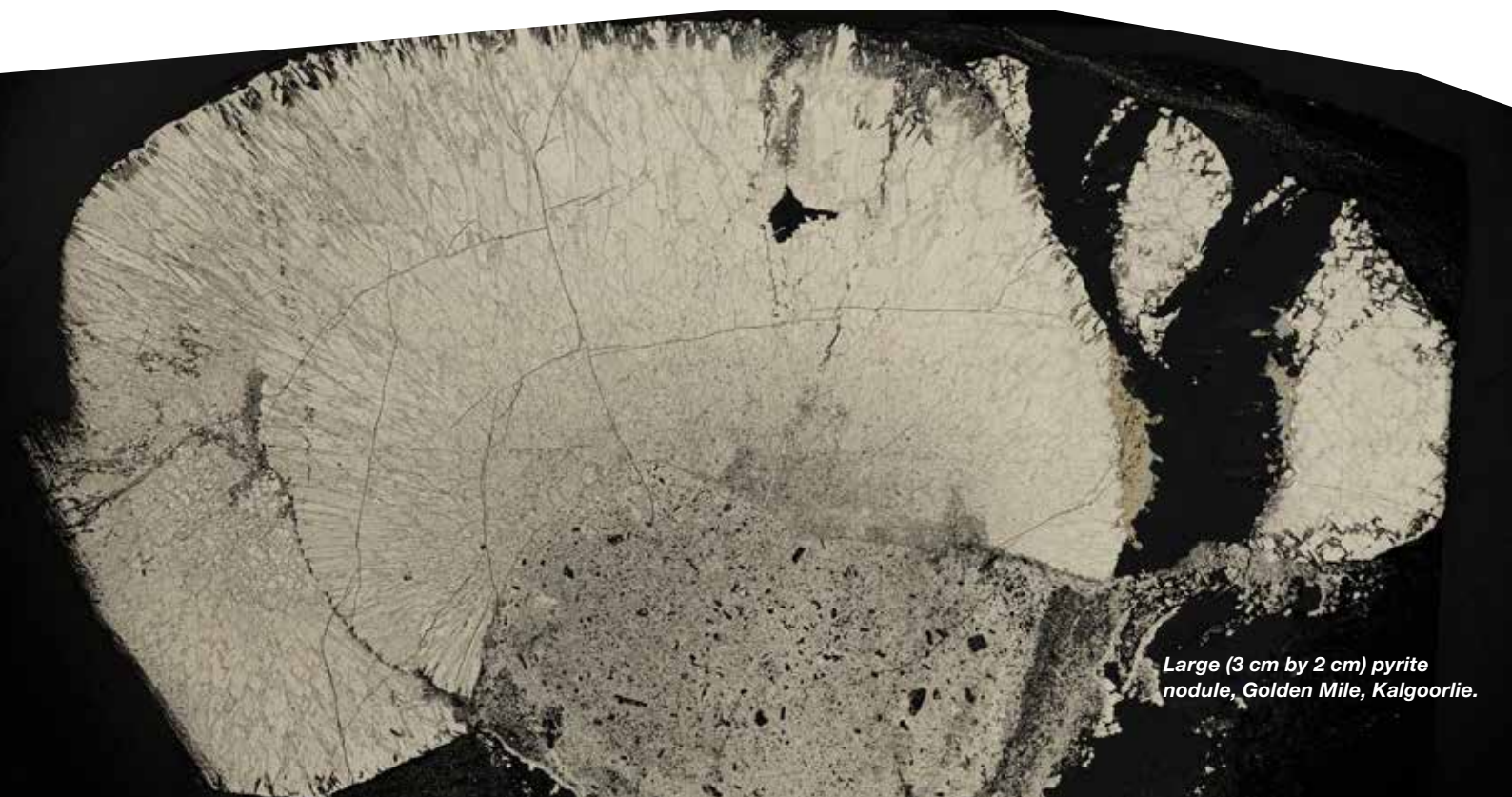


LA-ICP-MS image showing distribution and relative abundance of mercury-202 (Hg202) in the large pyrite nodule from the Golden Mile (see image at bottom of page). The nodule core is relatively enriched compared to the rim. CPS = counts per second.

for developing fertility and vector scores for both VHMS and orogenic pyrite, and enable any pyrite drill intersection to be classified as background, distal, proximal or a high priority target. A high priority VHMS target has been defined for follow-up by applying this pyrite vectoring technique to six recent co-funded EIS drill holes in WA.

The three isotopes of lead, ^{206}Pb , ^{207}Pb and ^{208}Pb , have been measured by LA-ICP-MS on each pyrite at the same time as the multi-element analysis. This enables rapid scan Pb isotope ratio analysis for $^{207}\text{Pb}/^{206}\text{Pb}$ and $^{208}\text{Pb}/^{206}\text{Pb}$, and provides information on the timing of the hydrothermal system and potential for younger overprint hydrothermal activity.

The combination of pyrite laser multi-element analysis and scan Pb-isotopes on the same pyrites provides robust fertility and vector indicators for pyrite intersections in drill holes. The technique is relatively inexpensive compared to the cost of a drill hole. Costs are around \$2,500 per drill hole (assuming a 500m hole with 5 pyritic zones sampled and 50 pyrite analyses for 35 elements, including Pb-



Large (3 cm by 2 cm) pyrite nodule, Golden Mile, Kalgoorlie.

isotope ratios). This is about 30% of the cost for a down-hole EM survey. Both techniques have the potential to detect distal off-hole anomalies. A report was delivered to GSWA outlining the results of the project.

Following on from the success of this project, a new industry funded project is in the development stage to apply the Power of Pyrite technique on a series of mine and exploration case studies. The new project will investigate extending the vectoring protocols to VHMS, sedimentary Cu, sediment-hosted gold and SEDEX/MVT deposits. A project agreement has also been signed with the Geological Survey of South Australia to investigate the application of the technique to a number of sites in South Australia.

INTEGRATED GEOLOGY AND GEOPHYSICAL MODELLING AND EXPLORATION TARGETING IN THE LYELL-ROSEBERY REGION

Leader: Anya Reading

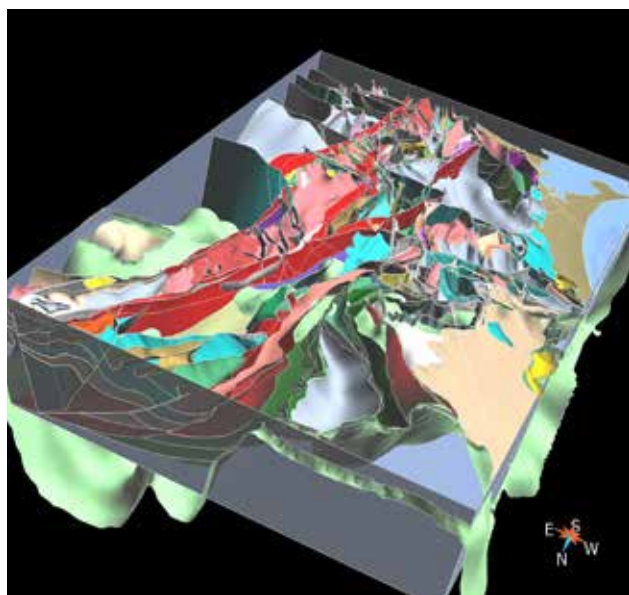
Team Members: Daniel Bombardieri, Michael Roach

Student: Jie Yu

Collaborators: Tim Chalke, Mark Duffett

This collaborative project with Mineral Resources Tasmania (MRT) aims to improve knowledge of prospective regions of western Tasmania using an integrated approach.

New geological mapping by MRT is underway, and new geophysical data were collected as part of Jie Yu's Honours project. A major research exercise by Daniel



A collaborative project with Mineral Resources Tasmania has resulted in a high resolution 3D model of the Rosebery-Lyell region, western Tasmania. The model is currently being tested against existing magnetic and gravity data via 3D potential field calculations and is nearing completion. Resulting model products will assist exploration for tin and other base metals in this richly mineralised province.

Bombardieri has combined vast amounts of diverse geological knowledge into one 3D GOCAD environment. This information has been subjected to a rigorous analysis process and includes key metadata incorporating petrophysical properties and confidence criteria. This has resulted in a major research output, a new 3D geological and geophysical model of the Lyell-Rosebery region. The new model is exceptional in its level of detail and the care with which balanced cross-sections, for example, have been used as constraints to sub-surface structure. The model will be refined in ongoing work in 2015 and is available through MRT to aid mineral exploration and economic growth in western Tasmania.

METAMORPHIC ARCHITECTURE OF THE WESTERN GAWLER CRATON

Leader: Jacqui Halpin

Collaborators: Rian Dutch, Anthony Reid

The generation and preservation of hydrothermal or magmatic-related mineral systems is strongly depth dependent. This is because major changes in fluid pressure and composition occur as deeper magmatic or metamorphic fluids interact with other fluids and structures as they reach shallower crustal levels. These changes in fluid chemistry result in the precipitation of ore minerals.

This project, sponsored by the Geological Survey of South Australia (GSSA), involves quantification of the pressure-temperature-time (P-T-t) history of selected key regions across the western Gawler Craton that can be used to infer crustal architecture and quantify crustal palaeo-depths. Outputs can be fed into prospectivity models to inform the practice of exploration. A preliminary report was delivered to GSSA in 2014, which is summarised as follows:

The deeply buried and sparsely sampled western Gawler Craton remains poorly understood in terms of gross crustal architecture and tectonic evolution. Work to date on the Christie Domain has concentrated on the P-T-t evolution of high-grade metapelitic gneisses of the Archean-Early Paleoproterozoic Mulgathing Complex (the Christie Gneiss). New in situ monazite dating suggests high-grade metamorphism and anatexis occurred between 2470 ± 4 Ma and 2437 ± 5 Ma, with near-peak conditions at 2460 ± 4 Ma at Challenger, Blackfellow Hill and Mt Christie during the Sleafordian Orogeny. Phase equilibria modelling suggests peak metamorphic conditions reached $P \sim 6-7$ kbar at $T \sim 800-860$ °C across this region. These conditions represent paleodepths of $\sim 20-25$ km and elevated average thermal gradients of $35-45$ °C/km at ~ 2.46 Ga. Heat conduction through thinned lithosphere during extension, coupled with heat advection through repeated magma flux, primed the basin for focussed deformation during inversion. Orogenesis thickened the previously thinned crust to close to normal thickness, such that limited post-peak decompression occurred and the P-T path was dominated by cooling.



PhD student
Subira Sharma.

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

Leader: Garry Davidson

Team Members: David Cooke, Craig Winter

Collaborators: James Cleverley, Hesham Harbi, June Hill, Michael Nugus, Nick Oliver, Heidi Pass

While carbonate-based C-O isotopes are well accepted tools in ore genesis research, this project is aimed at identifying hidden, nuanced applications, by combining mineral-specific C-O isotope data with spatial and paragenetic control, major and trace element analyses, and whole-rock geochemical data.

A sub-project involving this style of work is a study, funded by AngloGold Ashanti, of C-O isotope variation in the Sunrise Dam gold deposit in the Archean Yilgarn of Western Australia. In 2014, the main activity was hyperspectral analysis of carbonate composition for samples that have previously been analysed for C-O isotopes. The data from this analysis was then compared with sparse electron microprobe data, and particularly with carbonate staining for chemical composition. The aim was to determine whether a ready proxy for the C-O isotope signal could be developed to assist exploration.

A second application involved C-O analysis of gold deposits and prospects through the Late Proterozoic to Cambrian arc sequences of Saudi Arabia, with a view to developing a better understanding of the affinities of this mineralisation (magmatic, VHMS, orogenic gold, etc). This work was published in *Ore Geology Reviews* during the year (Harbi et al).

A third application was Heidi Pass's contribution to the 'alkalic porphyry' special issue of *Economic Geology*, in which C-O isotope data was modelled as part of the evidence to support a carbonate assimilation model to account for the highly carbonated character of the British Columbian Mt Polley Cu-Au deposit, Canada.

AUSTRALIAN HYDROTHERMAL IOCG AND RELATED DEPOSITS

Leader: Garry Davidson

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

Student: Subira Sharma

Collaborators: Bryan Bowden, Robert Creaser, Geoff Fraser, Hamish Freeman, Thomas Rodemann, Roger Skirrow, Pat Williams

The principal areas of IOCG research in 2014 were at Prominent Hill (SA) and Mt Dore-Merlin (Qld). NB. Research on the giant Olympic Dam deposit is reported under its own project heading.

Prominent Hill

The main activity relating to Prominent Hill was the submission of a paper to *Mineralium Deposita* on the Ar-Ar systematics (and supporting U-Pb zircon, monazite and apatite systematics) of a carefully selected sample set designed to constrain the age of sericite at the Cu-Au deposit, which is closely related to the emplacement of Cu-Au mineralisation. Work also continued on the interpretation of Re-Os data from Prominent Hill, produced by Robert Creaser's U Alberta lab, based on a diverse range of mineralised and barren samples.

Mount Dore-Merlin

Subira Sharma's PhD study continued, this year focussing on the role of graphite at the Merlin Mo-Re deposit within the Cloncurry IOCG belt. The laser Raman equipment housed in the UTAS Central Science Laboratory (CSL) has proven to be extremely useful for evaluating graphite-molybdenite mixes and determining the crystallinity of the graphite. Subsequently, Thomas Rodemann from CSL, who is an expert in this equipment, has been inducted into the project group.



Believe it or not, this is PhD student Jacob Mulder, sitting on Jacob Quartzite, at Jacob's Boat Harbour, NW Tasmania.

THEME 6 – DATES AND PLATES

AGE, AFFINITY AND PROVENANCE OF TASMANIAN PROTEROZOIC METASEDIMENTARY SUCCESSIONS

Leader: Jacqui Halpin

Student: Jacob Mulder

Collaborators: Grace Cumming, Nathan Daczko, John Everard

This project grew from the successful application of combined authigenic monazite and detrital zircon dating in constraining the depositional age of the Proterozoic Rocky Cape Group in NW Tasmania, which culminated in 2014 with a paper (Halpin et al.) in *Precambrian Research* and a presentation at the Australian Earth Sciences Convention in Newcastle.



Jacqui Halpin being interviewed about the new model for Nuna for the evening TV news.

This approach will now be used for poorly dated Proterozoic units and inliers elsewhere in western Tasmania, including (Rocky Cape Group correlated) siliciclastic successions at Woolnorth and the Clark Group in the Jubilee region, as well as in the turbidite-dominated Oonah Formation and correlates.

During 2014, the provenance of the Rocky Cape Group was examined through palaeocurrent and detrital zircon (including Hf-isotope) analysis as part of Jacob Mulder's PhD project. These results indicate that the Rocky Cape Group was sourced from a combination of basement terranes exposed in southwest Laurentia and under ice-cover in East Antarctica (the Mawson Craton), suggesting close proximity of these blocks between 1.45–1.3 Ga.

This study presents a new model for the configuration of Nuna that includes Proterozoic Tasmania, and suggests that extension during the breakup of Nuna left thinned continental substrate between the Mawson Craton and southwest Laurentia, onto which the Rocky Cape Group was deposited prior to ~1.3 Ga.

TECTONIC RECONSTRUCTION OF EAST GONDWANA

Leader: Jacqui Halpin

Students: Sally Watson, Toban Wild

Collaborators: Mike Coffin, Nathan Daczko, Robyn Gardner, Andy Gleadow, Fred Jourdan, Barry Kohn, Chris Mays, Luke Milan, Pat Quilty, Jeff Stilwell, Joanne Whittaker, Simon Williams

This project aims to constrain the age and affinity of recently recovered dredge samples from enigmatic tectonic features in the Perth Abyssal Plain, offshore Western

Australia, and to integrate these data with other geological and geophysical datasets to produce a holistic plate tectonic reconstruction for East Gondwana.

During 2014, a paper (Gardner et al.) on the age and affinity of one of two newly discovered submarine microcontinents was accepted for publication in *Gondwana Research*. This study demonstrates, for the first time, that the Gulden Draak Knoll comprises a rifted continental fragment of East Gondwana. A revised tectonic reconstruction suggests that the Gulden Draak Knoll is part of the Indian conjugate to both the Antarctic Wilkes Land margin, and Australian Naturaliste Plateau, and sits along strike of a major structure termed the Indo–Australo–Antarctic Suture, recently mapped from geophysical interpretations in Antarctica.

Other major outcomes during 2014 included an invited talk (Whittaker et al.) on these results presented at EGU in Vienna, the commencement of a new PhD project (Sally Watson) on the evolution of East Gondwana breakup and the influence of the Kerguelen plume, and a collaboration with Monash University through the completion of an Honours project by Toban Wild, which provides fascinating new insights into the palaeontology and palaeoecology of a fragment of Greater India.

STRUCTURE OF SE AUSTRALIA USING MULTIPLE GEOPHYSICAL METHODS

Leader: Anya Reading

Team Member: Michael Roach

Students: Ashby Cooper, Simone Pilia

Collaborators: Ross Cayley, Nick Direen, Mark Duffett

Funded under ARC Linkage, through the UTAS Discipline of Earth Sciences, this project seeks to improve the understanding of the broad-scale structure of SE Australia.

In previous years, seismic stations were installed surrounding Bass Strait for the collection of ambient seismic and teleseismic data. During 2014, the seismic tomography and other geophysical datasets were processed and combined to form new 3D images of the Australian continent in this region. This work was carried out at Australian National University with PhD student Simone Pilia, who graduated during the year. A paper has been accepted for publication in *Gondwana Research*.

Analysis of deep crustal structure was carried out by UTAS Honours student Ashby Cooper. The project effectively shows how the Victorian and Tasmanian crust is connected and proves the success of ambient seismic techniques in improving the resolution of regional scale seismic tomography. Partner organisations in the research were Mineral Resources Tasmania, Geoscience Victoria and FrOGTECH.

LOOKING FORWARD

The coming year will be a period of further evolution for the Module. While a number of projects are scheduled to come to a natural conclusion, new projects will continue to come on stream, and some of the existing studies are expected to find a new lease of life, following adjustments to align the research objectives with the evolving needs of the minerals industry.

One of the main highlights will be the commencement of the AMIRA P1153 project, entitled 'Applying the explorers' toolbox to discover porphyry and epithermal Cu, Au and Mo deposits'. The project, which builds on the success of AMIRA P1060 and its predecessors, will be launched via a start-up meeting in June.

Negotiations with industry sponsors are in progress to extend the excellent research conducted within the Ore Deposits of SE Asia project, via a new initiative to investigate the tectonics and origin of Cu-Au mineralisation of the Western Myanmar-Sumatra Terrane.

A petrophysical and geophysical investigation begins in 2015, which aims to improve the knowledge of the broad-scale structure of NW Tasmania. The study is to be conducted in collaboration with Mineral Resources Tasmania and Mira Geoscience.

Many of the existing projects are expected to have a fruitful year. Anticipated activities include:

- Major sample collection and mapping of copper mineralisation and surrounding alteration will be undertaken in the McArthur Basin, in collaboration with the Northern Territory Geological Survey.
- Rebecca Carey will be Co-Chief Scientist on an expedition to the Havre Volcano in the Kermadec Arc, New Zealand, which aims to investigate the seafloor deposits of a remarkable submarine eruption that occurred in 2012, which turned out to be the largest event of its type ever recorded.
- A new PhD project related to the 'VHMS Research – Ancient' project will commence at Myra Falls, Vancouver Island.
- New industry funded research is in the development stage to apply the Power of Pyrite technique on a series of mine and exploration case studies, and investigate extending the vectoring protocols to VHMS, sedimentary Cu, sediment-hosted gold and SEDEX/MVT deposits.
- A regional map will be produced of the metamorphic grade for the central-northern Gawler Craton, which will be used as a tool for future exploration.
- A seismic tomography study will be completed, incorporating data from a wider region of SE Australia and final analysis of the Bass Strait deep structure.

MODULE

GEOMETALLURGY

OBJECTIVE

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

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 an holistic approach, it identifies attributes that contribute to the realised value of a resource, and enables ore variability to be factored into the flow sheet, infrastructure design, and the production and quality forecasts over the life-of-mine. This includes traditional attributes, such as grade, as well as less traditional factors such as concentration of deleterious elements, hardness (crushability, grindability), mineral species and abundance, mineral liberation, metallurgical recovery, acid generating potential, neutralising potential and smelter enabling characteristics.

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

Over the past decade, the extent of research related to geometallurgy has significantly increased, spurred mainly by an increased interest in the discipline by the minerals industry.

This increase in industry involvement led to the large AMIRA P843 and P843A (GeM^{III}) collaborative projects that ran from 2005 to 2013 and were successful in developing an array of geometallurgical methods and protocols in the areas of mineralogy, comminution and flotation – which were subsequently tested on case study sites in active mines.

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

HIGHLIGHTS

- Geometallurgy included as a theme in the new Industrial Transformation Research Hub – Transforming the Mining Value Chain.
- CODES is an Essential Research Participant in the CRC ORE II application.
- Significant technology transfer of GeM^{III} research, including presentations in Australia, the UK, and Chile; plus a short course in South Africa. Confidential research reports also released to sponsors for the Los Bronces and Frieda River case studies, which were conducted in collaboration with CRC ORE.
- Fieldwork conducted in collaboration with CRC ORE to identify future opportunities in the geomet-environmental field.
- Geometallurgy included as part of the Geo-logging short course.
- Julie Hunt appointed Module Leader – Ron Berry retained as part of the team as a University Associate.
- Graduation of MSc student Paula Montoya.



MEET THE TEAM



LEADER:
Julie Hunt

TEAM MEMBER:

Ron Berry

PHD STUDENTS:

Angela Escolme, Cassady Harraden

MASTERS STUDENT:

Paula Montoya

COLLABORATORS:

CRC ORE:

Taryn Noble, Anita Parbhakar-Fox

CSIRO:

Louise Fisher

GHD:

Hugh Tassell

HOT CHILI:

Warren Potma

JKMRC/UQ:

Dee Bradshaw

MINASSIST:

Al Cropp, Will Goodall

MINERAL RESOURCES TASMANIA:

David Green

UNIVERSITY OF EXETER, UK/CRC ORE:

Bernd Lottermoser

THE YEAR IN REVIEW

A PERIOD OF TRANSITION

The past year has been a period of transition for geometallurgy at CODES. The AMIRA Geometallurgical Mapping and Mine Modelling (GeM^{III}) project had officially ended the previous year, which happened to coincide with the end of CODES funding as an Australian Research Council Centre of Excellence, and the retirement of the leader of the Recovery Program, Ron Berry.

Initially, there was an expectation that GeM^{III} could continue via a further extension project. However, after a thorough review by all stakeholders, it was decided that the project had achieved all its major objectives, and the time was right to move on to other challenges. The achievements of this initiative have been covered in detail in previous annual reports, but in summary the project successfully delivered a number of key benefits to industry partners, including improved forecasting, reduced technical risk, enhanced economic optimisation of mineral production, and more efficient use of the resource.

At the completion of its tenure as a funded Centre of Excellence, CODES decided to reassess its research model. Key objectives were to ensure that all the well established and valued research capabilities were maintained, while enhancing the structure to better reflect the Centre's strengths. The review resulted in an end to the old five program system, with the introduction of a four module model to take its place. As testimony to the success of GeM^{III}, and the importance CODES places on this area of research, Geometallurgy was named as one of the four modules, alongside Ore Deposits: Characterisation and Context, Enabling Technologies, and Training.

STRONG PLATFORM

COLLABORATIONS

The establishment of the Geometallurgy Module sets a strong platform to build on the success of GeM^{III}, and the large number of collaborations established over eight highly successful years of applied research. One of the strongest of these collaborations has been with CRC ORE, primarily due to its close relationship with UTAS via the Discipline of Earth Sciences. For example, Geometallurgy Module team member, Ron Berry, was a member of the CRC ORE Technical Advisory Panel during the year, and a number of CODES staff and students are actively involved in its research projects.

As a testament to this close relationship, CODES has been included as an Essential Research Participant in CRC ORE's application to extend its tenure as a Co-operative Research Centre by six years. The key challenge for CRC ORE II will be to address the declining productivity in the minerals industry, which is partly due to the propensity for mining companies to focus on quantity over quality during

the previous mining boom. CODES expertise in areas such as ore deposit modelling, postgraduate training and ore characterisation will play a key role in the CRC, pending a successful outcome to the application.

The research performed by CRC ORE II will be 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. The foundation research partner in this program is the CSIRO, and fellow research partners include the University of Adelaide and the National Research Council Canada.

In addition to the links with CRC ORE, strong collaborations have been established with over 20 companies and institutions over the life of GeM^{III}, which will continue to be fostered in the years ahead.

THE ARC INDUSTRIAL TRANSFORMATION RESEARCH HUB

A significant event for the Geometallurgy Module during 2014 was the awarding of one the Australian Research Council's Industrial Transformation Research Hubs to CODES and a group of its research partners. Quantifying Geometallurgical Characteristics is one of only three themes within the Hub, which is named Transforming the Mining Value Chain. While the new Hub covers a wide spectrum of mining processes, geometallurgy will play a key role in its activities. This will include geometallurgical and geo-environmental characterisation of ores and wastes through automated core logging and spectral analysis of drill core. This will enable 3-D exploration, mining and geometallurgical models to be developed that are continually updated as the exploration or resource drilling program continues.

The Hub was in the process of confirming sponsors and performing preparatory work in 2014, but is expected to be fully operational by mid-2015.

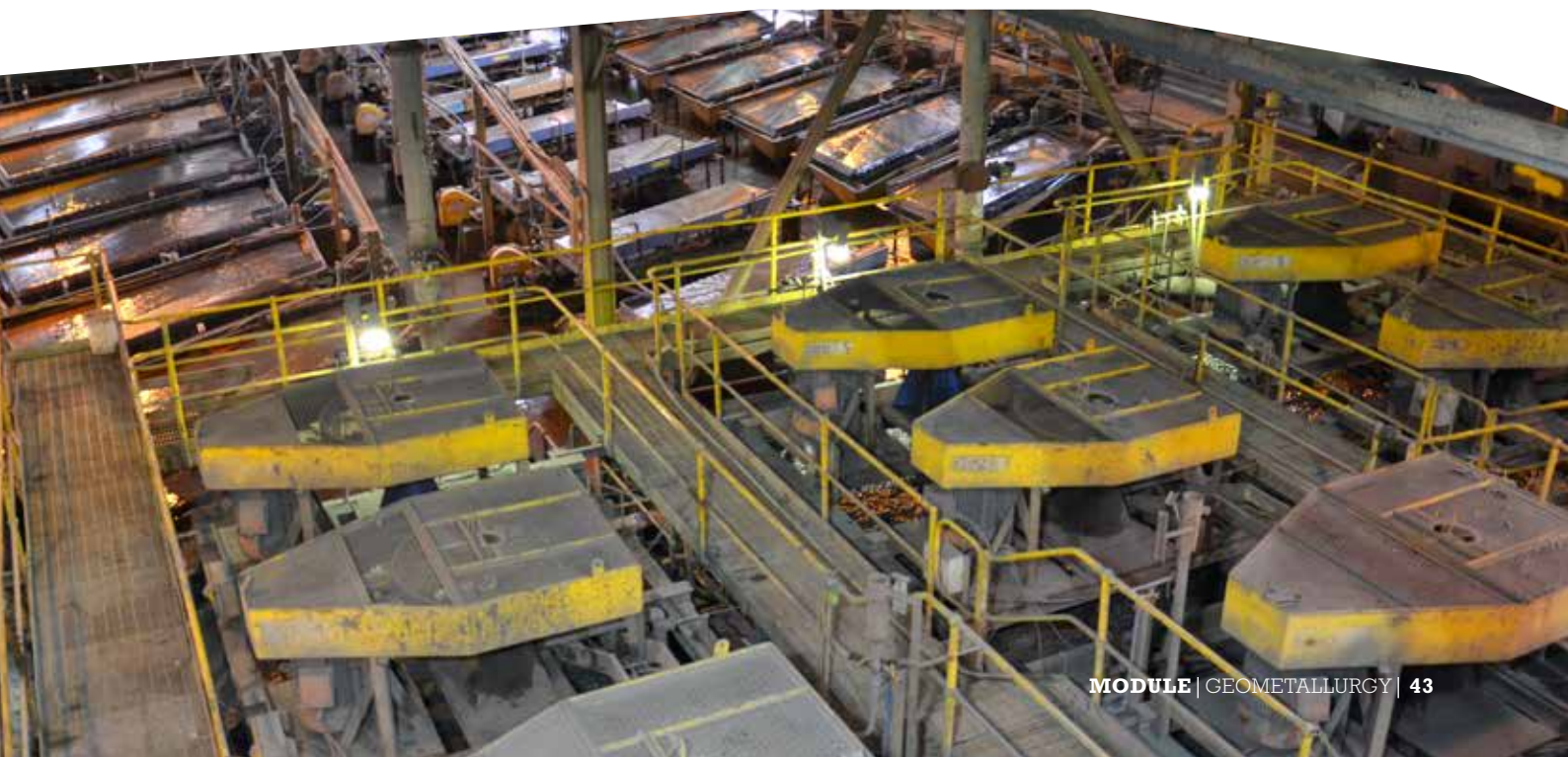
TECHNOLOGY TRANSFER

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

- Ron Berry and Julie Hunt presented a poster at the Australian Earth Sciences Convention in Newcastle, entitled 'Non-destructive geometallurgical logging for prospect evaluation'.
- Ron and Julie also joined forces at Geometallurgy 2014 in London, where they presented a paper on 'Core logging, chemistry, mineralogy and small-scale hardness tests to estimate comminution indices'.
- PhD student Angela Escolme attended the International Conference in Geometallurgy in Santiago, Chile, where she presented a poster on her thesis studies involving ore characterisation and geometallurgical modelling at the Productura copper-gold-molybdenum deposit in Chile.
- Also in Chile, Ron Berry and Julie Hunt teamed up with Dee Bradshaw from JKMRC/UQ, and Will Goodall and Al Cropp from MinAssist, to present 'Communicating and integrating geometallurgical data along the mining value chain' at the International Mineral Processing Congress in Santiago.

A number of confidential research reports were presented to industry, including those related to the controls on geochemistry and mineralogy deportment by size at Anglo American's Los Bronces deposit in Chile, and PanAust's Frieda River operation in Papua New Guinea. These studies were conducted via collaborations with CRC ORE.

Below: Processing plant at Renison tin mine, Tasmania.





Cyclone-gravity separator.

SHORT COURSES

The Geometallurgy Module members provided significant inputs to two short courses during the year. The inaugural Geo-logging course was held in September at Mineral Resources Tasmania (MRT), with Julie Hunt and Ron Berry leading a session that demonstrated a range of techniques and equipment that could be used on drill core to obtain data related to ore characterisation. The course was led by CODES in collaboration with MRT and the local branch of GHD – an international professional services company.

The second input was made as part of the Acid Rock Prediction short course at the University of Cape Town, South Africa, in November, where Julie Hunt, Anita Parbhakar-Fox (CRC ORE), and Bernd Lottermoser (University of Exeter, UK / CRC ORE) presented talks on the geometallurgical aspects of this field of research. The course formed part of the Process Mineralogy '14 conference.

POSTGRADUATE RESEARCH

MSc student Paula Montoya, who finished her studies the previous year, graduated during 2014. Paula was supported by AngloGold Ashanti for her project involving a case study related to comminution research at the La Colosa porphyry gold deposit in Colombia.

PhD student Angela Escolme continued with her project entitled: Predicting recovery in porphyry deposits: A geological perspective. As reported earlier, Angela presented some of her findings at the International Conference in Geometallurgy in Santiago, Chile.

New PhD student, Cassady Harraden, joined the team late in the year. Cassady's project is under negotiation with potential sponsors.

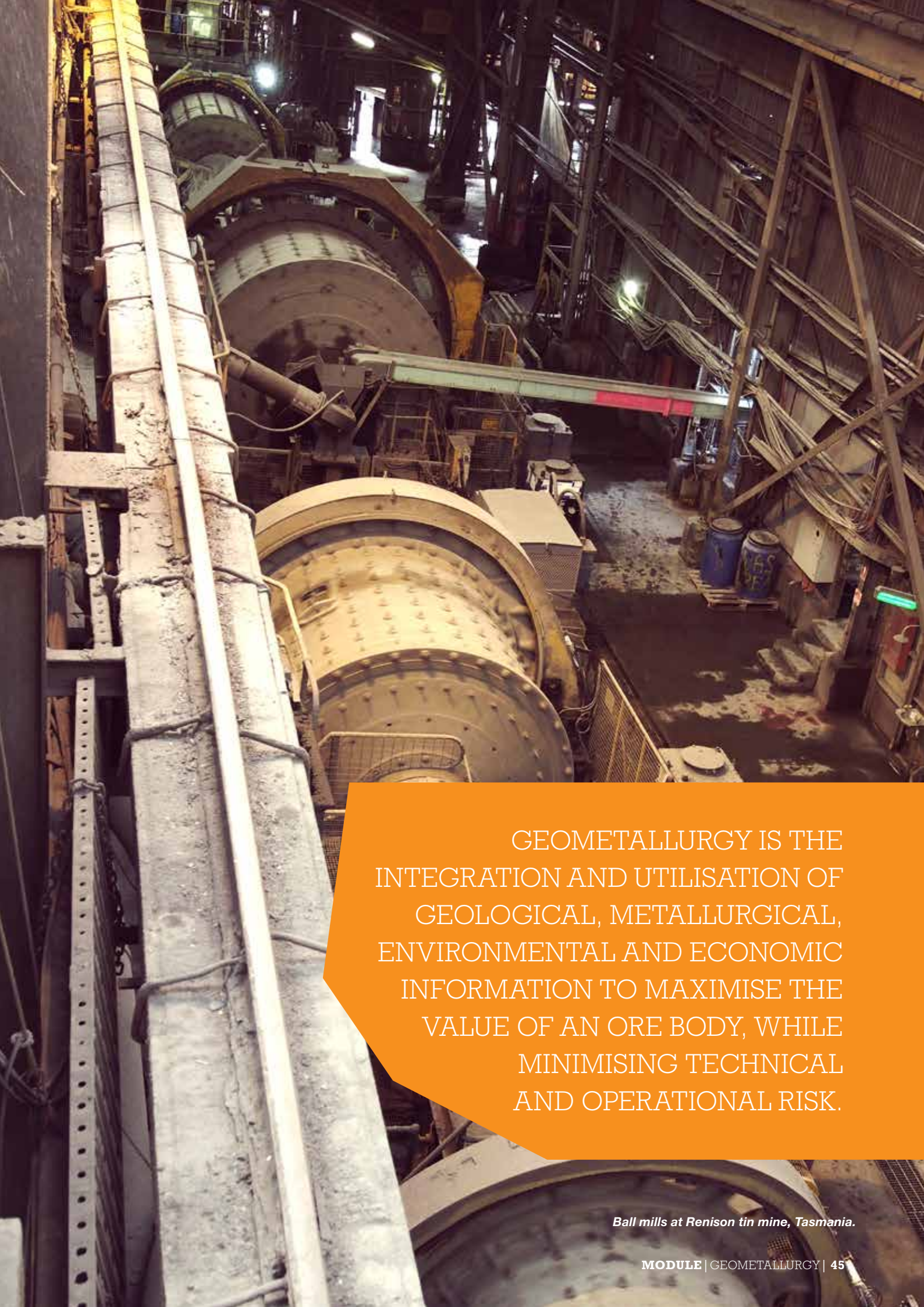
LOOKING FORWARD

The coming year is expected to see a significant increase in activities within the Geometallurgy Module as it continues its transition into developments post GeM^{III}. The close collaboration with CRC ORE will continue to play a key role in research projects, particularly those related to the environmental aspects of the discipline. Fieldwork has been conducted recently in conjunction with CRC ORE to identify potential collaborative projects in this area, and a number of opportunities will be further investigated in 2015.

Providing the application for CRC ORE II is successful, collaborations with the CRC will increase even further from mid-2015, specifically in the areas of ore deposit modelling, postgraduate training and ore characterisation. As an Essential Research Participant, CODES will work alongside other world class organisations, including the Institute for Photonics and Advanced Sensing (IPAS) at the University of Adelaide. This collaboration will utilise CODES expertise in ore geology and mineralogy, plus its extensive library of reference materials for a range of ore deposit types, to conduct a rock sensing project using the latest laser technology.

The Geometallurgy Module will continue to focus on research related to geometallurgical characterisation of different deposit types. This research is expected to increase appreciably when the Industrial Transformation Research Hub – Transforming the Mining Value Chain – is fully operational, which is scheduled for the middle part of the year.

With confidentiality agreements on the GeM^{III} project due to expire early in 2015, the impartation of the innovating and groundbreaking findings of this research is expected to continue and increase during the latter half of 2015.



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.

Ball mills at Renison tin mine, Tasmania.

MODULE

ENABLING

TECHNOLOGIES

OBJECTIVES

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

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

INTRODUCTION

The Enabling Technologies Module explores and develops novel analytical and data interpretation techniques based on the latest technological and algorithmic developments, such as a number of high spatial resolution microprobes and big data knowledge discovery techniques. This helps in the understanding, exploration and exploitation of deep earth resources.

Current research projects focus predominantly on expanding the capabilities of laser ablation inductively-coupled plasma mass-spectrometry (LA-ICP-MS) for geological applications, development of algorithms for big data knowledge discovery, modelling of geological processes, analytical data reduction, and the development of new, user friendly software packages.

The analytical projects using LA-ICP-MS include in-situ multi-element analysis and imaging of element distribution within minerals; in-situ isotope analysis, focussing on a range of U-Pb dating applications and Pb isotope measurements; development of calibration standards; and technological developments aimed at enabling simultaneous analysis by LA-ICP-MS and laser-induced breakdown spectroscopy (LIBS).

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.





Alex ('Al') Cuisson polishing samples in CODES' lapidary facility.

HIGHLIGHTS

The main focus in 2014 was on understanding fundamentals of LA-ICP-MS and developing new algorithms for big data knowledge discovery and analytical data processing.

Analytical developments included:

- Utilising a femtosecond pulse width laser to further investigate the ablation processes of sulfide minerals, in collaboration with ETH Zurich.
- Developing increased understanding of how laser aerosols are broken down, ionised and detected in the ICP-MS system.
- Developing techniques for manufacturing a new calibration standard for sulfide analysis characterised by better homogeneity of Se, Ti, Au and Pt.
- Precise measurements of laser ablation crater depths in zircon leading to a better understanding of current limitations of accuracy of the LA-ICP-MS technique and how to improve on these limitations.

Computational developments included:

- A comprehensive review paper on big data machine learning techniques to gain new understandings of lithology and geological contact mapping, published in *Computers and Geosciences*.
- A new technique for incorporating spatial context into data-driven lithology prediction.
- A new computer application for the animated visualisation of big data.

Module Leader, Leonid Danyushevsky, was elected as a Fellow of the Mineralogical Society of America (MSA). Fellows are appointed on the basis of having contributed significantly to the advancement of geochemistry, petrology, or allied sciences. Less than 3% of past Fellows have been from Australia, and Leonid is the first Tasmanian to receive this highly prestigious honour.

MEET THE TEAM



LEADER:
Leonid
Danyushevsky

TEAM MEMBERS:

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

PHD STUDENTS:

Sarah Gilbert, Stephen Kuhn, Elena Lounejeva, Peter Morse

COLLABORATORS:

AGILENT TECHNOLOGIES

David Death, Fred Fryer, Toshiaki Matsuda, Paul Perry

AUSTRALIAN NATIONAL UNIVERSITY

Malcolm Sambridge

ETH ZURICH, SWITZERLAND

Detlef Günther, Joachim Koch, Daniel Tabersky

GEOSCIENCE AUSTRALIA

Patrice de Caritat

IOWA STATE UNIVERSITY, USA

Sam Houk

LAURIN TECHNIC

Michael Shelley

MINERAL RESOURCES TASMANIA

Ralph Bottrill, Mark Duffett, Kyen Knight, Andrew McNeill, Richie Woolley

MOSCOW STATE UNIVERSITY, RUSSIA

Alexey Ariskin, Pavel Plechov

NEWCREST MINING

Anthony Harris

NORRIS SOFTWARE

Ashley Norris

QUEENSLAND UNIVERSITY OF TECHNOLOGY

Charlotte Allen

RIO TINTO

Paul Agnew, Alan Kobussen

UNIVERSITE DU QUEBEC A CHICOUTIMI, CANADA

Dany Savard

UNIVERSITY OF ABERDEEN, SCOTLAND

Nicolas Rawlinson

UNIVERSITY OF TASMANIA

Henry Duh

CORE PROJECTS

THEME 1 – ANALYTICAL DEVELOPMENTS

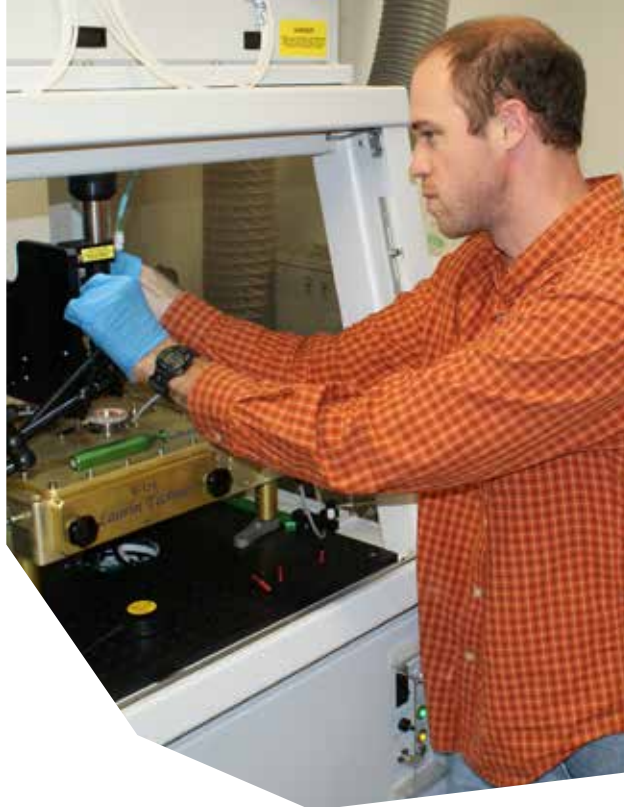
- Fundamentals of ICP-MS
- Fundamentals of laser ablation
- Element mapping by LA-ICP-MS
- Calibration standards for LA-ICP-MS
- LA-ICP-MS instrumentation development
- U-Pb dating

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

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

THEME 3 – COMPUTATIONAL KNOWLEDGE DISCOVERY FOR GEOSCIENCE

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



Jay Thompson operating the RESOLUTION laser probe.

applications. Specifically, the project aims to better understand how laser ablation aerosols are broken down and ionised in the argon plasma and where interference species are forming.

This year the research has focussed on:

- The measurement of ion energies in ICP-MS during laser ablation compared to conventional solution ICP-MS.
- The measurements of oxide formation rates in various matrices, in order to understand where oxide interferences are forming, and to apply correction factors to analyses of geological materials.
- The addition of diatomic gases to laser ablation ICP-MS to test the effects on sensitivity and interference formation.

A better understanding of the instrumentation will enable enhancements in the methods used at CODES, as well as improving instrument design.

PROJECT SUMMARIES

THEME 1 – ANALYTICAL DEVELOPMENTS

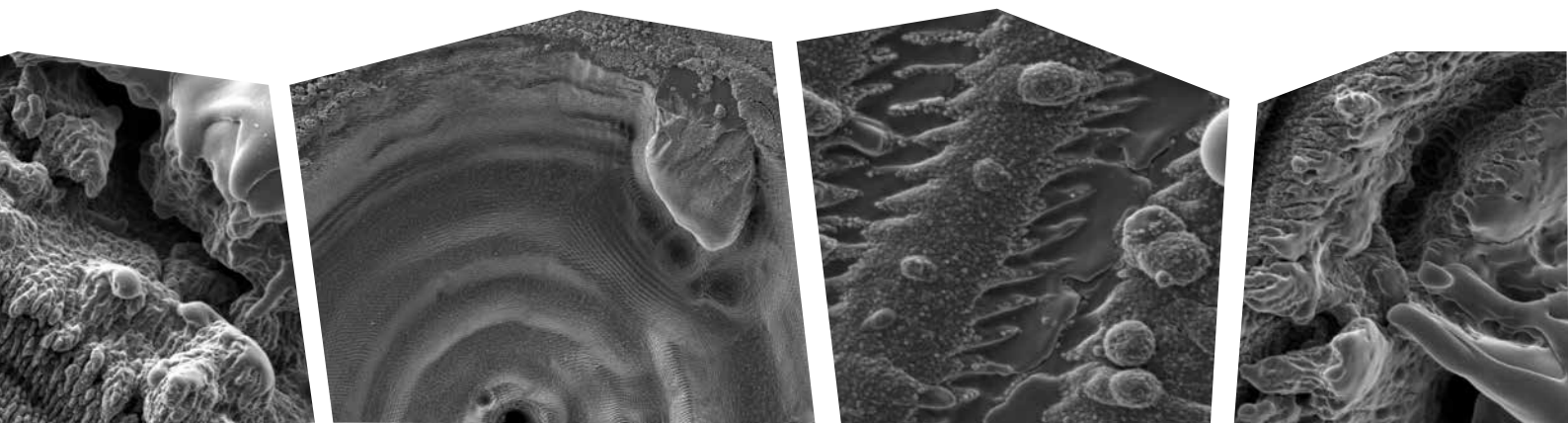
FUNDAMENTALS OF ICP-MS

Leaders: Jay Thompson, Leonid Danyushevsky

Team Members: Sarah Gilbert, Paul Olin

Collaborators: Fred Fryer, Sam Houk

This project investigates physical processes occurring in ICP-MS instrumentation used for laser ablation



FE-SEM images of laser ablation craters in pyrite.

FUNDAMENTALS OF LASER ABLATION

Leaders: Sarah Gilbert, Leonid Danyushevsky

Team Member: Jay Thompson

Collaborators: Charlotte Allen, David Death, Fred Fryer, Detlef Gunther, Joachim Koch, Toshiaki Matsuda, Paul Perry, Dany Savard, Michael Shelley, Daniel Tabersky

This research is investigating the physical and chemical processes that occur during laser ablation, in order to improve the analysis of geological materials by LA-ICP-MS.

During 2014, the team focussed on:

- An investigation into the ablation processes and element fractionation between Fe and S during the ablation of sulfide minerals for the three different types of lasers at CODES, as well as a femtosecond pulse width laser at ETH Zurich. This investigation was part of Sarah Gilbert's PhD project and was presented at the European Workshop of Laser Ablation in London.
- A study of the ablation craters, and the amount of melting that occurs around them, in different sulfide minerals, utilising the imaging capabilities of the FE-SEM at the Central Science Laboratory (UTAS). This study also formed part of Sarah Gilbert's PhD project.
- A comparison of the amount of signal drop during the ablation of sulfide minerals on seven different types of lasers at CODES, ETH Zurich, QUT and Université du Québec à Chicoutimi.

ELEMENT MAPPING BY LA-ICP-MS

Leader: Sebastien Meffre

Team Members: Leonid Danyushevsky, Paul Olin, Sasha Stepanov

Key objectives are to develop new analytical procedures and algorithms for mapping the distribution of trace elements in geological materials by LA-ICP-MS. This year the main focus was on:

- Improving the efficiency of element map acquisition.
- Changes in the analytical protocols and instrument cleaning routines to allow long multi-day and overnight runs, using the Laurin Technic S155 laser ablation sample cell.
- Further testing and refining of the automated mineral identification and matrix correction algorithms to allow sulfur to be used in mineral identification.
- Development and implementation of the algorithm for data processing from analytical sessions that use two different calibration standards.
- Optimisation of algorithms for applying median filters and processing multiple images, acquired simultaneously.

CALIBRATION STANDARDS FOR LA-ICP-MS

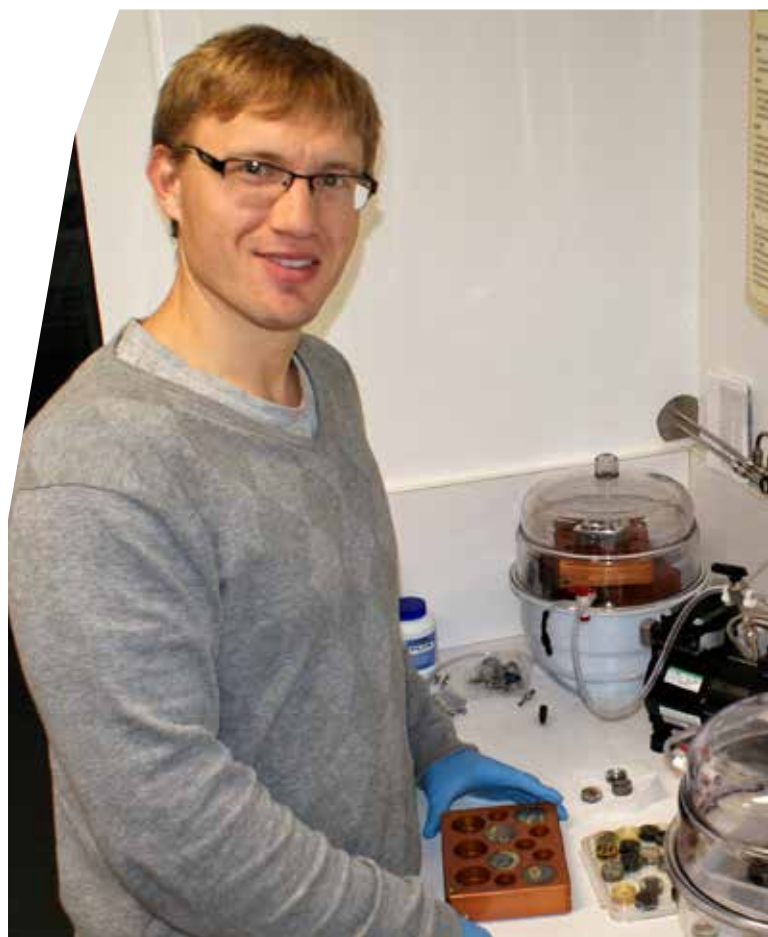
Leaders: Ivan Belousov, Leonid Danyushevsky

Team Members: Sarah Gilbert, Elena Lounejeva, Paul Olin, Jay Thompson

Collaborators: Ralph Bottrill, Detlef Günther, Daniel Tabersky, Richie Woolley

This project is aimed at the development and characterisation of new calibration standards for LA-ICP-MS analysis of various geological materials. The focal points for the past year were:

- Fabrication of a new calibration standard for LA-ICP-MS analysis of sulfides that replaces, and improves upon, the standard currently used (fabricated in 2003). One of the major improvements is a more homogeneous distribution of volatile elements Se, Tl, Au, Pt, Ag and Te. Several approaches to fabrication of the new standard were investigated, including one based on improving the preparation procedure used currently. A borate flux with a low melting temperature was mixed with sulfide powders and doped with other elements. The recently acquired Claisse M4 LPG fluxer was employed to ensure better temperature controls and mixing within a shorter preparation time. The resultant glass discs proved to be significantly more homogeneous.



Aleksandr (Sasha) Stepanov preparing samples for laser ablation analysis.



Collaborator Ashley Norris
from Norris Software.

- Pressed pellets made from nano-particle powders were tested as an alternative to glass discs for producing a standard for sulfide analysis. Iron sulfide nano-particles produced by flame spray synthesis at ETH Zurich were also tested, but proved to be heterogeneous for a wide range of elements.
- Testing commenced of a recently acquired planetary ball-mill (Fritsch Pulverisette 7), which is being used for grinding mixtures of natural sulfide minerals to produce a homogeneous powder with nano-scale particle sizes. This testing will continue in 2015.

LA-ICP-MS INSTRUMENTATION DEVELOPMENT

Leader: Leonid Danyushevsky

Team Members: Sarah Gilbert, Paul Olin, Jay Thompson

Collaborator: Michael Shelley

This project tests, designs and develops new instrumentation to ensure continuing advances in geological LA-ICP-MS applications. Example developments include ablation cells, the interface between the laser and the mass-spectrometer, and testing new types of laser microprobes and mass-spectrometers. The main activities during the year were related to understanding the effect of the configuration of the smoothing devices, within the interface between the laser probe and ICP-MS, on signal smoothness and wash-out times, plus testing the applicability of a simultaneous detection ICP-MS model (SpectroMS from SPECTRO Analytical Instruments GmbH, Kleve, Germany) for LA-ICP-MS applications.

U-PB DATING

Leader: Jay Thompson

Team Members: Leonid Danyushevsky, Sebastien Meffre

The objectives of this research are to use analytical developments to improve the precision and accuracy of U-Pb dating by LA-ICP-MS, and expand the range of minerals that can be dated using this method.

This year, the team focussed on gaining a better understanding of the limits of accuracy of U-Pb analysis of zircon. Zircons of known ages, and varied trace element compositions, were analysed under a range of conditions, which enabled the system to be optimised to provide the most accurate analyses with the lowest age offset between zircons.

By using an optical profiler at the Central Science Laboratory at UTAS, the team was able to measure the depth of the ablation craters very precisely and compare them to the measured age offsets. This exercise greatly aided the team's understanding of the matrix effects between zircons, and led to a series of experiments aimed at minimising these effects. Subsequently, the team has significantly extended the observations from previous studies, which have shown that zircons with a higher radiation dose ablate deeper, resulting in age overestimation. In addition, by determining age offsets for apatite minerals with different compositions, they have gained a much better understanding of the matrix effects when dating apatites.

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, 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 LA-ICP-MS analytical facility, 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 2014 were directed toward developing advanced meta-data handling algorithms for user-friendly and efficient processing of the acquired data, using multiple calibration and internal standards. The first fully functional beta-version is scheduled for in-house testing in mid-2015.



Matt Cracknell (left)
discussing research
findings with PhD
student Stephen Kuhn.

MODELLING OF CRYSTALLISATION AND MELTING PROCESSES

Leader: Leonid Danyushevsky

Collaborators: Alexey Ariskin, Pavel Plechov

The aims of this project are to:

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

In 2014, work continued on developing a new model for plagioclase-silicate melt equilibrium under hydrous conditions at variable pressures. An updated version of Petrolog3 was made available on the Petrolog home page (<http://petrolog.web.ru>).

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

This project uses big data machine learning techniques to gain new understandings of the lithology and geological contact mapping in difficult or poorly exposed terranes.

The successful proof of concept studies were published this year in the high-profile international journal *Computers and Geosciences* and a key case study from NW Tasmania was published in *The Australian Journal of Earth Sciences*. Matt Cracknell obtained his PhD during the year, with a project centred on this work.

Following these successes, an expression of interest for a full proposal was circulated by AMIRA International, which has received a positive initial response. The AMIRA P1166 project proposes to run case studies, in consultation with industry partners, to facilitate technology and skills transfer, tailored to individual ore exploration contexts.

PhD student Stephen Kuhn, who joined the team in September, will progress the techniques, which employ a combination of supervised (Random Forests) and unsupervised (Self-Organising Maps) methods. The new project will trial the methods across several contrasting ore deposit environments to optimise workflows for practical use.

TECHNIQUE DEVELOPMENT IN COMPUTATIONAL KNOWLEDGE DISCOVERY FROM HIGH-D DATA

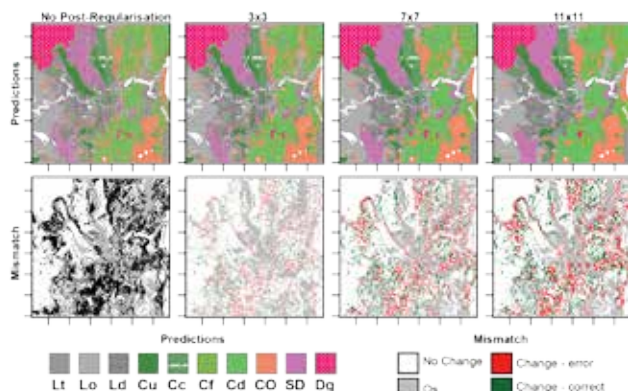
Leader: Anya Reading

Team Member: Matt Cracknell

Collaborator: Patrice de Caritat

This project is aimed at computational knowledge discovery from high-dimensional (high-D) data. Highlights of the year included:

- Development of a new technique that incorporates spatial context information into a workflow for predicting lithology from high-D data, which improves the percentage of correctly predicted 'pixels'. Importantly, the improvements are made with no significant penalty in computational time; hence, the method is readily



Reclassification of Random Forests lithology predictions with different post-regularization (PR) filter dimensions. An increase in PR filter dimensions results in an improvement in prediction accuracy of geological features that are larger than the PR filter dimension.

applicable and may be run on portable computers of reasonable specification. A paper on this work is scheduled to be published in *JSTARS*, an applied spatial science journal.

- Exploring the application of big data techniques to regolith signatures. This work has now been extended using significant national datasets, in collaboration with Geoscience Australia, and submitted for publication. Matt Cracknell received a 'best paper' award at a specialist workshop held in Western Australia for a presentation related to this research.

GEODATA ANALYTICS, VISUALISATION AND DECISIONS

Leader: Anya Reading

Student: Peter Morse

Collaborator: Henry Duh

This project expands the scope of research undertaken within CODES and the Discipline of Earth Sciences into geodata analytics and innovative visualisation strategies. By utilising the existing expertise in technique development and the practical application of methods in computational geophysics and Earth informatics, the project focusses on using the visualisation as part of the data inference process, rather than being simply a way of viewing the final output.

During 2014, PhD student Peter Morse developed a computer application for the animated visualisation of big data. This application uses highly capable strategies from the field of computer graphics to analyse scientific data formats. Large data files are accessed via the Australian NeCTAR (National e-Research Collaboration Tools and Resources) cloud. A presentation on the application and an illustrative case study were presented at the American Geophysical Union meeting in San Francisco, December 2014.

LOOKING FORWARD

During 2015, research activities will focus on continuing analytical and algorithmic developments, and contributing to the activities of the Australian Research Council (ARC) Industrial Transformation Research Hub: Transforming the Mining Value Chain (TMVC).

Module research within TMVC will concentrate on developing data processing algorithms for high data generating scanning sample characterisation equipment, such as the Corescan drill-core logger; applying big data approaches to geoenvironmental prediction; and building laser ablation sample cells capable of accommodating large sections of drill core.

The installation of two new excimer laser systems early in 2015 will enable further comparison between laser types, and an investigation into the effects of changing the laser wavelength, pulse width and optical geometry.

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

- Understanding ion energy in argon plasma, that will highlight differences between solution and laser ablation ICP-MS.
- Development and testing of the new calibration standard for sulfide analysis by LA-ICP-MS.
- Matrix effect in U-Pb dating of zircons by LA-ICP-MS.

Further analytical developments will involve gaining a better understanding of the matrix effects in apatites, and improving the mineral identification and matrix correction algorithms during imaging of trace element distribution within minerals, using LA-ICP-MS.

Market testing is planned for the AMIRA P1166 project proposal, which puts forward the concept of using big data machine learning techniques to gain new understandings of the lithology and geological contact mapping in difficult or poorly exposed terranes.

MODULE TRAINING



TEAM LEADERS:

Jocelyn McPhie
and Robert Scott

OBJECTIVES

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

INTRODUCTION

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

Training activities also play a vital role in the Centre's research program via a wide array of student theses, which are integral to research activities throughout the other three Modules.

In recognition of these attributes, CODES has developed a Module within its new structure dedicated solely to training. This ensures that training continues to play a key role in the Centre, and also has the necessary structure and platform to expand and evolve.

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

HIGHLIGHTS

It was a busy and highly productive year for the Training Module, which included a number of accolades and achievements.

The HDR Program continued to demonstrate its popularity in overseas markets, attracting a cohort of 37 international students representing 18 nationalities. It is also pleasing to note that the program achieved a record high of seven Australian enrolments, though this could partly be a reflection of tighter employment conditions in the industry.

The Master of Economic Geology Program had a very good year, also achieving a record high, with 52 active participants, coupled with strong attendances at all three of its short courses for 2014.

A highlight for the postgraduate students was the SEG Student Chapter field trip to Portugal and Spain, where they gained first hand experience of the renowned Iberian Pyrite Belt – one of the most important and abundant VHMS districts in the world.

The students also received a raft of awards and grants, which are listed in the SEG Student Chapter section featured later in this Module report.

In September, CODES partnered with consulting company GHD and Mineral Resources Tasmania to run the Advances in Geo-logging short course. This much anticipated industry-focussed course was structured to enhance the geo-logging skills of the participants, with the key aims of improving technical results, profitability and efficiency for their employers.



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 the research activities of the Centre of Excellence. Ninety per cent of HDR projects are integrated into the Centre's three research modules and about two-thirds of the projects involve collaborations with the minerals industry.

CODES' success in attracting HDR students from overseas is underpinned by its international reputation as a research training centre. The 2014 cohort included 37 international students representing 18 nationalities.

There were 54 students enrolled in the program during 2014 (50 PhD and 4 MSc or MExploration Geoscience), which included nine new PhD students – Alexander Cherry (Australia), Cassady Harraden (USA), Rachel Harrison (Australia), Jacob Heathcote (Australia), Stephen Kuhn (Australia), Elena Lounejeva (Australia), Larriana Morgan (Australia), Indrani Mukherjee (India), and Jacob Mulder (Australia). Thirteen PhD students and one MSc student had theses under examination, nine of whom graduated: Matt Cracknell, Hugo Galván, Dan Gregory, JianXiang Guan, Roisin Kyne, Takayuki Manaka, Daniele Redi, Selina Wu, and Paula Montoya (MSc).

The number of thesis submissions and graduations reduced the effective PhD workforce to 42. In addition, two students suspended their candidature for part of the year, one chose to study part-time, and two withdrew (one PhD and one MSc), reducing the effective HDR workforce to 38.



A selection of PhD graduates and their supervisors. From left: Ross Large*, Vic Braniff, Bruce Gemmell*, Dan Gregory, Roisin Kyne and Matt Cracknell.*

Notwithstanding this natural attrition, both the figures for the effective workforce and new enrolments are on par with the previous year. It should also be noted that the intake of seven Australian HDR students in 2014 was a record high, possibly reflecting the tighter employment situation in the minerals industry.

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

MASTER OF ECONOMIC GEOLOGY PROGRAM

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

The Centre's Master of Economic Geology Program has enjoyed another busy and successful year, with active enrolments in the program reaching an all time high of 52 students, coupled with strong attendances at all three of the short courses.

THE SHORT COURSES IN 2014

VOLCANOLOGY AND MINERALISATION IN VOLCANIC TERRAINS

In March, Jocelyn McPhie, Bruce Gemmell and Rebecca Carey led a group of 19 participants to New Zealand's North Island to examine modern volcanic systems as part of the ever-popular Volcanology and Mineralisation in Volcanic Terrains short course. The second part of this field-based unit was led by Jocelyn, Rebecca and Ross Large, who took the group to the west coast of Tasmania to examine the well mineralised and altered Cambrian Mt Read Volcanics. This hands-on course provides an excellent introduction to the processes and products of different eruption styles, contrasts in scale and structure of volcanoes, identification of key volcanic facies associations, and interpretation of facies variations. Mineralisation and alteration processes related to hydrothermal systems in subaerial and submarine volcanic environments and implications for mineral exploration are also addressed.

EXPLORATION IN BROWNFIELD TERRAINS

Robert Scott led the Exploration in Brownfield Terrains short course in June, which was attended by 22 participants.

This unit is designed to bring students up-to-date with the latest exploration techniques and approaches to compiling and working with historical datasets. Exploration in data-rich environments, close to existing mines, has become a preferred method of enhancing company resources in recent years. This trend has led to a sustained interest in this course, which covers cutting-edge technologies in geophysics, geochemistry and 3D visualisation, and uses real data from world-class mineralised districts. Highlights of the course were presentations by expert teaching staff from CODES and the minerals industry. The leading minerals industry professionals and consultants who provided tuition included Heidi Pass (Reflex Geochemistry), Andrew Cantwell and Jacob de Lacey (Leapfrog3d), Kim Denwer (MMG, Rosebery) and John Holliday (Consultant).

ORE DEPOSIT MODELS AND EXPLORATION STRATEGIES

Twenty-four Masters students and six participants from the minerals industry attended the final short course of the year, Ore Deposit Models and Exploration Strategies, held over the last two weeks of October.

The first six days of the course utilised an interactive format of lectures and practical exercises to provide an up-to-date synopsis for a range of key ore deposit types, addressing topics such as location, characteristics, genesis and exploration strategies. Deposit types covered were sediment-hosted U, Cu and Pb-Zn, volcanic-hosted massive sulfide and sea-floor hydrothermal, Carlin-type sediment-hosted Au, porphyry and epithermal, orogenic, and Witwatersrand Au. The second week featured two workshops, each lasting two days. The first was entitled Alteration Geochemistry and Targeting, and was led by invited speaker, Scott Halley. The second was entitled Breccias in Hydrothermal and Ore-forming Environments, and was led by David Cooke, with the support of invited speakers Nick Oliver and Stephen Cox. On the final day, the students gave short presentations on a range of ore deposit types not formally covered in the course.

CHANGES TO ADMINISTRATION

A number of administrative changes took place during the year in order to bring the course structure into line with the new Student Management system adopted by UTAS. As a result, students who commenced their Masters degrees prior to April 2014 continued under the original course structure (S7R), receiving 0.20 credit points per unit (eight in total); while those who commenced after that date study under the new course structure (S7W), receiving 0.25 credit points per unit (eight in total). New unit codes have been introduced as part of the new system, but dual coding will operate during the transition phase to cater for students enrolled under the old course structure.

Top: PhD graduate Dr Selina Wu with supervisor Andrew McNeill (MRT). **Centre:** From left: Maria Lourdes Faustino, Saranya Nuanla-ong (Thailand), and Billy Beas at the Ore Deposit Models and Exploration Strategies short course. **Bottom:** Bruce Gemmell collecting a water sample for a pH test at Champagne Pool, Waiotapu Geothermal Park, NZ.



GOOD YEAR FOR ENROLMENTS AND COMPLETIONS

Ten new students joined the program in 2014, and one past student re-activated their enrolment, bringing the total number of UTAS-based students active in the national program to a new record of 52. Growth of the program appears set to continue, with seven new admissions and one re-activated enrolment expected to be processed early in 2015. This reflects the growing recognition and popularity of the Masters program with industry-based geoscientists, and confirms UTAS/CODES as the institute of choice for its completion.

It was also a good year for graduations and completions, with eight students graduating: Corrie Chamberlain, Glen Diemar, Rachel Harrison, Kane Maxwell, Joshua Phillips, Tatjana Pucko, Michelle Puskas and Scott Randall. A further five students completed the degree and are eligible to graduate in 2015: Lynelle Beinke, Truong Le, Neil Macalalad, Michael Musialike and Ned Summerhayes. It is particularly pleasing to note that five of the twelve students who recently completed the program incorporated a research thesis (worth 25%) as part of their degree.

THE PROGRAM FOR 2015

- 13 – 27 March: Ore Deposits of South America (KEA706/KEA707)
- 8 – 19 June: Ore Deposit Geochemistry, Hydrology and Geochronology (KEA704/KEA709)
- 19 – 30 October: Geometallurgy (KEA702/KEA711)

HONOURS PROGRAM

The total number of students enrolled in the program was 13 for the first half of the year and 14 thereafter, after accounting for students that either enrolled or completed mid-year.

Out of this cohort, Wasim Hashmi joined the group from Monash University, Anthony Benn from Macquarie University, Natnaree Chandraprasert from the University of New South Wales, Naomi Potter from UWA, and Supitchaya Paipana from Chulalongkorn University in Thailand. The remaining students came to the program via an undergraduate degree at the University of Tasmania.

Eight of the Australian projects were based in Tasmania. Four of the international projects involved fieldwork, in Myanmar (2), Thailand and New Caledonia. The Tasmanian projects were sponsored by Venture Minerals, Mineral Resources Tasmania, MMG Rosebery, Grange Resources, DPIPWE, Nyrstar, the Derwent River Estuary Program and the Australian Research Council. The mainland projects were supported by Anglo American, CBH Resources, Sandfire Resources, QGC, and OZ Minerals (Prominent Hill). The projects in Myanmar were sponsored by the National Prosperity Gold Production Group.

CODES thanks the sponsors for their valued support, with a special mention to QGC, Venture Minerals, CBH Resources, the Derwent River Estuary Program, and the Myanmar-based National Prosperity Gold Production Group, all of whom were supporting the program for the first time. The sponsorships have been vital to the success of the projects, and the development of the students during a crucial phase of their studies.

The degree coordination continued under the supervision of Garry Davidson, with the welcome addition of the respected structural and economic geologist David Selley, who manages the coursework component of the Honours candidature.



Participants in the Volcanology and Mineralisation in Volcanic Terrains short course on White Island, New Zealand.

HONOURS COURSEWORK PROGRAM

CODES offers three short courses, five to eight days in duration, as part of the Minerals Tertiary Education Council (MTEC) Minerals Geoscience Honours and Victorian Institute of Earth and Planetary Sciences (VIEPS) Honours coursework programs.

EXPLORATION FIELD SKILLS MAPPING CAMPS (in partnership with MTEC)

Course Leader: Robert Scott

Course Demonstrators: Sean Johnson, Erin Lawlis, Jacob Mulder, Evan Orovan, Josh Phillips, Nathan Steeves

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

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

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

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

The eight-day camp is held twice each year, in February and March. In 2014, a total of 39 students, from eight different universities, attended the camps.

ORE DEPOSIT MODELS (in partnership with VIEPS)

Course Presenters: David Cooke, Garry Davidson, Bruce Gemmell, Ross Large, Robert Scott, David Selley

In May, 16 students from Victoria attended the five-day Ore Deposit Models Honours-level short course, which provides an introduction to the key features of several major classes of economically important mineral deposits.



Wasim Hashmi studying rock samples during the VIEPS Ore Deposit Models course.

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 deposits.
- Epithermal, porphyry copper and skarn deposits.
- Iron-oxide copper gold.
- Sediment-hosted and orogenic gold.
- Sediment-hosted uranium, copper and lead-zinc.

Each day of the course incorporated a mixture of lectures and practical exercises. Lectures covered the general characteristics and setting of the deposit types covered, 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, 11 students attended the Practical Igneous Petrology course, presented by Leonid Danyushevsky. The five-day program is a mixture of lectures and practical exercises, aimed at postgraduate students at Honours level and above with an interest in the formation and evolution of basic and ultrabasic magmas and their relationship to magmatic ore deposits.

Topics covered included:

- Key theoretical aspects of petrology, including units of concentration, solid solution and mineral formulas, activities and equilibrium, the phase rule, mass balance, phase diagrams, and equilibrium/fractional crystallisation.
- Examination of a large layered intrusion (the Dovyren Magmatic Complex in Siberia), the effects of pressure and H₂O on melting and crystallisation, the causes of melting and crystallisation.
- An introduction to the concept of distribution coefficients for trace elements.
- Trace elements in the main rock-forming minerals.
- Modelling of crystallisation and studies of melt inclusions.
- Examples from MORB, subduction-related lavas and komatiites.

STUDENT PROJECTS

IN AUSTRALIA

Project locations are shown in capitals. Unless marked otherwise, student projects shown here are PhDs.

1. Anderson, Michael. SA (Hons)

Analysis of wide angle reflection and refraction data, Mount Woods area, South Australia.

2. Apukhtina, Olga. SA

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

3. Baker, Wayne. WA (Hons)

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

4. Barbosa De Souza, Luziane. NSW (Masters)

Webbs silver project, NSW.

5. Benn, Anthony. NSW (Hons)

Geology of the Racecourse Prospect, NSW: Economic geology, geochronology, geochemistry, and paragenesis of a Cu-mineralised I-type granitoid suite.

6. Cave, Ben. VIC

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

7. Cavill, Chloe. VIC (Masters)

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

8. Chandraprasert, Natnaree. TAS (Hons)

Stratigraphy, structure and volcanology between the Mount Black Fault and the Rosebery Fault in the north-end of Rosebery Mine, western Tasmania.

9. Cherry, Alexander. SA

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

10. Condon, Jo. WA (Masters)

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

11. Copper, Ashby. TAS (Hons)

The crustal structure of the Bass Strait region from combined passive seismic methods.

12. Diemar, Glen. SA (Masters)

Geochronology of hydrothermal REE minerals and their relationships with economic mineralisation at the Olympic Dam breccia complex, South Australia.

13. Eshaghi, Esmaeil. TAS

Petrophysical and geophysical investigation of western Tasmania.

14. Farias, Pablo. NT (Masters)

TBA (An aspect of uranium deposits in NT).

15. Fox, Jodi. TAS

Basaltic volcanic successions in Tasmania and on Heard Island.

16. Gilmore, Phil. NSW (Masters)

An aspect of the geology of the Koonenberry Belt, NSW.

17. Gregory, Dan. WA

The trace element composition of sedimentary pyrite: Factors affecting uptake and uses of the data for determining paleo-ocean conditions.

18. Harvey, Alistair. QLD (Hons)

Depth to basement below the Bowen and Surat Basins, Chinchilla, Queensland.

19. Hashmi, Wasim. TAS (Hons)

Sn-W-Ta-Nb in micas and their relationship to granite fractionation in western Tasmania.

20. Hawke, Margy. WA

Geology of the DeGrussa Cu-Au-Ag volcanic-hosted massive sulfide deposit, Western Australia.

21. Haycroft, Melanie. NSW (Hons)

The eastern mineralisation, Broken Hill, NSW.

22. Holmes, Travis. TAS (Hons)

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

23. Hong, Wei. TAS

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

24. Hoye, Jonathon. NSW (Masters)

An aspect of the geology of North Parkes, NSW.

25. Huang, Qiuyue. SA

Mafic dykes at Olympic Dam.

26. Hughes, Stuart. TAS (Hons)

Quantifying and characterising heavy metal contamination and sedimentation rates in the Derwent Estuary.

27. Jackson, Laura. TAS (Hons)

Geochemical and mineralogical characterisation of tailings: Evaluating the benefits of water covers as a rehabilitation strategy, Savage River Mine, Tasmania.



28. Kyne, Roisin. NSW

Genesis and structural architecture of the CSA Cu-Ag (Pb-Zn) mine, Cobar, New South Wales.

29. Lower, Chantelle. SA (Masters)

An aspect of the geology of the Olympic Dam deposit.

30. McAdam, Will. TAS (Hons)

Geophysical investigation of the Mole Creek area, Tasmania.

31. Morgan, Larriana. NT

Controls on copper mineralising process in the central McArthur Basin, NT (Redbank Package), and its implications for the metallogeny of extensional basins.

32. Mukherjee, Indrani. NT

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

33. Mulder, Jacob. TAS

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

34. Pascual, Richelle. TAS

The characteristics and role of colloidal silica fluids in the formation of the Grieves Siding Zn-Pb prospect, western Tasmania.

35. Pereira da Fonseca, Pedro. TAS

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

36. Sharma, Subira. QLD

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

37. Steadman, Jeff. WA

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

38. Vejelyte, Irma. SA

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

39. Wu, Selina. TAS

Volcanic hosted massive sulfide deposits of the Que-Hellyer Volcanics, western Tasmania.

40. Yilmaz, Onur. NSW (Masters)

The Mount Carrington epithermal Au and Ag-Au deposits, NSW: Potential for porphyry-style mineralisation.

41. Yu, Jie. TAS (Hons)

A geophysical investigation of the Mt Lindsay-Lynch Hill area, western Tasmania.

OUTSIDE AUSTRALIA

Project locations are shown in capitals. Unless marked otherwise, student projects shown here are PhDs.

1. Baker, Fabian. ARMENIA (Masters)

Amulsar HSE Au deposit, Armenia.

2. Basori, Mohd Basril Iswadi Bin. MALAYSIA

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

3. Beas Caceras, Billy. PERU (Masters)

Petrography and mineragraphy of volcanic rocks and age dating of La Zanja Mine, Peru.

4. Berkenbosch, Heidi. NEW ZEALAND

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

5. Calderon-Tipiani, Cesar. PERU (Masters)

Chanca low sulfidation deposit, Peru.

6. Cave, Ben. CANADA, NEW ZEALAND

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

7. Celiz, Djohanne. PHILIPPINES (Masters)

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

8. Chen, Jing. CHINA

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

9. Erskine, Tobias. MYANMAR (Hons)

Geology, structure and mineralisation characteristics of the Modi Taung gold deposit, Myanmar.

10. Escolme, Angela. CHILE

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

11. Faustino, Maria Lourdes M. PHILIPPINES (Masters)

Plio-pleistocene intrusive history and ore paragenesis of Bayugo porphyry Cu-Au deposit Surigao Del Norte, Philippines.

12. Firmansyah, Arga. INDONESIA (Masters)

The Pangulir porphyry-epithermal prospect, Indonesia.

13. Galván-Gutiérrez, Víctor Hugo. MEXICO

Palmarejo carbonate-base metal epithermal Ag-Au district, Chihuahua, México.

14. Guan, JianXiang. CHINA, USA

Origin of associated magnetite and sulfide mineralisation in large gabbroic intrusions: An LA-ICP-MS study of minerals and melt inclusions from the Panzhihua and Taihe intrusions in Emeishan LIP and Duluth Complex.

15. Harraden, Cassady. TANZANIA

Geometallurgical project in Tanzania.

16. Harrison, Rachel. INDONESIA (Masters & PhD)

Tujuh Bukit Cu-Au porphyry-epithermal deposit, Java, Indonesia.

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. Jimenez Torres, Carlos Andres. PHILIPPINES

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

20. Johnson, Sean. FINLAND, ESTONIA, SWEDEN, RUSSIA

Trace elements in metalliferous black shales.

21. Kamvong, Teera. THAILAND, LAOS

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

22. Lawlis, Erin. PNG

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

23. Le, Xuan Truong. VIETNAM (Masters)

Mineralisation of Me Xi gold deposit, Vietnam.

24. Macalalad, Neil. INDONESIA (Masters)

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

25. Makoundi, Charles. MALAYSIA

Geochemistry of Phanerozoic black shales in Peninsular Malaysia: Relationships to gold mineralisation.

26. Manaka, Takayuki. VIETNAM

Geology and mineralisation characteristics of the Phuoc Son goldfields, central Vietnam.

27. McLelland, Rebecca. NEW ZEALAND (Masters)

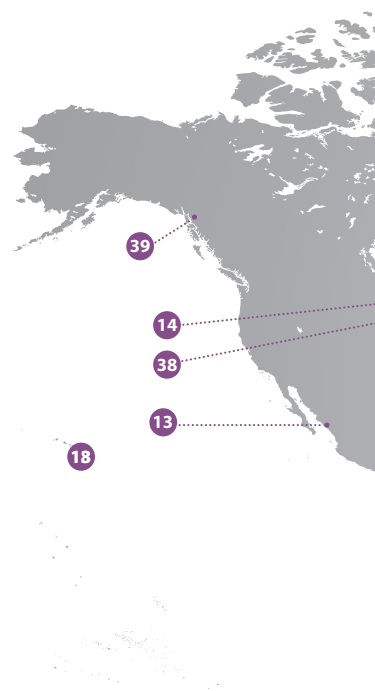
Gold mineralisation at the Reefion Goldfield, New Zealand.

28. Montoya, Paula. COLOMBIA (Masters)

Comminution studies: La Colosa case study.

29. Mukherjee, Indrani. INDIA

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



30. Musialike, Michael. ZAMBIA (Masters)

Controls on gold mineralisation at Matala and Dunrobin, Zambia (Luirigold).

31. Nuanla-Ong, Saranya. MYANMAR (Masters)

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

32. Orovan, Evan. FIJI

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

33. Paipana, Supitchaya. THAILAND (Hons)

Geochemistry and mineralisation characteristics of Bo Thong antimony-gold deposit, Chonburi province, Eastern Thailand.

34. Piquer Romo, Jose Meulen. CHILE

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

35. Redi, Daniele. ITALY

A contribution to the understanding of the eruptive behaviour of Somma-Vesuvius; A mineral chemistry perspective.

36. Rinne, Marc. PNG

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

37. Serrano, Lina. (U Padova) ARGENTINA, MAURITANIA, MALI

The magmatic province of Patagonia and sills from Mauritania and Mali: Examples of silicic and basaltic large igneous provinces.

38. Steadman, Jeffrey. USA

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

39. Steeves, Nathan. USA

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

40. Sykora, Stephanie. PNG (Masters)

The geological, structural, geochemical and genetic significance of anhydrite veins and cemented breccias at the Lihir gold deposit, Papua New Guinea.

41. Testa, Francisco. ARGENTINA, CHILE

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

42. Traynor, Jonathon. MYANMAR (Hons)

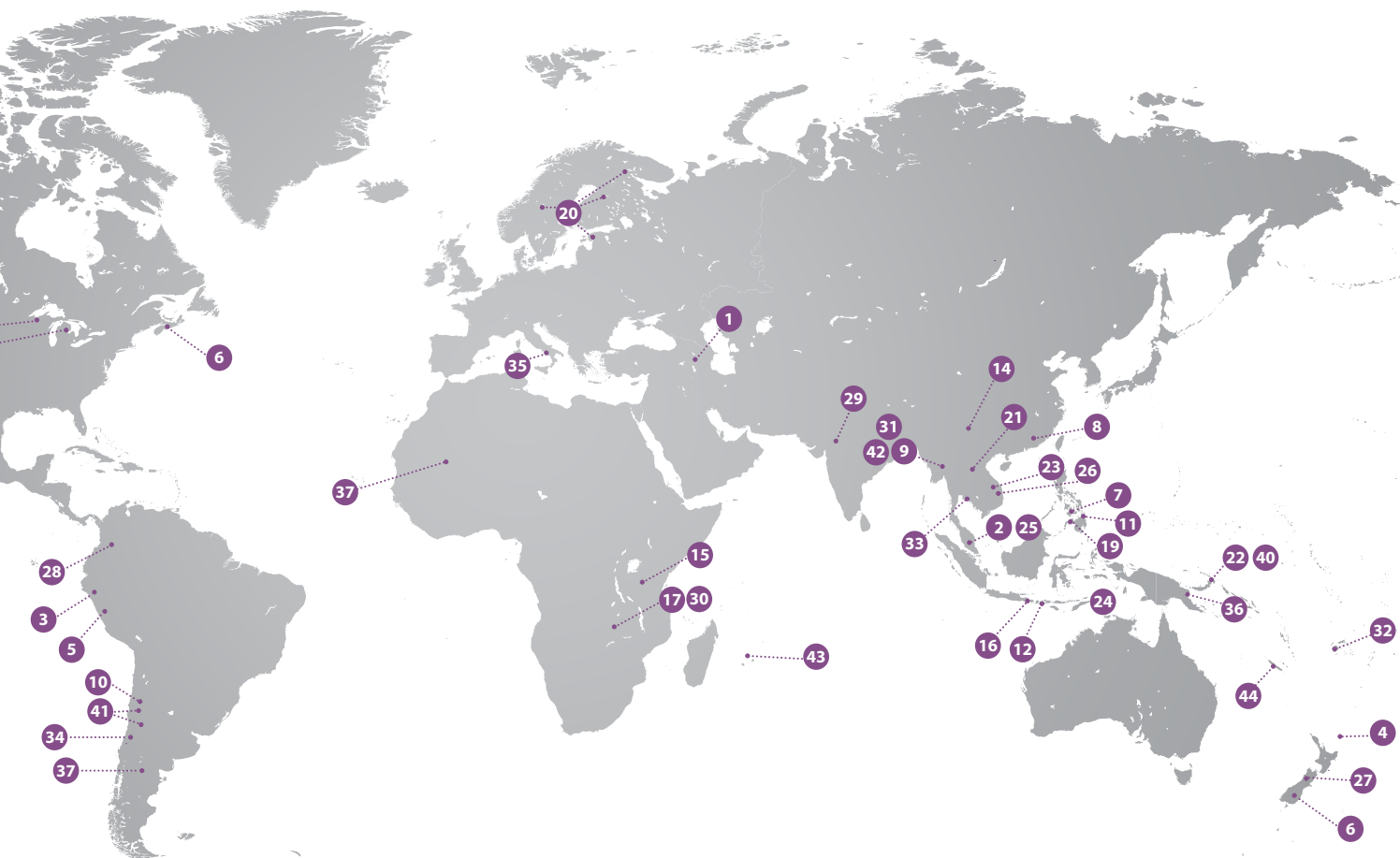
Geology, structure and mineralisation of Shwezin vein, Modi Taung, Myanmar.

43. Vergani, Daniele. FRANCE

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

44. Whitten, Matthew. NEW CALEDONIA (Hons)

Kone Formation (New Caledonia) – a sedimentary record of the final stages of Gondwana breakup.



LAB-BASED PROJECTS

Unless marked otherwise, student projects shown here are PhDs.

Cracknell, Matt

Machine learning for geological mapping: Algorithms and applications.

Gal, Martin

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

Gilbert, Sarah

Development of analytical methods and standard reference materials for the determination of trace element concentrations and isotopic ratios in sulfur-rich minerals and silicate glasses.

Kuhn, Stephen

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

Lounejeva, Elena

Geochemical signature of syngenetic and diagenetic pyrite from marine sediments as a paleo-environmental tool.

McMahon, Claire

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

Morse, Peter

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

Potter, Naomi (Hons)

The eruption dynamics of the 23rd February 2013 event at Mt Etna.

Strochnetter, Andrew (Hons)

Circulation of the southwest Pacific Ocean during the penultimate deglaciation.

Wells, Lydia (GDipSci)

Long-term assessment of the weathering characteristics of sulfide materials.

PhD Student Subira Sharma operating the PicoTrace high pressure digestion equipment.



CODES SEG Student Chapter Committee for the first part of the year, from left Margy Hawke, Sean Johnson (President), Stephanie Sykora, Angela Escolme, and Erin Lawlis.



SOCIETY OF ECONOMIC GEOLOGISTS (SEG) STUDENT CHAPTER

The CODES SEG Student Chapter makes an immeasurable contribution to the lives of postgraduate students during their time at the university. It provides a catalyst for bringing together people from widely different cultures and backgrounds, helping them to settle quickly into life on campus, and feel a welcome part of both CODES and the local community.

This is achieved through a full and varied range of social and professional development activities that cater for all interests.

PROFESSIONAL DEVELOPMENT

The highlight of the year's professional development activities was the much anticipated field trip to the Iberian Pyrite Belt, sponsored by the SEG and AMIRA International. The participants followed this renowned mineral belt for a large part of its 250 kilometre length, which starts in Alcacer do Sal in Portugal and ends in Sevilla in Spain. A memorable stop on the itinerary was a tour of the Lousal Mining Village, a 19th and 20th century sulfur mine that has been converted into a science centre. Other high points included visits to Somincor's massive Neves-Corvo copper-zinc operation in Portugal, and the famous Rio Tinto copper deposit in Spain. This latter deposit is currently owned by EMED Mining, but is recognised as being the birthplace of Rio Tinto, which is now one of the world's leading mining and metals companies. The Portugal leg of the trip was led by Professor Jorge Relvas from the University of Lisbon, with Professor Reinaldo Saez Ramos from Huelva University taking over in Spain.



THE SEG STUDENT CHAPTER
PLAYS A VITAL ROLE IN BOTH
THE SOCIAL AND PROFESSIONAL
DEVELOPMENT ASPECTS OF
LIFE ON CAMPUS.

*SEG Student Chapter group on a drilling
platform at the new Magdalena deposit,
near Minas Agua Tenidas, Spain.*

Another field trip was conducted later in the year, but this time it was much closer to home in western Victoria. The one week excursion was led by Professor David Cooke and Dr Rebecca Carey, who introduced seven students to the maar volcanoes and associated volcanic features of the Newer Volcanic Province.

This year's Mike Solomon Lecture was delivered by the highly respected geologist, Professor Noel White. This annual event is held in honour of the esteemed UTAS/ CODES teacher and researcher, Mike Solomon, who passed away in 2009. Noel was an appropriate choice for the lecture as he had completed his PhD at UTAS under Mike's astute and expert supervision.

A number of students also participated in various conferences during the year, including the Specialist Group in Tectonic and Structural Geology (SGTSG) Biennial Meeting in Thredbo, NSW; the Australian Earth Sciences Convention in Newcastle, NSW; SEG 2014 in Keystone, Colorado, USA, and GEOMET 2014 in Santiago, Chile. Participation included four talks and seven poster presentations.

An innovation in 2014 was the introduction of a series of informal talks, which were held late in the afternoon on alternate Fridays. Students took turns to present a short 20 minute technical talk, followed by a 20 minute slide show of images, usually from field trips. Snacks and refreshments were on hand during and after each presentation, which added to the relaxed setting in which the students could hone their presentation skills and socialise.

SOCIAL EVENTS

The social events play a vital role in helping students from all corners of the globe settle into an environment and culture that are often very different to what they have known. They also help to develop a sense of camaraderie within the group, and establish friendships that often endure long after graduation.

Events organised by the Student Chapter included a quiz night, wine tastings, participation in a UTAS soccer tournament, barefoot lawn bowls and several raffles and



competitions. In addition, Student Chapter members participated in a host of other social events including weekly soccer games, dragon boat racing, ice hockey, indoor volleyball, badminton and squash. There were also a number of get togethers to celebrate various national and international milestones such as Christmas, Halloween, Diwali, American Independence Day and Canada Day.

Although the Student Chapter is mostly comprised of PhD students, it also plays an important role in welcoming other postgraduate students. For example, in 2014 the Chapter welcomed new Honours students with a traditional barbeque, and organised welcome drinks for the predominantly industry-based students who participated in the two on-campus Masters short courses.

AWARDS AND GRANTS

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

- Angela Escolme and Stephanie Sykora – Graduate Student Fellowships.
- Richelle Pascual and Jing Chen – Hugh E. McKinstry Student Research Awards.
- Indrani Mukherjee – Student Research Award.
- Subira Sharma – Field Trip Travel Grant.
- Stephanie Sykora – First place in the student poster presentation category at the SEG's annual conference in Keystone, Colorado, USA. Stephanie's poster was adjudged the best out of 179 posters from entrants from around the globe.

In addition to the SEG awards, Sam Holt received the GSA's David Groves Medal for 'the best paper in the *Australian Journal of Earth Sciences* by a young Australian' and Martin Gal received an American Geophysical Union (AGU) 'Outstanding Student Paper Award' at the 2014 AGU Fall Meeting in San Francisco.

Top: SEG Student Chapter Committee for the latter half of the year. From left Indrani Mukherjee, Nathan Steeves, Angela Escolme (President), Larriana Morgan and Erin Lawlis.
Bottom: PhD students Ben Cave (kneeling) and Jing Chen at the Rio Tinto deposit in Spain.





Hugh Tassell from GHD (centre) shows participants how to use a field conductivity meter during the Geophysics for Geologists and Engineers course.

COURSES FOR INDUSTRY

Through the day-to-day interactions with the minerals industry, it became increasingly apparent that there was a growing need for specialised courses aimed at re- and up-skilling their workforce. To address this need, CODES decided to introduce a range of courses aimed primarily at the working geologist. The first of these courses, Geophysics for Geologists and Engineers, was introduced in 2013, which was augmented by Advances in Geo-logging in 2014.

Similar to the Master of Economic Geology Program, the courses are structured to provide intensive, high quality training with minimal disruption to the working lives of the participants.

GEOPHYSICS FOR GEOLOGISTS AND ENGINEERS

Course Presenters:

CODES: Michael Roach

GHD: Hugh Tassell

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

Eight participants attended the six-day course, which provided an up-to-date overview of the application of

geophysical methods in mineral exploration, mining, geotechnical investigations, and environmental assessments.

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

ADVANCES IN GEO-LOGGING

Course Presenters:

CODES: Bruce Gemmell, Julie Hunt, Jocelyn McPhie, Michael Roach, Robert Scott

GHD: Tim Cartledge, Lee Evans, Graham Grainger, Hugh Tassell, Robert Virtue

MRT: David Green, Andrew McNeill

In September, CODES, Mineral Resources Tasmania (MRT) and GHD combined to present the four-day course: Advances in Geo-logging, which was attended by 21 students and seven industry participants.

The course provides a thorough understanding of the latest logging techniques, and how they can be used to improve geo-investigation and planning, while reducing risk, costs and uncertainty within the mining environment. It promotes a holistic approach to core logging during mineral exploration drilling projects, with the goal of maximising the quality, type and utility of data obtained. A key feature of the four days is the practical nature of the course content, which is structured to include lectures each morning from leading industry professionals, followed by extensive practical sessions in the afternoons.

Topics covered included:

- Approaches to geological scan, graphic and structural logging.
- Logging and interpretation of altered mineralised rocks in drill core.
- Best practice in geotechnical logging for assessments of ground conditions relevant to mine planning and design, and the construction of infrastructure such as buildings, roads, tunnels, waste dumps and dams.
- New methods and equipment for obtaining geometallurgical, mineralogical and geophysical information from drill core.
- How information obtained during early-stage (exploration) drilling can help identify future hydrological and geoenvironmental issues, such as aquifer impacts and potential for waste rock acid generation and metalliferous drainage problems.

On the final afternoon, attendees undertook a practical assessment, utilising the skills and knowledge obtained during the course to log selected cores.



LOOKING FORWARD

It is expected to be another good year for the Training Module in 2015. The indications are that the HDR program will continue to achieve strong enrolment figures for international students, and the recent success in attracting local applicants will be emulated.

The Master of Economic Geology Program is scheduled to have a full schedule of three short courses, including the field-based Ore Deposits of South America in March. Enrolments in this program are also expected to match or exceed the high levels achieved in 2014, and it is likely that the milestone of 100 graduates will be achieved before the end of the year.

The Honours coursework program will continue via collaborations with the Minerals Tertiary Education Council (MTEC) and the Victorian Institute of Earth and Planetary Sciences (VIEPS).

CODES will build on its focus on courses for industry, with Geophysics for Geologists and Engineers being held in February, and negotiations to be held with stakeholders to run Advances in Geo-logging later in the year.

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

There will also be a change of leadership in 2015, with Anya Reading taking over the responsibilities of Co-Module Leader and Graduate Research Co-ordinator from Jocelyn McPhie. Jocelyn officially retired at the end of 2014, but has been retained by CODES and the University in an honorary capacity. CODES thanks Jocelyn for her outstanding contribution to the Centre.

Co-leader Michael Roach (far right) leads a practical demonstration during the Geophysics for Geologists and Engineers course.



Jumping kids cause micro earthquakes, being measured on a seismometer by Michael Roach.

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, during which many of the regular activities on the calendar were complemented by a number of new initiatives, both on campus and in the local community.

OUT AND ABOUT IN THE COMMUNITY

One of the highlights of the activities in the community resulted from Rebecca Carey being nominated as a Young Tassie Scientist for National Science Week. Rebecca subsequently became part of a group of four scientists who visited 19 schools in the north of the state, where she gave a total of 30 presentations to students, ranging from Preparatory through to Year 12. Her talks covered her intriguing research into submarine volcanoes, which utilises robotic vehicles to gather rocks and fauna from the seafloor for analysis.

Another highlight was when the curator of the Rock Library, Izzy von Lichten, helped build two giant model spiders for the Bookend Trust's Sixteen Legs exhibition, held

in Hobart. The 5.5 metre wide cave-dwelling arachnids formed an integral part of an event that focussed on the mysterious and extraordinary world of Tasmania's underground cave systems. The Bookend Trust is a UTAS-based not-for-profit initiative that seeks to inspire students to pursue careers in science.

Izzy continued her good work at the local Calvin Christian School, where she taught a class of Year 10 students about local geology as part of CSIRO's Scientists in Schools program. She also mentored a Year 9 student from Ogilvie High School who had a strong interest in minerals. The weekly mentoring was performed as part of the national Big Picture Program, which connects young people with an adult in the community who has expertise that matches the person's interest.

Other notable activities involved Dan Gregory, Jocelyn McPhie, Peter McGoldrick, and Sharon Allen. Dan and Jocelyn each gave public lectures on their research at the Royal Society of Tasmania. Jocelyn took three Year 8 classes to the local foreshore in Sandy Bay to look at Tertiary basalt, Permian limestone, and Jurassic dolerite rocks. Sharon conducted a similar field trip to the area to show Year 3 and 4 students from Waimea Heights Primary aspects of erosion. Finally, Dan and Peter arranged rock collections for a number of local schools.

ACTIVITIES ON CAMPUS

Activities on campus began with the Science Experience initiative, which has become a regular feature on the early part of the outreach calendar. This national program provides the opportunity for Year 9 and 10 students to participate in a series of hands-on science activities under the guidance of researchers. This year's visit was led by Jacqui Halpin and included an interactive look at a variety of Tasmanian rocks using petrological microscopes.

Staff and students played a major role in the University's annual Open Day, which attracted over 10,000 people across all Tasmanian campuses and centres. Activities included a simulation of a mass extinction, where young and old were invited to throw meteorites (soft balls) at blow-up dinosaurs; a simulated volcanic eruption, with the aid of baking soda and red dye; and measurements of 'seismic events', created by jumping children and a sledgehammer.

CODES again played host to two groups from Taroona Scouts, who have been regular visitors to the Centre for a number of years. The groups comprised a mix of scouts, parents and scout leaders, who were guided through the lapidary section and various exhibits by Simon Stephens.

Two groups of students toured the Rock Library as part of the Cave ART initiative, which aims to demonstrate how art techniques are important to preserving fossil specimens, and creating large scientifically accurate displays.

The year also saw the usual mix of visits by groups representing various schools and age levels.

MEDIA

In addition to coverage in specialised media, CODES promoted the geosciences to the wider community via a variety of channels at state, national and international levels. Two of the main highlights were the extensive worldwide media coverage for Rebecca Carey's research on the eruption at the Havre Volcano, and the work by Jacqui Halpin and Peter McGoldrick, which discovered a prehistoric link between Tasmania and North America. Coverage included radio and TV interviews, plus features in leading international publications and websites.

Other activities that attracted general media coverage were the public lecture by Dan Gregory; and the geology-related blog maintained by Stephanie Sykora, who was interviewed by ABC Radio. Jocelyn McPhie conducted four radio interviews on various subjects during the year, and also featured in a major article in the *Sunday Tasmanian*. The Sixteen Legs exhibition, mentioned earlier, also received widespread coverage.

Top: Izzy von Lichten with one of the giant spiders she helped build. **Centre:** Jacqui Halpin explains the intricacies of Tasmania's rocks to students participating in Science Experience. **Bottom:** Jocelyn McPhie explains the geology of the local foreshore to Year 8 students.



INDUSTRY LINKS AND RESEARCH COLLABORATIONS

OBJECTIVES

- To be a research focus for the national and international minerals industry.
- Strategically collaborate with other top-level national and international research groups in the field of ore deposits, mineral exploration technologies and mineral processing.

CODES is recognised as a world leader in industry-linked, collaborative ore deposit research. Strong relationships have been developed with a range of industry partners and researchers who invest in, support, and contribute to, research projects. Fostering and growing these national and international collaborations is a key strategic focus.

INDUSTRY LINKS AND SYNERGIES

CODES has strong, enduring and mutually beneficial links with a group of major Australian and international mining companies. These links have been critical for funding CODES' research, and for technology transfer to the mining and mineral exploration community.

In 2014, the group of CODES' industry partners comprised of six Australian and international mining companies: Anglo American, AngloGold Ashanti, Buenaventura, Newcrest Mining, Rio Tinto, and Teck Resources.



*The AMIRA P1060 team
at the project's final meeting.*



Partner companies provide support of up to \$75,000 in cash per year to the core research budget of the Centre. Senior representatives of these companies sit on the Science Planning Panel, along with other government and university researchers. This panel meets annually to discuss the results of CODES' research and potential directions for new research.

INDUSTRY PARTNERSHIP OPPORTUNITIES

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

Major benefits of a partnership agreement include enhanced prospects of discoveries, optimisation of existing reserves, first call on geoscience graduates, and access to a world-class research team and state-of-the-art facilities. For further details of partnership opportunities, contact the Director, Bruce Gemmell: E. bruce.gemmell@utas.edu.au Tel. +61 3 6226 2893.

Andrew McNeill from Mineral Resources Tasmania (MRT), centre, supervising a joint CODES/MRT booth at IMARC in Melbourne.

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 2014 it funded AMIRA P1060 Enhanced geochemical targeting in magmatic-hydrothermal systems.

RESEARCH COLLABORATIONS AND INTERNATIONAL VISITORS PROGRAM

In 2014, CODES further cemented its reputation for cultivating research collaborations with other Australian and international research organisations. Throughout the year, collaborative research was conducted with 56 international and 25 national organisations.



TECHNOLOGY TRANSFER

OBJECTIVES

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

TECHNOLOGY TRANSFER ACTIVITIES

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

Research results and technical developments in the applied research modules are transferred to end-users via regular research meetings, research reports, monographs, books, digital presentations and software packages, where appropriate. In 2014, 82 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 2014.

- *Basins, fluids and Zn-Pb ores. CODES Special Publication 2* (1999). Editors: O Holm, J Pongratz and P McGoldrick (1 copy).
- *Geophysical signatures of copper-gold porphyry and epithermal gold deposits, and implications for exploration* (2011). Author: T Hoschke (31 copies).
- *Giant ore deposits: Characteristics, genesis and exploration. CODES Special Publication 4* (2002). Editors: D Cooke and J Pongratz (3 copies).
- *New developments in Broken Hill-type deposits. CODES Special Publication 1* (1996). Editors: J Pongratz and G Davidson (2 copies).
- *The geology and origin of Australia's mineral deposits* (2000). Authors: M Solomon and D Groves (1 copy).
- *The geology of the Broken Hill Pb-Zn-Ag deposit, NSW, Australia* (2006). Author: A Webster (6 copies).
- *24ct Au workshop. CODES Special Publication 5* (2004). Editors: D Cooke, C Deyell and J Pongratz (1 copy).
- *Volcanic environments and massive sulfide deposits* (2000). Editors: JB Gemmell and J Pongratz (2 copies).
- *Volcanic textures: A guide to the interpretation of textures in volcanic rocks* (1993). Authors: J McPhie, M Doyle and R Allen (58 copies).
- *Altered volcanic rocks: A guide to description and interpretation* (2005). Authors: C Gifkins, W Herrmann and R Large (35 copies).

SHORT COURSES, WORKSHOPS AND CONFERENCES FOR END-USERS

Short courses and workshops continued to play a key role in the Centre's technology transfer activities. Throughout the year, a total of 16 courses were held at various locations around the world, including China, Indonesia, Myanmar, New Zealand and South Africa.

Total attendance by industry geologists, academic researchers and postgraduate students was 918, with 18 different presenters from CODES involved in delivering the lectures.

2014 SHORT COURSES/WORKSHOPS/ CONFERENCES LED BY CODES

Title	Presenters	No.	Location	Date
MTEC – Exploration Field Skills Mapping Camp	Robert Scott	20	Queenstown, Tasmania	9 – 16 February
Geophysics for Geologists and Engineers	Michael Roach , Hugh Tassell	8	CODES, Hobart	10 – 14 February
MTEC – Exploration Field Skills Mapping Camp	Rebecca Carey, Robert Scott, David Selley	20	Queenstown, Tasmania	9 – 16 March
Volcanology and Mineralisation in Volcanic Terrains	Rebecca Carey, Bruce Gemmell, Ross Large, Jocelyn McPhie	26	New Zealand and western Tasmania	16 – 30 March
Fluids in the Earth	Robert Bodnar, Leonid Danyushevsky , Maria-Luce Frezzotti, James Webster	110	Nanjing, China	10 – 14 May
VIEPS – Ore Deposit Models	David Cooke, Garry Davidson, Bruce Gemmell, Ross Large, Robert Scott, David Selley, Jeff Steadman	16	CODES, Hobart	12 – 16 May
VIEPS – Practical Igneous Petrology	Leonid Danyushevsky	11	CODES, Hobart	19 – 23 May
Exploration in Brownfields Terrains	Ron Berry , Andrew Cantwell, Matt Cracknell , Jacob de Lacey, Kim Denwer, David Green, John Holliday, Nic Jansen , Heidi Pass, Michael Roach, Robert Scott	22	CODES, Hobart	2 – 13 June
Advances in Geo-Logging	Tim Cartledge, Lee Evans, Graham Granger, David Green, Julie Hunt , Andrew McNeill, Jocelyn McPhie, Michael Roach, Robert Scott, Rob Virtue	28	Mineral Resources Tasmania, Hobart	8 – 11 September
Ore Deposit Models and Exploration Strategies	David Cooke , Stephen Cox, Garry Davidson, Bruce Gemmell , Scott Halley, Margy Hawke, Ross Large , Nick Oliver, Robert Scott, David Selley, Nathan Steeves	30	CODES, Hobart	20 – 31 October
Ore Deposit Models and Exploration	Zhaoshan Chang, Huayong Chen, David Cooke , Richard Goldfarb, David Leach, Chusi Lee, Joan Scott, Steven Scott, Noel White, Kaihui Yang	450	Shanghang, China	9 – 16 November
VHMS Deposits in SE Asia and China	Khin Zaw	38	Gaja Mada University, Indonesia	20 November
Acid Rock Drainage Prediction – Geometallurgy	Julie Hunt , Bernd Lottermoser, Anita Parbhakar-Fox	20	University of Cape Town, South Africa	20 November
VHMS Deposits in SE Asia and China	Khin Zaw	54	Padjadjaran University, Indonesia	24 November
Orogenic and Skarn Deposits	Khin Zaw	23	Geological Agency, Bandung, Indonesia	25 November
Tectonics and Ore Deposits of SE Asia	Khin Zaw	42	Hinhthada University, Myanmar	16 December

PERFORMANCE INDICATORS

PERFORMANCE AGAINST KPIS IN 2014–2018 STRATEGIC PLAN

	TARGET	2014
Research Findings		
Publications in international journals	50pa	55
Percentage of publications in high quality international journals	70%	76%
Reports to industry collaborators	80pa	82
Special Issues and/or research monographs	1 per 2 years	2
Invitations to give keynote conference presentations	10pa	3
Papers at national/international meetings	70pa	66
Research Training and Professional Education		
Percentage of HDR students attracted from interstate	25%	45%
Percentage of HDR students attracted from overseas	65%	48%
Number of Honours students in CODES' modules	15	8
Number of HDR students in CODES' modules	50	53
Percentage of students in projects linked with industry	80%	67%
Professional short courses/workshops for industry	4pa	16
International, National and Regional Links and Networks		
CODES' national or international conferences/workshops	1 per 2 years	0
Registrants at CODES' conferences/workshops	600pa	918
End-user Links		
Frequency of meetings with industry representatives	15pa	20
National Benefit		
CODES' research has input into a major mineral discovery	1 per 5 years	9 in 26 years



PhD student Qiuyue Huang at Dalton's Sand Pit, New Zealand, during the Volcanology and Mineralisation in Volcanic Terrains Master of Economic Geology short course.

FINANCES

2014 INCOME

Total CODES income was \$5.8 million (see Table 1). This was derived principally from UTAS (41%) and industry (30%) (see Figure 1). The main income streams over time are compared in Figure 2, showing the cessation of ARC Centre Grant funding at the end of 2013, as well as a reduction in industry funding, which coincides with the downturn in the mining industry.

SUMMARY OF THE MAIN INCOME STREAMS TO CODES IN 2014:

- **Commonwealth Government income:** The \$522k funding in this category was, once again, an increase compared to the previous year, and is now related to four State Survey (GSWA & GSSA) projects, as well as two projects funded by CSIRO.
- **Industry income:** Total industry funding was \$1.8 million, down from 2013. Much of this decrease was due to the recent completion of several large AMIRA projects, with no new AMIRA projects having yet commenced. However, it should be noted that several new AMIRA projects are in the pipeline.

- **Host institution support:** Funding from UTAS in 2014 was up compared to the adjusted* figure for 2013, mostly due to an increase in PhD related support. UTAS funding relates primarily to research salaries, PhD scholarships and income earned by the Centre from research output.

**It was incorrectly stated in the previous Annual Report that UTAS income for 2013 was \$1,626,301. This figure should have been \$2,371,982, which is now reflected in the adjusted figures and graphics contained in this current report.*

2015 INCOME ESTIMATES

With the end of ARC Centre Grant funding, the total income to CODES in 2014 was approximately half of that in 2013. However, later in the year, CODES was successful in winning an ARC Industrial Transformation Research Hub. Funding related to this grant is expected to flow into CODES by the middle of 2015, bolstering research funds within the Centre. Industry projects that will be part of the Hub are expected to come on-line shortly after the Hub's official commencement (e.g. AMIRA P1153).



TABLE 1**CASH INCOME FINANCIAL STATEMENT 2014**

	2014
ARC Grants	
Discovery Grants – income returned	-85
	-85
Other Commonwealth Government	
Specific Projects	515,404
Student Projects	7,000
	522,404
State Government	
Specific Projects	49,476
Student Projects	28,000
	77,476
Industry/private	
AMIRA International Projects	224,890
CODES Industry Partners	367,500
Minerals Council of Australia (MCA/MTEC)	63,800
Directly Funded Research Projects	782,698
Directly Funded Student Projects	304,281
Miscellaneous	32,195
	1,775,364
Contracts/consultancies/revenue raising	
Short Courses	120,464
Book Sales	33,113
Miscellaneous (incl. Analytical Services)	724,939
	878,515
University of Tasmania – host institution support	
Operating Grant	1,135,295
Scholarships and Tuition Fee Waivers	1,056,288
Strategic Projects	164,073
Miscellaneous	64,369
	2,420,024
Other income sources/interest	
Overseas Governments	20,000
Society of Economic Geologists – Student Scholarships	13,037
Student Support	59,056
Specific Projects	68,393
Miscellaneous	8,040
	168,525
Total annual income	5,842,223

FIGURE 1
TOTAL CASH INCOME 2014

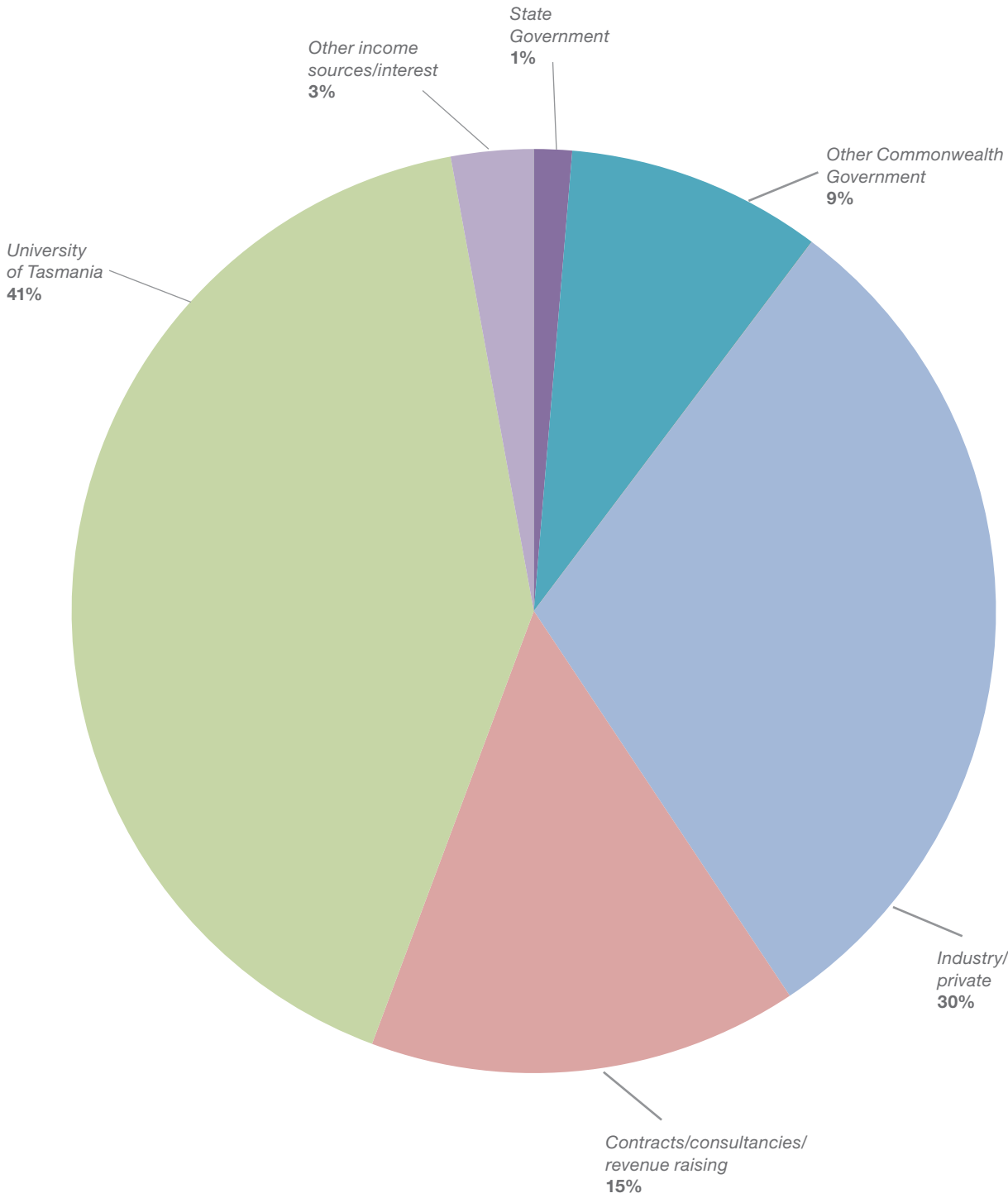
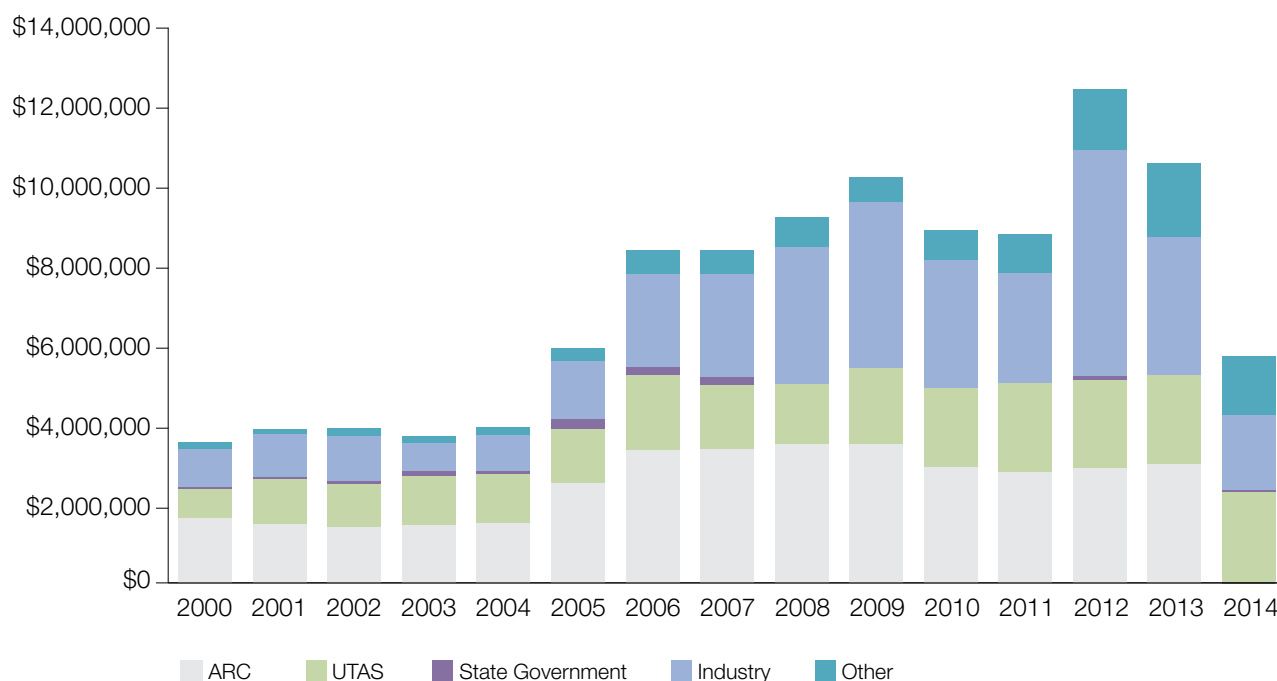


FIGURE 2

COMPARISON OF CODES MAIN INCOME STREAMS 2000–2014



Note: ARC Centre funding ended 2013.

NOTES TO, AND FORMING PART OF, THE FINANCIAL STATEMENTS FOR 2014

The financial pages of this Annual Report were prepared by Helen Scott (Senior Finance Officer – Science Engineering and Technology Hub). Data for the financial statements was extracted from UTAS systems, particularly its Finance System. All Financial Statements shown here have been reviewed by UTAS Central Finance.

INCOME STATEMENT EXPLANATIONS

The income figures in Table 1 represent actual income recorded in the UTAS Finance System or transferred internally from UTAS to CODES during 2014, with the following exceptions:

- \$85 of unspent ARC Discovery project funds were returned to the ARC, resulting in a negative income value for 2014.

- \$259k of AMIRA funds, related to the P843A and P1060 projects, were deposited into UTAS accounts, but were later transferred to research collaborators associated with these joint research projects. These funds will be listed as AMIRA income to those collaborators, and can therefore not be listed as income to CODES.

COMPARISON GRAPH EXPLANATIONS

The income figures in Figure 2 show all income received to CODES from various sources. However, the graph has been adjusted slightly to allow for the \$85 of unspent Discovery Grant income that was returned to the ARC in 2014.

2014 CODES' PUBLICATIONS

CHAPTERS IN BOOKS (5)

NAMES IN BOLD ARE AUTHORS THAT AFFILIATED THEIR ARTICLES TO CODES

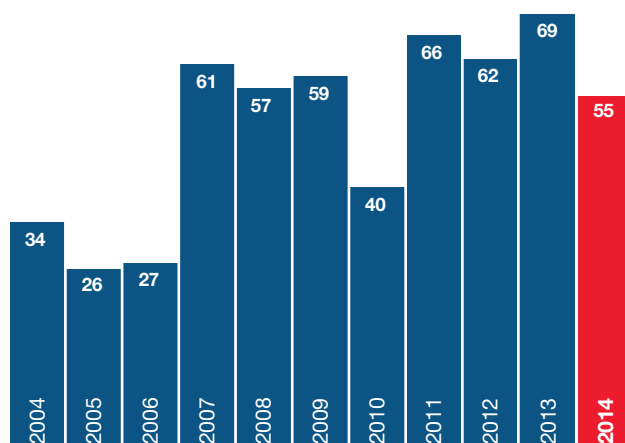
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*La Cruces mine in Spain – one of the stops on the
SEG Student Chapter's field trip to the Iberian Pyrite belt.*

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The SEG Student Chapter group at the new Magdalena deposit, near Minas Agua Tenidas, Spain. From left: Wei Hong, Quiyue Huang, Jing Chen and Irma Vejelyte.

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APPENDICES

CODES POSTGRADUATE STUDENTS 2014

GRADUATE DIPLOMA OF SCIENCE (1)

Student	Supervisors	Project	Support
Lydia Wells [^]	Noble	Long-term assessment of the weathering characteristics of sulfide materials	CRC ORE

BACHELOR OF SCIENCE (HONOURS) (19)

Student	Supervisors	Project	Support
Michael Anderson [^]	Roach	Analysis of wide angle reflection and refraction data, Mount Woods area, South Australia	OZ Minerals
Wayne Baker	Cas (Monash), McPhie	Lithostratigraphy, facies architecture, alteration and geochemistry of the footwall to the DeGrussa volcanic hosted massive sulfide deposit	Sandfire Resources
Anthony Benn [^]	Baker, Cooke	Geology of the Racecourse Prospect, NSW: Economic geology, geochronology, geochemistry, and paragenesis of a Cu-mineralised I-type granitoid suite	Anglo American
Natnaree Chandraprasert [^]	Carey, Scott	Stratigraphy, structure and volcanology of the sequence between the Mount Black and Rosebery faults, north-end Rosebery Mine Lease, western Tasmania	MMG
Ashby Cooper [^]	Reading, Direen	The crustal structure of the Bass Strait region from combined passive seismic methods	ARC
Tobias Erskine [^]	Zaw, Manaka	Geology, structure and mineralisation characteristics of the Modi Taung gold deposit, Myanmar	Ore Deposits of SE Asia Project, National Prosperity Company
Alistair Harvey [^]	Roach, Reading	Depth to basement below the Bowen and Surat Basins, Chinchilla, Queensland	QGC
Wasim Hashmi [^]	Stepanov, Meffre, Cooke	Sn-W-Ta-Nb in micas and their relationship to granite fractionation in western Tasmania	ES
Melanie Haycroft	G.Davidson	The eastern mineralisation, Broken Hill, NSW	CBH Resources
Travis Holmes	Cooke	Geometry, timing and controls on alteration and mineralisation at the Big Wilson Tin Prospect, NW Tasmania	Venture Minerals
Stuart Hughes [^]	Meffre, Chase (IMAS), Danyushevsky	Quantifying and characterising heavy metal contamination and sedimentation rates in the Derwent Estuary	Nyrstar, Derwent Estuary Program, IMAS
Laura Jackson [^]	Parbhakar-Fox, G.Davidson, Danyushevsky	Geochemical and mineralogical characterisation of tailings: Evaluating the benefits of water covers as a rehabilitation strategy, Savage River Mine, Tasmania	DPIPWE, Grange Resources
Will McAdam	Roach, Duffett (MRT)	Geophysical investigation of the Mole Creek area, Tasmania	MRT
Supitchaya Paipana [^]	Zaw, Salam	Geochemistry and mineralisation characteristics of Bo Thong antimony-gold deposit, Chonburi province, Eastern Thailand	Ore Deposits of SE Asia Project
Naomi Potter [^]	Carey, V.Kamenetsky	The eruption dynamics of the 23rd February 2013 event at Mt Etna	ARC
Andrew Strochnetter [^]	Noble, Chase (IMAS)	Circulation of the southwest Pacific Ocean during the penultimate deglaciation	UTAS
Jonathon Traynor	Zaw, Large	Geology, structure and mineralisation of Shwezin vein, Modi Taung, Myanmar	National Prosperity Company
Matthew Whitten	Meffre	Kone Formation (New Caledonia) - a sedimentary record of the final stages of Gondwana breakup	
Jie Yu [^]	Roach, Reading, Duffett (MRT)	A geophysical investigation of the Mt Lindsay-Lynch Hill area, western Tasmania	MRT

[^]Graduated.

MASTER OF ECONOMIC GEOLOGY (52)

Student	Supervisors	Project	Support
Michael Adams		coursework only	
Fabian Baker	Cooke	Amulsar HSE Au deposit, Armenia	Lydian International
Luziane Barbosa De Souza	Scott	Webbs silver project, NSW	Centric Minerals Management
Billy Beas Caceras	McPhie, Gemmell	Petrography and mineragraphy of volcanic rocks and age dating of La Zanja Mine, Peru	Minera La Zanja SRL
Lynelle Beinke*		coursework only	Heathgate Resources
Cesar Calderon-Tipiani	Gemmell	Chanca low sulfidation deposit, Peru	Buenaventura
Wayne Carter		coursework only	Silver Lake Resources
Glen Cathers		coursework only	
Chloe Cavill	G.Davidson	Geochemical classification of orebearing/metalliferous fluids of the Costerfield region	Mandalay Resources
Djohanne Celiz	Cooke	The geology, alteration, and mineralisation of the Sagay deposit in northern Negros, Philippines	Freeport-McMoran Exploration Corporation
Corrie Chamberlain^		coursework only	Minera IRL Patagonia S.A.
Glen Diemar^	V.Kamenetsky, Ehrig (BHP Billiton), McPhie	Geochronology of hydrothermal REE minerals and their relationships with economic mineralisation at the Olympic Dam breccia complex, South Australia	BHP Billiton Olympic Dam
Lucas Doherty		coursework only	
Fumba Donzo		coursework only	Leighton Contractor
Peter Duerden	Cooke, Crawford	TBA	Alkane
Pablo Farias	Davidson	TBA (An aspect of uranium deposits in NT)	Cameco Australia
Maria Lourdes M. Faustino	Cooke	Plio-pleistocene intrusive history and ore paragenesis of Bayugo porphyry Cu-Au deposit Surigao Del Norte, Philippines	DFAT, Philex Mining
Franco Ferreyra		coursework only	
Arga Firmansyah	Cooke	The Pangulir porphyry-epithermal prospect, Indonesia	PT. Pamapersada Nusantara
Greg Fortune§		coursework only	
Phil Gilmore	G.Davidson	An aspect of the geology of the Koonenberry Belt, NSW	Geological Survey of NSW
David Groombridge		coursework only	Silver Lake Resources
Rachel Harrison^	Cooke	Tujuh Bukit Cu-Au porphyry-epithermal deposit, Java Indonesia	Intrepid Mines
Kyle Hodges		coursework only	Sirius Resources
Jonathon Hoyer	Cooke	An aspect of the geology of North Parkes, NSW	Northparkes Mine
Danny Huisman		coursework only	BHP Billiton
Oliver Judd§		coursework only	
Thomas Langley		coursework only	
Xuan Truong Le*	Zaw	Mineralisation of Me Xi gold deposit, Vietnam	Axiom Mining, Hanoi University of Mining and Geology, Ore Deposits of SE Asia Project
Esther Little		coursework only	DGR Global, Archer Resources
Chantelle Lower	Ehrig (BHP Billiton) and TBA	An aspect of the geology of the Olympic Dam deposit	BHP Billiton
Thomas Lucas		coursework only	Ivanhoe Australia
Neil Macalalad*	Cooke	Geology, alteration, mineralisation and vectoring to porphyry centre in the Aisasur prospect, Irian Jaya, Indonesia	Anglo American
Imam Malik		coursework only	
Kane Maxwell^		coursework only	Peabody Energy Australia

*Degree completed, not yet graduated. ^Graduated. §Withdrawn/terminated.

Student	Supervisors	Project	Support
Rebecca McLelland	Scott	Gold mineralisation at the Reefion Goldfield, New Zealand	Oceana Gold
Joanne Morrison	Cooke	TBA	Newcrest Mining
Michael Musialike*	Scott	Controls on gold mineralisation at Matala and Dunrobin, Zambia (Luirigold)	Copperbelt University
Saranya Nuanla-Ong	Zaw	Paragenesis, pyrite geochemistry and ore fluids at Htongyi gold veins, Myanmar	Ore Deposits of SE Asia Project, National Prosperity Company
Joshua Phillips^		coursework only	Newcrest Mining
Chris Piggott		coursework only	Sirius Resources
Tatjana Pucko^		coursework only	Inova Resources
Michelle Puskas^		coursework only	Inova Resources
Scott Randall^		coursework only	AngloGold Ashanti
Alan Riles		coursework only	Riles Integrated Resource Management, AMC
Stephanie Robertson		coursework only	Inova Resources
Markus Staubmann		coursework only	Sirius Resources
Edward Summerhayes*		coursework only	Silver Lake Resources
Chris Thaus		coursework only	Copper Mines of Tasmania
Nevil Vanderslink		coursework only	Arrium Mining
Peter Watson		coursework only	Gnomic Exploration Services
Onur Yilmaz	Cooke	The Mount Carrington epithermal Au and Ag-Au deposits, NSW: Potential for porphyry-style mineralisation	

MASTER OF EXPLORATION GEOSCIENCE (1)

Student	Supervisors	Project	Support
Jo Condon	Gemmell	Ore types of the DeGrussa and Conductor 1 Ore lenses of the DeGrussa VHMS deposit, Western Australia	Sandfire

MASTER OF SCIENCE (3)

Student	Supervisors	Project	Support
Myall Hingee§	Reading, Fullager (Fullagar Geophysics), Roach	Approximate Inverse Mapping (AIM) inversion of Transient Electromagnetic (TEM) data	AMIRA P1022, UTAS
Paula Montoya^	Berry, Hunt	Comminution studies: La Colosa case study	AngloGold Ashanti, GeM Project
Stephanie Sykora	Cooke, Selley, Jansen	The geological, structural, geochemical and genetic significance of anhydrite veins and cemented breccias at the Lihir gold deposit, Papua New Guinea	Newcrest Mining, UTAS

DOCTOR OF PHILOSOPHY (51)

Student	Supervisors	Project	Support
Olga Apukhtina	V.Kamenetsky, McPhie, Maas (UMelb)	Stable isotopes (C, S and O) and halogens (Cl, F) in gangue and ore minerals at Olympic Dam: Evaluation of mantle and crustal contributions to mineralisation	BHP Billiton Olympic Dam, UTAS
Mohd Basril Iswadi Bin Basori*	Zaw, Large	Geology of volcanic hosted massive sulfide (VHMS) deposits in Central Belt, Peninsular Malaysia	Malaysian Govt, Ore Deposits of SE Asia Project
Heidi Berkenbosch	Gemmell, McNeill (MRT), Christie (GNS Science)	Geochemistry of hydrothermal mineral chimneys from Brothers volcano, Kermadec Arc	CoE, GNS Science, UTAS, SEG, AusIMM, Australian Synchrotron
Ben Cave	Large, Danyushevsky	A metamorphic source for tungsten in metasedimentary-hosted orogenic gold deposits	UTAS, CoE

*Degree completed, not yet graduated. ^Graduated. §Withdrawn/terminated.

Student	Supervisors	Project	Support
Jing Chen	Cooke, Zhang	The geology, mineralisation, alteration and fluid evolution of Zijinshan ore field, Fujian Province, China	UTAS, Chinese Govt
Alexander Cherry	V.Kamenetsky, McPhie, Ehrig (BHPBilliton)	Petrology, provenance and composition of bedded sedimentary facies in the Olympic Dam deposit	UTAS
Matt Cracknell [^]	Reading, Foster	Machine learning for geological mapping: Algorithms and applications	UTAS, CoE
Angela Escolme	Cooke, Hunt, Berry	Ore characterisation and geometallurgical modelling at the Productora Cu-Au-Mo deposit, Chile	UTAS, Hot Chili, CSIRO, AusIMM
Esmail Eshaghi	Reading, Roach	Petrophysical and geophysical investigation of western Tasmania	UTAS
Jodi Fox	McPhie, Carey	Basaltic volcanic successions in Tasmania and on Heard Island	UTAS, CoE
Martin Gal	Reading, Ellingsen (Physics)	The development of array and single station methods for the analysis of on-land ambient seismic signals from deep ocean storms and coastal sources	UTAS
Víctor Hugo Galván-Gutiérrez [^]	Cooke, Gemmell, McPhie	Palmarejo carbonate-base metal epithermal Ag-Au district, Chihuahua, México	IPRS, Coeur d'Alene
Sarah Gilbert	Danyushevsky, Large	Development of analytical methods and standard reference materials for the determination of trace element concentrations and isotopic ratios in sulfur-rich minerals and silicate glasses	CoE, CODES, Agilent Technologies
Dan Gregory [^]	Large, Meffre, Bull	The trace element composition of sedimentary pyrite: Factors affecting uptake and uses of the data for determining paleo-ocean conditions	CSIRO, CoE, UTAS
JianXiang Guan [^]	Danyushevsky, Crawford	Origin of associated magnetite and sulfide mineralisation in large gabbroic intrusions: A LA-ICP-MS study of minerals and melt inclusions from the Panzihua and Taihe intrusions in Emeishan LIP and Duluth Complex	CoE, UTAS
Cassady Harraden	Meffre, Berry, Roach, Hunt	Geometallurgical project in Tanzania	UTAS
Rachel Harrison	Cooke	Tujuh Bukit Cu-Au porphyry-epithermal deposit, Java Indonesia	
Margy Hawke	Gemmell, Large, G.Davidson	Geology of the DeGrussa Cu-Au-Ag volcanic-hosted massive sulfide deposit, Western Australia	UTAS, Sandfire Resources
Jacob Heathcote	Scott, G.Davidson	Gold distribution and association at the Kansanshi copper-gold deposit Zambia: Processes responsible for gold precipitation and implications for ore zone delineation and recovery	First Quantum Minerals
Sam Holt	Carey, McPhie, Allen	Understanding of basaltic eruption dynamics and mechanisms: Effusive and explosive eruptions in Hawaii	UTAS, CoE
Wei Hong	Cooke, Zhang, Fox	Magmatic-hydrothermal volatile exsolution and mineralisation in Tasmanian Sn granites	UTAS, CoE
Qiuyue Huang	V.Kamenetsky, McPhie, Allen	Mafic dykes at Olympic Dam	UTAS, CoE
Carlos Andres Jimenez Torres	Cooke, White, Baker	Bantug lithocap, Negros Island, Philippines: Mineralogy, textures, and chemistry	UTAS Foundation, AMIRA P1060
Sean Johnson	Large, Meffre, McGoldrick	Trace elements in metalliferous black shales	UTAS, CoE, Mining Institute of Scotland, ANZIC-IODP, ECORD, NERC, Talvivaara Mining, GTK
Teera Kamvong [*]	Zaw, Meffre	Geology and genesis of porphyry-skarn Cu-Au deposits at the Northern Loei and Truong Son Fold Belts, Thailand and Laos	IPRS, ARC Linkage, CoE, SEG, PanAust, Ore Deposits of SE Asia Project
Stephen Kuhn	Reading, Cracknell, Roach	The application of machine learning algorithms for lithological mapping and minerals targeting in key ore deposit settings	
Roisin Kyne [^]	Berry, Gemmell, Scott	Genesis and structural architecture of the CSA Cu-Ag (Pb-Zn) mine, Cobar, New South Wales	UTAS, Cobar Management
Erin Lawlis	Cooke, Jansen	Au-bearing pyritic ore of Lihir, Papua New Guinea: Its physiochemical character and nature of the causative fluids	Newcrest Mining, UTAS, SEG

^{*}Degree completed, not yet graduated. [^]Graduated. [§]Withdrawn/terminated.

Student	Supervisors	Project	Support
Elena Lounejeva	Danyushevsky, Large	Geochemical signature of syngenetic and diagenetic pyrite from marine sediments as a paleo-environmental tool	ARC, CODES
Alexey Lygin [§]	V.Kamenetsky, McNeill (MRT)	The geology, geochemistry and genesis of the Avebury Ni deposit, Tasmania	CoE, UTAS, MMG Exploration
Charles Makoundi	Zaw, Large	Geochemistry of Phanerozoic black shales in Peninsular Malaysia: Relationships to gold mineralisation	IPRS, UTAS, Ore Deposits of SE Asia Project
Takayuki Manaka [^]	Zaw, Meffre	Geology and mineralisation characteristics of the Phuoc Son goldfields, central Vietnam	CoE, UTAS, Ore Deposits of SE Asia Project, SEG, Besra
Claire McMahon	G.Davidson	Distribution of, and controls upon, pyrite trace element content of hydrothermal alteration zones at Hercules VHMS ore deposit, Tasmania and NICO IOCG ore deposit, Northwest Territories, Canada	ARC
Larriana Morgan	G.Davidson, Bull, Selley	Controls on copper mineralising process in the central McArthur Basin, NT (Redbank Package), and its implications for the metallogeny of extensional basins	NTGS, UTAS
Peter Morse	Reading, Lueg (Computing)	Combined computational and human interaction strategies in knowledge generation from spatial and spatiotemporal information	UTAS, CODES
Indrani Mukherjee	Large, Halpin, Meffre	Pyrite trace element chemistry of black shales of the “boring billion” period	UTAS, SEG, AMIRA
Jacob Mulder	Meffre, Halpin, Berry, Scott	From Nuna to Gondwana: An evaluation of the early tectonic history of Tasmania	UTAS, CODES
Evan Orovan	Cooke, Harris	Geology, geochemistry and genesis of the Namosi porphyry Cu-Au deposits, Fiji	CODES, Newcrest Mining, SEG
Richelle Pascual	V.Kamenetsky, Noble, Goemann	The characteristics and role of colloidal silica fluids in the formation of the Grieves Siding Zn-Pb prospect, western Tasmania	CoE, UTAS, CRC ORE
Pedro Pereira da Fonseca	McPhie, McNeill (MRT), Relvas (GeoFCuL)	Facies analysis and correlations in complex mineralised submarine volcanic successions: Mount Read Volcanics, western Tasmania	Portuguese Govt (FCT), CoE
Jose Meulen Piquer Romo*	Cooke, Berry, Scott	Structural geology of the Andes of Central Chile: Evolution, controls on magmatism and the emplacement of giant ore deposits and implications for exploration	Chilean Govt, Codelco, AMIRA P1060
Daniele Redi [^]	Danyushevsky, De Vivo (UNINA), Lima (UNINA)	A contribution to the understanding of the eruptive behaviour of Somma-Vesuvius; A mineral chemistry perspective	University of Naples, CoE
Marc Rinne*	Cooke, Jansen	Geology and genesis of the contrasting Wafi-Golpu porphyry-epithermal deposit, Papua New Guinea	Newcrest Mining, Harmony Gold, Morobe Mining Joint Venture, UTAS
Lina Serrano (UPadova) [^]	V.Kamenetsky, McPhie	The magmatic province of Patagonia and sills from Mauritania and Mali: Examples of silicic and basaltic large igneous provinces	University of Padova
Subira Sharma	G.Davidson, Cooke	Evaluation of links between Merlin-style Mo-Re mineralisation and magmatism in the Cloncurry fold belt, Queensland: Implications for exploration	UTAS, Inova Resources
Jeff Steadman*	Large, Bull, G.Davidson	BIFs, black shales, and gold deposits: A re-evaluation	CoE, CSIRO, Integra Mining
Nathan Steeves	Gemmell, Large, Hannington (UOttawa)	Ore genesis of the Greens Creek VHMS Deposit, Alaska: Implications for mining, milling and exploration	Hecla Mining, UTAS
Francisco Testa	Cooke, Baker	Tourmaline breccia pipes: San Francisco de los Andes, Argentina and Rio Blanco-Los Bronces, Chile	UTAS, AMIRA P1060
Irma Vejelyte	V.Kamenetsky, McPhie, Ehrig (BHPBilliton)	Mafic magmatism in the Gawler Craton: Distribution, composition, timing, sources and tectonic setting	UTAS, CoE
Daniele Vergani	McPhie, Carey	The 2007 explosive activity at Piton de la Fournaise volcano (Reunion): Constraints on the eruptive processes by the volcanological study of the erupted deposits	UTAS, CoE
Selina Wu [^]	Gemmell, Large	Volcanic hosted massive sulfide deposits of the Que-Hellyer Volcanics, western Tasmania	Bass Metals

*Degree completed, not yet graduated. [^]Graduated. [§]Withdrawn/terminated.



White Island, New Zealand

MAJOR EXTERNALLY FUNDED RESEARCH PROJECTS*

AMIRA PROJECTS 2014

Investigators	Project	Industry Partners	Period	AMIRA Funding for 2014	Misc Funding for 2014	Additional Funding for 2014
Cooke, Gemmell, Baker, White, Fox, Zhang, Thompson, Lounejeva, Chen (Guangzhou), Hollings (Lakehead), J.Wilkinson (Imperial), C.Wilkinson (Imperial)	AMIRA P1060. Enhanced geochemical targeting in magmatic-hydrothermal systems	Anglo American Exploration Australia, AngloGold Ashanti Australia, Barrick (Australia Pacific), BHP Billiton Marketing Asia, Codelco, Compania de Minas Buenaventura, Eldorado Gold, First Quantum Minerals, Freeport McMoRan Australasia, Gold Fields, G-Resources, Inmet Mining, Intrepid Mines, Lundin Mining, MMG Australia, Newcrest Mining, Newmont USA, Rio Tinto Exploration, Teck Resources, Vale Exploration, Xstrata Copper	2011–2014	\$484,000	\$53,499	\$20,000 (Lakehead University)

ARC DISCOVERY GRANTS 2014

Investigator	Project	Period	ARC Funding for 2014	Misc Funding for 2014
Carey	Submarine volcanoes: Degassing of silicic magma with implications for ascent and eruption processes	2011–2014	**	\$0

INDUSTRY AND OTHER EXTERNALLY FUNDED RESEARCH GRANTS 2014

Investigators	Project	Funding Body	Period	Funding for 2014	Misc Funding for 2014
Cooke, Jansen, Selley, Harris (Newcrest)	Exploring the porphyry environment	Newcrest Mining	July 2009 – 2016	\$359,365	\$0
Large, Danyushevsky	Research and development in mineral deportment and exploration	Newcrest Mining	2012–2016	\$235,000	\$0
Orth	Paleoprotozoic mafic magmatism of the Kimberley Basin, Western Australia	Geological Survey of Western Australia	2014–2015	\$212,948	\$0
Orth	Carson Volcanics-Hart Dolerite Large Igneous Province project	Geological Survey of Western Australia	2012–2014	\$81,475	\$0
Scott, Heathcote (student)	Gold distribution and association at the Kansanshi copper-gold deposit Zambia	Kansanshi Mining	2014–2017	\$78,000	\$0
Large, Meffre, Gregory	South Australia pyrite, hematite and magnetite fingerprint database	Geological Survey of South Australia	2012–2015	\$66,000	\$0

Investigators	Project	Funding Body	Period	Funding for 2014	Misc Funding for 2014
Hunt	Sensor based sorting technologies for waste dumps and stockpiles associated with bulk mining	CSIRO	2014	\$60,981	\$0
Gemmell, Beas (student)	Petrography and mineragraphy of volcanic rocks and age dating of La Zanja Mine, Peru	Minera La Zanja	2014	\$53,735	\$0
Khin Zaw, Salam, Large, Burrett, Lai, Khositantont (DMR Thailand), Tran (Hanoi), Rosana (Padjadjaran), Subandrio (ITB, Bandung), Crow (ex BGS, London), Azman (Uni Malaya, Kuala Lumpur), Sanematsu (ASIT, Japan)	Ore Deposits of SE Asia (extension)	Indochine Resources Ltd, Issara Mining, MMG, Monument Mining, Besra, Phu Bia Mining, PT Antam, Tigers Realm Minerals, Anglo American Exploration, Newcrest Mining	2011–2014	\$50,000	\$5,400
Halpin	Metamorphic architecture of the central-northern Gawler Craton	Geological Survey of South Australia	2015^	\$50,000	\$0
Reading, Bombardieri	A geophysical investigation of western Tasmania	Mineral Resources Tasmania	2012–2014	\$49,476	\$0
Cooke, Hunt, Berry, Escolme (student)	Ore characterisation and geometallurgical modelling at the Productora Cu-Au-Mo deposit, Chile	Hot Chili	2013–2016	\$38,786	\$0
		CSIRO	2014–2016	\$7,000	\$0
		AusIMM	2014	\$2,500	\$0
Gemmell, Steeves (student)	Ore genesis of the Greens Creek VHMS Deposit, Alaska: Implications for mining, milling and exploration	Hecla Mining Company	2013–2016	\$47,000	\$0
Danyushevsky	LAM data reduction software development	Rio Tinto	2014–2016	\$45,000	\$0
Large, G.Davidson, Meffre, Belousov	Development and application of a Yilgarn pyrite and magnetite fingerprint database	Geological Survey of Western Australia	2012–2015	\$44,000	\$0
G.Davidson, Cooke, Sharma (student)	Evaluation of links between Merlin-style Mo-Re mineralisation and magmatism in the Cloncurry fold belt, Queensland: Implications for exploration	Inova Resources	2013–2016	\$25,000	\$0
		Society of Economic Geologists	2014	\$2,205	\$0
LI (visitor)	Zircon U-Pb dating for granite and trace element compositions of sulfides from the deposits on the northern and southern margins of the North China Craton: Implications for orogenic belt evolution and mineralisation	China Scholarship Council/ Peking University	2013–2014	\$21,580	\$0
Qing (visitor)	The origin of concealed gold and polymetallic orbodies in Southern China	China Scholarship Council/ China Gold Resources	2013–2014	\$20,000	\$0
Large, Gregory, Steadman, Wu	Peak Gold project	Drummond Gold	2014–2015	\$18,985	\$0
Large, Meffre, McGoldrick, Johnson (student)	Trace elements in metalliferous black shales	ANZIC-IODP	2014	\$17,250	\$0
Cas (Monash), McPhie, Baker (student)	Lithostratigraphy, facies architecture, alteration and geochemistry of the footwall to the DeGrussa volcanic hosted massive sulfide deposit	Sandfire Resources	2014–2015	\$12,000	\$0

*Projects with greater than \$2,000 external funding per year. **All project funding received, project still active.

^Project funding received before commencement. ‡‡Full project funding received in one year.

Investigators	Project	Funding Body	Period	Funding for 2014	Misc Funding for 2014
Roach, Reading, Duffett (MRT), Yu (student)	A geophysical investigation of the Mt Lindsay Area, western Tasmania	Mineral Resources Tasmania	2014	\$10,000	\$0
G.Davidson, Haycroft (student)	The eastern mineralisation, Broken Hill, NSW	CBH Resources	2014–2015	\$10,000	\$0
Roach, Duffett (MRT), McAdam (student)	Geophysical investigation of the Mole Creek area, Tasmania	Mineral Resources Tasmania	2014–2015	\$10,000	\$0
Parbhakar-Fox, G.Davidson, Danyushevsky, Jackson (student)	Geochemical and mineralogical characterisation of tailings: Evaluating the effect of the Northern Pond on the Old Tailings Dam, Savage River Mine, Tasmania	DPIPWE	2014	\$8,000	\$0
Cooke, Zhang, Chen (student)	The geology, mineralisation, alteration and fluid evolution of Zijinshan ore field, Fujian Province, China	Society of Economic Geologists	2014	\$6,388	\$0
Sanematsu (visitor)	Granite geochemistry and related REE deposits in Southeast Asia	Japan Society for the Promotion of Science	2013–2015	\$5,000	\$0
Roach, Reading, Harvey (student)	Geophysical interpretation of the Eastern Surat Basin Basement	QGC	2014–2015	\$5,000	\$0
Cooke, Berry, Scott, Piquer (student)	Structural geology of the Andes of Central Chile: Evolution, controls on magmatism and the emplacement of giant ore deposits and implications for exploration	Society of Economic Geologists	2014	\$2,355	\$0
Cooke, Selley, Sykora (student)	The geological, structural, geochemical and genetic significance of anhydrite veins and cemented breccias at the Lihir gold deposit, Papua New Guinea	Society of Economic Geologists	2014	\$2,089	\$0
Cooke, Faustino (student)	Plio-pleistocene intrusive history and ore paragenesis of Bayugo porphyry Cu-Au deposit Surigao Del Norte, Philippines	DFAT	2014–2015	\$2,000	\$0
McPhie, V.Kamenetsky, M.Kamenetsky	Setting, age and architecture of the Olympic Dam Au-Cu-U deposit, SA	BHP Billiton Olympic Dam Corp	July 2010–2014	**	\$0
McNeill, Feig, Falloon, D.H.Green	Sulfur and metal evolution in parental mid ocean ridge basalt magmas	IODP (via Australian National University)	2012–2015	**	\$0
V.Kamenetsky, McPhie, Apukhtina (student)	Stable isotopes (C, S and O) and halogens (Cl, F) in gangue and ore minerals at Olympic Dam: Evaluation of mantle and crustal contributions to mineralisation	BHP Billiton Olympic Dam Corp	2012–2015	**	\$0

*Projects with greater than \$2,000 external funding per year. **All project funding received, project still active.

^Project funding received before commencement. ‡Full project funding received in one year.

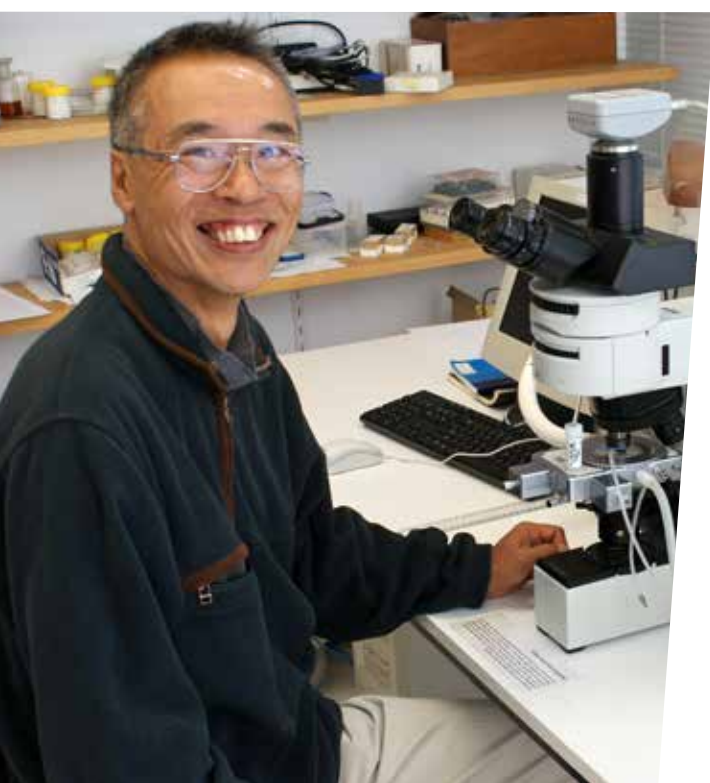
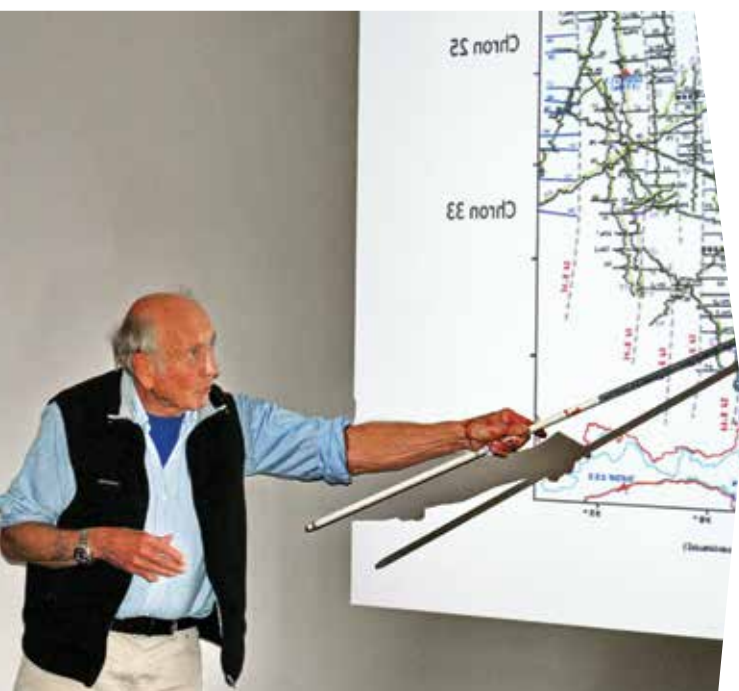
VISITORS TO CODES 2014

INDUSTRY VISITORS

NAME	COMPANY
Paul Agnew	Rio Tinto
Debora Araujo	Rio Tinto
Timothy Baker	Eldorado Gold
Tim Bauer	Eldorado Gold
Tim Chalke	Mira Geoscience
Bill Close	Consultant
Paul Cromie	Anglo American
Iain Dalrymple	Teck Resources
Mary Doherty	Newmont
Kathy Ehrig	BHP Billiton
David First	Freeport McMoRan Australasia
Fred Fryer	Agilent Technologies
Will Goodall	MinAssist
Anthony Harris	Newcrest Mining
Mary Harris	Rio Tinto
Paul Hilliard	Sandfire
John Holliday	Newcrest Mining
Tim Ireland	First Quantum
Alan Kobussen	Rio Tinto
John Landmark	Anglo American
Toshiaki Matsuda	Agilent Technologies
Brian Minty	Minty Geophysics
Colin Moorhead	Newcrest Mining
Robert Moye	Consultant
David Murphy	AngloGold Ashanti
Javier Ortuzar	Anglo American
Heidi Pass	Consultant
Paul Polito	Anglo American
Lynn Pryer	FrOGTECH
Adele Seymon	AMIRA International
Trevor Shaw	Glencore
Michiel van Dongen	MMG
Peter Walker	Vale
Mike Whitbread	MMG
Noel White	Consultant
Tom Woolrych	Blackthorn Resources

NATIONAL ACADEMIC AND GOVERNMENT VISITORS

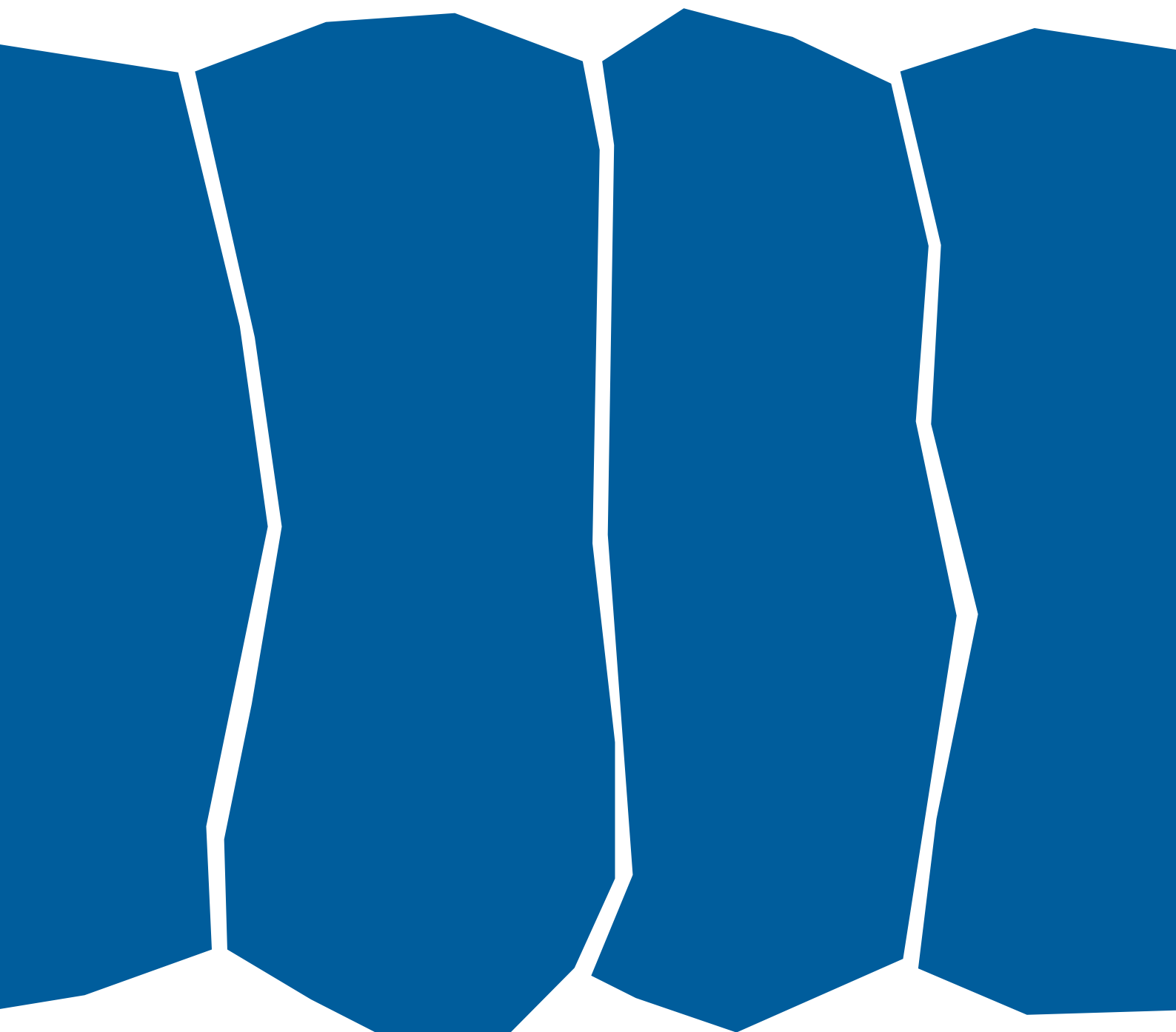
NAME	INSTITUTION
John Adam	Macquarie University
Steve Barnes	CSIRO
Edwin Bonilla	NICTA
Ray Cas	Monash University
Ross Cayley	Geoscience Victoria
Cristina Ciobanu	University of Adelaide
Peter Coghill	CSIRO
Nigel Cook	University of Adelaide
Patrice de Caritat	Geoscience Victoria
Mark Duffett	Mineral Resources Tasmania
Ashleigh Hood	University of Melbourne
Alison Hughes	EPA Division
Dave Huston	Geoscience Australia
Terry Mernagh	Australian National University
David Moore	Monash University
Gerrit Olivier	Institute of Mine Seismology
Simone Pilia	Australian National University
Carl Spandler	James Cook University
Daniel Steinberg	NICTA
Steve Walters	CRC ORE



INTERNATIONAL ACADEMIC AND GOVERNMENT VISITORS

NAME	INSTITUTION
Alexey Ariskin	Moscow State University, Russia
Sandeep Chandola	Society of Exploration Geophysicists, Malaysia
Huayong Chen	Guangzhou Institute of Geochemistry, China
Sofia Chistyakova	University of the Witwatersrand, South Africa
Rosario Esposito	Naples University, Italy
Fred Fryer	Massachusetts Institute of Technology, USA
Yoshihiko Goto	Muroran Institute of Technology, Japan
Dave Hale	Colorado School of Mines, USA
Koichi Hayashi	Geometrics, USA
Brian Hoal	Society of Economic Geologists, USA
Peter Hollings	Lakehead University, Canada
Marlon Jean	Leibniz Universitat, Germany
Rais Latypov	University of the Witwatersrand, South Africa
Yubang Li	State Key Laboratory of Ore Deposit Geochemistry, China
Jim Mortensen	University of British Columbia, Canada
Kiyoaki Niida	University of Hokkaido, Japan
Michael Perfit	University of Florida, USA
Terry Plank	Columbia University, USA
Eugenii Pushkarev	Institute of Geology and Geochemistry, Russia
Peter Sorjonen-Ward	Geological Survey of Finland
Yuri Taran	UNAM, Mexico
Jamie Wilkinson	Imperial College London, UK

Visitors to CODES during the year, from the top: Alexey Ariskin (Moscow State University) Fred Fryer (Agilent Technologies), Yoshihiko Goto (Muroran Institute of Technology)



CODES

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ISSN 1440-6411

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