

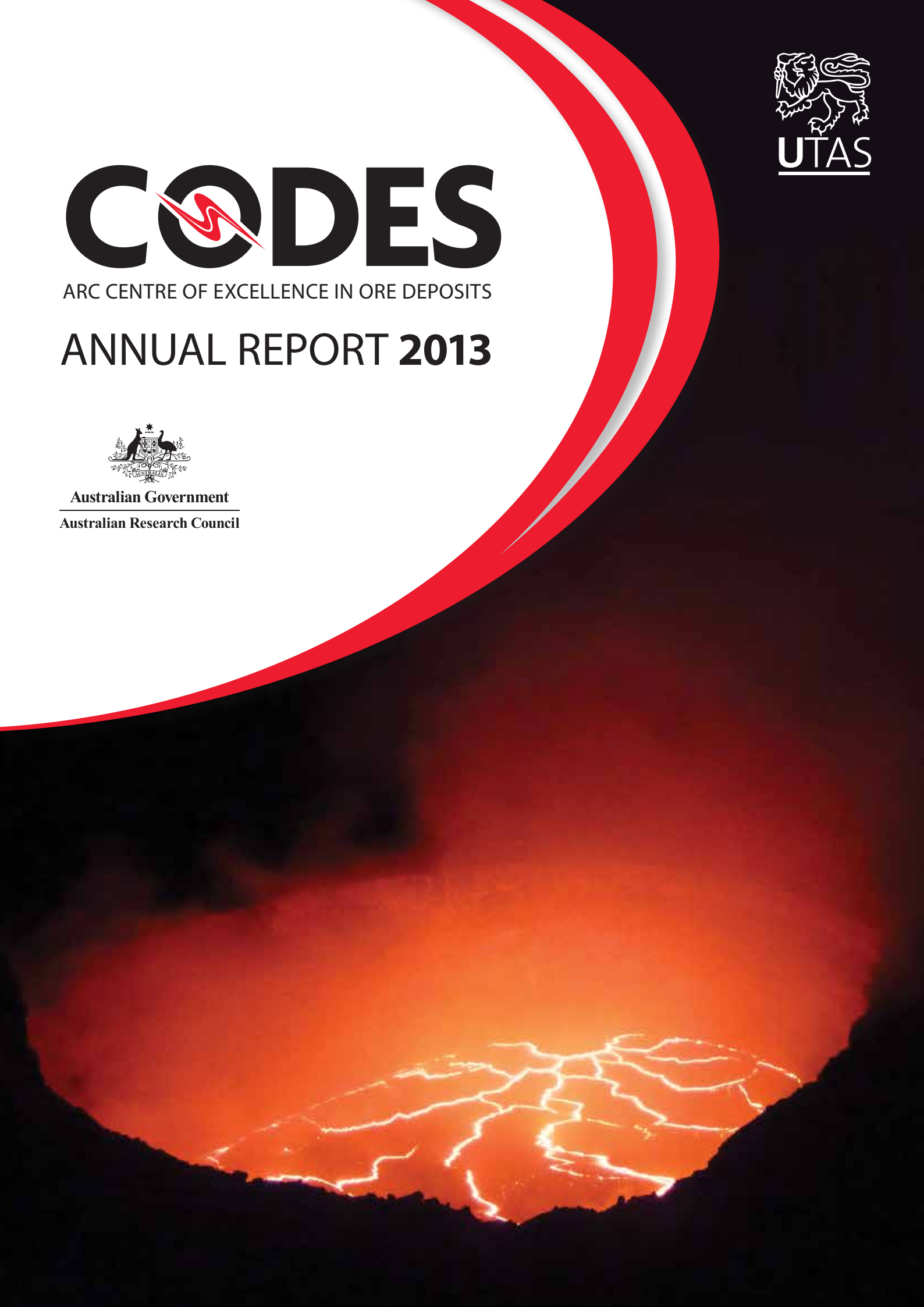
CODES

ARC CENTRE OF EXCELLENCE IN ORE DEPOSITS

ANNUAL REPORT 2013



Australian Government
Australian Research Council





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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.

Front cover: Lava lake within Kilauea caldera, Hawaii.
Back cover: Jocelyn McPhie at Kilauea caldera, Hawaii.
Right: Lava lake within Kilauea caldera, Hawaii.
Photography for the cover, this spread, and page 31 by PhD student Sam Holt.

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

LIFE AS AN ARC CENTRE

It has been a momentous year for CODES, which brings to an end 24 highly successful years as an ARC-funded Centre in various forms – starting as a Key Centre in 1989, becoming a Special Research Centre in 1997, and finally a Centre of Excellence in 2005.

It has been a remarkable period of growth, by any standards. Starting with a handful of staff working on a few small Australian-based projects, we have grown to have one of the largest university-based research groups in the world, working in over 30 countries spread across six continents. There have been far too many highlights to include here, but a few that warrant special mention are:

- Consistently meeting and/or exceeding Performance Indicators as stipulated by the ARC – see page 6 for a summary of our performance as a Centre of Excellence.
- Over 100 PhD and 80 Master of Economic Geology students have graduated since 1989, with many now holding senior positions in the minerals industry.
- Twenty-four years of continuous ARC and AMIRA funding for research.
- Twenty-two AMIRA projects completed with total industry funding over \$18 million.
- Leading university publisher for papers in the journal of *Economic Geology*.
- First to develop and publish the laser ablation sulfur isotope analytical technique and the LA-ICP-MS trace element imaging technique for sulfide minerals, both of which have enormous impact and potential applications to ore genesis studies and metallurgy.
- Development of mineral chemistry fingerprinting and vectoring tools that have created a step change in minerals exploration practice (AMIRA P765/765A/1060).
- Created the foundation research group for the development and growth of geometallurgy as a major research discipline in Australia and internationally (AMIRA P843/843A – GeM^{III}).
- Provided major contributions to revising the ore deposit exploration models for VHMS deposits, SEDEX deposits, epithermal gold-silver deposits, porphyry copper-gold-molybdenum deposits and carbonaceous shale-hosted gold deposits.
- Research contributed significantly to the discovery of three major ore deposits: Kencana epithermal gold deposit, Indonesia; Rosebery Y lens VHMS deposit Tasmania; and Myrtle Basin SEDEX Zn-Pb-Ag deposit, Northern Territory. In addition, CODES trained geologists were involved in the discovery of several new deposits globally.



THE PAST YEAR

The past year has been another exceptional period for CODES. Our successes have been many, as this Annual Report attests. Of particular importance was the commissioning and opening of the Newcrest Laser Ablation Analytical Facility, which significantly increases our capacity for laser ablation analyses for both footprint and geometallurgical research. All our research activities are underpinned by our technological capabilities, and this new facility will help cement our position as leaders in ore deposit characterisation. We thank Newcrest for its considerable support in helping this laboratory come to fruition.

We also thank all our industry partners for their ongoing support, including Buenaventura, who we are pleased to say has joined the group as a Gold Sponsor. I believe that it is a sign of confidence in the future of CODES that one of South America's largest precious metal mining companies has invested in our research. It is also good that it widens the global spread of our group.

There were a number of individual achievements during the year. The Society of Economic Geologists (SEG) announced that the SEG Gold Medal for 2013 will be awarded to Honorary Research Professor Noel White, and the Silver Medal to Deputy Director David Cooke. This is tremendous recognition to both Noel and David and cements their places with the greats of economic geology.

It was another exceptional year for our graduate research and training program, and first mention must go to Jacob Mulder, who received the highest grade for any Honours student studying the earth sciences since UTAS records began. Jacob's grade of 93% led to him being nominated for the highly prestigious University Medal.

The higher degree by research program had a healthy enrolment figure of 52 students. This figure included 40 international students representing 24 nationalities, bearing further testament to the fact that students come from all around the world to seek out a CODES qualification.

It was also a good year for our Master of Economic Geology Program, which had a very healthy figure of 49 UTAS-based students active in the program.

Three units were presented during the period, which were either at capacity or had record enrolments. This was an outstanding performance, especially as this was the first year without MTEC funding.

I am very pleased to report that in 2013 the Centre had more refereed journal articles published than in any other year in our 24-year history. The figure of 69, and the fact that our researchers have consistently exceeded this ARC Performance Indicator, is all the more commendable when one considers the high number of

industry reports that they produce each year. Among this year's figure were 45 papers from the Program One team, demonstrating that, while CODES has a focus on industry-driven outcomes, it still has a very strong base of fundamental research.

There were numerous research highlights during the period. The final meeting of AMIRA P843A was held in Brisbane, bringing this phase of the Geometallurgy Mapping and Mine Modelling (GeM^{III}) project to a close. This highly successful project has made a significant contribution to the testing and application of geometallurgy protocols that define mine variability in processing performance. During its final year, the team compiled eight years' of research into a 'compendium of results' and presented it to sponsors.

Case studies of Chuquicamata, Escondida, Andina and Los Bronces were also completed, with the reports being submitted to sponsors.

The value of our PhD students to our research activities was again in the spotlight when Jeff Steadman made a highly significant discovery of gold-bearing sedimentary pyrite nodules in the Black Flag Beds, well south of Kalgoorlie, Western Australia. This discovery has major implications for gold ore genesis models in the Yilgarn terrane. A paper on the studies has been published in *Precambrian Research*.

Also in the Discovery Program, the VPem3D modelling and inversion program was completed for ground, downhole, or airborne TEM. The program performs 3D inversions of TEM data more than 10 times faster than previously available methods. And the AMIRA P1041 project (Application of new technologies to gold deposits) was successfully completed, with sponsors deeming that all objectives had been met. The team has published several papers during the year, including an article in *Economic Geology* on the gold deportment and genesis of the Carbon Leader Reef in the Witwatersrand Basin, South Africa.

Two of our finest researchers, Associate Professor Ron Berry and Dr Peter McGoldrick, retired at the end of 2013 after many years of distinguished service to both CODES and the School of Earth Sciences. They have made substantial contributions to research and teaching and will be sorely missed. I wish them all the very best in their well-earned retirements.

THE FUTURE

As our tenure as an ARC centre comes to an end, our vision is to remain the global leader in minerals geoscience research and training, while being the research partner of choice to provide pre-competitive IP in economic geology, ore genesis, mineral exploration, geometallurgy and geoanalytical advances.

In the immediate future, CODES will develop the next generation of ore deposit models and exploration technologies required to sustain resource security well into the 21st century, and train the next generation of leaders in exploration and ore deposit research.

Starting from January 2014, there will be four new integrated research modules, entitled: Ore Deposit Characterisation, Geometallurgy, Enabling Technologies and Training. These modules will provide the opportunity for a step-change in exploration techniques for metal discovery and new practices for sustainable mining. The modules combine fundamental projects addressing key earth science research questions and applied projects seeking solutions to problems of direct relevance to the minerals industry. More details on these

modules are provided in the Research Framework section of this report, starting on page 8.

You may have noticed from looking at the cover of this report that CODES has a new logo. We decided to do this to herald the start of a new era for the centre, while taking the opportunity to simplify the logo and give it a cleaner look. Nevertheless, great care was taken to retain key elements in order to maintain strong links with our past.

There is no doubt that the loss of CoE funding will have an impact on our income, but CODES will continue to undertake high quality research and produce top graduates. However, we have developed an integrated financial plan to secure long-term funding and the continued success of the Centre. Key elements of this plan include a performance-based operating budget from UTAS, industry partnerships, one-on-one projects, AMIRA funding for specific projects, ARC Discovery and Linkage Grants, industry-focused short courses and workshops, and an application to be an Industrial Transformation Research Hub.

I believe that the future bodes well for CODES. We are fostering new partnerships with companies such as Buenaventura, while strengthening our collaborations with other stakeholders. Examples include a new project working with Mineral Resources Tasmania on a 3D geological model for the Rosebery area, the opening of the Newcrest analytical facility, and a new major international five-year research collaboration with Hefei University in China.

I thank all the staff, students and the Advisory Board for their hard work and support in 2013. It has been a long and successful journey since 1989. CODES staff and students, UTAS, the ARC, industry partners, collaborators, and our many other supporters can all be proud of what has been achieved over this period. Although this year is the end of the ARC centre era, it also marks the start of a new era. I have every confidence that CODES will build on these achievements and continue to be one of the world's leading centres for research and training in minerals geoscience.

Professor J Bruce Gemmell,
Director and Chief Operations Officer.

STATISTICS AT A GLANCE – 2013

Academic Research Staff	59
Postgraduate Students	123
Major Research Projects	47
Countries Involved	30
Publications in Refereed Journals	69
Research Reports to Industry	84
Workshops and Short Courses:	
Number	17
Countries	10
Attendees	1,047
Funding:	
Industry	\$3.7 million
ARC	\$3.2 million
UTAS	\$1.6 million
Worldwide Collaborations:	
Industry	73
Institutes and Universities	116

OUTPUTS AS A CENTRE OF EXCELLENCE

CODES attained Australian Research Council (ARC) Centre of Excellence (CoE) status in 2005, and successfully applied for an extension in 2008, taking its tenure as a CoE to the end of 2013. In accordance with ARC rules, no further extensions are permitted.

During this period, the Centre has consistently exceeded virtually all the Performance Indicators set by the ARC. Areas where it has excelled include:

- Building an extensive network of national and international collaborations.
- Establishing projects in around 30 countries on six continents.
- Consistently exceeding targets for publications, while delivering an exceptionally high number of reports to industry.
- Establishing a worldwide reputation for excellence in postgraduate training, with a high proportion of graduates progressing to senior positions within the minerals industry.
- Achieving integration between fundamental and applied research through a team-based series of Programs.
- Garnering strong industry support through a highly collaborative, outcome-driven research model, which has been reflected in a consistently high ratio of industry funding.

Success in these areas is illustrated by the statistics in the tables below:

	ARC TARGETS 2006 TO 2013*	ACHIEVED FIGURES 2006 TO 2013*
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PUBLICATIONS

Refereed journal articles	360 (45)	439 (55)
Papers at national and international meetings	520 (65)	800 (100)
Invited keynotes	80 (10)	107 (13)

* ARC targets changed during the period. Therefore, bracketed figures and percentages are yearly averages. Other figures are totals over the period of the CoE.

GRADUATE RESEARCH AND TRAINING

Percentage of HDR students attracted from interstate	40%	30%
Percentage of HDR students attracted from overseas	35%	62%
Honours students in Centre programs	80 (10)	106 (13)
Percentage of students in projects linked to industry	50%	74%
Employment of graduates by the minerals industry	> 65%	77%

COLLABORATIONS

Percentage of Australian cross institutional projects	30%	42%
Collaborative projects with other global centres/groups	80 (10)	137 (17)
International and national visitors	320 (40)	837 (105)

TECHNOLOGY TRANSFER

Reports to industry	520 (65)	1,139 (142)
Professional short courses/workshops for industry	40 (5)	158 (20)
Registrants at the abovementioned courses/workshops	600(75)	6,028 (753)
Industry visitors	520 (65)	660 (82)
Frequency of meetings with industry representatives	100 (12)	167 (21)
Frequency of meetings with AMIRA Research Co-ordinator	80 (10)	104 (13)

FINANCE

Matched funding	One-to-one ratio (i.e. ARC funds should be matched by funds from other sources)	ARC funds were matched, and exceeded, by an average of 1 to 2.3
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Left: 2013 PhD graduate Gisela Cobenas. **Middle:** Dr Patrick Mercier-Langevin, one of many high profile visitors over the life of the Centre. **Right:** Professor Ross Large (L) underground at the Mponeng mine in South Africa. The former Director played a key role in the formation and development of CODES. **Opposite:** Part of the group from the previous year's 'Fluids in the Earth' short course in Italy – one of 158 short courses, conferences and workshops led by CODES over its tenure as a Centre of Excellence.



RESEARCH FRAMEWORK

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 59 highly qualified research staff and 123 postgraduate students, further cementing its position as the largest university-based team of ore deposit researchers in the world.

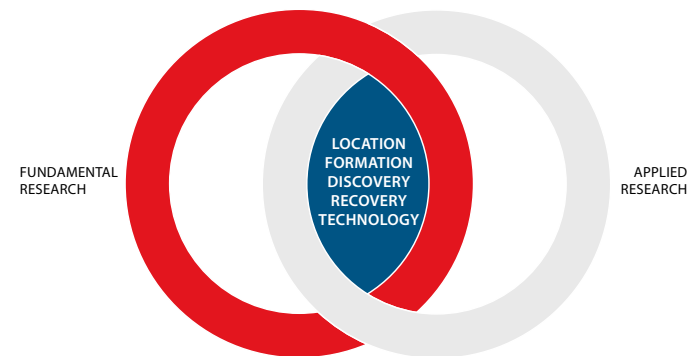
Highly productive worldwide collaborations have been developed with over 70 industry companies, plus a host of joint research initiatives with 116 institutions and universities – 22 in Australia and 94 overseas. It currently has major research projects spanning 30 countries, and is the leading academic group to publish in *Economic Geology*. In 2013, it maintained its reputation for delivering excellence in technology transfer by producing 84 reports to industry and conducting 17 workshops and short courses in 10 countries, spread across all six permanently inhabited continents.

THE FIVE PROGRAMS

The Centre has adopted an holistic approach to the science that encompasses all areas of the research cycle. This has been achieved throughout its tenure as a Centre of Excellence through five major research programs – Location, Formation, Discovery, Recovery and Technology. In very basic terms, these programs can be explained as follows:

- **LOCATION** seeks to improve our knowledge of the tectonic and geological controls on the location of ore deposits.
- **FORMATION** develops practical, process-based ore genesis models to help explorers understand the formation of deposits.
- **DISCOVERY** focuses on the acquisition, processing and interpretation of scientific ore deposit data to assist in the discovery of minerals.
- **RECOVERY** is an integrated, cross-disciplinary field that seeks to enhance mineral processing techniques and optimise mineral recovery rates.
- The **TECHNOLOGY** Program uses a combination of traditional and cutting-edge technological developments to improve the understanding and, subsequently, advance the exploration and exploitation of minerals.

These five programs, together with a team-based approach, have formed the foundations of CODES' ability to provide a seamless transition between fundamental and applied research.



TRANSITION TO A FOUR MODULE MODEL

At the end of 2013, CODES' tenure as an ARC-funded Centre of Excellence came to an end. As part of its strategic planning, management decided to adopt a four module structure for 2014, and beyond.

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. This model would also position it to meet the evolving needs of the minerals industry and other stakeholder groups.

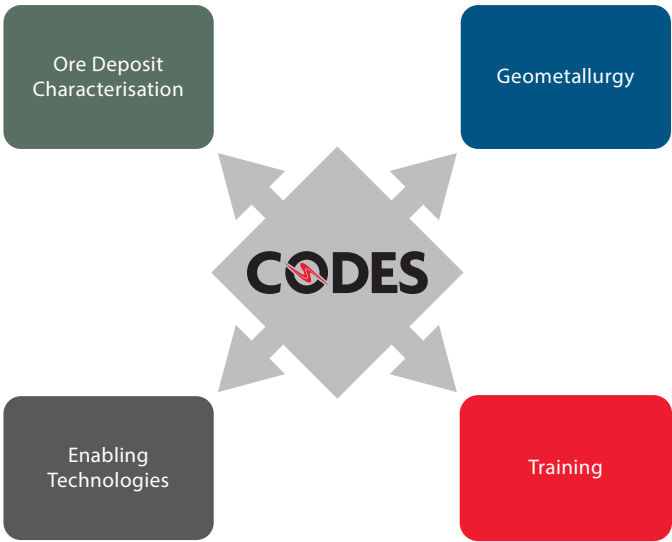
The new integrated research modules provide the opportunity for a step-change in exploration techniques for metal discovery, new practices for sustainable mining, a steady supply of world class geoscience graduates, as well as creating a platform to meet the training and up-skilling needs of the minerals industry.



Opposite: Fe-oxide material from near the Kul-Yurt-Tau pyrophyllite deposit, Urals, Russia.

THE NEW MODULES FOR 2014

- **ORE DEPOSIT CHARACTERISATION** will provide 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.** Building on the success of the GeM project, this module will 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** will produce innovative analytical and computational tools, and facilitate technology transfer to the minerals exploration and geoanalytical industries.
- **TRAINING** will build 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.



NEWCREST MINERAL RESEARCH FACILITY OPENS

The Newcrest-funded laser ablation facility opened in August, further enhancing CODES capabilities in ore characterisation. The Centre now has four cutting-edge laboratories catering for LA-ICP-MS analysis. In addition, it has reciprocal arrangements with the UTAS Central Science Laboratory,

which has an extensive suite of complementary equipment, particularly in the areas of electron microscopy, ICP-MS, and Mineral Liberation Analysis (MLA).

The R&D program within the new facility is aimed primarily at developing calibration standards for sulfide analysis and LA-ICP-MS data reduction software for multi-standard calibrations and image quantification, including identification and size determination of micro-inclusions.



Kathryn Stewart from Newcrest Mining addresses the guests at the opening of the Newcrest mineral research facility.

HUB, NODES AND INTERNATIONAL PARTNERS

CODES is based at the University of Tasmania, with satellite facilities, known as nodes, at the University of Queensland, University of Melbourne, Australian National University, and CSIRO. This structure has provided an exceptionally strong mix of skills and facilities by combining the research strengths of CODES' UTAS Hub with the diverse range of expertise available through the nodes. The nodes' strengths have included:

- Metallurgy and mineral processing (University of Queensland).
- Structure of ore deposits (Australian National University).
- Isotope geochemistry (University of Melbourne).
- Micro-beam analytical techniques (CSIRO).

The strengths of these Australian nodes have been complemented by four strong partnerships with the University of British Columbia, the Colorado School of Mines, Imperial College London and the Russian Academy of Sciences, which have provided an ideal platform for international research projects and augmented the Centre's access to the latest technology.

Although the Hub and Nodes structure ceased at the end of its tenure as an ARC-funded Centre of Excellence, CODES will continue to build strong collaborative relationships with its key collaboration partners.



- Hub
- Node
- International Partner

STAFF AND 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 David Cooke (Deputy Director), the Advisory Board and the Executive Committee.

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, 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.

CENTRE RESEARCH COMMITTEE

The Centre Research Committee includes all collaborating partner chief investigators. It meets annually to discuss research progress, new research opportunities and particularly to focus on effective collaborative activities across all Centre partners.

EXECUTIVE COMMITTEE

The Executive Committee consists of the Centre Director, Deputy Director, Graduate Research Co-ordinator, five program leaders and administrative managers. It meets approximately six times a year, working closely with the Director to develop the Centre's goals, strategies and performance indicators.



Left: Advisory Board meeting. Right: CODES Director Bruce Gemmell, Advisory Board Chair Paul Heithersay.

STAFF MOVEMENTS 2013

APPOINTMENTS

Dr Ivan Belousov has been appointed as a mineralogist.

Mary Frey was appointed on a short-term contract in a business development role.

Dr Jane Higgins has been appointed as PA to the Director, Bruce Gemmell.

Takayuki Manaka submitted his PhD thesis during the year and was appointed as a junior research fellow, working on the Ore Deposits of SE Asia project.

Dr Paul Olin has been appointed as a laboratory analyst within the LA-ICP-MS facilities. Dr Olin was formerly with Boise State University, Idaho, USA.

Dr David Selley has returned to CODES after a period working for BHP Billiton in Singapore. David has been appointed as a research fellow and the co-ordinator for Honours coursework.

DEPARTURES

Five academic staff and six professional staff members left the CODES Hub during the year.

ACADEMIC STAFF David Hutchinson, Andrew McNeill, Abhisit Salam, Ralf Schaa, and Helen Thomas.

PROFESSIONAL STAFF Three professional staff were relocated to centralised administration hubs as part of a general UTAS restructuring program. Those affected were finance staff Claire Rutherford and Helen Scott, plus IT Officer Keith Dobson. In addition, Deborah Macklin and Karen Mollross took up positions within other areas of UTAS, and Christine Higgins left the university.

Mary Frey's short-term contract in the role of business development came to an end in December.



Science Planning Panel meeting.

CODES STAFF

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	40
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, geomettallurgy	Hon
Dr Daniel Bombardieri, BSc Hons, PhD (UTAS)	3D potential field modelling	60
Dr Stuart Bull, BSc Hons, PhD (Monash)	Clastic and carbonate sedimentology and volcanology	Hon
Dr Rebecca Carey, BSc Hons (UTAS), PhD (U Hawaii)	Volcanology	100
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	100
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
Dr Nathan Fox, MSc Hons (Imperial), PhD (UTAS)	Porphyry Cu-Au and HS epithermal	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 Nic Jansen, BSc Hons (St Mary's), PhD (UTAS)	Porphyry Cu-Au and HS epithermal	100

NAME		%
Dr Maya Kamenetsky, PhD (UTAS)	MLA-SEM, geomettallurgy, petrology	100
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 Lyudmyla Koziy, PhD (UTAS)	Fluid flow modelling	50
Dr Chun-kit Lai, BSc, MPhil (HKU), PhD (UTAS)	Petrology, geochemistry and tectonics of SE Asia	100
Professor Ross Large, BSc Hons (UTAS), PhD (UNE)	Volcanic-hosted and sediment-hosted base metal and gold ores	100
Dr Takayuki Manaka, MSc, PhD (UTAS)	Ore deposits of SE Asia	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
Dr 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	50
Dr Rob Scott, BSc Hons, PhD (Monash)	Structural geology, gold deposits / MTEC Senior Lecturer and Masters Program Coordinator	50
Dr Aleksandr Stepanov, MSc (Novosibirsk), PhD (ANU)	Geochemistry of rare metals	100
Dr Lejun Zhang, BSc, PhD (HFUT)	Porphyry Cu-Au and HS epithermal	100

ACADEMIC/RESEARCH STAFF BASED AT COLLABORATIVE INSTITUTIONS

NAME		%	NAME		%
Dr Grant Ballantyne	JKMRC, University of Queensland	15	Dr Weihua Liu	CSIRO	10
Dr Stacey Borg	CSIRO	70	Dr Roland Maas	University of Melbourne	10
Professor Deirdre Bradshaw	JKMRC, University of Queensland	10	Professor Emmanuel Manlapig	JKMRC, University of Queensland	10
Mr Alan Cocker	WH Bryan Mining Geology Research Centre, University of Queensland	20	Dr Khoi Ke Nguyen	JKMRC, University of Queensland	60
Professor Stephen Cox	Node Leader: Australian National University	30	Dr Bence Paul	University of Melbourne	100
Professor Mark Hannington	University of Ottawa	Hon	Mr Steven Pooley	JKMRC, University of Queensland	14
Professor Peter Hollings	Lakehead University	Hon	Professor Malcolm Powell	JKMRC, University of Queensland	20
Associate Professor Janet Hergt	Node Leader: University of Melbourne	10	Dr Chris Ryan	Node Leader: CSIRO	20
Professor Murray Hitzman	Colorado School of Mines	20	Mr Patrick Walters	JKMRC, University of Queensland	40
Mr John Jackson	JKMRC, University of Queensland	15	Dr Yicai Wang	JKMRC, University of Queensland	45
Mr Harri Kokkonen	Australian National University	20	Dr Dion Weatherley	JKMRC, University of Queensland	20
Dr Jamie Laird	CSIRO	100	Dr Noel White	Consultant	Hon
Dr Janine Lay	JKMRC, University of Queensland	10			

TECHNICAL/ADMINISTRATIVE STAFF

NAME			%	NAME			%
Mr Steve Calladine	Communications Manager	100		Ms Caroline Mordaunt, BA Hons (King's College London)	Administrative Assistant	20	
Mrs Michele Chapple-Smith	Lapidary Technician	40					
Mr Peter Cornish	Laboratory Manager	50		Dr Paul Olin, BA (SOU), MSc, PhD (WSU)	Laboratory Analyst	100	
Mr Alex Cuison	Lapidary Technician	80					
Ms Sarah Gilbert, BSc Hons (UTAS)	Laboratory Manager ICP-MS	100		Ms June Pongratz	Publications	15	
Dr Jane Higgins, BIS, BAntSt Hons, PhD (UTAS)	Personal Assistant to the Director	80		Mr Jay Thompson, BSc Hons, MSc (U Iowa)	Laboratory Analyst	100	
Mr Ian Little, BSc Hons (UTAS)	Laboratory Analyst	100		Mrs Jennifer Thompson, BSc (OSU), MSc (U Iowa)	Laboratory Analyst	100	
Ms Elena Lounejeva	Laboratory Analyst	100		Ms Isabella von Lichtan, BSc Hons (UTAS)	Curator / Administrative Assistant	25	
Mrs Katie McGoldrick	Laboratory Assistant	40					

ADVISORY BOARD

NAME	
Chair: Paul Heithersay	DMITRE-Geological Survey of SA
Deputy Chair: Paul Agnew	Rio Tinto Exploration
Ben Ackerman	Newcrest Mining
Margaret Britz	Dean, Faculty SET, UTAS
Graham Carr	CSIRO
David Cooke	CODES, UTAS
Stephen Cox	Australian National University
Kim Creak	Mineral Resources Tasmania (MRT)
Paul Cromie	Anglo American
Joe Cucuzza	AMIRA International
Leonid Danyushevsky	CODES, UTAS
Andrew Davies	Teck Resources

NAME	
Cathryn Dickins	St Barbara
Bruce Gemmell	CODES, UTAS
John Holliday	Consultant
Richard Malysiak	BHP Billiton
Jocelyn McPhie	CODES, UTAS
Steve Turner	Newmont Exploration, Perth
Andrew Wells	Exec Dir, RPP&D, UTAS



Science Planning Panel meeting attendees.

EXECUTIVE COMMITTEE

NAME	
Chair: Bruce Gemmell	Director, CODES
Ron Berry	Recovery (4) Program Leader
Steve Calladine	Communications Manager
David Cooke	Formation (2) Program Leader & Deputy Director, CODES
Leonid Danyushevsky	Technology (5) Program Leader

NAME	
Garry Davidson	Discovery (3) Program Leader
Jocelyn McPhie	Location (1) Program Leader, Head of Earth Sciences & Co-ordinator Graduate Research
Helen Scott*	Finance Manager
*Committee member for part of the year.	

*Committee member for part of the year.

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

NAME	
Chair: Bruce Gemmell	Director, CODES
Ben Ackerman	Newcrest Mining
Paul Agnew	Rio Tinto Exploration
Cynthia Awruch	Research Manager, SET, UTAS
Margaret Britz	Dean, Faculty SET, UTAS
Graham Carr	CSIRO
David Cooke	CODES, UTAS
Stephen Cox	Australian National University
Kim Creak	Mineral Resources Tasmania (MRT)
Paul Cromie	Anglo American
Joe Cucuzza	AMIRA International
Andrew Davies	Teck Resources
Cathryn Dickins	St Barbara

NAME	
Paul Heithersay	DMITRE-Geological Survey of SA
John Holliday	Consultant
Raul Hollinger	Unity Mining Limited
Tony Hope	GHD
Andrew McNeill	Mineral Resources Tasmnia (MRT)
Jocelyn McPhie	CODES, UTAS
Kenzo Sanematsu	Geological Survey of Japan
Adele Seymon	AMIRA International
Wayne Stange	JKMRC, University of Queensland
Kathryn Stewart	Newcrest Mining
Steve Turner	Newmont Exploration

GRADUATE RESEARCH AND TRAINING

Students enrolled in the UTAS Higher Degree by Research (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 five research programs and about two-thirds of the projects involve collaborations with the minerals industry. Although most students are based at UTAS in Hobart, a small number work with partner institutions.

In addition to the main HDR Program, the Centre plays a key role in up-skilling industry-based employees through courses such as those offered by the Master of Economic Geology Program. CODES also has a highly regarded Honours program, which includes students conducting a range of industry-sponsored projects in Tasmania, mainland Australia and overseas. Many of these students use this degree as a stepping stone to an HDR, or senior positions within the minerals industry.

HDR PROGRAM

CODES' success in attracting HDR students from overseas is underpinned by its international reputation as a research training centre. The 2013 HDR cohort included 40 international students representing 24 nationalities, 22 of whom were at least partly funded by Centre of Excellence scholarships. In addition, the HDR program has been generously supported by UTAS in the form of living allowance scholarships for Australian students, and tuition fee waivers for international students. On the termination of the ARC Centre of Excellence grant at the end of 2013, CODES PhD scholarships can no longer be offered to international students, and the Centre will be dependent on ongoing UTAS and industry support to recruit internationally.

There were 52 students enrolled in the UTAS HDR Program during 2013 (48 PhD and 4 MSc), which included thirteen new PhD students – Ben Cave (Australia), Jing Chen (China), Angela Escolme (Australia), Esmail Eshaghi (Iran), Jodi Fox (Australia), Martin Gal (Austria), Sam Holt (Australia), Peter Morse (Australia), Lina Serrano (Colombia), Subira Sharma (India), Nathan Steeves (Canada), Irma Vejelyte (Lithuania), and Daniele Vergani (Italy). Paula Montoya (Colombia) and Stephanie Sykora (Canada) began as MSc students. Twelve PhD students and one MSc student had theses under examination, seven of whom graduated: Mathieu Ageneau, Victoria Braniff, Lindsey Clark, Gisela Cobenas, Abhisit Salam, Bronto Sutopo, and Stacey Leichliter (MSc).

The number of thesis submissions and graduations reduced the effective PhD workforce to 39. In addition, two students suspended their candidature for part of the year, and three chose to study part-time, further reducing the effective PhD workforce slightly. Notwithstanding this natural attrition, both

the figures for the effective workforce and new enrolments were significantly higher than 2012. It should also be noted that the intake of five Australian HDR students in 2013 was a record high, possibly reflecting the tighter employment situation in the minerals industry.

SEG STUDENT CHAPTER

The CODES SEG Student Chapter plays a vital role in the social integration and professional development of the cosmopolitan mix of students that make up the postgraduate cohort. The international nature of the chapter is suitably reflected by its recent Presidents. In 2011, it was Pedro Fonseca (Portugal) and Jeff Steadman (USA). In 2012, it was Dan Gregory (Canada) and Francisco Testa (Argentina), and in 2013 Francisco continued in the role until the election in October when Scotsman Sean Johnson took over the reins. Sean is currently supported by a committee with an equally international mix, which includes two Canadians, plus representatives from Australia, India and England – and the committee prior to October included members from Russia and China.

Working as a team, the students have organised a wide range of social and professional development activities during the year. Recreational pursuits included ice hockey, wine tasting, barbecues, house warmings, weekly meetings at a local watering hole, and dragon boat racing – with a lot of help from former student member (Dr) Nic Jansen.

The centre point of the professional development activities was the field excursion in July and August to Russia, with a particular focus on the mineral-rich Southern Urals. The group visited a number of mines, which were mainly exploiting VHMS and mesothermal gold deposits. Included in the trip was the Ore Genesis Conference at the Russian Academy of Sciences and a short stint of sightseeing in Moscow. Each of the students on the trip, plus the two industry participants, delivered oral and poster presentations at the conference.

The excursion was organised by the Student Chapter, led by Peter McGoldrick from CODES, plus Valeriy Maslennikov and Igor Zhukov from the Russian Academy of Sciences, and sponsored by AngloGold Ashanti, Barrick Australia, CODES, Data Metallogenica and the SEG.

It was good to welcome back former PhD student Andrea Agangi, who visited CODES again late in the year, and included a talk as part of the chapter's ongoing seminar series. Andrea is now working at the University of Johannesburg.

Erin Lawlis and Sean Johnson were successful in gaining SEG Fellowship Awards.



Opposite: PhD students Olga Apukhtina, Francisco Testa and Dan Gregory examining high grade VHMS ore during the SEG Student Chapter's excursion to the Southern Urals, Russia.

HONOURS PROGRAM

The total number of UTAS Honours enrolments was 14, counting students in the year of their completion. This is lower than the previous year's figure of 18, but that was a year in which the intake was much higher than average. Out of this year's cohort, Sam Poker and Sam Cross joined the group from Monash University, Greg Clarke from the University of Western Australia, and Vikraman Selvaraja from ANU. The remaining ten students were graduates from UTAS.

There was a reasonable spread of projects amongst the disciplines, but with a bias towards economic geology (6), and to a lesser extent geophysics (3) and metamorphic petrology/geochronology (2). There were also single projects in the fields of sedimentology, and geometallurgy. Seven of the projects were based in mainland Australia, with five in Tasmania – including Jacob Mulder's project in the island's remote deep-south. This year's most exotic location was chosen by Vikraman Selvaraja, who was working in Indonesia (Gosowong). The Tasmanian projects were supported by Mineral Resources Tasmania, MMG Rosebery and Unity Mining, with the mainland and overseas projects being supported by Independence Group, Lynas Corporation, Newcrest Mining, Rio Tinto Exploration, Signature Gold, and Sirius Resources. CODES gratefully acknowledges the support of these sponsors.

The Honours year was again administered by Garry Davidson, with Peter McGoldrick supervising the coursework aspects. Peter retired at the end of 2013, and the Centre, and particularly everyone involved in the Honours program, thank him for the huge contribution he has made over many years.

Student supervision roles were widely shared between Garry Davidson (3), Michael Roach (3), Rob Scott (2), David Cooke, Ron Berry, Tony Crawford, Jocelyn McPhie, and Nic Jansen. Additional co-supervision was provided by Anya Reading (3), Julie Hunt, Sebastien Meffre, Andrew McNeill (MRT), Mark Duffett (MRT), Stuart Bull, Ron Berry, Nic Jansen, Nathan Fox, David Cooke, Ross Large, Bruce Gemmell and Jacqui Halpin.

Although it is not usual to cover student grades in this report, an exception is being made in the case of Jacob Mulder, who produced the highest grade for any UTAS Earth Sciences Honours student on record – stretching back over 22 years. Jacob received a remarkable 93% for his thesis titled Structure and metamorphism of the Cox Bight-Red Point area, south west Tasmania. In recognition of his achievement, Jacob has been nominated for the prestigious UTAS University Medal, which he will receive in January 2014.

The Exploration and Skills Mapping Course was again held twice during the year, attracting a high number of students from UTAS and mainland universities.



Ore Deposits of South America short course participants in Chile, from left, at Monte Verde, Los Andes, and Cordillera Domeyko.

MASTER OF ECONOMIC GEOLOGY PROGRAM

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

The Centre's Master of Economic Geology Program continued the positive trends of recent years, with another strong performance in 2013, presenting three coursework units that were either at capacity or had record enrolments. Fourteen new people enrolled during the year, bringing the total number of UTAS-based students active in the national program to 49. It was also another good year for completions, with six students graduating: Margaret Hawke, Yungu Lim, Jonathon Robbeson, Linda Sprigg, Yong Zhang and Stanley Zutah. A further three students completed their degrees late in the year, and are eligible to graduate in 2014: Corrie Chamberlain, Tatjana Pucko and Michelle Puskas.

In March, David Cooke, Lejun Zhang and Michael Roach led a large group comprising fifteen Masters students, five industry participants and four CODES PhD students to Chile and Peru for the Centre's most enterprising and logistically challenging short course, Ore Deposits of South America. This highly practical, field-based course gave students first-hand experience of the remarkable giant ore bodies of the Andes, and included visits to the world's largest open cut and underground mines. Deposit types visited included porphyry, epithermal, IOCG, skarn and MVT. The mix of adventure, breathtaking scenery, expert tuition, and exposure to extraordinary geology make this biennial course one of the most popular and memorable on the Masters Program calendar.

In June, David Cooke took the helm again to lead the second short course for the year, Ore Deposit Geochemistry, Hydrology and Geochronology. The course is designed to introduce participants to a range of geochemical, isotopic, hydrological and geochronological techniques used to interpret ore genesis and ore forming environments. David was assisted by expert teaching staff from CODES, various research institutes, and the minerals industry. Included in a long list of invited speakers were Shaun Barker (University of Waikato), Phil Blevin (GSNSW), Jess Robertson and Graham Carr (CSIRO), Lesley Wyborn (Geoscience Australia), plus leading minerals consultants Scott Halley and Nick Oliver.

Although this is always one of the more popular courses on the calendar, no one was quite expecting to receive a record enrolment of 35 Masters students – the largest ever for a course in the national Minerals Geoscience Masters program. The two-week course was also attended by two industry participants, plus a healthy number of staff and students from CODES, which meant that the sixty-seater venue was full to capacity on most days.

The final Master of Economic Geology unit for the year was Geometallurgy, which built on the success of the inaugural course, held in March of the previous year. The course was originated to meet a need from industry, which has increasingly focused on this highly specialised field to increase the efficiency and profitability of its operations.

The course program started in late October and was again led by Julie Hunt and Ron Berry from CODES. Julie and Ron were ably assisted by Dee Bradshaw from UQ, consultant Toni Kojovic, and Anita Parbhakar-Fox and Taryn Noble from UTAS/ CRC ORE.

Over 12 intensive days, the course covered all the key aspects of this highly specialised field, including rock properties, sample selection, mineralogy, comminution and mineral processing, statistical analysis and modelling, environmental issues, and finances. One of the most popular features of the inaugural course was a short, two-day field trip to western Tasmania. As a result of the positive feedback about this portion of the course, the excursion was expanded this year to three full days, encompassing visits to Metals X's Renison tin mine, Grange Resources' Savage River iron ore mine and Port Latta operation, and the ALS Laboratory in Burnie. Once again, this was a well attended course with 27 participants, comprising 23 Masters students, two industry participants and two CODES PhD students.

It is pleasing to note that the positive predictions made in last year's report have come to fruition, despite this being the first year without MTEC funding. Although significant challenges still lie ahead, the attendance and enrolment figures over the past twelve months provide ample evidence that the Master of Economic Geology Program at CODES has a positive future.

THE PROGRAM FOR 2014:

- 16 – 30 March: Volcanology and Mineralisation in Volcanic Terrains (KEA703)
- 2 – 13 June: Exploration in Brownfield Terrains (KEA705)
- 20 – 31 October: Ore Deposit Models and Exploration Strategies (KEA701)



Left: Honours graduate Jacob Mulder with his University Medal. Right: Supervisor Khin Zaw with graduates Abhisit Salam (PhD) and Joe Knight (Honours).

STUDENT PROJECTS

IN AUSTRALIA

Project locations are shown in capitals. Unless marked otherwise, student projects shown here are field and lab-based PhD projects.

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. Arnold, Sam. TAS (Hons)

Spatial variability of sphalerite composition in W lens, Rosebery Mine, western Tasmania.

4. Baker, Wayne. TAS (GDipSci)

The correlations and exploration significance of the Natone Volcanics, Rosebery Group, western Tasmania.

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

Webbs silver project, NSW.

6. Braniff, Victoria. TAS

Integration of geotechnical and structural data from Savage River Mine, Tasmania.

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. Clarke, Andrew [ANU]. NSW (Hons)

Vein formation at Endeavour 48 porphyry Cu-Au deposit, eastern Australia.

10. Clarke, Greg. SA (Hons)

Origin of breccias in the Vulcan South IOCG prospect, Gawler Craton, South Australia.

11. Cross, Sam. QLD (Hons)

A geochemical assessment of the prospectivity of the Fletchers Awl region, Queensland.

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. Ferguson, Matthew. WA (Hons)

Mineral paragenesis and geometallurgical characteristics of the Karlawinda Deposit, Western Australia.

15. Fox, Jodi. TAS

The volcanic history of Heard Island.

16. Gilmore, Phil. NSW (Masters)

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

17. Gregory, Daniel. WA

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

18. Hawke, Margy. WA

Geology of the DeGrussa VMS deposit, WA.

19. Hong, Wei. TAS

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

20. Huang, Qiuyue. SA

Mafic dykes at Olympic Dam.

21. Kyne, Roisin. NSW

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

22. Lower, Chantelle. SA (Masters)

An aspect of the geology of the Olympic Dam deposit.

23. Lygin, Alexey. TAS

The geology, geochemistry and genesis of the Avebury Ni deposit, Tasmania.



PhD student Evan Orovan presenting to the Science Planning Panel.

24. Mulder, Jacob. TAS (Hons)

The structure and metamorphism of the Cox Bight-Red Point Area, southwest Tasmania.

25. Officer, Caitlyn. TAS (Hons)

Stable isotope (S +/- C-O) and pyrite trace element anatomy of the Henty Gold Deposit, Tasmania, with emphasis on the zonation around the high grade Read Zone.

26. Pascual, Richelle. TAS

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

27. Pereira da Fonseca, Pedro. TAS

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

28. Phythian, Daniel. WA (Hons)

Geophysical investigation of Mt. Weld carbonatite, Laverton, Western Australia.

29. Poker, Sam. TAS (Hons)

A geophysical investigation of the northern extent of the Meredith Granite, northwest Tasmania.

30. Rowlands, Will. VIC (Hons)

Petrophysical properties and geophysical response of the Benambra (VHMS) deposits, Victoria.

31. Rush, Jacqueline. NSW (Hons)

Geology of the Marsden Cu-Au porphyry deposit, NSW.

32. Sharma, Subira. QLD

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

33. Steadman, Jeffrey. WA

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

34. Thomas, Lauren. WA (Hons)

Geochronology and metamorphism of the magmatic Ni-Cu Nova deposit, Albany-Fraser Range, WA.

35. Vejelyte, Irma. SA

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

36. Wu, Selina. TAS

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

LAB-BASED PROJECTS

Chauhan, Mitesh [JKMRC]

Application of small scale flotation testing.

Cracknell, Matthew

Machine learning for geological mapping: Algorithms and applications.

Davidson, John (GDipSci)

Magnetic anomalies in continent ocean transition zones.

Escolme, Angela

Predicting recovery in porphyry deposits: A geological perspective.

Gal, Martin

The development of array 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.

Hingee, Myall (Masters)

Approximate Inverse Mapping (AIM) inversion of Transient Electromagnetic (TEM) data.

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.

Wells, Lydia (GDipSci)

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

OUTSIDE AUSTRALIA

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

1. Ageneau, Mathieu. PNG

Geology of the Kapit ore zone and comparative geochemistry with Minifie and Lienetz ore zones, Ladolam Gold Deposit, Lihir Island, Papua New Guinea.

2. Baker, Fabian. ARMENIA (Masters)

Amulsar HSE Au deposit, Armenia.

3. Basori, Mohd Basril Iswadi Bin. MALAYSIA

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

4. Beas Caceras, Billy. PERU (Masters)

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

5. Berkenbosch, Heidi. NEW ZEALAND

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

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

Chanca low sulfidation deposit, Peru.

7. Cave, Ben. NEW ZEALAND

A metamorphic source for tungsten in metasedimentary-hosted orogenic gold deposits; Insights from Otago, New Zealand.

8. Chen, Jing. CHINA

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

9. Clark, Lindsey. INDONESIA

The geology and genesis of the Kencana epithermal Au-Ag deposit, Gosowong Goldfield, Halmahera Island, Indonesia.

10. Cobenas Benites, Gisela. SW PACIFIC

The behaviour of metals during differentiation of subduction-related lavas: A case study of active submarine volcanoes on the Hunter Ridge, SW Pacific.

11. Erskine, Tobias. MYANMAR (Hons)

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

12. Galván-Gutiérrez, Víctor Hugo. MEXICO

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

13. 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.

14. Harrison, Rachel. INDONESIA (Masters)

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

15. Holt, Sam. USA

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

16. Jimenez Torres, Carlos Andres. PHILIPPINES

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

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

The effect of metamorphic grade on trace element mobility in black shales.

18. 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.

19. Lawlis, Erin. PNG

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

20. Le, Xuan Truong. VIETNAM (Masters)

Mineralisation of Me Xi gold deposit, Vietnam.

21. Lechlitter, Stacey. COLOMBIA (Masters)

Gold deportment and geometallurgical recovery model for the La Colosa, porphyry gold deposit, Colombia.

22. Lim, Yungu. CAMBODIA (Masters)

Geological setting and mineralisation characteristics of the Kratie North deposit, central Cambodia.

23. Makoundi, Charles. MALAYSIA

Trace element variation in Phanerozoic shale sequences in Malaysia: implications for gold metallogeny of Sibumasu terrane.

24. Manaka, Takayuki. VIETNAM

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

25. McLelland, Rebecca. NEW ZEALAND (Masters)

Reefton Goldfield, New Zealand.

26. Montoya, Paula. COLOMBIA (Masters)

Comminution studies: La Colosa case study.

27. Musialike, Michael. ZAMBIA (Masters)

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

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

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

29. Orovan, Evan. FIJI

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

30. Paipana, Supitchaya. THAILAND (Hons)

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

31. 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.

32. Redi, Daniele. ITALY

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

33. Rinne, Marc. PNG

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

34. Salam, Abhisit. THAILAND

A geological, geochemical and metallogenic study of the Chatree epithermal deposit, Phetchabun Province, central Thailand.

35. Selvaraja, Vikraman. INDONESIA (Hons)

Determining the nature and zonation of advanced argillic alteration and applying suitable geochemical exploration vectors in the Gosowong epithermal district, Indonesia.

36. Serrano, Lina. ARGENTINA, MAURITANIA, MALI

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

37. Steadman, Jeffrey. USA

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

38. Steeves, Nathan. USA

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

39. Sutopo, Bronto. INDONESIA

The Martabe Au-Ag high-sulfidation epithermal mineralisation in the Tapanuli Selatan district, North Sumatra Province, Indonesia: Implications for ore genesis and exploration.

40. Sykora, Stephanie. PNG (Masters)

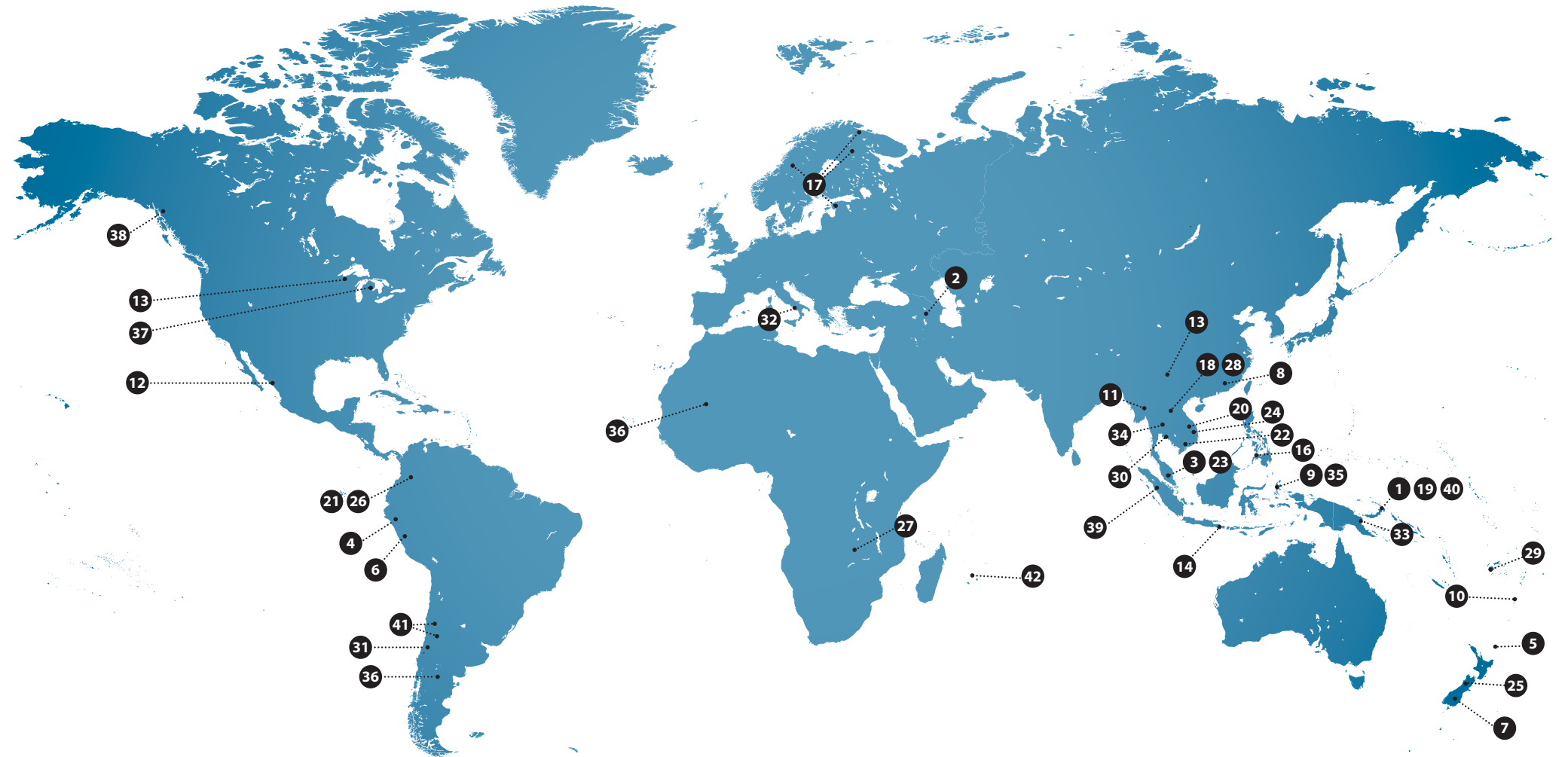
The geological, geochemical and genetic significance of the anhydrite seal, Ladolam gold deposit, Lihir, PNG.

41. Testa, Francisco. ARGENTINA, CHILE

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

42. 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.



PROGRAM ONE LOCATION

OBJECTIVE

To understand the links between tectonic setting, magmatism, basin evolution and ore deposit formation in modern and ancient settings.

INTRODUCTION

The Location Program focuses on igneous petrology and geochemistry, tectonics, and volcanology and their application to ore-forming processes. Researchers work across microscopic to regional scales, and undertake laboratory and field-based studies, to better understand the major controls on the location, timing and size of ore deposits, particularly those in arc-backarc settings and continental rift basins. The program includes fundamental and more strategic projects, several of which are conducted in close collaboration with industry colleagues.

This is the final year that this research will be reported under the Location Program banner. From 2014, these activities will fall under the newly-formed Ore Characterisation Module, which will focus on providing end-users with process-based models for the formation of high value metalliferous ore deposits, and the tools to determine prospective regions for exploration and vectoring.

This new module enables the excellent research performed within Program One to continue and grow, while providing a broader, end-user focused platform for the research team.

HIGHLIGHTS

- The team published 45 refereed papers in 2013.
- A Special Issue on the 'Tectonics and Metallogeny of mainland SE Asia' was published by *Gondwana Research* (online only at that stage). This volume contains 13 papers by Program One team members, and presents outcomes of research conducted in the Ore Deposits of SE Asia project, led by Professor Khin Zaw.
- Vadim Kamenetsky and colleagues published a paper in *Nature Communications* on recently discovered kimberlites in Antarctica. The discovery demonstrates that Cretaceous kimberlite volcanism occurred contemporaneously over a vast area, on all Gondwanan continents.
- Peter McGoldrick presented an invited keynote paper at the Russian Academy of Sciences International Conference on Ore Genesis, held in Miass. Peter summarised the 'Biological and geochemical features of ~1.6 Ga sea floor vents from northern Australia', using results of research on global ocean chemistry, marine basins and mineralisation (Project P1A3).
- Gisela Cobenas and JianXiang Guan submitted their PhD theses.
- Three new volcanology PhD projects were initiated on Heard Island, Piton de la Fournaise (Reunion Island) and Kilauea, Hawaii.



Top: Volcanic vent, Reunion Island.
Bottom: Kathy Ehrig (BHP Billiton) with PhD students Qiuyue Huang and Olga Apukhtina at Olympic Dam.



LEADER JOCELYN McPHIE

TEAM MEMBERS

Sharon Allen, Mike Baker, Ron Berry, Stuart Bull, Rebecca Carey, Tony Crawford, Leonid Danyushevsky, Paul Davidson, Trevor Falloon, Sandrin Feig, Karsten Goemann, David Green, Jacqui Halpin, Maya Kamenetsky, Vadim Kamenetsky, Joe Knight, Chun-kit Lai, Ross Large, Elena Lounejeva, Roland Maas, Takayuki Manaka, Peter McGoldrick, Sebastien Meffre, Abhisit Salam, Khin Zaw

PHD STUDENTS

Olga Apukhtina, Mohd Basril Iswadi Bin Basori, Gisela Cobenas, Pedro Fonseca, Jodi Fox, Dan Gregory, JianXiang Guan, Sam Holt, Qiuyue Huang, Sean Johnson, Teera Kamvong, Alexey Lygin, Charles Makoundi, Daniele Redi, Lina Serrano, Jeff Steadman, Irma Vejelyte, Daniele Vergani

MASTERS STUDENTS

Glen Diemar, Xuan Truong Le, Yungu Lim, Saranya Nuanla-Ong

HONOURS STUDENTS

Natnaree Chandraprasert, Tobias Erskine, Supitchaya Paipana

COLLABORATORS

- AUSTRALIAN NATIONAL UNIVERSITY Steve Eggins, Jorg Hermann, Marc Norman, Hugh O'Neill
- BHP BILLITON, OLYMPIC DAM Kathy Ehrig
- BRITISH GEOLOGICAL SURVEY Mike Crow
- BROWN UNIVERSITY, USA Alberto Saal
- CHIANG MAI UNIVERSITY, THAILAND Phisit Limtrakun, Sampan Singharajwarapan, Weerapan Srichan
- COLORADO STATE UNIVERSITY, USA Holly Stein
- CONSULTANT, THAILAND Clive Burrett
- DEPARTMENT OF MINERAL RESOURCES, THAILAND Pol Chaodumrong, Somboon Khositantont
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- GNS, NEW ZEALAND Chris Adams, Mike Rosenberg
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- INSTITUTE OF TECHNOLOGY, INDONESIA Andri Subandrio
- JAMSTEC, JAPAN Kenichiro Tani
- KAGOSHIMA UNIVERSITY, JAPAN Kazuhiko Kano
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- ROYAL HOLLOWAY, UNIVERSITY OF LONDON, UK Ian Watkinson
- RUSSIAN ACADEMY OF SCIENCES Valeriy Maslennikov
- SMITHSONIAN INSTITUTION, USA Richard Fiske
- TERRAMIN AUSTRALIA Ken Cross
- UNIVERSITI KEBANGSAAN, MALAYSIA Wan Fuad Wan Hassan, Mohd Rozi Umor
- UNIVERSITY COLLEGE OF SCIENCE, SCHOOL OF GEOLOGY, IRAN Mirsaleh Mirmohammadi
- UNIVERSITY OF ADELAIDE Cristiana Ciobanu, Nigel Cook

- UNIVERSITY OF BREMEN, GERMANY Wolfgang Bach, Janis Thal
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- UNIVERSITY OF MISSOURI, USA Ray Coveney
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- UNIVERSITY OF OTAGO, NEW ZEALAND James White
- UNIVERSITY OF PADJADJARAN, INDONESIA Mega Rosana
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- UNIVERSITY OF SYDNEY Geoff Clarke, Simon Williams
- UNIVERSITY OF TASMANIA Donna Satterthwait
- UNIVERSITY OF WESTERN AUSTRALIA Mark Barley
- UNIVERSITY OF WESTERN SYDNEY Lin Sutherland
- VS SOBOLEV INSTITUTE OF GEOLOGY AND MINERALOGY, RUSSIA Sergei Smirnov, Victor Thomas
- YALE UNIVERSITY, USA Noah Planavsky
- YUKON GEOLOGICAL SURVEY, CANADA Patrick Sack

CORE PROJECTS

- THEME 1A
GEODYNAMIC CONTROLS ON THE FERTILITY OF FOLDBELTS, CRATONS AND SEDIMENTARY BASINS
- P1A3 Global ocean chemistry, marine basins and mineralisation
- P1A4A Ore deposits of SE Asia
- P1A7 Geochronology of the Rocky Cape Group
- P1A8 Trace element and oxygen trends in the ocean through time*
- THEME 1B
MAGMAS, VOLATILES AND METALS
- P1B1 Felsic magmas in volcanic arcs and intraplate volcanic provinces – eruption style, degassing processes, fluid evolution and links to mineralisation
- P1B3B Melt-melt immiscibility and the origin of magnetite-apatite deposits
- P1B4 The distribution of volatile and metallic elements in oceanic glasses and melt inclusions: Implications for fractional crystallisation and degassing during seafloor basaltic magmatism*
- P1B5 Phase and chemical composition of high-temperature hydrothermal systems undergoing interaction between silicate rocks/magmas and aqueous fluid*
- *New initiative

PROJECT SUMMARIES

- THEME 1A
GEODYNAMIC CONTROLS ON THE FERTILITY OF FOLDBELTS, CRATONS AND SEDIMENTARY BASINS
- P1A3 GLOBAL OCEAN CHEMISTRY, MARINE BASINS AND MINERALISATION
- LEADER Peter McGoldrick
- COLLABORATORS Tim Lyons, Noah Planavsky, Donna Satterthwait
- The three aims of this project 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 Proterozoic sedimentary Zn mineralisation.
- Peter McGoldrick has discovered a number of distinct microorganisms preserved on bedding surfaces of carbonaceous shales from the 1.59 Ga Century Zn deposit, using a scanning electron microscope (SEM). Several of these fossils are large and morphologically complex, and could be eukaryotes (of unknown affinities). Further work will

involve attempting to separate fossils from the rock using conventional acid digestion and maceration techniques.

The Cr isotope study of 1.4 Ga Roper Group samples was in abeyance for most of 2013, partly due to Noah Planavsky's move from California to Connecticut. Recently, LA-ICP-MS mapping on several Roper samples was carried out by Peter McGoldrick in order to characterise the Cr (and other trace element) distribution in these samples.

P1A4A ORE DEPOSITS OF SE ASIA

LEADER Khin Zaw

TEAM MEMBERS Tony Crawford, Joe Knight, Chun-kit Lai, Ross Large, Takayuki Manaka, Sebastien Meffre, Abhisit Salam

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This project commenced in October, 2011, building on the successful 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. The scope

of the research has been extended to encompass the whole of mainland SE Asia and Sumatra.

The aims are to:

- Undertake a regional tectonic and metallogenic analysis of the mineralised fold belts in mainland SE Asia.
- Undertake deposit-scale studies to characterise many of the important ore deposits.
- Provide sponsor companies with an increased understanding of ore deposit location, formation and evolution.
- Provide a new understanding of the geological and tectonic events that formed ores deposits.
- Provide a new, well-constrained, dated, and documented geological framework to enable better exploration targeting.

Substantial field work was completed during the year in southern and central Myanmar, at the Me Xi gold deposit in Vietnam, and in eastern Thailand and central Malaysia. Of the 415 samples collected throughout the region, 181 samples have been dated and geochemically characterised.

Three quarterly reports were submitted in 2013, which included the following highlights:

- Detrital U-Pb zircon evidence suggests that South China (including NE Vietnam) was attached to the Tethyan Himalaya section of Gondwana, consistent with palaeontological and palaeoclimatic evidence from South China, NW Vietnam and central Laos. It also suggests that Sibumasu was attached to NW Australia, as indicated by the Palaeoproterozoic zircons in clasts from the glaciomarine Kaeng Krachan Group of Phuket Island.

- The Ha Lang-Song Hien Boundary Zone and Tam Ky-Phuoc Son Suture Zone are two of the most important Palaeozoic sutures in eastern Indochina, hosting important orogenic gold deposits.
- The Indochina Terrane includes at least five Cu-Au metallogenic belts/zones and a variety of Cu- and Au-bearing deposits are present, indicating the high prospectivity of the region.
- Within Mogok Metamorphic Belt (MMB) in Myanmar, three distinct magmatic-metamorphic and mineralisation events were recorded: Jurassic (200–170 Ma), Early Cretaceous (140–105 Ma) and Late Cretaceous to Miocene (75–15 Ma).
- Granitoids in southeastern Myanmar can be classified into I-type magnetite-series, I-type ilmenite-series, fractionated I-type ilmenite-series and S-type granites. U-Pb zircon ages of the granites become gradually younger (85 to 48 Ma) from east (back-arc side) to west (island-arc side).

P1A7 GEOCHRONOLOGY OF THE ROCKY CAPE GROUP

LEADERS Peter McGoldrick, Jacqui Halpin

COLLABORATORS Clive Calver, John Everard

The project has the single aim of better constraining the depositional age of major units within the Proterozoic Rocky Cape Group, Tasmania. In a paper (Halpin et al.) submitted to *Precambrian Research*, it is shown that the Rocky Cape Group has a shared provenance with the higher-grade metasedimentary units of nearby King Island; the newly derived depositional ages also overlap and support the correlation of these rock associations. On the basis of current datasets, there are no obvious correlations that can be made with Mesoproterozoic basins preserved in mainland Australia. Instead, an overlap in the timing of deposition and detrital zircon signatures suggests the Tasmanian Mesoproterozoic succession best correlates with the c. 1.45–1.37 Ga upper Belt-Purcell Supergroup (Missoula and Lemhi groups) of western North America.

This project is now complete.

P1A8 TRACE ELEMENT AND OXYGEN TRENDS IN THE OCEAN THROUGH TIME

LEADER Ross Large

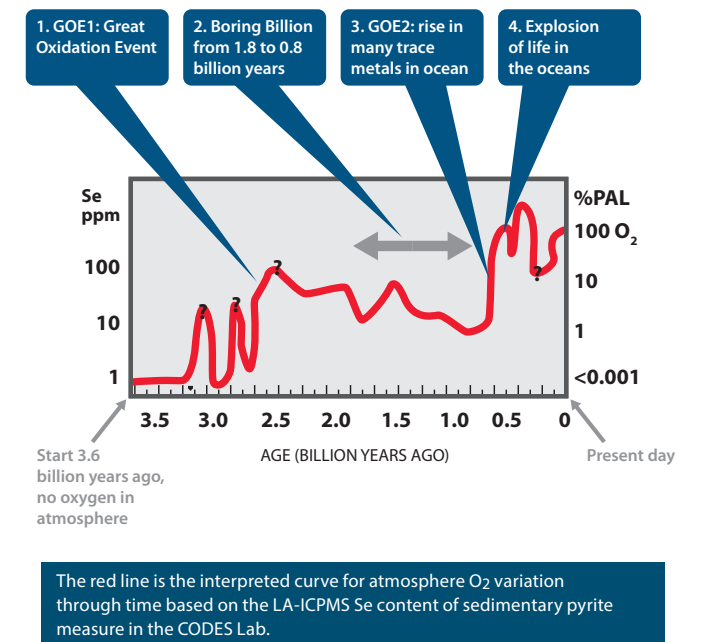
TEAM MEMBERS Stuart Bull, Leonid Danyushevsky, Jacqui Halpin, Elena Lounejeva, Peter McGoldrick

STUDENTS Dan Gregory, Sean Johnson, Charles Makoundi, Jeff Steadman

COLLABORATORS Clive Calver, Ray Coveney, David Huston, John Long, Tim Lyons, Valeriy Maslennikov, Patrick Sack, Peter Sorjonen-Ward

This project is using the technology developed by CODES to analyse trace elements in hydrothermal pyrite in ore systems to investigate sedimentary pyrite in seafloor organic-bearing sedimentary rocks. Sedimentary pyrite is the focus as it adsorbs a vast array of trace elements from seawater, and thus can be used as a proxy for ocean chemistry. The aim is to build a history of 25 trace element concentration curves for the global ocean and to use these curves to interpret how atmospheric O₂ has varied through time.

OXYGEN CURVE OVER 3.5 BILLION YEARS



To date, over 2,000 sedimentary pyrites from 131 black shale samples have been analysed, covering 77 time intervals from 3,515 million years ago to the present day. Preliminary results have been accepted for publication in *Earth and Planetary Science Letters*.

In general, the trace element patterns show significant variation of several orders of magnitude in the Archean 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 time, other elements (e.g. Mo, Zn, Mn) have generally increased, and a further group initially increased and then decreased (Se, U, V). These changes appear to be controlled by many factors, particularly the oxygenation cycles of the Earth's atmosphere/oceans, the composition of exposed crustal rocks, and cycles of ocean anoxia. The findings show 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. Positive jumps in Mo and Se concentrations prior to the Great Oxidation Event (GOE1, c. 2.5 Ga) suggest pulses of oxygenation as early as 2,950 Ma, whereas similar rises in the same elements at 660 Ma place the rise of Neoproterozoic oxygenation (GOE2) earlier than previously considered. A flat to declining pattern of several redox sensitive trace elements (Se, Mo, U, Cu, Ni) in pyrite through most of the Proterozoic suggests the possibility that a gradual drop in atmosphere oxygenation, reaching a minimum in the Cryogenian, prior to GOE2.

The team propose that the Se content of sedimentary pyrite is a robust proxy for oxygenation of the atmosphere. Se content of pyrite is preferred to other redox sensitive proxies (e.g. Mo, Zn, U, V) because it is concentrated in pyrite several times compared to the black shale matrix, it is evenly distributed through the structure of sedimentary pyrite, and it is tightly held by substitution for S, and thus the concentration is not easily changed by diagenesis or metamorphism.



Ore Deposits of SE Asia team members visiting the National Prosperity Gold Production Group in Myanmar.

THEME 1B MAGMAS, VOLATILES AND METALS

P1B1 FELSIC MAGMAS IN VOLCANIC ARCS AND INTRAPLATE VOLCANIC PROVINCES – ERUPTION STYLE, DEGASSING PROCESSES, FLUID EVOLUTION AND LINKS TO MINERALISATION

LEADERS Jocelyn McPhie, Vadim Kamenetsky

TEAM MEMBERS Sharon Allen, Rebecca Carey, Karsten Goemann, Maya Kamenetsky, Roland Maas, Sebastien Meffre

STUDENTS Olga Apukhtina, Glen Diemar, Pedro Fonseca, Jodi Fox, Sam Holt, Qiuyue Huang, Daniele Redi, Lina Serrano, Irma Vejelyte, Daniele Vergani

COLLABORATORS Andrea Agangi, Wolfgang Bach, Ray Cas, Kathy Cashman, Hamish Cattell, Jim Cole, Ken Cross, Kim Denwer, Kathy Ehrig, Richard Fiske, Yoshi Goto, Bruce Houghton, Emily Johnson, Martin Jutzeler, Kazuhiko Kano, Andrea Di Muro, Michael Poland, Jorge Relvas, Carlos Rosa, Mike Rosenberg, Yoshi Tamura, Kenichiro Tani, Janis Thal, Olga Vasyukova, Paul Wallace, James White

This project concentrates on volatiles and metals in felsic magmas, using a combination of melt inclusion research and physical volcanology. One of the aims is to explore how degassing of felsic magmas affects eruption styles and products, and the influences of magmatic volatiles on related hydrothermal systems.

In a *Journal of Petrology* paper (Johnson et al. 2013), a detailed assessment was presented of the crystallisation and degassing histories of rhyolites in the Taupo Volcanic Zone (TVZ), New Zealand, and the behaviour of metals during differentiation. None of the analysed metals appear to partition into the vapour during ascent and degassing, as indicated by the overlap in metal concentrations in the most evolved melt inclusions and pumice glasses. These results imply that, given the remaining metal and chlorine concentrations in the rhyolites upon eruption, the voluminous rhyolites emplaced in the upper crust of the TVZ could be a viable source of some metals, chlorine, and other species to the hydrothermal systems via leaching of the rocks by heated, meteoric waters.

Papers in the *American Mineralogist* (Vasyukova et al. 2013) and *Contributions to Mineralogy and Petrology* (Vasyukova et al. 2013) reveal significant diversity in cathodoluminescence (CL) patterns in quartz from six porphyry deposits. In these papers, it is proposed that quartz in porphyry stocks primarily crystallises in-situ after magma emplacement and, thereafter, prolonged crystallisation, involving at least two more stages of crystallisation under continuous cooling, produces additional CL textures. This interpretation is consistent with all CL features observed, and is also in agreement with the existing model for the formation of porphyry-style deposits.

Internationally renowned volcanologist, Professor Stephen Self, visited CODES and IMAS in January, funded by a UTAS Visiting Fellow Grant. During the visit, two manuscripts were advanced to publication stage, a workshop on the dynamics of explosive eruptions was convened, and two public lectures were presented on flood basalts and explosive super-eruptions – both to full houses. Dr Andrea Agangi, University of Johannesburg, also

visited CODES, funded by a UTAS Visiting Scholar Grant. CODES is collaborating with Dr Agangi in research on the Proterozoic Rooiberg Felsite in South Africa, a voluminous felsic unit comparable to the Gawler Range Volcanics in South Australia.

Over the past decade, a unique set of submarine silicic pumice samples has been collected from the modern seafloor and young, formerly submarine, successions. This has been accomplished with the support and collaboration of Yoshi Tamura (IFREE), Kenichi Tani (JAMSTEC), Kazuhiko Kano (Kagoshima University), and other international scientists. Sharon Allen and Rebecca Carey have analysed microtextural and compositional data that reveal the details of submarine eruption dynamics, and have been able to demonstrate that pumice vesicularity can be used as a proxy for eruption intensity. Their results were presented at the IAVCEI Scientific Assembly in Kagoshima and are the subject of two manuscripts in preparation.

Former PhD student, Martin Jutzeler, has had a paper accepted by the *Geological Society of America Bulletin* on the Ohanapecoh Formation, Washington, USA, demonstrating how the facies characteristics relate to submarine explosive eruptions. Martin has another manuscript on a similar topic in review with the *Bulletin of Volcanology*.

Three new PhD projects commenced in 2013. Jodi Fox began research on the volcanic evolution of Heard Island, and will participate in a research cruise in 2014. Sam Holt is studying the dynamics of high fountain events in recent eruptions of Kilauea, Hawaii, and Daniele Vergani is investigating the 2007 eruption of Piton de la Fournaise, Reunion Island, focussing on a comprehensive eruption chronicle using multiple datasets.

OLYMPIC DAM PROJECT

Research on the supergiant Olympic Dam Cu-Au-U-Ag deposit is conducted in collaboration with Kathy Ehrig, BHP Billiton, and Roland Maas, from the University of Melbourne Node. A comprehensive review of the geology, mineralogy, composition and textures of the deposit (Ehrig et al. 2013) was published in a *Special Publication of the Society of Economic Geologists*. PhD students, Qiuyue Huang and Olga Apukhtina, have collected substantial new data. Qiuyue has been studying the compositions, ages, relationships and affinities of mafic dykes, and Olga has been analysing a complicated assemblage of carbonate minerals. New PhD student, Irma Vejelyte, joined the project and began research on the Wirrda Well prospect, southeast of Olympic Dam.

P1B3B 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

The Fanshan study is continuing, and additional samples have been obtained. Extensive melt inclusion studies on these and previous samples have provided considerable evidence of melt/melt immiscibility with silicate, carbonate, sulfide, and Fe-Ti oxide components observed in various combinations in a range of melt inclusions. Three co-authored papers were published this year, in *Geology*, *Ore Geology Reviews*, and the *Journal of Geosciences*.



Opposite: Lava lake within Kilauea caldera, Hawaii.

P1B4 THE DISTRIBUTION OF VOLATILE AND METALLIC ELEMENTS IN OCEANIC GLASSES AND MELT INCLUSIONS: IMPLICATIONS FOR FRACTIONAL CRYSTALLISATION AND DEGASSING DURING SEAFLOOR BASALTIC MAGMATISM

LEADER Vadim Kamenetsky

COLLABORATORS Ilya Bindeman, Enrico Bonatti, Steve Eggins, Emily Johnson, Mark Kendrick, Dmitry Kuzmin, Marc Norman, Alberto Saal, Weidong Sun, Paul Wallace, Jon Woodhead

Magnesian basaltic glasses from the Miocene Macquarie Island ophiolite (SW Pacific) are being used to understand the effects of progressive partial melting of mantle peridotite, and subsequent magma crystallisation and degassing on the composition of mid-ocean ridge basalts. These glasses show exceptional compositional diversity in major, trace lithophile, volatile and metallic elements, and metalloids. The estimated relative degree of incompatibility during mantle melting provides constraints on the siderophile, chalcophile and volatile element abundances in the model 'primitive' and 'depleted' mantle sources. The studied glasses can be further used to explore mantle source compositions, including mineral phases involved in magma generation, and processes controlling fractionation of chemical elements in both the mantle source and mantle-derived melts.

Measurement of Br/Cl, I/Cl and K/Cl, together with correlations between Cl and other trace elements, demonstrate that the halogens in the Macquarie Island glasses had a mantle source and were not influenced by seawater contamination. Cl, Br and K were not statistically fractionated during partial melting, crystallisation or degassing of CO₂ from these melts. The measured δD and $\delta^{18}O$ of the Macquarie Island glasses are identical to those in average global MORB. The observed

lack of variation is consistent with a bulk melting model in which water is rapidly scavenged into the first partial melt. The narrow ranges of δD and $\delta^{18}O$ in normal mantle are mostly due to the buffering effect of clino- and orthopyroxenes in the residual assemblage.

These results have been published in three papers in *Chemical Geology* and *Geochimica et Cosmochimica Acta*.

P1B5 PHASE AND CHEMICAL COMPOSITION OF HIGH-TEMPERATURE HYDROTHERMAL SYSTEMS UNDERGOING INTERACTION BETWEEN SILICATE ROCKS/MAGMAS AND AQUEOUS FLUID

LEADER Vadim Kamenetsky

COLLABORATORS Irina Andreeva, Vladimir Naumov, Vsevolod Prokofiev, Sergei Smirnov, Nadia Suschevskaya, Victor Thomas, Olga Vasyukova,

Consideration of hydrosilicate liquids (HSL) in nature can elucidate the accumulation and transport of some mineral and ore-forming components at the transition from magmas to hydrothermal fluids. Experiments using Na₂O–SiO₂–H₂O, with the addition of NaF, NaCl and metallic Ta, showed that the formation of HSL occurred when initial Na₂O exceeded 2 wt.%. Neither NaF nor NaCl have a significant effect on the formation of HSL. The HSL concentrates F, whereas Cl partitions into the aqueous fluid. With addition of Ta, the HSL becomes metal-enriched. Natural analogs of experimental HSL can be found among 'melt/fluid' inclusions entrapped in quartz and other minerals of miaroles in granite pegmatites and rare-metal granites. The HSL is a novel medium enabling extreme concentrations of lithophile ore metals at the magmatic-hydrothermal transition.

Results were published in two papers in *Petrology* and provide insights into the mineral- and ore-forming potential of HSL.



PhD student Sam Holt in his field area of Hawaii mapping volcanic facies.

OUTLOOK

As reported in the Introduction, from 2014, these research activities fall under the broader umbrella of the newly-formed Ore Deposit Characterisation Module. This is expected to be a seamless transition, with all planned activities and projects continuing, as scheduled.

Key activities for the coming year will be the completion of the highly successful Ore Deposits of SE Asia project, and the subsequent negotiations with industry sponsors for a new project covering the tectonic setting and origin of Cu-Au mineralisation in the western Myanmar-Sumatra Terrane.

It is also expected to be a busy year in terms of publications, with a host of papers to be completed and/or submitted as part of the new Module, including:

- The Century organisms and Sherwin Formation Cr isotope manuscripts.
- Four manuscripts related to the felsic magmas project.
- Two manuscripts on magnetite-apatite deposits and pegmatite research.
- Four manuscripts related to research on melt immiscibility, kimberlite parental magmas, carbonatites and large igneous provinces.

Finally, microprobe studies will be conducted on the new Fanshan samples. This is a continuation of the magnetite-apatite deposits and pegmatite research, covered by two of the manuscripts mentioned above.

Etna Volcano erupting.



PROGRAM TWO FORMATION

OBJECTIVE

To develop practical, process-based models for the formation of hydrothermal and magmatic ore deposits that will help increase discovery rates for Australia's deep earth resources.

INTRODUCTION

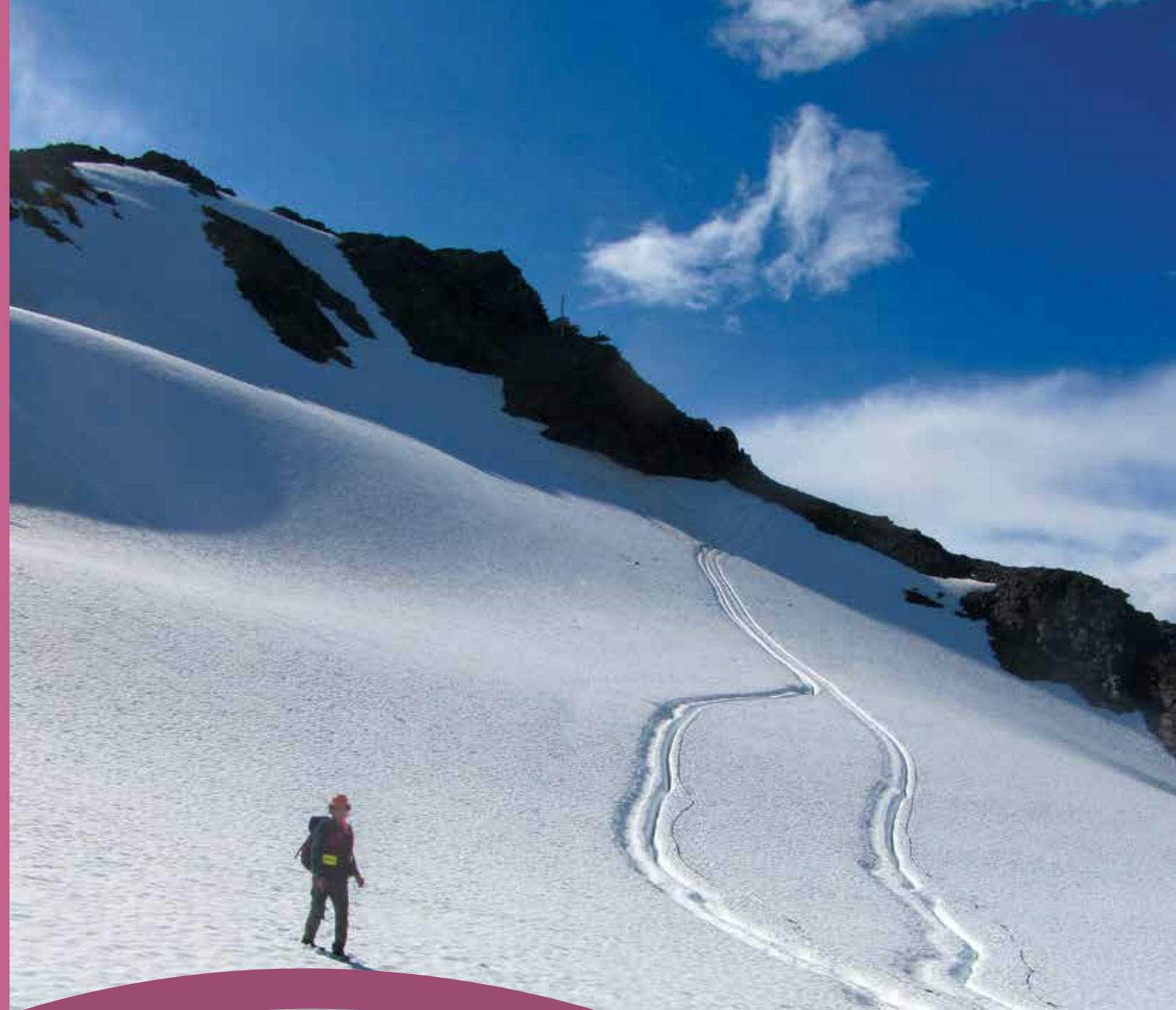
Ore deposits form when chemical and physical processes cause dramatic changes in metal solubilities in hydrothermal fluids or magmas. These processes vary between deposit classes, and also between individual deposits. Evaluating the relative and absolute effectiveness of different ore-forming processes is essential for the development of new, process-based exploration models.

The Formation Program has two major research themes. Ore-Forming Processes investigates fundamental problems in ore genesis, taking advantage of CODES' unparalleled access to world-class ore deposits, well-constrained sample suites and data sets, and cutting-edge technologies. These technologies are accessed via Program 5, the nodes, and international collaborators. This theme aims to generate high profile publications, targeting high impact journals such as *Science*, *Nature*, *GCA*, *EPSL* and *Geology*.

The second research theme is Ore Deposit Characterisation. In order to understand how ore deposits form, it is essential that alteration and mineralisation features are carefully documented, both in the field and in the laboratory. This applied research activity generates essential data for understanding deposit formation and refining mineral exploration models, which makes this theme strongly linked to Program 3. One of the aims is to publish key papers and special issues describing and interpreting world-class ore deposits in *Economic Geology* and *Mineralium Deposita*.

HIGHLIGHTS

- Successful implementation of a fully coupled hydro-mechanical modelling approach that is being used to explore permeability enhancement and fluid pathways in intrusion-related hydrothermal systems.
- Huge variations in boron isotopes identified in tourmalines from western Tasmanian Sn granites, implying major physicochemical changes during phase separation.
- Publication of a synthesis of CODES-Newcrest collaborative research outcomes from Australia, PNG and Fiji in *SEG Special Publication 17*.
- Paper on 'High-precision U-Pb zircon chronostratigraphy of the Mount Read Volcanic Belt in western Tasmania, Australia: implications for VHMS formation' has been accepted for publication in *Economic Geology*.
- Collaboration between CODES and Hefei University leads to new five-year collaborative research project funded by the Chinese Government.
- New PhD studies initiated at Merlin Mo-Re deposit, Cloncurry, and La Productura IOCG deposit, Chile.



Top: Nathan Steeves during a day of mapping in Alaska.
Bottom: Helicopter during field trip to Alaska.



LEADER DAVID COOKE

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MOROBE MINING JOINT VENTURE Doug Menzies, Betty Tekeve

NEWCREST MINING Benjamin Ackerman, Will Clarke, Dean Collett, Mike Erceg, Dave Finn, Nick Fitzpatrick, Warwick Fortune, Stephanie Grabovickic, Anthony Harris, John Holliday, Fiona Karaut, Colin McMillan, Gustav Nortje, Jon Rutter, Daud Silitonga, Geoff Smart, Dadan Wardiman

NORTHERN TERRITORY GEOLOGICAL SURVEY Masood Ahmad

NORTH PARKES MINES Pamela Naidoo

OZ MINERALS Hamish Freeman

QUEEN'S UNIVERSITY, CANADA Dan Layton-Matthews

RIO TINTO EXPLORATION Mawson Croaker

TECK Kevin Byrne, Amber Henry

UNIVERSITY OF ALBERTA, CANADA Robert Creaser

UNIVERSITY OF BRITISH COLUMBIA, CANADA Greg Dipple

UNIVERSITY OF BRITISH COLUMBIA (MDRU), CANADA Thomas Bissig, Jim Mortensen, Dick Tosdal

UNIVERSITY OF MANITOBA, CANADA Mostafa Fayek

UNIVERSITY OF OTTAWA, CANADA Mark Hannington

ZIJIN MINING GROUP, CHINA Jingping Qi, Kaihui Yang

CORE PROJECTS

THEME 2A ORE-FORMING PROCESSES

P2A2A Fracture arrays in intrusion-related ore systems – controls on the dynamics of fluid flow, vein formation and the generation of giant deposits

P2A3 Efficiency of ore-forming processes

THEME 2B ORE DEPOSIT CHARACTERISATION

P2B1A Exploring the porphyry environment

P2B1B Porphyry and skarn mineralisation in China

P2B1D Shallow and deep-level alkalic mineral deposits

P2B3B Genesis of volcanic-hosted copper-lead-zinc-silver-gold massive sulfide deposits

P2B3C Hydrothermal event recognition and target vectoring in volcano-sedimentary strata

P2B3D Active base- and precious-metal-rich massive sulfide depositions

P2B4 Iron oxide copper-gold and related deposit types

PROJECT SUMMARIES

THEME 2A ORE-FORMING PROCESSES

P2A2A FRACTURE ARRAYS IN INTRUSION-RELATED ORE SYSTEMS – CONTROLS ON THE DYNAMICS OF FLUID FLOW, VEIN FORMATION AND THE GENERATION OF GIANT DEPOSITS

LEADER Stephen Cox

STUDENT Andrew Clarke

COLLABORATORS David Beck, Arnd Flatten, Pamela Naidoo

Fully coupled hydro-mechanical modelling techniques are being used to explore generation of fluid pathways associated with fracture growth in intrusion-related hydrothermal systems. The 3D simulations explore controls on fluid migration from source cupolas into initially low permeability host rocks. Failure and associated permeability enhancement is driven largely by progressive fluid pressurisation; the orientation of the stress field plays a key role in controlling the geometry and distribution of high permeability pathways. The most intense fracture damage is localised around the upper parts of cupolas, as seen in many porphyry Cu-Au systems. However, away from the cupola, segments of pre-existing fault networks are re-activated and localise flow. The simulations illustrate progressive migration of a permeability enhancement front away from the fluid source via re-activated faults, as well as along segments of lithological contacts. The modelling is providing new insights about the dynamics of coupling between fluid pressurisation, deformation and permeability enhancement in intrusion-related ore systems. Ongoing analysis is exploring how fluid

production rates, stress states, the intrinsic permeability of host rocks, and depth of cupolas influences the 3D evolution of fluid pathways and potential distribution of ore. The modelling is complemented by ongoing field-based structural analysis of fluid pathways in intrusion-related, and other hydrothermal systems, as well as by high pressure - high temperature experiments exploring the dynamics of permeability creation and destruction in stressed rock in the presence of high temperature, reactive pore fluids.

P2A3 EFFICIENCY OF ORE-FORMING PROCESSES

LEADER David Cooke

TEAM MEMBERS Nathan Fox, Lejun Zhang

STUDENT Wei Hong

COLLABORATOR Mostafa Fayek

The PhD study of magmatic-hydrothermal evolution from Tasmanian Sn granites by Wei Hong has led to a new research collaboration on boron isotopes with Mostafa Fayek from the Department of Geological Sciences at the University of Manitoba. Wei Hong spent one week in Manitoba conducting boron isotope analyses on tourmaline from western Tasmanian Sn granites, and found huge isotopic variations (up to 20 ‰) in individual crystals. Initial results of the B isotope study were presented at the Tasmanian Geoscience Forum in December. A field campaign to eastern Tasmanian Sn granites was conducted in July. Two new Honours studies on Tasmania Sn granites were negotiated in late 2013, and will commence in early 2014.

THEME 2B ORE DEPOSIT CHARACTERISATION

P2B1A EXPLORING THE PORPHYRY ENVIRONMENT

LEADERS David Cooke, David Selley, Nic Jansen

STUDENTS Erin Lawlis, Evan Orovan, Marc Rinne, Jacqueline Rush, Vikraman Selvaraja, Stephanie Sykora

COLLABORATORS Benjamin Ackerman, Will Clarke, Dean Collett, Robert Creaser, Mike Erceg, Dave Finn, Nick Fitzpatrick, Warwick Fortune, Stephanie Grabovickic, Anthony Harris, John Holliday, Fiona Karaut, Colin McMillan, Doug Menzies, Gustav Nortje, Ron Reid, John Rutter, Daud Silitonga, Geoff Smart, Betty Tekeve, 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 Australia and the South West Pacific region.

This collaboration is advancing the conceptual models and exploration techniques at the relevant deposits and districts, with the new knowledge being passed directly to Newcrest geologists through on-site training. The collaboration is enabling Newcrest to be at the forefront of ore deposit research and to capitalise on developing better vectoring towards epithermal and porphyry centres. The close working relationship is facilitated by Newcrest's strong leadership in research, both logistically and financially.

Nic Jansen is testing and refining the lithocap exploration developed at CODES (through the AMIRA P765, P765A, and

P1060 projects), by seeking to gain a better understanding of the alunite geochemistry at the Wafi lithocap and Lihir steam-heated clay blanket. David Selley joined the team mid-year, adding invaluable structural expertise. David and Nic have initiated a detailed study of the structure and alteration of the Gosowong district, Indonesia.

Current student research activities include PhD studies aiming to gain a better understanding of the geology of the Kapit NE ore body at the Lihir gold deposit (Erin Lawlis), Wafi-Golpu porphyry-epithermal deposits (Marc Rinne), and the Namosi porphyry deposits in Fiji (Evan Orovan). Stephanie Sykora is undertaking a Master's thesis on understanding the anhydrite seal at the Lihir gold deposit. In addition, two Honours studies were completed during the year by Jacqueline Rush on the Marsden porphyry deposit (NSW), and Vikraman Selvaraja on the advanced argillic alteration domain overlying the Gosowong deposit.

P2B1B PORPHYRY AND SKARN MINERALISATION IN CHINA

LEADERS Taofa Zhou, David Cooke

TEAM MEMBER Lejun Zhang

STUDENTS Jing Chen, Zhanke Li, Shiwei Wang

COLLABORATORS Huayong Chen, Yu Fan, Chengbiao Leng, Jingping Qi, Noel White, Kaihui Yang, Feng Yuan

A PhD study by Jing Chen on the Zijin high sulfidation copper-gold deposit was initiated in August, supported by Zijin Mining Group and the China Scholarship Council. Visiting PhD student Shiwei Wang spent most of the year at CODES. Shiwei was researching the Shaxi, Shujiadan and Dongguashan porphyry copper-gold deposits for his PhD study on the metallogeneses of the middle and lower Yangtze metallogenic belt.

Visiting Professor Chengbiao Leng conducted research on the Zhongdian porphyry system and Kukeazi sediment-hosted massive sulfide deposit. Visiting PhD student Zhanke Li completed his PhD study of the metallogeneses of the porphyry-related silver-lead-zinc deposits along the southern margin of the North China Craton.

The collaboration with the Hefei University of Technology has led to a new five-year collaborative research initiative, entitled: The ore-forming systems of intra-continental porphyry-skarn copper-gold and magnetite-apatite iron deposits in the Middle-Lower Yangtze River Valley metallogenic belt in eastern China. The research will commence in 2014 and is being funded by the Chinese Government.

P2B1D SHALLOW AND DEEP-LEVEL ALKALIC MINERAL DEPOSITS

LEADERS David Cooke, Thomas Bissig

COLLABORATORS Adam Bath, Jacqueline Blackwell, Kevin Byrne, Greg Dipple, Amber Henry, Patrick McAndless, Paul McInnes, Heidi Pass, Chris Rees, Jon Rutter, Dick Tosdal, Wojciech Zukowski

The alkalic project aimed to document the characteristics and determine the genesis of alkalic porphyry deposits of British Columbia and alkalic epithermal deposits of PNG and Australia. The project involved collaboration with UBC and was supported by nine industry sponsors. Additional financial

support derived from grants from the Natural Sciences and Engineering Research Council of Canada (NSERC) and Geoscience BC. Research results from the Lihir PhD study by Jacqueline Blackwell were published in Harris et al. (2013). The alkalic special issue of *Economic Geology* will be published in issue 4, 2014, which will conclude this project.

P2B3B GENESIS OF VOLCANIC-HOSTED COPPER-LEAD-ZINC-SILVER-GOLD MASSIVE SULFIDE DEPOSITS

LEADER Bruce Gemmell

TEAM MEMBERS Ross Large, Khin Zaw

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

COLLABORATORS Andrew McNeill, Jim Mortensen

The genesis of volcanic-hosted copper-lead-zinc-silver-gold massive sulfide deposits is being investigated across the spectrum of massive sulfide deposit types, from typical seafloor VHMS (zinc-lead-copper-silver-gold) deposits, through sub-seafloor shallow-water, replacement gold-rich epithermal styles, to deep sub-volcanic intrusion-related copper-gold-rich styles. In 2013, 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 is completing her PhD study on the VHMS Deposits in the Que-Hellyer Volcanics, western Tasmania. Selina is 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 began 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 submitted 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. Barite layers are present locally and overlying the massive sulfide lenses. At Bukit Ketaya, massive sulfide forms as stratiform sheets, overlain by a layer of Mn-Fe-rich exhalites and barite. The research was funded by Malaysian Government Scholarships and the Ore Deposits of SE Asia project.

Two student projects continued at Sandfire Resources' new VHMS discovery 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, mineral chemistry and sulfur isotopes of the prospects.

The first phase of a project aimed at improving the age, and geochronological, constraints on the development of the Mount Read Volcanic Belt (MRV) was completed, in collaboration with Jim Mortensen (UBC). Work included U-Pb dating of zircons, which produced many new dates that have helped to constrain the timing of the development of



Opposite: Bruce Gemmell, Nathan Steeves and Darwin Green (Constantine Metal Resources) during field trip to Alaska.



Bornite-chalcopyrite ore from Myra Falls, Canada.

the MRV and associated VHMS mineralisation. A manuscript was accepted for publication, and will appear in *Economic Geology* in 2014. A second phase of age dating throughout the MRV is underway.

P2B3C HYDROTHERMAL EVENT RECOGNITION AND TARGET VECTORING IN VOLCANO-SEDIMENTARY STRATA

LEADER Bruce Gemmell

TEAM MEMBER Ross Large

COLLABORATORS Wayne Goodfellow, Mark Hannington, Dan Layton-Matthews, Thomas Moneke, Jan Peter, Steve Piercy

This CAMIRO (Canadian Mining Industry Research Organization-Exploration Division)-funded project aimed to provide an improved understanding of the concentrations and behaviour of trace metals associated with volcanic-hydrothermal processes in marine sedimentary and volcano-sedimentary successions, and to develop new tools (mineralogical, geochemical, isotopic) to discriminate potentially mineralised versus unmineralised horizons in many mineralised districts. A final sponsors meeting was held in Vancouver in September, which concluded this project. The results of this research are confidential to the CAMIRO sponsors.

P2B3D ACTIVE BASE- AND PRECIOUS-METAL-RICH MASSIVE SULFIDE DEPOSITIONS

LEADER Bruce Gemmell

STUDENT Heidi Berkenbosch

COLLABORATORS Andrew McNeill, Cornel de Ronde

Heidi Berkenbosch's PhD project at Brothers volcano, in the Tonga-Kermadec arc, continued in 2013. This collaborative project with GNS, New Zealand (Cornel de Ronde) is investigating the ore and gangue mineralogy, textures, paragenesis, mineral chemistry and copper isotopes of the sulfide-sulfate chimneys.

A paper on the Cu isotopes of the chimneys has been submitted to *Economic Geology*. This is further to a paper detailing the mineralogy, textures and mineral chemistry of the chimneys that was published in the journal in 2012.

P2B4 IRON OXIDE COPPER-GOLD AND RELATED DEPOSIT TYPES

LEADER Garry Davidson

TEAM MEMBERS Mike Baker, Ron Berry, Stuart Bull, David Cooke, Julie Hunt, Sebastien Meffre, Karin Orth, Bence Paul

STUDENTS Greg Clarke, Angela Escolme, Claire McMahon, Subira Sharma

COLLABORATORS Masood Ahmad, Huayong Chen, James Cleverley, Mawson Croaker, Geoff Fraser, Hamish Freeman, Hamish Johns, Jim Morrison, Robert Moye, Geoff Phillips, Warren Potma, Grant Osborne, Roger Skirrow

This project aims to provide a better understanding of IOCG deposits, which remain one of the great ore deposit enigmas of modern times. Key activities in 2013 were as follows:

- Inova Resources (formerly Ivanhoe Australia) is sponsoring a PhD study by Subira Sharma evaluating the role of granitic fluids at the Merlin Mo-Re deposit, Cloncurry.
- Honours student Greg Clarke undertook a project on the Vulcan Cu-Au prospect (~ 30 km NW of Olympic Dam), supported by Rio Tinto Exploration, who are in joint venture with Tasman Minerals at the site. The study focused on the breccia complex architecture, and involved dating and detailed paragenetic analysis.
- A PhD study by Angela Escolme at La Productura IOCG deposit (Chile) was initiated late in the year, sponsored by Hot Chili.
- Also in the latter part of the year, a proposal was being modified for an AMIRA project entitled 'Uranium, copper and precious metals in oxidising sedimentary basin: controls on ore formation and location'. It is expected that this proposal will be distributed to potential sponsors in 2014.

OUTLOOK

This is the final year that these activities will be reported under the Formation Program. From next year, this program will merge with the Location and Discovery Programs to form one of the four new Modules: Ore Deposit Characterisation. Notwithstanding this change, all ongoing projects that were reported this year will continue as normal.

Plans for 2014 include a wide variety of activities within Australia and internationally. Close to home in Tasmania, detailed geochemical investigations will be conducted into the magmatic-hydrothermal transition textures from the Tasmanian Sn granites. While on mainland Australia, a major field campaign will be held at the Merlin Mo-Re deposit in Cloncurry, Queensland.

A little further afield, PhD studies will be completed at Wafi-Golpu (PNG) and Namosi (Fiji), while field studies will continue at Gosowong (Indonesia) and Lihir (PNG). In addition, a new field program is to be initiated at Mt Kasi (Fiji), and a PhD project will commence at Myra Falls, Canada.

In China, the five-year research collaboration with Hefei University of Technology in the middle and lower Yangtze metallogenic belt is scheduled to commence, and the PhD study in the Zijin mining district will continue. While in South America, a major field campaign will be conducted at the La Productura IOCG deposit in Chile.

The year's activities will also include a collaboration with Beck Engineering (Sydney, Berlin) for the completion of modelling to explore the dynamics of fracture-controlled flow relevant to formation of porphyry Cu-Au systems.

A highlight in terms of journal articles will be the publication of the alkalic special issue of *Economic Geology*. Other notable achievements will be the publication of the first paper outlining the new detailed geochronological data for the Mount Read Volcanics, and the publication of a paper on the Cu isotopes of the Brothers volcano black smoker chimneys.

PROGRAM THREE DISCOVERY

OBJECTIVE

To develop techniques for the acquisition and interpretation of ore deposit geophysical and geochemical data that will assist in the discovery of Australia's deep earth resources.

INTRODUCTION

The Discovery Program leverages off CODES' extensive, broad-based research expertise to enhance the development of geophysical, geochemical and geological models for specific world-class ore deposits. The program is structured around two key themes: innovative techniques for discovery, and integrated exploration models for discovery.

CODES has built on its traditional strengths in ore deposit geology and geochemistry by expanding its geophysics capability, which employs a comprehensive suite of geophysical and mathematical techniques in a diverse mix of projects around the world.

HIGHLIGHTS

- In the course of his PhD studies, Jeff Steadman made a highly significant discovery of gold-bearing sedimentary pyrite nodules in the Black Flag Beds, well south of Kalgoorlie, Western Australia. This discovery has major implications for gold ore genesis models in the Yilgarn terrane. A paper on the studies has been published in *Precambrian Research*.
- The VPem3D modelling and inversion program was completed for ground, downhole, or airborne TEM. The program performs 3D inversions of TEM data more than 10 times faster than previously available methods.
- Development of the Rosebery Area (Tasmanian base metal province) 3D geological model.

- A well-attended Leapfrog course was completed as part of the Program's role in maintaining geochemical software in CODES.
- Article published in *Geophysics* on the use of the ambient seismic tool for determination of the depth of cover in mineralised settings.
- An article on the data inference approach to forcing large diverse data sets to yield incisive information received the 'Bright Spot' editor's highlight in *Geophysics*.
- AMIRA P1060 Sponsors Meeting held in Townsville, Queensland.
- Completion of PhD thesis by Victoria Braniff; and Honours theses by Sam Poker and Vikraman Selvaraja.
- PhD theses corrections were submitted and approved for Mathieu Ageneau and Lindsey Clark.
- Successful completion of the AMIRA P1041 project (Application of new technologies to gold deposits), with sponsors deeming that all objectives had been met. The team has published several papers during the year, including an article in *Economic Geology* on the gold deportment and genesis of the Carbon Leader Reef in the Witwatersrand Basin, South Africa.



Bottom: Bruce Gemmell during field work in Utah, USA.
Top: Core samples at Prominent Hill.



LEADER GARRY DAVIDSON

TEAM MEMBERS

Mike Baker, Ron Berry, Daniel Bombardieri, Stuart Bull, David Cooke, Leonid Danyushevsky, Nathan Fox, Bruce Gemmell, Sarah Gilbert, David Hutchinson, Nic Jansen, Vadim Kamenetsky, Ross Large, Elena Lounejeva, Sebastien Meffre, Anya Reading, Michael Roach, Abhisit Salam, Ralf Schaa, Rob Scott, Jennifer Thompson, Craig Winter, Lejun Zhang

PHD STUDENTS

CODES Mathieu Ageneau, Victoria Braniff, Lindsey Clark, Matt Cracknell, Hugo Galvan, Dan Gregory, Carlos Jimenez, Erin Lawlis, Alexey Lygin, Jose Piquer, Jeff Steadman, Bronto Sutopo, Francisco Testa

IMPERIAL COLLEGE LONDON Adam Pacey

MASTERS STUDENTS

CODES Djohanne Celiz, Myall Hingee

LAKEHEAD UNIVERSITY Ayat Baig, Wes Lueck, Emily Smyk

HONOURS STUDENTS

Sam Poker, Vikraman Selvaraja

COLLABORATORS

ANGLOGOLD ASHANTI Rob Burnett, Mark Doyle, Michael Nugus

AUSTRALIAN NATIONAL UNIVERSITY Nicholas Rawlinson, Malcolm Sambridge

CLUMP MOUNTAIN GEOSCIENCE Pat Williams

CONSULTANT Noel White

CSIRO James Cleverley, June Hill

EPIGENESIS CONSULTING Marcus Tomkinson

FULLAGAR GEOPHYSICS Peter Fullagar

GEOLOGICAL SURVEY OF FINLAND Peter Sorjonen-Ward

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA Peter Haines, Arthur Hickman

GEOSCIENCE AUSTRALIA David Huston

GRANGE RESOURCES Roger Hill

GUANGZHOU INSTITUTE OF GEOCHEMISTRY, CHINA Huayong Chen

HOLCOMBE COUGHLIN OLIVER Nick Oliver

IMPERIAL COLLEGE LONDON, UK Clara Wilkinson, Jamie Wilkinson

LAKEHEAD UNIVERSITY, CANADA Peter Hollings

McARTHUR RIVER MINING Edward Morris

MINERAL RESOURCES TASMANIA Ralph Bottrill, Mark Duffett, Andrew McNeill, Jafar Taheri

MMG Steve Beresford

MONASH UNIVERSITY Michael Asten, Chris Wilson

NEWCREST MINING Anthony Harris

OZ MINERALS Mark Allen, Jorge Benavides, Hamish Freeman, Charles Funk, Nick Smith, Marcel Van Eck

RUSSIAN ACADEMY OF SCIENCES Valeriy Maslennikov, Svetlana Maslennikova

SIRIUS RESOURCES Jeff Foster

TARBIAT MODARES UNIVERSITY, IRAN Ali Sholeh

UNIVERSITY OF ALBERTA, CANADA Robert Creaser

UNIVERSITY OF CALIFORNIA RIVERSIDE, USA Tim Lyons

UNIVERSITY OF JOHANNESBURG, SOUTH AFRICA Bradley Guy

UNIVERSITY OF OTAGO, NEW ZEALAND David Craw

UNIVERSITY OF QUEENSLAND Tony Webster

YUKON GEOLOGICAL SURVEY, CANADA Patrick Sack

CORE PROJECTS

THEME 3A

INNOVATIVE TECHNIQUES FOR DISCOVERY

P3A1C The rapid approximate inversion of TEM data (AMIRA P1022)

P3A2A Ambient seismic energy techniques

P3A3A Data inference techniques applied to diverse geoscientific datasets

P3A4A Western Tasmanian geophysics*

THEME 3B

INTEGRATED EXPLORATION MODELS FOR DISCOVERY

P3B1B Enhanced geochemical targeting in magmatic-hydrothermal systems (AMIRA P1060)

P3B1C Low- and high-sulfidation epithermal mineral deposits

P3B2A Sediment-hosted gold-arsenic-tellurium deposits: genesis & exploration models (includes part of AMIRA P1041)

P3B5C The geology and genesis of the Avebury Ni deposit – implications for exploration

P3B6A Structure and formation of the Savage River magnetite deposit

P3B7A Iron oxide copper-gold and related deposit types

P3B8 Application of carbonate C-O isotopes to gold exploration: Sunrise Dam, Yilgarn Craton*

*New initiative

PROJECT SUMMARIES

THEME 3A

INNOVATIVE TECHNIQUES FOR DISCOVERY

P3A1C (AMIRA P1022) THE RAPID APPROXIMATE INVERSION OF TEM DATA

LEADER Peter Fullagar

TEAM MEMBER Ralf Schaa

STUDENT Myall Hingee

AMIRA P1022 was successfully concluded in August. During the course of the three-year project, capabilities for fast approximate 3D inversion of downhole, ground, or airborne TEM data were developed. The key deliverables were:

- VPem3D – a 3D modelling and inversion program for ground, downhole, or airborne TEM.
- VPview – a graphical user interface to expedite VPem3D modelling and inversion.
- Know-how and interpretational insights were gained from the application of the project software to downhole, ground, and airborne TEM data from sponsors' exploration sites.

The project met, or even exceeded, expectations in most areas. The new algorithm performs 3D inversion of TEM data

more than 10 times faster than other available methods. In one highly impressive demonstration (Figure 1), borehole TEM data from a Rio Tinto site was inverted in just two minutes, while the resulting conductivity model was comparable to using conventional 3D TEM inversion software, which requires a run time of more than a week.

Inversion speed is achieved by transforming dB/dt or B-field decays to 'resistive limits', which in effect reduces multi-channel TEM inversion to a single channel magnetic inversion. Each model cell contributes to the resistive limit response as a magnetic dipole. Conductivity-depth imaging and 3D geological constraints are employed to restore as much as possible of the time-depth information that is lost as a result of the conversion to resistive limits. The models can carry lithological attributes as well as conductivity. Incorporation of lithology expedites integrated interpretation. It also permits different inversion options, specifically homogeneous property inversion and geometry inversion, in addition to conventional heterogeneous property inversion (Figure 2).

The research built on the results of Ralf Schaa's PhD study. The project was conducted in collaboration with Fullagar Geophysics, and sponsored by AngloGold Ashanti, Gold Fields, and Rio Tinto. Mira Geoscience contributed as a commercial partner.

Figure 1

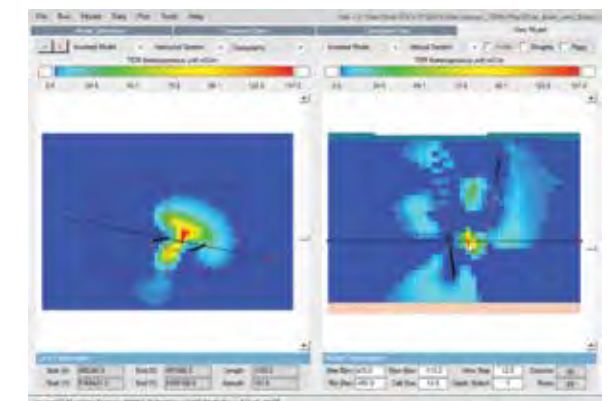


Figure 1: Horizontal (left) and vertical (right) sections through the VPem3D conductivity model after inversion of downhole TEM data. This model was generated more than 10 times faster than previously available methods.

Figure 2

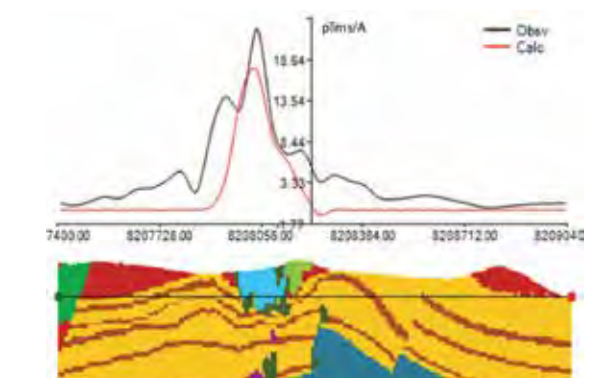


Figure 2: Vertical section through geological model, with observed (black) and calculated (red) resistive limit profiles above. The conductivities of mineralised breccia units (light blue and light green) have been optimised via homogeneous property inversion.

P3A2A AMBIENT SEISMIC ENERGY TECHNIQUES

LEADER Anya Reading

COLLABORATORS Charles Funk, Nick Smith

This project has successfully proven the concept of using ambient seismic energy in finding the depth of cover in a minerals exploration setting. Work was completed with the publication of a paper in *Geophysics* – the leading international journal for applied geophysics. In order to raise awareness of the method amongst the Australian geophysics and exploration community, the results were also presented at the 2013 ASEG meeting in Melbourne, with another paper published in the ASEG volume *PREVIEW* for that conference.

P3A3A DATA INFERENCE TECHNIQUES APPLIED TO DIVERSE GEOSCIENTIFIC DATASETS

LEADER Anya Reading

STUDENT Matthew Cracknell

COLLABORATOR Andrew McNeill

This project has successfully proven the concept of using machine learning strategies in knowledge discovery using high-dimensional inputs of disparate geoscience data layers. This has resulted in new findings from existing data, including the identification of alteration zones and new exploration targets in regions of difficult terrane and limited rock exposure. The new techniques being developed reached maturity during the year, enabling a high level of attainment: four papers were published (or accepted) directly relating to this work.

P3A4A WESTERN TASMANIAN GEOPHYSICS

LEADER Anya Reading

TEAM MEMBERS Daniel Bombardieri, Michael Roach

STUDENT Sam Poker

COLLABORATORS Mark Duffett, Andrew McNeill

This project commenced in 2013, and has strong collaborative links with Mineral Resources Tasmania (MRT) and its West Tasmania Geoscience Initiative. Through combining geological and geophysical constraints, the research is developing a new understanding of the deep geological structure of western Tasmania.

Next generation 3D geological modelling being used by the team brings together lithological and structural field

observations with gravity and magnetic modelling. In the first instance, the 3D geological models may be refined with the best possible constraints from all available information. Remaining anomalies are of key importance, as they highlight where facies changes mineralisation or alteration systems have been overlooked, and also provide other new insights into details of regional structure.

This work is being driven by Daniel Bombardieri, who is a joint appointment between CODES and MRT. The research has already led to the development of a 3D model for the Rosebery area, which will potentially assist exploration for tin and other base metals in this mineral province. Further developments will be assisted significantly by recent upgrades to the petrophysics laboratory at UTAS/CODES.

THEME 3B INTEGRATED EXPLORATION MODELS FOR DISCOVERY

P3B1B (AMIRA P1060) ENHANCED GEOCHEMICAL TARGETING IN MAGMATIC-HYDROTHERMAL SYSTEMS

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, 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 is being conducted in collaboration with Lakehead University and Imperial College London, and has the support of 20 industry sponsors, making it the largest exploration-based research project in AMIRA's history.

The aims are 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

is 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 are being further investigated, with the objective of developing new tools for exploration in these areas through analysis of pre-existing and new sample suites. Blind site testing is being 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 is to investigate the effects on various protoliths (limestones, sandstones, granite, etc.).

Since project commencement, field campaigns have been conducted in the USA, Canada, Indonesia, Chile, Peru, Panama, Colombia, the Philippines and Argentina. Sponsor meetings in 2013 were held in Townsville, Queensland in May and at CODES in November. The project is scheduled to conclude in June 2014.

P3B1C LOW- AND HIGH-SULFIDATION EPITHERMAL MINERAL DEPOSITS

LEADERS Bruce Gemmell, David Cooke

TEAM MEMBER Nic Jansen

STUDENTS Mathieu Ageneau, Lindsey Clark, Hugo Galvan, Erin Lawlis, Vikraman Selvaraja, Bronto Sutopo

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.

LOW SULFIDATION DEPOSITS

- Research continued on the Newcrest's Gosowong Goldfield deposit, Halmahera Island, Indonesia via an Honours study by Vikraman Selvaraja. Vikraman's project was focused on the mineralogy and geochemistry of the advanced argillic alteration in the goldfield.
- 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 also supported by Newcrest.
- A manuscript is in preparation for submission to *Economic Geology*, based on the PhD research of Ali Sholeh (Tarbiat Modares University, Iran), who visited CODES in 2012 to undertake petrologic, mineragraphic 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 theses corrections were submitted and approved for Mathieu Ageneau and Lindsey Clark on the Ladolam Au deposit in PNG, and the Kencana deposit in Indonesia, respectively.

P3B2A SEDIMENT-HOSTED GOLD-ARSENIC-TELLURIUM DEPOSITS: GENESIS & EXPLORATION MODELS

LEADERS Ross Large, Sebastien Meffre

TEAM MEMBERS Leonid Danyushevsky, Garry Davidson, Sarah Gilbert, David Hutchison, Elena Lounejeva, Abhisit Salam, Rob Scott

STUDENTS Dan Gregory, Jeff Steadman

COLLABORATORS Rob Burnett, Dave Craw, Mark Doyle, Bradley Guy, Peter Haines, Arthur Hickman, Tim Lyons, Valeriy Maslennikov, Svetlana Maslennikova, Patrick Sack, Peter Sorjonen-Ward

The AMIRA-funded aspects of this project (P1041) were completed during the year.

The aims of the AMIRA project were to test the following:

- The application of new LA-ICP-MS technologies to the resolution of gold deportment and exploration trace element signatures in a range of gold deposits.
- The use of pyrite chemistry as a vector tool in the halo of several gold deposits.

Nine case study sites were provided by the sponsor companies for evaluation, utilising the new LA-ICP-MS technologies developed in the project to determine gold deportment and trace element signatures.

- Wafi epithermal gold deposit, PNG (Newcrest)
- Mt Olympus sediment-hosted gold deposit, WA (Sipa)
- Witwatersrand Carbon Leader Reef (CLR), South Africa (AngloGold Ashanti)
- McPhillamys volcanic-hosted gold deposit, NSW (Newmont)
- Golpu porphyry copper-gold deposit, PNG (Newcrest)
- Hope Bay greenstone-hosted gold deposit, Canada (Newmont)
- Chatree epithermal gold deposit, Thailand (Issara)
- Matarbe epithermal gold deposit, Indonesia (G Resources)
- Geita Hill, BIF-hosted gold deposit, Tanzania (AngloGold Ashanti)

The case studies provided an excellent test for the capabilities of the LA-ICP-MS technology and, in each case, the primary questions relating to gold deportment and exploration trace element signatures were successfully answered. These results have subsequently been combined with petrographic studies and, in some cases, MLA analysis.

The CODES laboratory team has made very significant progress in developing new interpretation methods, refining computer reduction processes and reducing the costs of analysis for end-users. A new analytical package has been developed that provides cost effective gold deportment, exploration signatures and vector testing procedures. This package is now available to the project sponsor companies and other end-users.

Several publications from the team have appeared during the year, including a paper in *Economic Geology* on gold deportment and the genesis of the Carbon Leader Reef in the Witwatersrand Basin, South Africa.

A highly significant discovery of gold-bearing pyrite nodules in Black Flag Beds, well south of Kalgoorlie, was made by Jeff Steadman in the course of his PhD studies. This work, which was published in *Precambrian Research*, has major implications for gold ore genesis models in the Yilgarn terrane in Western Australia.



Left: Tourmaline orbicules in Heemskirk granite, western Tasmania. **Middle:** Peter Hollings and Mike Baker at Cobre Panama mine in Panama. **Right:** AMIRA P1060 meeting attendees.

P3B5C THE GEOLOGY AND GENESIS OF THE AVEBURY Ni DEPOSIT— IMPLICATIONS FOR EXPLORATION

LEADER Vadim Kamenetsky

STUDENT Alexey Lygin

COLLABORATORS Steve Beresford, Jeff Foster, Andrew McNeill

The serpentinite-hosted Averbury nickel sulfide deposit in Tasmania is the world's largest known hydrothermal deposit, and provides an unprecedented opportunity to understand sources of metals and fluids responsible for this style of economic mineralisation.

It has been found that a rare type of hydrothermal nickel sulfide mineralisation relates to post-magmatic and post-metamorphic modification of peridotites, rather than to magmatic differentiation processes. This study shows that serpentinisation of the Ni-rich olivine in the Cambrian peridotites of the Mclvor Hill Complex, followed by metasomatic transformation related to the Devonian granite intrusion, were instrumental in the economic accumulation of nickel sulfides. This model has implications for exploration for similar deposits in the region.

P3B6A STRUCTURE AND FORMATION OF THE SAVAGE RIVER MAGNETITE DEPOSIT

LEADERS Ron Berry, Rob Scott

STUDENT Victoria Braniff

COLLABORATORS Ralph Bottrill, Roger Hill, Edward Morris, Jafar Taheri, Tony Webster, Chris Wilson

The Savage River magnetite deposit is hosted by strongly deformed Neoproterozoic meta-sedimentary and meta-volcanic rocks (schists) of the Arthur Metamorphic Complex, in NW Tasmania. Grange Resources has owned and operated the mine since 2009. The purpose of its research collaboration with CODES was to develop a structural model for the magnetite ore bodies and their immediate host rocks, and to improve prediction of geotechnical performance of the planned and future pit designs. The study combined principles and techniques of geotechnical engineering and field-based structural geology. A key component of the study was to investigate links between the distribution of unfavourably-orientated brittle features (controlling pit wall stability) and ductile feature fabrics formed during the Cambrian (Tyennan) and Devonian (Tabberabberan) orogenies. This project was completed in 2013, with the submission (and subsequent awarding) of Victoria Braniff's PhD thesis, entitled 'Integration of geotechnical and structural data from Savage River Mine, Tasmania'.

Victoria's study identified unfavourably-oriented hematite-filled joints as the release surfaces for the majority of recent failures at the mine. These joints were found to be concentrated within a 10–60 m wide damage zone along, and to the east of, the subvertical, N-S striking Eastern Contact Fault (ECF), which bounds the highest grade magnetite ores (to the west). Similar problematic damage zones were identified west of the Magnesite Fault, which locally forms the western boundary to the magnetite deposits. The ECF reactivates an older mylonite zone, which records dip-slip movement under greenschist facies metamorphic conditions.

Similar zones of mylonitic fabric development are widespread throughout the immediate host rocks at Savage River. U-Pb dating of monazite suggests these mylonites are of Devonian age. Similarly oriented Cambrian mylonite zones record strike-slip displacement, contain biotite, and locally preserve hornblende and higher pressure amphiboles, such as ferrowinchite.

P3B7A IRON OXIDE COPPER-GOLD AND RELATED DEPOSIT TYPES

LEADER Garry Davidson

TEAM MEMBERS Stuart Bull, Sebastien Meffre

COLLABORATORS Mark Allen, Jorge Benavides, Robert Creaser, Hamish Freeman, Marcus Tomkinson, Marcel Van Eck, Pat Williams

This project has been predominantly based on the Prominent Hill IOCG deposit, South Australia. The main project concluded in 2012, and no further funding was forthcoming. However, funding had been set aside for a Nd isotope study of Prominent Hill, co-ordinated by Pat Williams from Clump Mountain Geoscience, with analytical work being undertaken at the University of Alberta by Robert Creaser. This sub-project used well characterised samples from this and previous CODES-based projects. All major lithologies were analysed in 2013. The next phase of the work is to integrate these results with other findings of this confidential project, during the write-up for refereed journals.

P3B8 APPLICATION OF CARBONATE C-O ISOTOPES TO GOLD EXPLORATION: SUNRISE DAM, YILGARN CRATON

LEADER Garry Davidson

TEAM MEMBER Craig Winter

COLLABORATORS James Cleverley, June Hill, Michael Nugus, Nick Oliver

This new project developed out of a smaller halo-focused project in 2011, involving components of lithogeochemistry, hyperspectral analysis, stable isotope geochemistry and integration with drillcore features such as vein density, intensity of alteration, and gold grade. From an isotopic perspective, the aims are to determine the usefulness of C-O isotopes for detecting ore halos, while identifying barren from mineralised systems, and constraining the genetic model of ore formation. There have been significant advances in understanding of C-O variation in Archean orogenic gold systems, with an appreciation that this variation is very much larger than known from earlier studies around the world, which predominantly involved very limited sample populations.

The work at Sunrise Dam has been focused on determining the scale of variability in and around individual lodes, and subsequently using this information to establish an appropriate sample density to extend outwards into the rock mass. In 2013, the project produced ~100 analyses of two drill holes that transected deeper lodes. These holes have been analysed at close scale using a large number of geochemical techniques. Work also commenced on evaluating the use of carbonate-staining to cheaply identify carbonate generations, which may help optimise selection of samples for C-O work.

The project, which is solely funded by AngloGold Ashanti, will continue until July 2014.

OUTLOOK

In 2014, the Discovery Program will fall under the domain of the Ore Characterisation Module (see Research Framework starting on page 8 for further details). However, all current and active projects in this program will continue.

A highlight of the coming year will be the completion of the geophysical modelling work in the base metal and tin province in western Tasmania, and subsequent preparation of material for publication. Also in the geophysics area, the P3A3A team plan to investigate the viability of a potential new AMIRA project that will build on the success of the machine learning approach to large data sets. In spite of the downturn in exploration activities, this proposal has some chance of success because existing data may be used and no 'on-site' logistical support is necessarily required.

In June 2014, the highly successful AMIRA P1060 project will draw to a close, marked by a final Sponsors Review Meeting at CODES. However, the team plan to seek support for a further extension project to enable this valuable research to continue. Also in the exploration models theme, a paper will be finalised on the collaborative Nd-isotope studies at Prominent Hill in South Australia, with the aim of it being published in a top refereed journal later in the year.

There were a number of positive outcomes for students in past year, and it is pleasing to note that a new PhD study is soon to be initiated on the Don Nicholas low to intermediate sulfidation deposit in Patagonia, Argentina.

Negotiations will also commence with Mexican-based exploration companies with a view to gaining support for further Au-Ag epithermal deposit research. And several spin-off projects from AMIRA P1041 are expected to get underway during what looks to be a very full year of activities.

Marmolejo volcano, Chile.

PROGRAM FOUR RECOVERY

OBJECTIVE

To create and develop a series of small-scale, low-cost, practical geometallurgical tools, protocols, proxies and processing indices for the purpose of ore-body domaining and mine planning.

INTRODUCTION

Over the past decade, the extent of research conducted within the field of geometallurgy has significantly increased. Industry recognition of this growing discipline, and the subsequent need for new large-scale, integrated geometallurgical research, resulted in the development of the AMIRA P843 (Geometallurgical Mapping and Mine Modelling) project, which has commonly become known as GeM^{III}.

The project commenced in July 2005, in collaboration with the University of Queensland (UQ), with a vision to establish a collaborative, cross-discipline research platform to support the emerging role of geometallurgy in providing predictive inputs into mine planning, economic optimisation and sustainability. During its initial four-year period, GeM^{III} became the fastest growing and largest foundation project in AMIRA's 50-year history, which led to an extension of the project (AMIRA P843A) in 2009. Over the project's full lifespan, it has been highly successful in developing an array of geometallurgical methods and protocols in areas of comminution and flotation. It has incorporated aspects of mining, liberation, recovery (flotation and leaching) and environmental impact, and carried out important larger scale, site-specific case studies aimed at evaluating these methods in active mines – paying careful attention to the potential for integration of the findings into resource models, mine planning and optimisation studies.

AMIRA P843A, which was completed in 2013, has made a significant contribution to the testing and application of geometallurgy protocols that define mine variability in processing performance. The measurement of comminution behaviour has reached a mature stage and is now migrating to the companies that provide specialised services to the mining industry, including the project's five supplier sponsors.

Although this project came to a conclusion in mid-2013, planning is underway for an AMIRA continuation project – see the Outlook section at the end of this Program report for further details.

HIGHLIGHTS

GENERAL

- Final meeting held for AMIRA P843A.
- Eight years' research compiled into a 'compendium of results' and presented to sponsors.
- Protocols for photographic recording of core have been taken up by several sponsors and are in practice at mine sites.
- Site based protocols for measuring proxies for core hardness are being applied at several sites and are receiving wider recognition.
- In line with the GeM^{III} project's ongoing commitment to technology transfer, the team led, and helped present, the Geometallurgy unit of the Master of Economic Geology Program, held towards the end of the year.
- Program Leader Associate Professor Ron Berry retired.

- Dr Will Goodall from UQ-JKMRC appointed to define and lead the extension to the AMIRA P843A project, which will be called AMIRA P843B (see Outlook section).

THEME 2 (P4A2)

Integrated Blast Modelling

- Release of IFragX blast fragmentation modelling software to sponsors.

THEME 3 (P4A3)

Deterministic Comminution Modelling

- Interactive CD on comminution testing released.

THEME 4 (P4A4)

Texture-based Liberation and Recovery Modelling

- Conducted a major review of texture relevant to liberation, including a review of proxies for gold grain size.
- Protocol established for combined Bond Mill Work Index, and batch flotation test conducted on small samples.

THEME 5 (P4A5)

Predictive Leaching Indices

- Selective leaching tests validated.
- Standard operating procedures released for diagnostic and selective leaching, agglomeration and rheology tests.

THEME 6 (P4A6)

Specialist Analytical and Support Software

- Large-scale trial conducted of STORC (structure from core) and SupLCORE (support for core logging) software.

(P4A7) Case Studies and Technology Transfer

- Case studies of Chuquicamata, Escondida, Andina and Los Bronces completed and reports submitted to sponsors.





LEADER RON BERRY

TEAM MEMBERS

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CSIRO MINERALS DOWN UNDER FLAGSHIP / PROCESS SCIENCE AND ENGINEERING Nicole Chapman, Laura Kuhar, Rachael Martin, Angus McFarlane, Rebecca Meakin, Patrick Merrigan, Dave Robinson, Nicole Turner
UQ – SMI Dee Bradshaw, Alan Cocker, Will Goodall, John Jackson, Luke Keeney, Toni Kojovic, Janine Lay, Emmy Manlapig, Simon Michaux, Khoi Nguyen, Italo Onederra, Steve Pooley, Malcolm Powell, Pat Walters, Steve Walters, Yicai Wang

PHD STUDENTS

CODES Angela Escolme
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MASTERS STUDENT

Paula Montoya

HONOURS STUDENT

Sam Arnold

CORE PROJECTS

Project P4A (AMIRA P843A) **GeM^{III} Geometallurgy Mapping and Mine Modelling** is split into the following six themes, plus a sub-project covering case studies and technology transfer.

THEME 1 (P4A1)
Predictive Environmental Indices. N.B. This Theme has been transferred to CRC ORE.

THEME 2 (P4A2)
Integrated Blast Modelling

THEME 3 (P4A3)
Deterministic Comminution Modelling

THEME 4 (P4A4)
Texture-based Liberation and Recovery Modelling

THEME 5 (P4A5)
Predictive Leaching Indices

THEME 6 (P4A6)
Specialist Analytical and Support Software

(P4A7)
Case Studies and Technology Transfer

PROJECT SUMMARIES

THEME 1 (P4A1)
PREDICTIVE ENVIRONMENTAL INDICES

As reported in the 2012 Annual Report, this theme has been transferred to CRC ORE, with involvement via UTAS Earth Sciences.

THEME 2 (P4A2)
INTEGRATED BLAST MODELLING

LEADER Alan Cocker

TEAM MEMBERS Ron Berry, Toni Kojovic, Angus McFarlane, Simon Michaux, Khoi Nguyen, Italo Onederra

STUDENT Hector Parra Galvez

This theme is divided into three parts. In the first part of the theme, the IFragX software, which integrates high-resolution bulk rock properties into advanced blast models, has been extended to interact with both the DomAln software and data relating to measurements taken while drilling.

IFragX was released to the sponsors in March and distributed in the final compendium of results.

In the second part of the theme, blast induced fragment conditioning for leach performance was tested on an artificial rock analogue blasted in barrels. Samples at various positions with respect to the blast centre were tested for comminution strength and leaching behaviour. The blast condition had a detectable effect on crushing strength but not on grinding behaviour. The leaching response to blast intensity was too weak to detect against the experimental noise. Other features of the rock were more important than the blast induced fracturing in the leaching experiments. No additional tests are planned in this area.

In the third part of the theme, a final version of the STORC (structure from oriented core) software program was released, complete with a manual. A large-scale trial, based on 500 metres of sponsor core, demonstrated that this software can produce orientation data on fracture patterns suitable for mine planning.

THEME 3 (P4A3)
DETERMINISTIC COMMINUATION MODELLING

LEADER Toni Kojovic

TEAM MEMBERS Julie Hunt, Luke Keeney, Malcolm Powell, Pat Walters

All programs in Theme 3 are complete, and a digital manual has been released for the comminution methods. This manual includes testing methodologies, videos of testing practices, technical reports and other information for use in the application of the selected tests. The documents in the folder are searchable and a general index has been developed to assist with researching the application of each test.

THEME 4 (P4A4)
TEXTURE-BASED LIBERATION AND RECOVERY MODELLING

LEADER Dee Bradshaw

TEAM MEMBERS Ron Berry, Julie Hunt, Janine Lay, Emmy Manlapig, Khoi Nguyen, Steve Walters, Yicai Wang

STUDENTS Mitesh Chauhan, Angela Escolme

The objective of this theme is to develop appropriate methodology to populate deposit block models with recovery predictions that incorporate inherent geological variability. The major development in 2013 was the demonstration that the 1.5 litre batch flotation test is superior to the MSI approach. Coupling the 1.5 litre batch flotation test with a sieved fraction from the Bond Work Index proxy method, based on a planetary ball mill, gives a practical protocol for quantitative measurement of processing performance in a porphyry Cu system.

During 2013, textural analysis for prediction of liberation and the grade recovery curve continued. Software development has provided new capability in the analysis of unclassified images. SupLCore (beta version) was released, with a manual. An example of this application was reported based on 5,000 metres of core. The TextureLets (advanced texture parameterisation) software was released as an alpha version, but has not undergone large-scale trials.



Processing control room at the Savage River mine, Tasmania.



THEME 5 (P4A5) PREDICTIVE LEACHING INDICES

LEADERS Dave Robinson, Laura Kuhar

TEAM MEMBERS Nicole Chapman, Lyudmyla Koziy, Rachael Martin, Angus McFarlane, Rebecca Meakin, Patrick Merrigan, Nicole Turner

This theme comprises five parts:

- Development of small-scale tests (diagnostic leaching, selective leaching, agglomeration, rheology).
- Integrated mineralogical feed characterisation.
- Numerical simulation of leach pad hydrology.
- Use of pre-conditioning for leach optimisation (with Theme 2).
- Class-based modelling of leaching performance and use of blend response curves.

The team focused mainly on the delivery of small-scale tests for use in geometallurgical applications. To ensure these methods can be implemented at mining operations, a standard operating procedure manual has been supplied containing detailed information on how to conduct tests.

The numerical hydrology model for a leach pad was based on a multiple porosity model. Porosity measurements from a controlled blast experiment (conducted in conjunction with Theme 2) showed that blast intensity does not have a significant effect on leaching behaviour. A synthesis report was included in the compendium of P843A results.

THEME 6 (P4A6) SPECIALIST ANALYTICAL AND SUPPORT SOFTWARE

LEADER Ron Berry

TEAM MEMBERS Julie Hunt, Dave Hutchinson, Luke Keeney, Khoi Nguyen

This theme provides technical support for various areas of the GeM^{III} project.

AMIRA P843 developed a new protocol for automated optical microscopy that has been used extensively in AMIRA P843A. An updated summary of this protocol was included in the final report.

The team also looked at laser Raman mineral mapping, with the initial conclusion being that while the accuracy of mineral recognition was good, the speed of processing may be too slow.

There have been continual discussions on how to collect and make optimal use of good quality photographs of drill core. The latest recommendations for taking good quality core photographs were covered in the core photography manual, which formed part of the final report. The STORC, SuplCore and TextureLets software modules were also developed to highlight applications based on good quality photographs.

Various projects on texture related to mineral processing were nucleated within this Theme, including one covering grain size determination and the use of sampling statistics to generate proxies for gold grain size. As they matured, all these results migrated to Theme 4.

Throughout the life of the extension project, researchers were often posed with the conundrum of what was the optimum number of samples to collect for analysis. While there is no right answer to this question, a discussion of the logic that can inform this process was included in a paper on sampling strategies.

(P4A7) CASE STUDIES AND TECHNOLOGY TRANSFER

LEADER Steve Walters

TEAM MEMBERS Ron Berry, Dee Bradshaw, Julie Hunt, Luke Keeney, Toni Kojovic, Pat Walters

Site-based case studies are a feature of the AMIRA P843A project carried out within Program 4. The aim of these studies is large-scale validation and comparative benchmarking, mainly of tools and methodologies developed in AMIRA P843. The studies are designed to support technology transfer through validation, enhancement and demonstration of outcomes.

Twelve sites were nominated by sponsors for case study scoping. This process entailed close consultation between researchers and nominated sites to identify specific high-impact areas of interest, and the potential benefit that could be used to validate tools and methodologies.

After scoping, nine site-based case studies were undertaken, encompassing large testing programs designed to develop and validate GeM^{III} testing methods and modelling concepts. Outcomes have involved proof of concept for individual site application, technology transfer to sponsor companies, and establishing pre-commercial support for emerging GeM^{III} testing methodologies. The last four case studies, at Escondida, Andina, Chuquicamata and Los Bronces, were completed in 2013.

OUTLOOK

EXTENSION PROJECT

With significant support from CODES' collaborating team members at UQ and CSIRO, the GeM^{III} AMIRA P843A project has 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.

As a result of these and other successes, there is strong support from the minerals industry to build on this platform. Therefore, various meetings and discussions were completed during 2013 aimed at identifying a forward program for the GeM^{III} project in the form of the AMIRA extension project P843B.

To facilitate the project's development, Will Goodall from UQ – JKMR has been appointed to lead this process, supported by Julie Hunt, Wayne Stange, Bruce Gemmell, Steve Pooley and John Jackson. Dr Goodall has extensive experience in gold mineralogy, mineral process development, gold ore characterisation, and geometallurgy.

The main aim of the extension project will be to continue to generate significant value for sponsors via the use of geometallurgical information in a production capacity. The project will provide a consolidation of tools developed in GeM^{III} to date, with a focus on their implementation and the achievement of reliable production forecasting for sponsor companies.

FINAL ACTIVITIES FOR AMIRA P843A

- Report results from AMIRA P843A at international conferences.
- Publish results, as confidentiality allows.
- Further develop Theme 1 – Predictive Environmental Indices through CRC ORE.

Dee Bradshaw demonstrating how to run a froth flotation device during the Master of Economic Geology Geometallurgy short course.



PROGRAM FIVE TECHNOLOGY

OBJECTIVE

Research activities within the Program are aimed at developing new analytical techniques, ensuring that research in the Centre is driven by innovative technology, and that the Centre is at the cutting edge of analytical developments of relevance to ore deposit research.

The program 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 Technology Program explores and develops novel analytical and data interpretation techniques based on the latest technological developments, such as a number of high spatial resolution microprobes. This helps in the understanding, exploration and exploitation of deep earth resources.

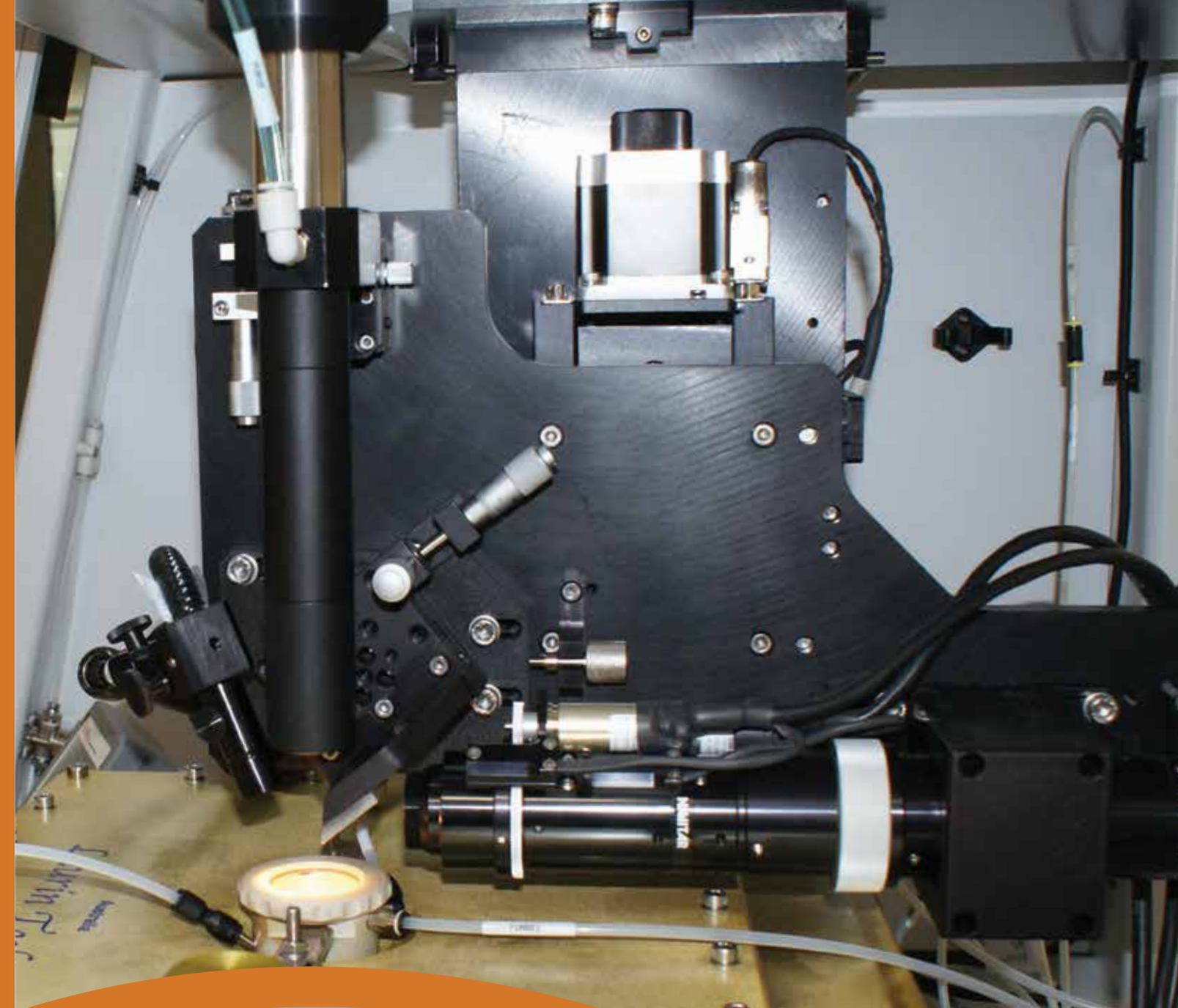
Current research projects focus mainly on expanding the capabilities of in-situ multi-element analysis by laser ablation (LA), inductively-coupled plasma mass-spectrometry (ICP-MS), in-situ isotope analysis by LA multi-collector (MC) ICP-MS, non-destructive multi-element analysis using nuclear (PIXE) and synchrotron-based X-ray microprobes (XFM), and development of new stable-isotope solution-based analytical techniques. Research activities also develop data interpretation tools, such as new algorithms and new user-friendly scientific software packages. These are used primarily for modelling the deep earth processes that lead to ore formation, and for processing of analytical data. Many of the projects have included close collaborations with Node partners, such as the University of Melbourne, CSIRO and the Australian National University.

HIGHLIGHTS

The major highlight of the year was the commissioning and launch of the Newcrest LA-ICP-MS Laboratory at CODES. This state-of-the-art facility is equipped with a Resonetics RESolution S-155 laser probe coupled to an Agilent 7700s quadrupole mass spectrometer. The high throughput laser ablation system enhances the Centre's capabilities in terms of ore deposit characterisation, which plays such a vital role in helping mining companies better understand their ore deposits, and subsequently enhance extraction and recovery outcomes. The facility was made possible via funding from Newcrest Mining.

Other highlights include:

- Commissioning of the new CSIRO NMP target chamber and control system, as well as software engineering of beam transport. The system is now complete and awaiting the arrival of the Maia array.
- The new revision B Maia detector achieved greatly improved energy resolution.
- Better understanding of ablation characteristics of pyrite led to improved analytical protocols for quantitative sulfide trace element analysis.
- Improvements in the LBIC on the CSIRO NMP system are expected to result in orders of magnitude improvement in both the sensitivity of the method and speed of analysis.
- Hydrothermal mineral replacement of calcite with As-bearing apatite reveals that complex mineral zoning patterns can form in hours and be destroyed by consequent reactions within days.



Top: Close-up of XRD equipment in the new laboratory.
Bottom: Paul Olin operating the new laser ablation system in the Newcrest laboratory.



LEADER LEONID DANYUSHEVSKY

TEAM MEMBERS

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BROOKHAVEN NATIONAL LABORATORY, USA Gianluigi De Geronimo, Tony Kuczewski, Zhi Yong Li, Peter Siddons

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VICTORIA UNIVERSITY OF WELLINGTON, NZ John Creech

WOODS HOLE OCEANOGRAPHIC INSTITUTION, USA Nobomichi Shimizu

CORE PROJECTS

THEME 5A

ADVANCING SPATIALLY RESOLVED MASS SPECTROMETRY

P5A1 LA-Q-ICP-MS analysis development

P5A2 New LA-Q-ICP-MS applications

P5A3 New LA-MC-ICP-MS applications

P5A4 New stable isotope MS applications

P5A4A Cracking the sulfate isotopic composition problem in ancient hydrothermal systems: Application of the Carbonate-Associated Sulfate (CAS) method

P5A5 Pyrite metallurgy

P5A6 Laser-ablation ICP-MS analysis of spatial variations of sulfur isotopic composition: Advancing applications in the field of ore deposit research

THEME 5B

ADVANCING NON-DESTRUCTIVE FOCUSED-BEAM SPECTROSCOPY

P5B1 Ion beam analysis development

P5B2 New ion beam applications

P5B3 Synchrotron X-ray probe development

P5B4 New synchrotron-based applications

THEME 5C

DATA INTERPRETATION TOOLS

P5C3 Modelling of crystallisation and melting processes

P5C5 LA-ICP-MS data reduction software

These results were presented at the 2013 Winter Plasma Conference in Poland.

- Modifications to the design of the interface between the laser ablation cell and ICP-MS to improve washout of signal after ablation, which is particularly relevant for the quantification of LA-ICP-MS images.
- Improving sample cleaning procedures and lowering effective detection levels to obtain more accurate low-level concentrations.
- Comprehending processes within the mass spectrometer plasma by better understanding ion kinetic energy during laser ablation ICP-MS. These results will be presented at the 2014 Winter Plasma Conference in Florida.
- Optimising and standardising plasma physical parameters for Laser Ablation.
- Testing new designs of smoothing devices between the laser and ICP-MS.
- Introduction of nitrogen for flushing the beam path to improve energy stability.

P5A2 NEW LA-Q-ICP-MS APPLICATIONS

LEADERS Leonid Danyushevsky, Sebastien Meffre

TEAM MEMBERS Ivan Belousov, Ian Little, Elena Lounejeva, Paul Olin, Alexandr Stepanov, Jay Thompson

STUDENT Sarah Gilbert

COLLABORATORS Fred Fryer, Detlef Gunther, Michael Shelley

New geological LA-Q-ICP-MS applications are being developed in the fields of ore deposit geology, igneous petrology, hydrothermal fluid chemistry and U-Pb dating of zircons and other minerals.

The main outcomes in the past year were:

- An investigation into the ablation characteristics and fractionation processes of different sulfide minerals has shown that ablation of pyrite generates particles of S with a different Fe/S ratio to that contained within the mineral. This investigation formed part of Sarah Gilbert's PhD project, and utilised imaging and analysis of ablated material using the FE-SEM at the UTAS Central Science Laboratory (CSL).
- An investigation was conducted into the element fractionation between Fe and S during the ablation process for the three different types of lasers at CODES, as well as fractionation during ablated particle transport. This investigation was also part of Sarah Gilbert's PhD project.
- Improved protocols were established for uraninite geochronology (smaller spot sizes and better targeting by using SEM / EMPA).
- Work has continued on U-Pb dating of several accessory phases including zircon, apatite, monazite, sphene, rutile, allanite, and uraninite. Enhancements in uraninite dating have improved the agreement between EMPA-based ages obtained at the UTAS CSL to those from the CODES LA-ICP-MS facilities.
- Different rock digestion methods were tested, including the use of ammonia bifluoride, to improve efficiency of solution analyses.

PROJECT SUMMARIES

THEME 5A

ADVANCING SPATIALLY RESOLVED MASS SPECTROMETRY

P5A1 LA-Q-ICP-MS ANALYSIS DEVELOPMENT

LEADERS Sebastien Meffre, Leonid Danyushevsky

TEAM MEMBERS Ian Little, Elena Lounejeva, Jay Thompson

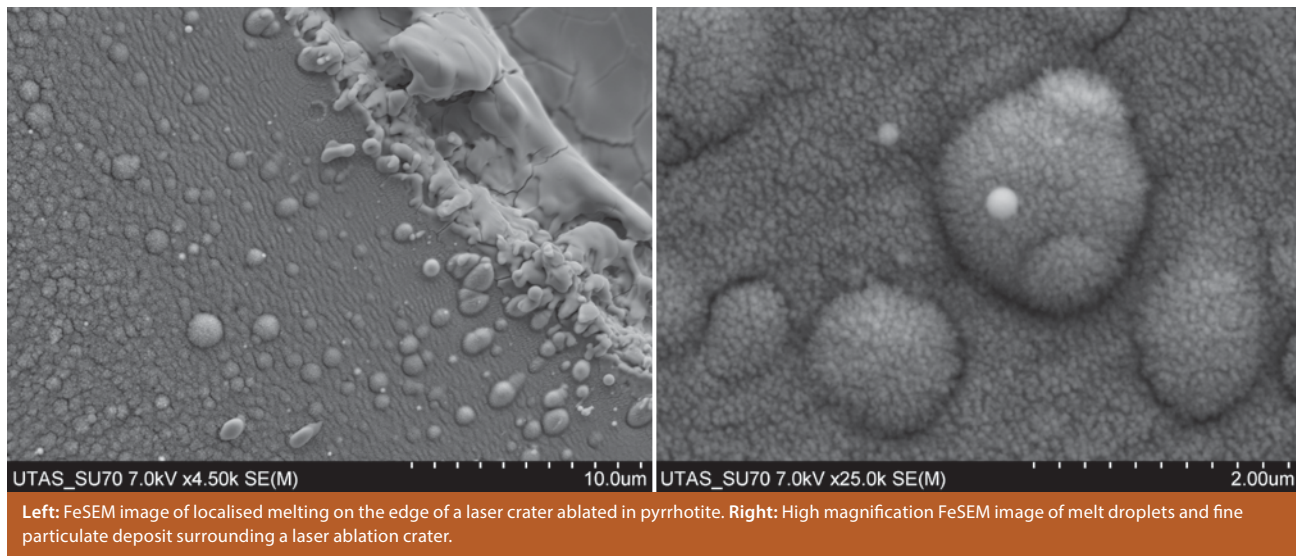
STUDENT Sarah Gilbert

COLLABORATORS Fred Fryer, Detlef Gunther, Michael Shelley

This project designs and develops new instrumentation to ensure continuing advances in geological LA-Q-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 focus during the year was on commissioning the Newcrest LA-ICP-MS facility and developing analytical protocols for analysis of sulfide minerals using a 193 nm Excimer laser.

Additional developments during the year involved:

- Decreasing element fractionation for trace element and U-Pb geochronology by modifying He flow in the S-155 cell.



- The development of laser analyses of rock powders for trace element analyses continued.
- Data reduction software for LA-ICP-MS continued to be developed and improved.
- In collaboration with ETH Zurich, work has started on the development of new calibration standards for LA-ICP-MS analysis of sulfide minerals.
- Work has continued on utilising lithium borate fusion as a means of improving on the formulation of calibration standards for sulfide analysis.

P5A3 NEW LA-MC-ICP-MS APPLICATIONS

LEADERS Bence Paul, Janet Hergt

TEAM MEMBERS Leonid Danyushevsky, Sebastien Meffre

STUDENT Ross Aston

COLLABORATORS Ashley Norris, Jon Woodhead

The aim of this project is to develop new analytical techniques for quantitative, in-situ analysis and the imaging of isotopic compositions of key elements in a range of geological materials. These techniques will lead to new spatially resolved information being available, which will help provide a better understanding of the processes involved in ore formation.

In 2013, the team developed an innovative approach to measuring samples containing multiple minerals ("MinMapper"), which combines principal component analysis with advanced image analysis to allow analysts to process their data on a mineral-by-mineral basis. Each phase can be reduced using a separate reference material and internal standard value. This method has the potential to be valuable in projects where, for example, the trace element concentrations of sulfides and silicates are required with improved precision. A paper describing this method has been accepted by *Geostandards and Geoanalytical Research*, and will be published in 2014.

P5A4 NEW STABLE ISOTOPE MS APPLICATIONS

LEADERS Bence Paul, Janet Hergt

TEAM MEMBERS Leonid Danyushevsky, Sebastien Meffre

STUDENT Heidi Berkenbosch

COLLABORATORS John Creech, Jon Woodhead

The aim of this project is to develop new analytical protocols for the measurement of non-conventional stable isotope compositions (e.g., Cu, Mo) that can be used to explore ore forming processes.

A detailed study of Cu isotopes in a range of ore minerals from the Brothers volcano in the Kermadec Arc was conducted by Heidi Berkenbosch and Bence Paul. This study examines Cu isotope variation between and within black smokers, which makes it one of the most rigorous and detailed studies of its type. The research was presented at the International Applied Geochemistry Symposium in November and a manuscript is being prepared for publication.

Additionally, a paper describing the team's advanced approach to double-spike deconvolution, which is fundamental to precise molybdenum isotope measurement, has been accepted for publication and will be published in 2014. This is a key step in providing accurate and reliable Mo isotopic information from Mo-bearing ore minerals.

P5A4A CRACKING THE SULFATE ISOTOPIC COMPOSITION PROBLEM IN ANCIENT HYDROTHERMAL SYSTEMS: APPLICATION OF THE CARBONATE-ASSOCIATED SULFATE (CAS) METHOD

LEADER Garry Davidson

TEAM MEMBER David Cooke

COLLABORATORS Ariel Pascoe

The aim of this project has been to chemically isolate structurally-bound sulfate in hydrothermal carbonate, and determine its isotopic composition. This potentially can be used to constrain the oxidation state of hydrothermal systems, as well as to assist the development of predictive ore genesis models. The strategy has been to use sequential chemical leaches of hydrothermal assemblages, because the typical S concentration of hydrothermal carbonate is < 200 ppm,

which in the past has been too low for laser-based isotopic spectrometry. In 2013, the most difficult chemical problem was tackled, i.e. isolating the sulfate component of carbonate that is mixed with percent levels of reactive di- and mono-sulfides, such as arsenian pyrite, chalcopyrite and sphalerite. At the completion of trials of known mixtures, it was concluded that the current technique still needs refining to improve the repeatability before publication of this work is possible.

P5A5 PYRITE METALLURGY

LEADERS Sebastien Meffre, Ross Large, Leonid Danyushevsky

TEAM MEMBERS Ron Berry, Aleksandr Stepanov, Helen Thomas

COLLABORATOR Kathryn Stewart

This project, funded by Newcrest Mining, aims to develop techniques to characterise differences in pyrite chemistry by comparing metallurgical composites from various grade ores. Ultimately, the project will provide a set of techniques (either petrographic, SEM or LA-ICP-MS-based) that can be used to produce metallurgic, or ore processing, indices for different types of ore.

This year, the project has focused on improving the LA-ICP-MS-based techniques used to investigate gold deportment for metallurgy.

The following activities were completed:

- Laser ICP-MS analytical procedures for the analysis of gold in pyrite at the Lihir Mine were optimised.
- New etching techniques were tested and developed to highlight the internal growth zones in pyrite, including the quantification of the etching response using automated optical microscopy.
- The relationship between ore grade and pyrite chemistry at the Lihir Mine was investigated, revealing that parts of the deposit with similar ore grades have different pyrite chemistry.

The project has proven that a combination of techniques (etching, MLA, LA-ICP-MS mapping) can provide trace element deportment information at a range of scales, both on intact and composite samples.

P5A6 LASER-ABLATION ICP-MS ANALYSIS OF SPATIAL VARIATIONS OF SULFUR ISOTOPIC COMPOSITION: ADVANCING APPLICATIONS IN THE FIELD OF ORE DEPOSIT RESEARCH

LEADER Leonid Danyushevsky

STUDENT Sarah Gilbert

COLLABORATORS David Death, Fred Fryer, Andrey Gurenko, Toshiaki Matsuda, Paul Perry, Nobomichi Shimizu

The sulfur isotope application developed in 2012 was successfully transferred between laser systems, resulting in improved precision with the Resonetics Excimer laser. Further investigation was undertaken into the optimal configuration of the interface tubing between the laser and the ICP-MS to improve precision and reproducibility, reduce the washout time between samples, and increase sample throughput. Sulfur isotope samples, previously compiled as standards for the technique, were further analysed by ion microprobe at

Le Centre de Recherches Pétrographiques et Géochimiques, resulting in a more robust characterisation of these standards.

Preliminary results from this project were presented at the European Conference on Plasma Spectrochemistry in February, and are currently being written-up for publication.

THEME 5B ADVANCING NON-DESTRUCTIVE FOCUSED-BEAM SPECTROSCOPY

P5B1 ION BEAM ANALYSIS DEVELOPMENT

LEADER Jamie Laird

TEAM MEMBER Chris Ryan

STUDENT Lloyd Grills

COLLABORATORS Robin Kirkham, Jeff McCallum, David Parry, Roland Szymanski

The aim of this project is to better understand the role of metal sulfide semiconductivity on the disposition of precious metals, such as gold.

The NMP upgrade was commissioned during the year in readiness for the Maia detector array, which will be installed in early 2014. Subsequently, the team spent the majority of its time on activities related to the redevelopment and software engineering of critical components on the NMP. Areas covered ranged from the slit objectives all the way through to the implementation of software control for the NMP target stage, camera and beam scanning. Several PIXE runs using the new system have achieved excellent results, albeit with the single channel X-ray detector.

P5B2 NEW ION BEAM APPLICATIONS

LEADER Jamie Laird

TEAM MEMBER Chris Ryan

STUDENT Lloyd Grills

COLLABORATORS Robin Kirkham, Jeff McCallum, David Parry, Roland Szymanski

This project focuses on methods for mapping electrical properties, such as the electric field in complex minerals, in order to gain a better understanding of the role of metal sulfide semiconductivity on the genesis of precious metals.

During the past year, the work was focused on developing a temperature capability for the LBIC measurement system, which is used to map the electric field distribution in minerals. This has required the use of galvo laser scanners, which has led to a more complicated design of the microscope. When complete, the sensitivity of the LBIC method is expected to be orders of magnitude better. Simulation of these improvements is the topic of a Master's thesis by Lloyd Grills.

In a related development, a scanning resistivity system is also being designed. This design is still at an early stage, but initial technical tests look promising. The method enables resistivity across an assemblage to be mapped and correlated with LBIC maps. Papers are currently being prepared for publication based on the results from the past two years.

P5B3 SYNCHROTRON X-RAY PROBE DEVELOPMENT

LEADER Chris Ryan

TEAM MEMBERS Stacey Borg, Weihua Liu

COLLABORATORS Ulrike Boesenberg, Joel Brugger, James Cleverley, Gianluigi De Geronimo, Martin de Jonge, Erica Donner, Paul Dunn, Barbara Etschmann, Gerald Falkenberg, Jean-Louis Hazemann, Rob Hough, Daryl Howard, Simon James, Murray Jensen, Robin Kirkham, Tony Kuczewski, Mel Lintern, Enzo Lombi, Gareth Moorhead, David Paterson, Peter Siddons, Kathryn Spiers, Denis Testemale, Zhi Yong Li

This project targets the development of new experimental equipment for probing samples of geological interest, using synchrotron radiation at the Australian Synchrotron (AS).

Progress in 2013 included:

- Revision B of the Maia detector was completed and achieved greatly improved energy resolution in tests at DESY. In 2014, this upgrade will also be installed on the Australian Synchrotron's XFM beamline, and on the CSIRO Nuclear Microprobe.
- The mAESTRO system, a high pressure-temperature synchrotron spectroscopy cell for solution studies, has been successfully recommissioned at Hutch C at the XAS beamline of the Australian Synchrotron, enabling in-situ measurement of metal speciation at high P-T.

P5B4 NEW SYNCHROTRON-BASED APPLICATIONS

LEADER Stacey Borg

TEAM MEMBERS Weihua Liu, Chris Ryan

COLLABORATORS Joel Brugger, James Cleverley, Barbara Etschmann, Jean-Louis Hazemann, Rob Hough, Denis Testemale

This project is directed towards continued development of new and existing synchrotron techniques for the study of metals and mineral species.

Major outcomes for 2013 include:

- Recommissioning of the mAESTRO high P-T XAS cell at the Australian Synchrotron.
- Research manuscript titled 'Complex mineral zoning patterns caused by ultra-local equilibrium at reaction interfaces' submitted to *Geology*.
- New synchrotron results on apatite mineral transformations have revealed that oxidation states of As in apatite are determined by arsenic species in the fluid.



PhD student Jeff Steadman operating the new laser ablation system.

THEME 5C DATA INTERPRETATION TOOLS

P5C3 MODELLING OF CRYSTALLISATION AND MELTING PROCESSES

LEADER Leonid Danyushevsky

COLLABORATOR 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 2013, work has continued on developing a new model for plagioclase-silicate melt equilibrium under hydrous conditions at variable pressures. In a parallel development, a suite of melt inclusions in olivine phenocrysts has been prepared for analysis. The aim is to measure the diffusion profiles around the inclusions that are to be used in developing models of tracer diffusion in olivine. An updated version of Petrolog3 was made available on the Petrolog home page (<http://petrolog.web.ru>).

P5C5 LA-ICP-MS DATA REDUCTION SOFTWARE

LEADER Leonid Danyushevsky

TEAM MEMBERS Sebastien Meffre, Jay Thompson

STUDENT Sarah Gilbert

COLLABORATOR Ashley Norris

This project is funded by Newcrest Mining as part of their support for the R&D program of the CODES LA-ICP-MS analytical facility. The aim is to develop comprehensive, user-friendly LA-ICP-MS data processing software, capable of:

- Quantification of data acquired with multiple calibration standards using 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.

The focus in 2013 was on developing prototype software that is capable of processing the acquired data, using multiple calibration and internal standards. The prototype is scheduled for in-house testing in mid-2014.

OUTLOOK

In 2014, CODES will maintain its focus on Technology through the Enabling Technologies Module, as the centre transitions from a five program to a four module structure.

The Technology Program has always played a vital role in underpinning all the Centre's research activities, and the formation of this module will enable the team to place even more focus on developing new geochemical approaches and analytical methods to aid the design of exploration tools.

The Newcrest laser ablation laboratory came on stream in 2013, adding significantly to the Centres' technological capabilities and services. CODES will continue to develop these services in 2014, closely aligned to the needs of the minerals industry. CODES has built a reputation for being one of the world's leading centres for ore characterisation, and the aim is to further enhance that standing in the future. Some of the ongoing activities include developing protocols for analysis of trace elements in rock powders by laser ablation ICP-MS and research on understanding the differences between dry and wet plasma conditions.

Although the Node arrangements will fall away with the ending of CODES tenure as an ARC-funded Centre of Excellence, it is anticipated that many of the strong collaborations will continue into 2014, and beyond. The CSIRO node will continue developments at the Australian Synchrotron (AS) and the CSIRO Nuclear Microprobe (NMP), including the installation of a new Maia 384B detector array as an upgrade to the XFM beamline at the AS, and the fitment of a new chamber to the NMP. These enhancements will greatly improve quantitative imaging of geological samples at the AS, and open up new capabilities for high definition PIXE imaging on the NMP. A more systematic study of trace-element zoning during mineral replacement is also planned, plus XAS experiments at the Australian Synchrotron into Ni, Zn and Eu speciation.

Mineralogist Ivan Belousov.



OUTREACH

CODES continued, and expanded, its program of outreach activities in 2013. The broad range of activities began early in the year when Jacqui Halpin and Rebecca Carey led a workshop for Year 11 students as part of the national Science Experience initiative. This workshop has been a mainstay on the calendar for a number of years now, and remains popular and well attended. Activities included a range of hands-on exercises aimed at fostering an interest in the geosciences amongst the young participants.

In a similar vein to Science Experience, the Centre accommodated a visit by students in years 10 to 12, which was organised via UTAS and the Australia and New Zealand Association for the Advancement of Science (ANZAAS). The visit was again led by Jacqui and Rebecca and included a number of hands-on exercises.

The Centre has always been amenable to requests from individual schools and colleges to visit its facilities, and characteristically the year was interspersed with visits from a variety of institutions, with ages ranging from pre-school through Year 12. The main co-ordinator of these visits was Michael Roach, but a number of other people provided support.

Michael also played a key role in activities outside the Centre by leading a series of geological excursions to Waterworks Reserve, in the foothills of Mount Wellington. In total, he took

ten classes from the local Ogilvie High School to the reserve, via five excursions. He also teamed up with Jocelyn McPhie for a similar type of field exercise for three Year 8 classes from Bridgewater High School, only on that occasion the venue was the traverse coastline of Sandy Bay.

Other activities out and about amongst the community included Ross Large addressing the Royal Society of Tasmania, where he presented a layman's version of the background and significance of his research into oxidisation levels in the oceans, over time. While at the other end of the age spectrum, Sharon Allen visited Waimea Heights Primary School, where she delivered a fun and educational talk on the geology of Hobart to preparatory and Year 1 youngsters.

Perhaps the most unusual outside activity of the year was contributed by Garry Davidson. Working in close collaboration with Mineral Resources Tasmania, Garry helped the Tasmanian Museum and Art Gallery create a unique rock wall that depicts the diverse geology of Tasmania, while doubling as an attractive artwork.

Rock Library curator Izzy von Lichten has long been a consistent contributor to the outreach program, but 2013 was a busy year even by her standards. Activities got off to a particularly interesting start when she played host to a film crew from the Stranger With My Face Film Festival, who used



The Rock Wall panel of cut and polished slices of Tasmanian rocks, designed to depict the state's unique geological formations.

the unusual backdrop of the Rock Library, and adjacent areas, to shoot footage for a short film. The film was screened at the Hobart-based festival in March, and has sparked an increased interest from local groups wishing to visit the Rock Library and associated geological exhibits.

CSIRO's Scientists in Schools is a national program that creates and supports long-term partnerships between school teachers and scientists. In support of this important initiative, Izzy assisted a teacher and a group of Year 9 and 10 students from the local Calvin Christian School with project work. In addition, she supervised a work experience student from the same school.

Izzy also played an active role in the CSIRO's Double Helix Science Club, assisting with the labelling of its rock and mineral collection, providing ideas on possible teaching directions to take with the samples, and selecting Tasmanian rock specimens (donated by CODES/UTAS) for its holiday teaching program. The club plays a valuable role in encouraging students to take an interest in science from an early age.

Izzy's already impressive collection of rock specimens was given a significant boost during the year when relatives of the late Derek Murray donated his substantial mineral collection to the Rock Library. The exceptional specimens provide an added incentive for people to visit the Centre. Mr Murray was a geologist and former UTAS student.

Late in the year, she was filmed by ABC TV for its *Open* program, which features a series of short documentaries in which individuals share their stories with viewers. The program is expected to be aired in 2014. To round off an eclectic mix of activities for Izzy, she was also interviewed on geological matters for ABC Radio's *Statewide Evenings* show. However, these were just two of a host of TV and radio interviews involving CODES staff during the year. Other highlights included Rebecca Carey featuring on the ABC TV's *7:30 Report*, and Bruce Gemmell, Ross Large and Rob Scott being interviewed (on separate occasions) for ABC Radio's *Breakfast with Ryk Goddard* program.

All activities were conducted in conjunction with the UTAS School of Earth Sciences.



Clockwise from top: Jacqui Halpin (far left) and Rebecca Carey (far right) lead Science Experience group. Jocelyn McPhie (centre) with students from Bridgewater High School. Garry Davidson in the Rock Garden with girls from Fahan School. Aleksandr 'Sasha' Stepanov with children from the Seagulls Child Care Centre. Izzy von Lichten (centre) with students from Calvin Christian School.

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 has been a key strategic focus throughout CODES’ tenure as an ARC Centre of Excellence, and will remain so into the future.

INDUSTRY LINKS AND SYNERGIES

CODES has strong, enduring and mutually beneficial links with a large 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 2013, the group of CODES’ industry partners comprised of eleven Australian and international mining companies: Anglo American, AngloGold Ashanti, Barrick Gold, BHP Billiton, Buenaventura, MMG, Newcrest Mining, Newmont Mining, Rio Tinto, St Barbara and Teck Resources.

Each of the partner companies provides support of \$15,000 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 and Advisory Board, along with other government and university researchers. The panel and board meet annually to discuss the results of CODES’ research and the potential directions for new research.

INDUSTRY PARTNERSHIP OPPORTUNITIES BEYOND 2013

At the end of 2013, CODES’ tenure as an ARC (funded) Centre of Excellence (CoE) came to an end, after eight highly successful years. The next phase of CODES’ evolution commences in January 2014, and includes a number of exciting new partnership opportunities that can be tailored to company requirements. Some companies have already signed-up for the new partnership program, and the indications are promising that the number will grow during 2014.

Major benefits of an alliance with CODES 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 beyond 2013, contact the Director, Bruce Gemmell: E. bruce.gemmell@utas.edu.au Tel. +61 3 6226 2893.

ROLE OF AMIRA INTERNATIONAL

AMIRA plays a vital role in facilitating the funding of collaborative research involving university research groups and the minerals industry. AMIRA has agreed to fund a series of research projects within the Centre, which will run over a period of three to four years.

In 2013, AMIRA funded these major projects for CODES:

- P843A (GeM^{III} project) Geometallurgical mapping and mine modelling.
- P1022 The rapid approximate inversion of TEM data.
- P1041 Application of new technologies to gold deposits.
- P1060 Enhanced geochemical targeting in magmatic-hydrothermal systems.

RESEARCH COLLABORATIONS AND INTERNATIONAL VISITORS PROGRAM

In 2013, CODES further cemented its reputation for cultivating research collaborations with other Australian and international research organisations. Throughout the year, collaborative research was conducted with 94 international and 22 national organisations.

During the tenure as a CoE, collaborative research between international and Australian-based partners was also facilitated via joint research appointments. The table on the next page details each of the collaborating institutions with the joint researchers and their funding source. These researchers were based at collaborating partner institutions and incorporated research visits to CODES throughout the term of their research projects.

RESEARCHERS WHO WORK JOINTLY IN CODES AND THE COLLABORATING ORGANISATIONS

INSTITUTION	COE ARC GRANT	NODE MATCHING FUNDS	INDUSTRY / AMIRA FUNDS	UNIVERSITY / CSIRO FUNDS
University of Queensland-Sustainable Minerals Institute (incl. Julius Kruttschnitt Mineral Research Centre & WH Bryan Centre)	Dee Bradshaw (2%), Khoi Ke Nguyen (25%), John Jackson (15%), Steven Pooley (14%), Malcolm Powell (8%), Emmanuel Manlapig (1%), Patrick Walters (7%), Yicai Wang (5%)	Janine Lay (3%), Yicai Wang (15%)	Grant Ballantyne (15%), Dee Bradshaw (8%), Alan Cocker (20%), Janine Lay (7%), Emmanuel Manlapig (9%), Khoi Ke Nguyen (15%), Malcolm Powell (12%), Patrick Walters (33%), Dion Weatherley (20%)	
University of Melbourne	Bence Paul			Janet Hergt, Roland Maas
Australian National University				Stephen Cox
CSIRO	Jamie Laird (50%), Stacey Borg (50%)	Jamie Laird (50%), Stacey Borg (50%)		Chris Ryan, Weihua Liu



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 the formation, location, discovery and recovery of ore deposits, and the development of innovative technologies to support these research endeavours. These initiatives create knowledge, processes, methods and solutions for the minerals industry and ore deposit researchers – locally, nationally and internationally.

Research results and technical developments in the applied research programs are transferred to end-users via regular research meetings, research reports, monographs, books, digital presentations and software packages, where appropriate. In 2013, 84 research reports were presented to industry clients, and meetings were 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.

- Altered volcanic rocks: A guide to description and interpretation (2005). Authors: C Giffkins, W Herrmann and R Large (50 copies sold in 2013).
- Basins, fluids and Zn-Pb ores – CODES Special Publication 2 (1999). Editors: O Holm, J Pongratz and P McGoldrick (2 copies sold in 2013).
- Geophysical signatures of copper-gold porphyry and epithermal gold deposits, and implications for exploration (2011). Author: T Hoshke (57 copies sold in 2013).
- Giant ore deposits: Characteristics, genesis and exploration. CODES Special Publication 4 (2002). Editors: D Cooke and J Pongratz (11 copies sold in 2013).

- New developments in Broken Hill-type deposits. CODES Special Publication 1 (1996). Editors: J Pongratz and G Davidson (4 copies sold in 2013).
- Ore Geology Reviews – Special Issue (April 2007): Mineral deposits of South China. Editors: Khin Zaw, S Peters, N Cook and Z Hou (no copies sold in 2013).
- The geology and origin of Australia’s mineral deposits (2000). Authors: M Solomon and D Groves (6 copies sold in 2013).
- The geology of the Broken Hill Pb-Zn-Ag deposit, NSW, Australia (2006). Author: A Webster (3 copies sold in 2013).
- 24ct Au workshop. CODES Special Publication 5 (2004). Editors: D Cooke, C Deyell and J Pongratz (2 copies sold in 2013).
- Volcanic environments and massive sulfide deposits (2000). Editors: JB Gemmell and J Pongratz (6 copies sold in 2013).
- Volcanic textures: A guide to the interpretation of textures in volcanic rocks (1993). Authors: J McPhie, M Doyle and R Allen (71 copies sold in 2013).

COMMERCIAL PRODUCTS AND PROCESSES

Geometallurgical research in Program 4, in collaboration with JKMRc at the University of Queensland, has the potential to deliver a number of commercial outcomes for industry. Due to the commercial-in-confidence nature of this research, details of the specific outcomes cannot be released at this time.

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 17 courses were held at various locations around the world. This included venues in ten countries on six continents, including Chile and Peru in South America; Canada in North America; China, Indonesia and Myanmar in the Asia Pacific region; Eritrea in Africa, and Italy and Turkey in Europe.

Total attendance by industry geologists, academic researchers and postgraduate students was 1,047, with 16 different presenters from the CODES’ Hub involved in delivering the lectures.

TITLE	PRESENTERS	NO.	LOCATION	DATE
SWIR	Nic Jansen	10	CODES, Hobart	23 January
Mineral Deposits in SE Asia	Chun-kit Lai, Takayuki Manaka, Kenzo Sanematsu, Khin Zaw	105	Mandalay University, Myanmar	31 January
Ore Deposits of South America Short Course	David Cooke, Michael Roach	25	Chile and Peru	9–23 March
Sediment-hosted Gold Short Course	Ross Large	10	James Cook University, Townsville	1–2 June
Melt Inclusions Short Course	Leonid Danyushevsky	50	Antalya, Turkey	6 June
Geochemistry, Hydrology and Geochronology Short Course	David Cooke (Leader), Shaun Barker, Ron Berry, Phil Blevin, Graham Carr, Tony Crawford, Leonid Danyushevsky, Garry Davidson, Bruce Gemmell, Scott Halley, Ross Large, Sebastien Meffre, Nick Oliver, Jess Robertson, Lesley Wyborn, Khin Zaw	62	CODES, Hobart	24 June–5 July
Stable Isotope Geochemistry	Garry Davidson	60	CODES, Hobart	2–3 July
Geometallurgical Mapping and Mine Modelling Annual Review	Ron Berry, Dee Bradshaw, Alan Bye, Nicky Chapman, Mitesh Chauhan, Alan Cocker, Joe Cucuzza, Julie Hunt, Dave Hutchinson, John Jackson, Toni Kojovic, Vanessa Liebezeit, Paul Linton, Angus McFarlane, Khoi Nguyen, Anita Parbhakar-Fox, Hector Parra, Wayne Stange, Steve Walters	40	Boulevard Gardens, Brisbane	10–12 July
Volcanoes and Their Products Short Course	Jocelyn McPhie	15	Bisha, Eritrea	16–18 August
Iolite Workshop	Bence Paul	25	Florence, Italy	24–25 August
Understanding Alteration: Use in Exploration and Development	Andrew Davies, Melissa Gregory, Bruce Gemmell, James Lang, Anne Thompson, John Thompson	60	Whistler, BC, Canada	23–24 September
Mineral Exploration Applications of Stable Isotopes	Shaun Barker, Larry Cathles, David Cooke, Kurt Kyser, Ryan Mathur	25	Whistler, BC, Canada	27 September
Fluids in the Earth Short Course	Leonid Danyushevsky	30	Naples, Italy	14–18 October
Tectonic and Mineral Deposit Types in SE Asia	Khin Zaw	40	Naypyidaw, Myanmar	26 November
Gold (Copper) Workshop: New Development for Discovery	David Cooke, Noel White	70	Bali, Indonesia	30 November–1 December
Ore Deposit Models and Exploration	Zhaoshan Chang, Huayong Chen, Yanjing Chen, David Cooke, Rich Goldfarb, Zengqian Hou, Ruizhong Hu, Shaoyong Jiang, David Leach, Chusi Li, Jianwei Li, Jingwen Mao, Pei Ni, Steve Scott, Xieyan Song, Weidong Sun, Noel White, Yuling Xie, Taofa Zhou	270	Hefei, China	9–12 December
Tectonic and Ore Deposits of SE Asia	Khin Zaw	150	University of East Yangon, Myanmar	12 December



Drying clay sample for geochemical analysis.

PERFORMANCE INDICATORS

PERFORMANCE MEASURE	TARGET	2013
RESEARCH FINDINGS		
Publications in international journals	50pa	69
Percentage of publications in A/A* journals	70%	68%
Reports to industry collaborators	80pa	84
Special Issues and/or research monographs	1 per 2 years	1
Invitations to give keynote conference presentations	10pa	7
Papers at national/ international meetings	70pa	80
INVESTIGATORS		
Average percentage of CIs research in Centre	70%	80%
Average percentage of PIs research in Centre	15%	35%
Percentage of team-based projects	80%	85%
Percentage of Australian cross institutional projects	30%	45%
RESEARCH TRAINING AND PROFESSIONAL EDUCATION		
Percentage of RHD students attracted from interstate	40%	15%
Percentage of RHD students attracted from overseas	40%	75%
Honours students in Centre programs	10	14
RHD students in Centre programs	45	49 PhD, 4 MSc
Percentage of students in projects linked with industry	50%	70%
Professional short courses/workshops for industry	5pa	17



Participants in the Ore Deposit Models workshop, Hefei University of Technology, China.

PERFORMANCE MEASURE	TARGET	2013
INTERNATIONAL, NATIONAL AND REGIONAL LINKS AND NETWORKS		
Centre national or international conferences /workshops	1 per 2 years	1 in 2012, 0 in 2013
Registrants at Centre's conferences /workshops	100pa	1,047
International and national visitors per year	50pa	90
Collaborative projects with other global centres/groups	10pa	15
External collaborators using Centre's equipment	10pa	22
END-USER LINKS		
Frequency of meetings with industry representatives	15pa	20
End-user representatives to Science Planning Panel and Advisory Board	20% / 50%	71% / 63%
Frequency of meetings with AMIRA Research Co-ordinator	10pa	12
Number of industry visitors to Centre	80pa	46
ORGANISATIONAL SUPPORT		
Annual cash contributions from UTAS	\$1,800,000	\$1,626,301
Annual cash support from other collaborating universities & CSIRO	\$205,000	\$590,284
Annual cash support from industry	\$2,000,000	\$3,701,670
Number of new organisations recruited to or involved in the Centre	1pa	1
GOVERNANCE		
Joint post-doctoral appointments between collaborating institutions/organisations	5	6 (2 CSIRO, 1 UMelb, 3 UQ)
Balance and experience of Advisory Board members		Excellent balance
Annual review of strategic and business plans		Yes
Effectiveness of Centre Research Committee		High
Effectiveness of Science Planning Panel		High
Public profile of Centre	High	High
NATIONAL BENEFIT		
Centre research has input into a major mineral discovery	1 per 5 years	0
Employment of Centre's graduates by minerals industry	>65%	80%

FINANCES

ARC CONTRACT AND GOVERNANCE

CODES became the Australian Research Council (ARC) Centre of Excellence (CoE) in Ore Deposits on 1 July, 2005. It was formerly an ARC Special Research Centre. The CoE contract with the Australian Government covered five years' funding from 2005 to 2010. At the mid-term review in November 2008, the ARC awarded an extension of funding for the period 2010 to 2013.

The Centre's financial affairs are conducted within the established procedures, controls and delegations of the University of Tasmania (UTAS) and the CoE's node universities and institutions. CODES has a policy of assigning budget responsibility to Node and Program Leaders, which is overseen by the Director.

To ensure the ARC's CoE requirements are met, an inter-institutional agreement was established by the UTAS Research Office, formally binding all participating institutions to the ARC CoE agreement, including funding allocations from the CoE to its nodes and agreed matching contributions made by those nodes.

The tables and figures presented in the following pages demonstrate the CoE has met the income and expenditure requirements of the current agreement.

2013 INCOME

Total CODES income was \$10.5 million (see Table 1). This was derived principally from industry (35%), the ARC (29%) and UTAS (16%) (see Figure 1). The main income streams over time are compared in Figure 2, demonstrating that ARC funding was exceeded beyond the original CoE agreement of 1:1 in every year of the CoE. The most growth was recorded in the industry stream, which on its own often equalled or exceeded the ARC income in any given year.

THE COE COLLABORATOR/CONTRIBUTOR CASH INCOME AGREEMENT

The CoE funding agreement with the ARC requires that approximately \$3 million per annum ARC funding be matched, dollar for dollar, with agreed core funding from collaborators/contributors (N.B. annual ARC funding was reduced from \$3 million pa to \$2.7 million pa for the extension period, 1.7.2010 to 31.12.2013). This combined cash income is used to fund

core research projects at the Centre. It should be noted that, in total, CODES received \$37.1 million more over the life of the Centre towards CoE projects than was specified in the original agreement. This was mainly due to:

- Annual indexation of the ARC CoE Grant
- Significantly increased industry and AMIRA International funding
- Income from book sales, short courses and laboratory analyses
- Pre-existing funding from UTAS, ARC and AMIRA, which extended into the CoE period.

All collaborator/contributor funding was paid to CODES annually, in cash, with the exception of funding from the CoE nodes, which was treated differently, as detailed under the heading 'CoE node income'.

In addition to the abovementioned cash income, the CoE received a considerable amount of in-kind support from its collaborators/contributors, with UTAS providing the most substantial portion.

The following is a summary of the main income streams to the CoE in 2013:

- **ARC INCOME:** ARC income received in 2013 comprised primarily of the CoE ARC Grant (\$3.1 million), with the addition of one Discovery Grant (\$0.1 million).
- **COE NODE INCOME:** The CoE's Australian nodes comprise the University of Queensland (UQ), University of Melbourne

(U Melb), Australian National University (ANU) and CSIRO. The CoE agreement requires CODES to transfer an agreed annual portion of its ARC CoE Grant income to each of the above nodes, to be expended at the node institutions. In return, the nodes agree to match this income with an agreed value of their own funds each year. Although these matching funds are counted as income to the CoE (Table 1), they are actually held and expended at the node institutions. Expenditure of both portions of node funding has been reported annually to CODES.

During 2013, all nodes received their agreed ARC income from CODES, as well as contributing their agreed matching funds. ANU had unspent ARC and matching funds, which were returned in 2013 to CODES and ANU, respectively, at the agreed ratio. CSIRO contributed additional node matching funds, beyond what was promised in the agreement, amounting to \$0.5 million.

- **STATE GOVERNMENT INCOME:** The agreed three-year funding from the State Government of Tasmania ceased at the end of 2007.
- **INDUSTRY INCOME:** Total industry funding in 2013 was \$3.7 million, of which the largest contribution (32%) was in the Industry – pre-existing and new projects category.

While industry funding decreased significantly compared to 2012, the trend remained positive when measured against prior years. The reduction in 2013 income was due to the following factors:

- Catch-up payments were received in 2012 for two AMIRA projects, as well as the SE Asia Project, while the normal, scheduled invoicing of agreed payments resumed in 2013.
- Start-up costs were received in the initial year (2012) of the Newcrest R&D laboratory contract, which included

significant contributions to equipment and building refurbishment. Contract payments for the project reduced in the second year (2013) as per the agreement.

In 2012, it was reported that there was a shortfall in Industry Partner income caused by the late finalisation of the CoE Extension Agreement. This shortfall was mostly eliminated in 2013, with the following exceptions:

- BHP Billiton operates on a financial year budget cycle and will therefore make its final six-month contribution to the CoE in early 2014.
- Newmont was unable to pay prior contributions to the value of 1.5 years, due to a reduction in budget and a change in management.
- **HOST INSTITUTION SUPPORT:** Core cash funding from UTAS in 2013 was significantly less than in 2012 due to a change in the university's operating model. UTAS funding relates primarily to research salaries, PhD scholarships and income earned by the Centre from research output. Regardless of the decrease in cash funding from UTAS in 2013, in-kind support was provided of approximately \$2.3 million during the year.

2014 INCOME ESTIMATES

With the completion of the CoE Grant at the end of 2013, overall income to CODES is expected to decrease accordingly in 2014. While new industry projects are being negotiated, and ARC Grants, such as Discoveries, are being applied for, the size of these new projects will not immediately counteract the loss of ARC Centre funding. CODES is pursuing various avenues to ensure this decrease in income is short-lived, and does not negatively impact research and training outcomes.

Table 1
Cash income financial statement 2005–2013

	(half year) 2005	2006	2007	2008	2009	2010	2011	2012	2013
ARC - Centre of Excellence Grant									
CoE agreed core funding* – 2005 grant indexation (not received until 2006)	0	31,500	0	0	0	0	0	0	0
CoE agreed core funding* – ARC grant	1,500,000	3,121,198	3,184,402	3,248,088	3,313,864	3,097,230	2,856,123	2,966,012	3,080,126
	1,500,000	3,152,698	3,184,402	3,248,088	3,313,864	3,097,230	2,856,123	2,966,012	3,080,126
CoE nodes matching funds (agreed matching funds held at node institutions)									
CoE agreed core funding*	0	295,000	255,000	250,000	237,500	242,500	190,000	292,500	590,284
Additional funding (pre-existing or new)	0	0	0	0	0	0	0	0	0
	0	295,000	255,000	250,000	237,500	242,500	190,000	292,500	590,284
Other ARC grants									
CoE agreed core funding*	0	0	0	0	0	0	0	0	0
Additional funding (pre-existing or new)	328,791	397,325	394,338	471,524	403,889	0	106,655	103,647	93,183
	328,791	397,325	394,338	471,524	403,889	0	106,655	103,647	93,183
Other Commonwealth Government									
CoE agreed core funding*	0	0	0	0	0	0	0	0	0
Additional funding (pre-existing or new)	7,184	19,649	24,666	62,680	2,046	87,856	4,364	194,988	202,475
	7,184	19,649	24,666	62,680	2,046	87,856	4,364	194,988	202,475
State Government									
CoE agreed core funding*	200,000	200,000	200,000	0	0	0	0	0	0
Additional funding (pre-existing or new)	68,000	852	4,000	8,000	2,500	2,396	3,556	98,951	0
	268,000	200,852	204,000	8,000	2,500	2,396	3,556	98,951	0
Local Government									
CoE agreed core funding*	0	0	0	0	0	0	0	0	0
Additional funding (pre-existing or new)	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0
Industry/private									
CoE agreed core funding*	868,646	1,582,507	1,825,010	2,158,677	2,182,472	1,298,919	716,463	1,312,160	1,310,030
Additional funding (pre-existing or new)	444,803	909,552	938,913	1,487,935	2,268,323	2,117,721	2,230,995	4,734,850	2,391,640
	1,313,448	2,492,059	2,763,923	3,646,611	4,450,795	3,416,640	2,947,458	6,047,010	3,701,670
Contracts/consultancies/revenue raising									
CoE agreed core funding*	0	0	0	0	0	0	0	0	0
Additional funding (pre-existing or new)	143,787	286,675	306,743	368,160	383,012	411,097	841,397	1,137,486	1,154,904
	143,787	286,675	306,743	368,160	383,012	411,097	841,397	1,137,486	1,154,904
University of Tasmania – host institution support									
CoE agreed core funding*	343,744	1,334,728	1,147,471	1,128,759	1,430,393	2,107,854	2,366,074	2,358,330	1,626,301
Additional funding (pre-existing or new)	383,623	678,064	566,682	468,267	589,489	0	0	0	0
	727,367	2,012,792	1,714,152	1,597,026	2,019,881	2,107,854	2,366,074	2,358,330	1,626,301
Other income sources/interest									
CoE agreed core funding*	0	0	0	0	0	0	0	0	0
Additional funding (pre-existing or new)	4,348	60,006	53,000	131,585	25,147	84,795	22,726	20,113	40,200
	4,348	60,006	53,000	131,585	25,147	84,795	22,726	20,113	40,200
Total annual income	4,292,926	8,917,056	8,900,226	9,783,674	10,838,635	9,450,368	9,338,352	13,219,037	10,489,144
Grand total of all income to date	85,229,418								

* Core funding listed in the CoE agreement and matched to the ARC funds

Figure 1
Total Cash Income 2013

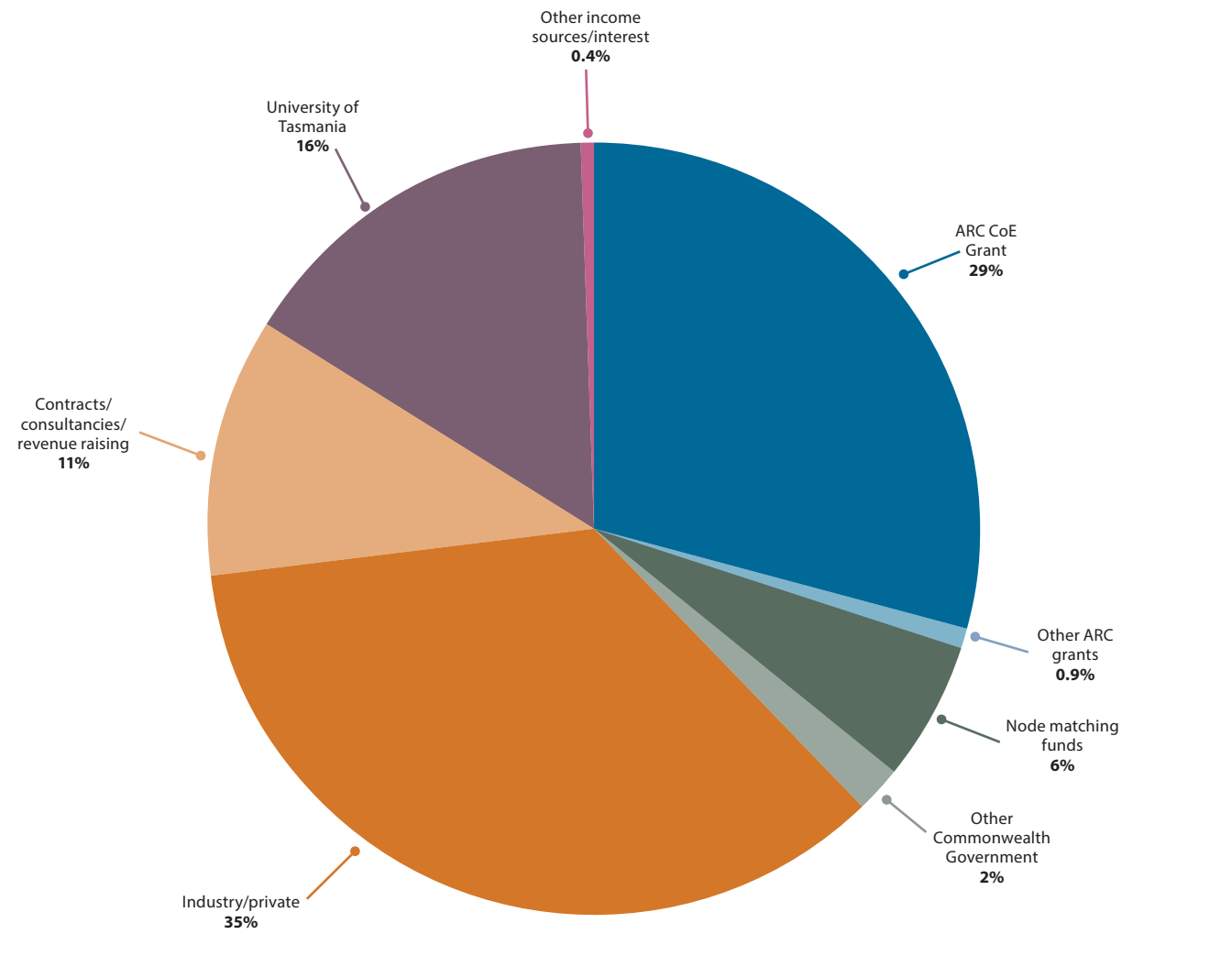
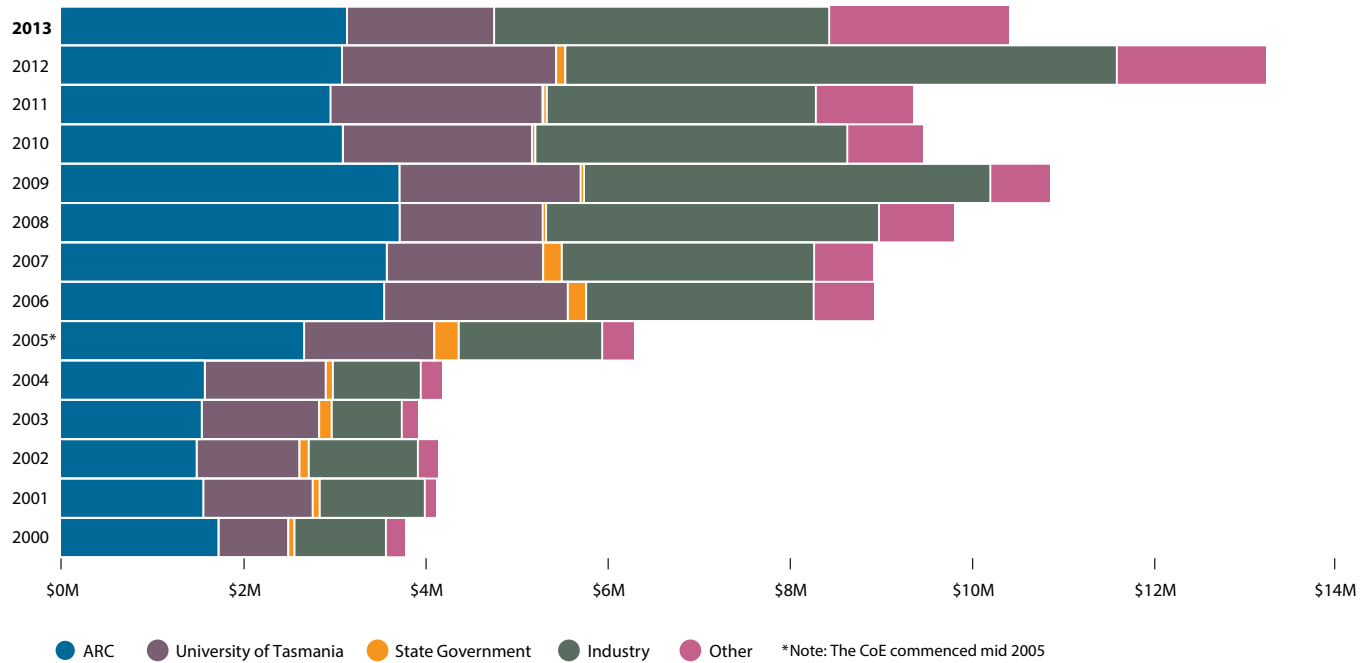


Figure 2
Comparison of CODES main income streams 2000–2013



2013 EXPENDITURE OF ARC COE GRANT

Summaries are provided in Table 2 and Figure 3 to show how CODES and its nodes have expended the ARC CoE Grant funds to date. As in past years, the major areas of expenditure in 2013 were salaries, student scholarships, laboratory analyses, and research and field travel. Most areas had similar or lower levels of expenditure when compared to 2012. However, salaries rose again due to an increase in CoE-paid research academics transitioning to new projects. Laboratory analyses also increased due to several analytically intensive projects that were run during the year.

The 2013 combined ARC CoE income and carry-forward of \$3.8 million was offset by expenditure of \$3.7 million. This leaves a carry-forward surplus of \$184k into 2014. A request has been made to the ARC for these funds to be used for final Centre wind-up costs, such as production of the 2013 CoE Annual Report and the final stages of scholarships. All node ARC fund balances were reconciled to zero at the end of 2013.

2014 EXPENDITURE ESTIMATES

The ARC CoE carry-forward amount is expected to be spent by the end of June 2014 in line with final reporting and Centre wind up costs.

NOTES TO, AND FORMING PART OF, THE FINANCIAL STATEMENTS FOR 2013

The financial pages of this Annual Report were prepared by Helen Scott (Senior Finance Officer- SET Hub). Data for the financial statements was extracted from the UTAS TechOne Financials System and CODES’ financial databases. All Financial Statements shown here have been reviewed and audited by UTAS.

INCOME STATEMENT EXPLANATIONS

The income figures in Table 1 represent actual income recorded in the University’s finance system or transferred

internally from UTAS to CODES during 2013, with the following exceptions:

- The CoE node matching funds are listed as cash income in the income statement (Table 1), but are not actually received as cash by the Centre. These matching funds, contributed by the nodes, are held and expended at the node institutions and reported annually to the CoE. They are listed as cash income in Table 1 to demonstrate that the nodes are providing their agreed annual contribution to the CoE
- \$552k of AMIRA funds, related to the P843A, P1022 and P1060 projects, were deposited into UTAS accounts, but were later transferred to research collaborators for the joint research projects. These funds will be listed as AMIRA income to those collaborators, and can therefore not be listed as income to CODES

In Table 1, sub-categories labelled ‘CoE agreed core funding’ are used to isolate core funding from other general funds. This is in accordance with the ARC requirement that the Centre demonstrates that these agreed core funds have been received each year.

Because of the six-month delay to the establishment of CODES as a CoE, very few agreed cash payments between the CoE and its nodes/collaborators were contributed in 2005. As a result, the payments for this six-month delay period were made during 2006. This has artificially inflated 2006 income

figures by approx \$400,000 (i.e. node income +\$50,000, UTAS +\$200,000, Industry Partners +\$130,000). Therefore, any comparison between 2006 and 2007 income figures needs to take this into account.

In 2008, there was a minor retrospective amendment made to the 2005 industry/private income figure, which has increased the 2005 income total by \$20,000. This relates to \$20,000 of CoE agreed 2005 income, which was paid in advance by Teck Cominco (now Teck Resources) in 2004. It has already been counted in the 2004 income statement of the SRC, but it is now listed again in the CoE’s 2005 data (in the year that it was due) to clearly demonstrate to the ARC that Teck Cominco has met its CoE funding obligations within the five-year CoE agreement period.

EXPENDITURE STATEMENT EXPLANATIONS

All expenditure categories are consistent with last year’s reports.

The expenditure financial statement and pie chart (Table 2 and Figure 3) include the following:

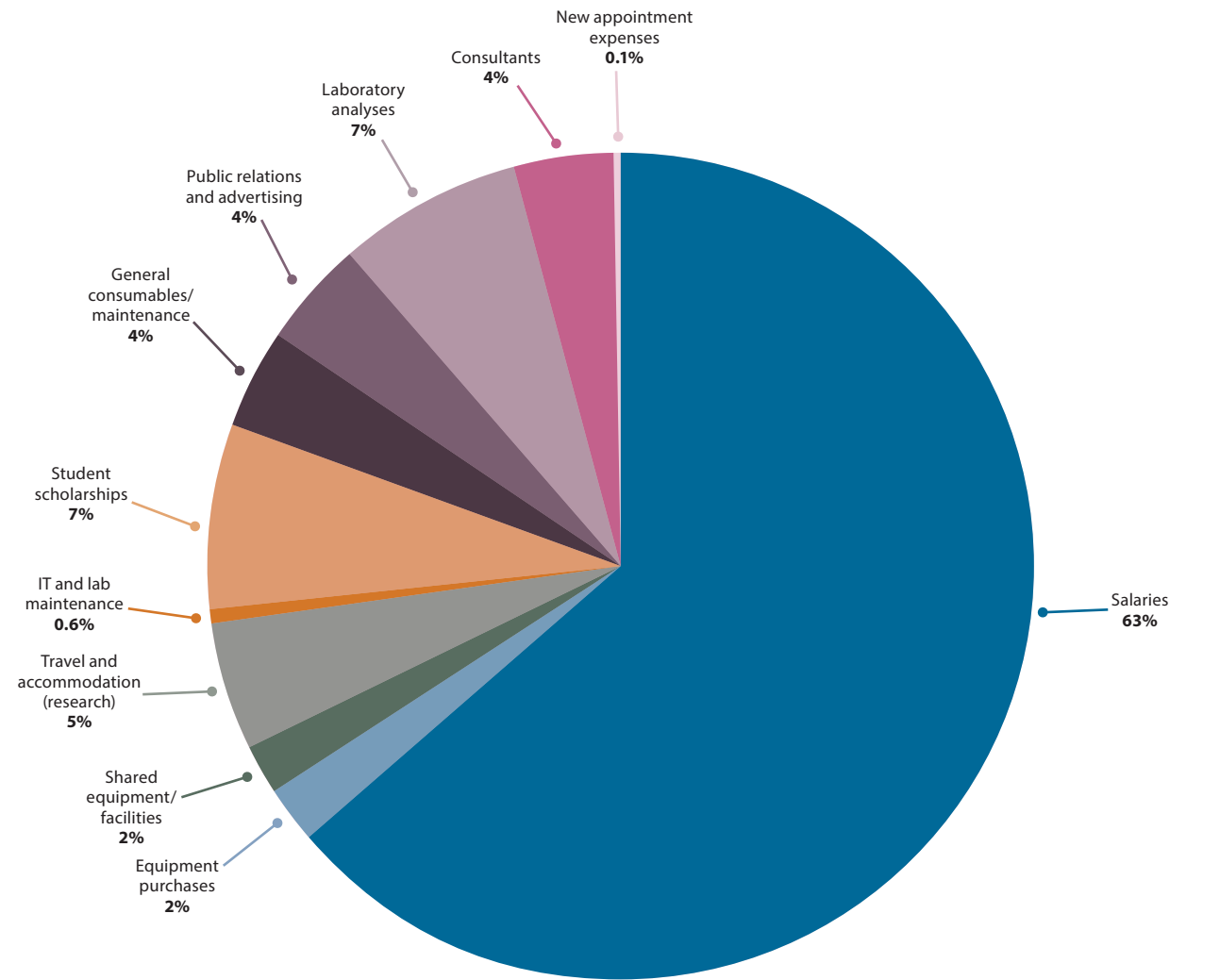
- CODES expenditure of ARC CoE Grant funds (administered by UTAS)
- The nodes’ expenditure of ARC CoE Grant funds (administered by the node institutions and reported annually to UTAS).

Table 2
Expenditure of ARC Centre of Excellence Grant 2005–2013 (CODES plus its nodes)

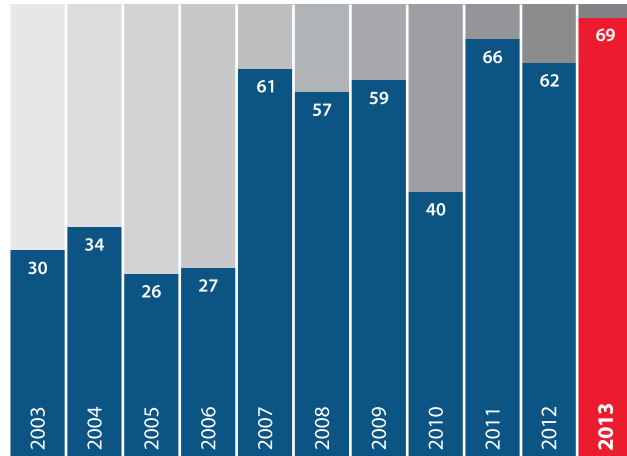
	(half year) 2005	2006	2007	2008	2009	2010	2011	2012	2013
Income									
Balance brought forward from previous year	0	954,886	1,345,188	711,979	55,741	(145,268)	372,323	652,363	755,586
Miscellaneous income (refund of expenses)	0	8,497	29,589	43,155	0	18,704	1,271	9,641	0
ARC income	1,500,000	3,152,698	3,184,402	3,248,088	3,313,864	3,097,230	2,856,123	2,966,012	3,080,126
	1,500,000	4,116,081	4,559,179	4,003,222	3,369,605	2,970,667	3,229,717	3,628,016	3,835,712
Expenditure									
Salaries	(348,511)	(1,237,351)	(1,833,309)	(2,335,312)	(1,705,835)	(1,332,826)	(1,251,890)	(1,920,821)	(2,314,316)
Equipment purchases	(890)	(83,645)	(305,991)	(70,624)	(85,292)	(35,392)	(87,855)	(68,310)	(73,200)
Equipment leased/hired	(362)	(22,635)	(6,894)	0	0	(500)	0	(280)	0
Shared equipment/facilities	(1,119)	(21,900)	(46,750)	(58,188)	(109,407)	(54,919)	(68,661)	(66,379)	(55,619)
Travel and accommodation (research)	(52,363)	(354,349)	(314,206)	(282,161)	(364,065)	(221,763)	(267,358)	(141,513)	(189,354)
IT and lab maintenance	(1,866)	(91,292)	(208,688)	(145,441)	(82,620)	(16,334)	(33,878)	(57,278)	(20,621)
Student scholarships	(31,856)	(297,768)	(349,671)	(346,311)	(384,141)	(401,617)	(387,684)	(281,100)	(266,118)
General consumables/maintenance	(67,517)	(244,347)	(217,941)	(246,561)	(199,512)	(127,799)	(169,402)	(107,361)	(155,867)
Public relations and advertising	(9,289)	(105,160)	(119,364)	(53,466)	(66,299)	(36,158)	(8,945)	(74,958)	(158,782)
Laboratory analyses	(29,900)	(212,256)	(307,733)	(288,411)	(369,447)	(247,363)	(189,124)	(179,132)	(269,972)
Consultants	0	(90,290)	(108,075)	(68,962)	(62,186)	(117,203)	(98,457)	31,384	(145,891)
Visiting academics	(9,002)	(9,900)	(19,311)	(41,665)	(61,221)	0	0	0	0
New appointment expenses	0	0	(9,267)	(10,381)	(22,523)	(5,564)	(14,101)	(624)	(2,088)
Miscellaneous	7,561	0	0	0	(2,323)	(906)	0	(6,057)	0
	(545,114)	(2,770,893)	(3,847,200)	(3,947,481)	(3,514,872)	(2,598,343)	(2,577,354)	(2,872,430)	(3,651,828)
Balance remaining at end of year	954,886	1,345,188	711,979	55,741	(145,268)	372,323	652,363	755,586	183,884

* From 2010 onwards, visiting academic expenditure is no longer itemised separately

Figure 3
Expenditure of ARC Centre of Excellence Grant 2013



2013 CODES' PUBLICATIONS



CHAPTERS IN BOOKS (2)

NAMES IN BOLD ARE AUTHORS THAT AFFILIATED THEIR ARTICLES TO CODES

Harris, A.C., **Cooke, D.R.**, Blackwell, J.L., **Fox, N.**, and **Orovan, E.A.**, 2013, Volcanotectonic setting of world-class alkali porphyry and epithermal Au ± Cu deposits of the Southwest Pacific, in Colpron, M., Bissig, T., Rusk, B.G., and Thompson, J.F.H., eds., SEG Special Publication, 17, p. 337–359.

Hollings, P., Sweet, G., **Baker, M.**, **Cooke, D.**, and Friedman, R., 2013, Tectonomagmatic controls on porphyry mineralization: Geochemical evidence from the Black Mountain Porphyry System, Philippines, in Colpron, M., Bissig, T., Rusk, B.G., and Thompson, J.F.H., eds., SEG Special Publication, 17, p. 301–335.

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Angerer, T., Hagemann, S.G., and **Danyushevsky, L.V.**, 2013, High-grade iron ore at Windarling, Yilgarn Craton: a product of syn-orogenic deformation, hypogene hydrothermal alteration and supergene modification in an Archean BIF-basalt lithostratigraphy: Mineralium Deposita, v. 48(6), p. 697–728.

Ariskin, A.A., **Danyushevsky, L.V.**, Bychkov, K.A., **McNeill, A.W.**, Barmina, G.S. and Nikolaev, G.S., 2013, Modeling solubility of Fe-Ni sulfides in basaltic magmas: The effect of nickel: Economic Geology, v. 108(8), p. 1983–2003.

Ariskin, A.A., Kostitsyn, Y.A., Konnikov, E.G., **Danyushevsky, L.V.**, **Meffre, S.**, Nikolaev, G.S., **McNeill, A.**, Kislov, E.V., and Orsoev, D.A., 2013, Geochronology of the Dovypren intrusive complex, northwestern Baikal area, Russia, in the Neoproterozoic: Geochemistry International, v. 51(11), p. 859–875.

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Repulse Gold Deposit, Australia: Economic Geology, v. 108(4), p. 667–690.

Berry, A.J., Yaxley, G.M., Hanger, B.J., Woodland, A.B., de Jonge, M.D., Howard, D.L., Paterson, D., and **Kamenetsky, V.S.**, 2013, Quantitative mapping of the oxidative effects of mantle metasomatism: Geology, v. 41(6), p. 683–686.

Burrett, C., **Zaw, K.**, **Meffre, S.**, **Lai, C.K.**, Khositanont, S., Chaodumrong, P., Udchachon, M., Ekins, S., and **Halpin, J.**, 2013, The configuration of Greater Gondwana – Evidence from LA ICPMS, U-Pb geochronology of detrital zircons from the Palaeozoic and Mesozoic of Southeast Asia and China: Gondwana Research, doi:10.1016/j.gr.2013.05.020.

Carey, R.J., Manga, M., Degruyter, W., Gonnermann, H., Swanson, D., Houghton, B., Orr, T., and Patrick, M., 2013, Convection in a volcanic conduit recorded by bubbles: Geology, v. 41(4), p. 395–398.

Chakhmouradian, A.R., Reguir, E.P., **Kamenetsky, V.S.**, Sharygin, V.V., and Golovin, A.V., 2013, Trace-element partitioning in perovskite: Implications for the geochemistry of kimberlites and other mantle-derived undersaturated rocks: Chemical Geology, v. 353, p. 112–131.

Chalot-Prat, F., Falloon, T.J., **Green, D.H.**, and William O. Hibberson, W.O., 2013, Melting of plagioclase + spinel lherzolite at low pressures (0.5 GPa): An experimental approach to the evolution of basaltic melt during mantle refertilisation at shallow depths: Lithos, v. 172–173, p. 61–80.

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Chen, W., **Kamenetsky, V.S.**, and Simonetti, A., 2013, Evidence for the alkaline nature of parental carbonatite melts at Oka complex in Canada: Nature Communications, 4, Article 2687.

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APPENDICES

NB. Please note that as this was CODES’ last year as a funded Centre of Excellence (CoE), an Activity Plan for future CoE activities is not included in this report. However, key activities for 2014 can be found in the Outlook section of each Program.

CODES POSTGRADUATE STUDENTS 2013

GRADUATE DIPLOMA OF SCIENCE (3)

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Wayne Baker^	McNeill (MRT), McPhie	The correlations and exploration significance of the Natone Volcanics, Rosebery Group, western Tasmania	MMG
John Davidson^	Whittaker (IMAS)	Magnetic anomalies in continent ocean transition zones	
Lydia Wells	Noble	Long-term assessment of the weathering characteristics of sulfide materials	CRC ORE

BACHELOR OF SCIENCE (HONOURS) (18)

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Michael Anderson	Roach	Analysis of wide angle reflection and refraction data, Mount Woods area, South Australia	OZ Minerals
Sam Arnold*	Berry, Hunt	Spatial variability of sphalerite composition in W lens, Rosebery Mine, western Tasmania	MMG
Natnaree Chandraprasert	Carey, Scott	Stratigraphy, structure and volcanology between the Mount Black Fault and the Rosebery Fault in the north-end of Rosebery Mine, western Tasmania	MMG
Andrew Clarke (ANU)	Cox (ANU)	Vein formation at Endeavour 48 porphyry Cu-Au deposit, eastern Australia	CoE
Greg Clarke^	G.Davidson, Bull	Origin of breccias in the Vulcan South IOCG prospect, Gawler Craton, South Australia	Rio Tinto
Sam Cross	G.Davidson, Fox	A geochemical assessment of the prospectivity of the Fletchers Awl region, Queensland	Signature Gold
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
Matthew Ferguson^	Crawford, Large	Mineral paragenesis and geometalurgical characteristics of the Karlawinda Deposit, Western Australia	Independence Group
Michael McGuire-Febey ⁶	McNeill (MRT), McPhie	Stratigraphy, structure and correlations of the Rosebery Group west of the Rosebery fault, Rosbery district, western Tasmania	MMG
Jacob Mulder^	Berry, Scott	The structure and metamorphism of the Cox Bight-Red Point Area, southwest Tasmania	CODES, SES, MRT
Caitlyn Officer	G.Davidson, Meffre	Stable isotope (S +/- C-O) and pyrite trace element anatomy of the Henty Gold Deposit, Tasmania, with emphasis on the zonation around the high grade Read Zone	Unity Mining
Supitchaya Paipana	Zaw, Salam	Geochemistry and mineralisation characteristics of Bo Thong antimony-gold deposit, Chonburi province, Eastern Thailand	Ore Deposits of SE Asia Project
Daniel Phythian*	Roach, Reading	Geophysical investigation of Mt. Weld carbonatite, Laverton Western Australia	Lynas Corporation
Sam Poker*	Roach, Reading	A geophysical investigation of the northern extent of the Meredith Granite, northwest Tasmania	MRT
Will Rowlands*	Roach, Reading	Petrophysical properties and geophysical response of the Benambra (VHMS) deposits, Victoria	Stockman Project
Jacqueline Rush^	Cooke, Jansen	Geology of the Marsden Cu-Au porphyry, NSW	Newcrest Mining
Vikraman Selvaraja^	Jansen, Cooke	Determining the nature and zonation of advanced argillic alteration and applying suitable geochemical exploration vectors in the Gosowong epithermal district, Indonesia	Newcrest Mining
Lauren Thomas	Scott, Halpin	Geochronology and metamorphism of the magmatic Ni-Cu Nova deposit, Albany-Fraser Range, Western Australia	Sirius Resources

MASTER OF ECONOMIC GEOLOGY (49)

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
Lynelle Beinke		coursework only	Heathgate Resources
Billy Beas Caceras	Gemmell	Petrography and mineragraphy of volcanic rocks and age dating of La Zanja Mine, Peru	Minera La Zanja SRL

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Cesar Calderon-Tipiani	Gemmell	Chanca low sulfidation deposit, Peru	Buenaventura
Wayne Carter		coursework only	Silver Lake Resources
Chloe Cavill	G.Davidson	Geochemical classification of orebearing/metalliferous fluids of the Costerfield region	Mandalay Resources
Djohanne Celiz		coursework only	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
Fumba Donzo		coursework only	Leighton Contractor
Peter Duerden	Cooke, Crawford	TBA	Alkane
Franco Ferreyra		coursework only	
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
Margaret Hawke^		coursework only	Sandfire Resources
Jonathon Hoye	TBA	TBA	Rangott Mineral Exploration
Danny Huisman		coursework only	BHP Billiton
Oliver Judd		coursework only	
Martin Kent		coursework only	Straits (Tritton Mines)
Chris Large		coursework only	Cam Bow
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
Yungu Lim^	Zaw	Geological setting and mineralisation characteristics of the Kratie North deposit, central Cambodia	Korea Resources Corporation
Esther Little		coursework only	DGR Global, Archer Resources
Chantelle Lower	Ehrig (BHPBilliton) and TBA	An aspect of the geology of the Olympic Dam deposit	BHP Billiton
Thomas Lucas		coursework only	Ivanhoe Australia
Imam Malik		coursework only	
Kane Maxwell		coursework only	Peabody Energy Australia
Rebecca McLelland	Scott	Reefton 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
Jonathan Robbeson^		coursework only	Signature Gold
Stephanie Robertson		coursework only	Inova Resources
Linda Sprigg^		coursework only	
Edward Summerhayes		coursework only	Silver Lake Resources
Nevil Vanderslink		coursework only	Arrium Mining
Peter Watson		coursework only	Gnomic Exploration Services
Yong Zhang^		coursework only	AngloGold Ashanti (Tropicana JV)
Stanley Zutah^		coursework only	Gold Fields

MASTER OF SCIENCE (4)

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Myall Hingee	Reading, Fullager (Fullagar Geophysics), Roach	Approximate Inverse Mapping (AIM) inversion of Transient Electromagnetic (TEM) data	AMIRA P1022, UTAS
Stacey Leichter [^]	Hunt, Berry	Gold deportment and geometallurgical recovery model for the La Colosa, porphyry gold deposit, Colombia	AngloGold Ashanti, GeM Project
Paula Montoya*	Berry, Hunt	Comminution studies: La Colosa case study	AngloGold Ashanti, GeM Project
Stephanie Sykora	Cooke, Selley, Jansen	The geological, geochemical and genetic significance of the anhydrite seal, Ladolam gold deposit, Lihir, PNG	Newcrest Mining, UTAS

DOCTOR OF PHILOSOPHY (49)

STUDENT	SUPERVISORS	PROJECT	SUPPORT
Mathieu Ageneau [^]	Cooke, Gemmell, Danyushevsky	Geology of the Kapit ore zone and comparative geochemistry with Minife and Lienetz ore zones, Ladolam Gold Deposit, Lihir Island, Papua New Guinea	Lihir Gold, Newcrest Mining, SEG, UTAS
Olga Apukhtina	V.Kamenetsky, McPhie, Maas (UMelb)	Stable isotopes (C, S and O) and halogens (Cl, F) in gangue and ore minerals at Olympic Dam: Evaluation of mantle and crustal contributions to mineralisation	BHP Billiton Olympic Dam, UTAS
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
Victoria Braniff [^]	Scott, Berry, Webster	Integration of geotechnical and structural data from Savage River Mine, Tasmania	Grange Resources
Ben Cave	Large, Danyushevsky	A metamorphic source for tungsten in metasedimentary-hosted orogenic gold deposits; Insights from Otago, New Zealand	UTAS, CoE
Mitesh Chauhan (JKMRC)	Napier-Munn (UQ)	Application of small scale flotation testing	GeM Project
Jing Chen	Cooke, Zhang	The geology, mineralisation, alteration and fluid evolution of Zijinshan ore field, Fujian Province, China	UTAS, Chinese Govt
Lindsey Clark [^]	Gemmell, Cooke, Micklethwaite	The geology and genesis of the Kencana epithermal Au-Ag deposit, Gosowong goldfield, Halmahera Island, Indonesia	Newcrest Mining, SEG
Gisela Cobenas Benites [^]	Danyushevsky, Falloon	The behaviour of metals during differentiation of subduction-related lavas: A case study of active submarine volcanoes on the Hunter Ridge, SW Pacific	UTAS, CoE
Matthew Cracknell*	Reading	Machine learning for geological mapping: Algorithms and applications	UTAS, CoE
Angela Escolme	Cooke, Berry, Hunt	Predicting recovery in porphyry deposits: A geological perspective	UTAS
Esmaeil Eshaghi	Reading	Petrophysical and geophysical investigation of western Tasmania	UTAS
Jodi Fox	McPhie, Carey	The volcanic history of Heard Island	UTAS, CoE
Martin Gal	Reading	The development of array methods for the analysis of on-land ambient seismic signals from deep ocean storms and coastal sources	UTAS
Victor Hugo Galván-Gutiérrez*	Cooke, Gemmell, McPhie	Palmarejo carbonate-base metal epithermal Ag-Au district, Chihuahua, Mexico	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
Daniel 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: An LA-ICP-MS study of minerals and melt inclusions from the Panzihua and Taihe intrusions in Emeishan LIP and Duluth Complex	CoE, UTAS
Margy Hawke	Gemmell, Large, Davidson	Geology of the DeGrussa VMS deposit, WA	UTAS, Sandfire Resources
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	The effect of metamorphic grade on trace element mobility in black shales	UTAS, CoE
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
Roisin Kyne*	Berry, Gemmell, Scott	Genesis and structural architecture of the CSA Cu-Ag (Pb-Zn) mine, Cobar, New South Wales	UTAS, Cobar Management

STUDENT	SUPERVISORS	PROJECT	SUPPORT
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
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	Trace element variation in Phanerozoic shale sequences in Malaysia: implications for gold metallogeny of Sibumasu terrane	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
Peter Morse	Reading, Lueg (Computing)	Combined computational and human interaction strategies in knowledge generation from spatial and spatiotemporal information	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
Abhisit Salam [^]	Zaw, Meffre, McPhie	A geological, geochemical and metallogenic study of the Chatree epithermal deposit, Phetchabun Province, central Thailand	Kingsgate Consolidated, IPRS, SEG, ARC Linkage, CoE, Ore Deposits of SE Asia Project
Lina Serrano	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
Jeffrey Steadman	Large, Bull, G.Davidson	BIFs, black shales, and gold deposits: A re-evaluation	CoE, CSIRO, Integra Mining
Nathan Steeves	Gemmell	Ore genesis of the Greens Creek VHMS Deposit, Alaska: Implications for mining, milling and exploration	Hecla Mining, UTAS
Bronto Sutopo [^]	Gemmell, Cooke	The Martabe Au-Ag high-sulfidation epithermal mineralisation in the Tapanuli Selatan district, North Sumatra Province, Indonesia: Implications for ore genesis and exploration	Newmont Mining
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

ACADEMIC AND GOVERNMENT RESEARCH
COLLABORATIONS WITH CODES IN 2013

NATIONAL COLLABORATIONS (IN ADDITION TO NODES)

INSTITUTION	RESEARCHER(S)	CODES COLLABORATOR(S)	PROJECT/RESEARCH FOCUS
ANU	Greg Yaxley, Brendon Hanger, Marc Norman, Andrew Berry	Vadim Kamenetsky	Kimberlites and flood basalts: linking primary melts with mantle and crustal sources
ANU	Trevor Ireland	Jacqueline Halpin, Ross Large	Trace elements and oxygen in the ocean through time
Australian Museum	Lin Sutherland	Sebastien Meffre	Links between tectonic setting, magmatism, basin evolution and ore deposit formation in modern and ancient settings
Australian Synchrotron	Daryl Howard, Simon James, Martin de Jonge, David Paterson, Kathryn Spiers	Chris Ryan	Synchrotron X-ray probe development
CSIRO	James Cleverley	David Cooke, Julie Hunt, Ron Berry	Iron oxide copper-gold and related deposit types
CSIRO	David Parry, Robin Kirkham, Mark Pearce	Jamie Laird	Ion beam analysis development
CSIRO	James Cleverley, Paul Dunn, Angela Halfpenny, Rob Hough, Simon James, Murray Jensen, Mel Lintern, Colin MacRae, Gareth Moorhead	Chris Ryan	Synchrotron X-ray probe development; New synchrotron-based applications
CSIRO	Naomi Clear, Craig Proctor	Leonid Danyushevsky	LA-Q-ICP-MS analysis development
Curtin University	Kliti Grice	Jacqueline Halpin, Ross Large	Trace elements and oxygen in the ocean through time
Defence Science and Technology Organisation (DSTO)	Geoff Nichols	Vadim Kamenetsky	Kimberlites and flood basalts: linking primary melts with mantle and crustal sources
DET CRC	David Giles	Sebastien Meffre	New LA-Q-ICP-MS applications
Flinders University	John Long	Jacqueline Halpin, Ross Large, Leonid Danyushevsky, Stuart Bull, Elena Lounejeva, Peter McGoldrick, Daniel Gregory	Trace elements and oxygen in the ocean through time
Geological Survey of Western Australia	Peter Haines, Arthur Hickman	Jacqueline Halpin, Ross Large	Trace elements and oxygen in the ocean through time
Geoscience Australia	David Huston	Bruce Gemmell	Low- and high-sulfidation epithermal mineral deposits
Geoscience Australia	David Huston, Terry Mernagh	Khin Zaw	Links between tectonic setting, magmatism, basin evolution and ore deposit formation in modern and ancient settings
Geoscience Australia	Roger Skirrow	Garry Davidson	Iron oxide copper-gold and related deposit types
Geoscience Australia	David Huston	Jacqueline Halpin, Ross Large	Trace elements and oxygen in the ocean through time
Macquarie University	Elena Belousova, William Griffin	Vadim Kamenetsky, Maya Kamenetsky	Kimberlites and flood basalts: linking primary melts with mantle and crustal sources
Macquarie University	Nathan Daczko	Jacqueline Halpin	Breakup of East Gondwana
Mineral Resources Tasmania	Clive Calver, John Everard	Jacqueline Halpin, Peter McGoldrick	Geochronology of the Rocky Cape Group
Mineral Resources Tasmania	Clive Calver	Jacqueline Halpin, Ross Large, Leonid Danyushevsky, Stuart Bull, Elena Lounejeva, Peter McGoldrick, Daniel Gregory	Trace elements and oxygen in the ocean through time
Monash University	Ray Cas	Jocelyn McPhie	Submarine volcanology
University of Adelaide	Joel Brugger, Barbara Etschmann	Chris Ryan	Synchrotron X-ray probe development; New synchrotron-based applications
University of Melbourne	Roland Maas, Andrea Giuliani, Mark Kendrick, John Woodhead, David Phillips	Vadim Kamenetsky	Kimberlites and flood basalts: linking primary melts with mantle and crustal sources
University of Melbourne	Roland Szymanski, Jeff McCallum	Jamie Laird	Ion beam analysis development
University of New South Wales	Ian Graham	Khin Zaw	Ore deposits of SE Asia
University of Queensland	Paulo Vasconcelos, Sue Golding	Khin Zaw	Ore deposits of SE Asia
University of Sydney	Maria Seton	Sebastien Meffre	Links between tectonic setting, magmatism, basin evolution and ore deposit formation in modern and ancient settings
University of Western Australia	Mark Barley, Lin Sutherland	Khin Zaw	Ore deposits of SE Asia

INTERNATIONAL COLLABORATIONS (IN ADDITION TO NODES)

INSTITUTION	RESEARCHER(S)	CODES COLLABORATOR(S)	PROJECT/RESEARCH FOCUS
Advanced Industrial Science Technology (AIST), Geological Survey of Japan	Kenzo Sanematsu	Khin Zaw	Ore deposits of SE Asia
BRGM, France	Pierre Maurizot	Sebastien Meffre	Links between tectonic setting, magmatism, basin evolution and ore deposit formation in modern and ancient settings
British Geological Survey	Mike Crow	Khin Zaw	Ore deposits of SE Asia
Brookhaven National Laboratory, USA	Gianluigi De Geronimo, Tony Kuczewski, Zhi Yong Li, Peter Siddons	Chris Ryan	Synchrotron X-ray probe development
Brown University, USA	Alberto Saal	Vadim Kamenetsky	The distribution of volatile and metallic elements in oceanic glasses and melt inclusions: Implications for fractional crystallisation and degassing during seafloor basaltic magmatism
Chiang Mai University, Thailand	Sampan Singharajwarapan, Phisit Limtrakun, Weerapan Srichan	Khin Zaw	Ore deposits of SE Asia
China University of Geosciences	Zhanke Li	David Cooke, Lejun Zhang	Porphyry and skarn mineralisation in China
Colorado School of Mines, USA	Murray Hitzman	Stuart Bull, David Selley	Origin and setting of Congolese-type copper deposits
Colorado School of Mines, USA	Thomas Monecke	Bruce Gemmell, Ross Large	Hydrothermal event recognition and target vectoring in volcano-sedimentary strata
Colorado State University, USA	Holly Stein	Khin Zaw	Ore deposits of SE Asia
CRPG, France	Andrey Gurenko	Leonid Danyushevsky	LA-Q-ICP-MS analysis development
Department of Geological Sciences, University of Manitoba, Canada	Mostafa Fayek	Wei Hong, David Cooke, Nathan Fox, Lejun Zhang	Efficiency of ore-forming process
Department of Mineral Resources (DMR), Thailand	Pol Chaodumrong, Somboon Khositanont	Khin Zaw	Ore deposits of SE Asia
Ehime University, Japan	Masayuki Sakakibara	Jamie Laird	New ion beam applications
ETH Zurich, Switzerland	Detlef Gunther	Leonid Danyushevsky	New LA-Q-ICP-MS applications
Geological Survey of Canada	Jan Peter	Bruce Gemmell, Ross Large	Hydrothermal event recognition and target vectoring in volcano-sedimentary strata
Geological Survey of Finland	Peter Sorjonen-Ward	Ross Large	Trace elements and oxygen in the ocean through time
Geological Survey of New Caledonia	Julien Collot	Sebastien Meffre	Links between tectonic setting, magmatism, basin evolution and ore deposit formation in modern and ancient settings
GFZ German Research Centre for Geosciences	Ilya Veksler, Jakob Keiding	Vadim Kamenetsky, Maya Kamenetsky	Kimberlites and flood basalts: linking primary melts with mantle and crustal sources
GFZ German Research Centre for Geosciences	Rainer Thomas	Paul Davidson	Melt-melt immiscibility and the origin of magnetite-apatite deposits
GNS, New Zealand	Cornel de Ronde	Bruce Gemmell	Genesis of volcanic-hosted copper-lead-zinc-silver-gold massive sulfide deposits
GNS, New Zealand	Michael Rosenberg	Rebecca Carey	Eruption dynamics
Guangzhou Institute of Geochemistry, China	Huayong Chen	Jing Chen, David Cooke, Noel White, Lejun Zhang	Porphyry and skarn mineralisation in China
Hanoi University of Mining and Geology, Vietnam	Hai Thanh Tran	Khin Zaw	Ore deposits of SE Asia
Hawaiian Volcano Observatory, USA	Michael Poland	Rebecca Carey	Basaltic explosive eruptions, Kiluaea
Hefei University of Technology, China	Taofa Zhou, Yu Fan, Shiwei Wang, Feng Yuan	David Cooke, Noel White, Lejun Zhang	Porphyry and skarn mineralisation in China
Imperial College London, UK	Jamie Wilkinson, Clara Wilkinson	David Cooke, Bruce Gemmell	Enhanced geochemical targeting in magmatic-hydrothermal systems
INGV, Catania, Italy	Daniele Andronico	Rebecca Carey	Eruption dynamics
Institut Neel and European Synchrotron Radiation Facility, France	Jean-Louis Hazemann, Denis Testemale	Chris Ryan	Synchrotron X-ray probe development
Institute of Earth Crust, Russia	Alexey Ivanov, Yulia Danilova	Vadim Kamenetsky	Kimberlites and flood basalts: linking primary melts with mantle and crustal sources
Institute of Geochemistry, Chinese Academy of Sciences	Chengbiao Leng	David Cooke, Lejun Zhang	Porphyry and skarn mineralisation in China

INSTITUTION	RESEARCHER(S)	CODES COLLABORATOR(S)	PROJECT/RESEARCH FOCUS
Institute of Geochemistry, Russia	Nadia Sushchevskaya, Vladimir Naumov	Vadim Kamenetsky	Unmixing in magmas: Melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
Institute of Geology of Ore Deposits, Petrography, Mineralogy, Russia	Vsevolod Prokofiev, Irina Andreeva	Vadim Kamenetsky	A melt inclusions pursuit into identity of carbonatite magmas and their economic potential
Institute of Mineralogy, Russia	Valery Maslennikov	Ross Large	Trace elements and oxygen in the ocean through time
Institute of Technology, Bandung, Indonesia	Andri Subandrio	Khin Zaw	Ore deposits of SE Asia
JAMSTEC, Japan	Ken Tani	Rebecca Carey, Sharon Allen, Jocelyn McPhie	Submarine volcanoes
Kagoshima University, Japan	Kazuhiko Kano	Rebecca Carey, Sharon Allen, Jocelyn McPhie	Submarine volcanoes
Lakehead University, Canada	Peter Hollings	David Cooke, Bruce Gemmell	Enhanced geochemical targeting in magmatic-hydrothermal systems
Lakehead University, Canada	Roger Mitchell	Vadim Kamenetsky	A melt inclusions pursuit into identity of carbonatite magmas and their economic potential
Lamont-Doherty Earth Observatory, USA	Enrico Bonatti, Yakov Weiss	Vadim Kamenetsky, Maya Kamenetsky	Unmixing in magmas: Melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
Leibniz Universität Hannover, Germany	Bernard Charlier	Vadim Kamenetsky, Paul Davidson	Unmixing in magmas: Melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
Max Planck Institute for Chemistry, Germany	Dmitri Kuzmin	Vadim Kamenetsky, Maya Kamenetsky	Kimberlites and flood basalts: linking primary melts with mantle and crustal sources
McGill University, Canada	Olga Vasyukova	Vadim Kamenetsky	Felsic magmas in volcanic arcs and intraplate volcanic provinces – eruption style, degassing processes, fluid evolution and links to mineralisation
MDRU, University of British Columbia, Canada	Thomas Bissig	David Cooke	Shallow and deep-level alkalic mineral deposits
Memorial University, Canada	Steve Piercy	Bruce Gemmell, Ross Large	Hydrothermal event recognition and target vectoring in volcano-sedimentary strata
Moscow State University, Russia	Pavel Plechov	Leonid Danyushevsky	Modelling of crystallisation and melting processes
Muroran Institute of Technology, Japan	Yoshi Goto	Jocelyn McPhie	Pillow lavas
Nanyang Technological University, Singapore	Chris Newall, Marina Belousova, Alexander Belousova	Khin Zaw	Ore deposits of SE Asia
National Oceanography Centre, UK	Martin Jutzeler	Jocelyn McPhie, Sharon Allen	Submarine explosive eruptions and facies
National University of Singapore	Grahame Oliver	Khin Zaw	Ore deposits of SE Asia
Natural History Museum, UK	Richard Herrington	Ross Large	Trace elements and oxygen in the ocean through time
Natural Science Museum, UK	Jamie Wilkinson	Jamie Laird	New ion beam applications
Nuclear Regulatory Authority, USA	Stephen Self	Jocelyn McPhie, Rebecca Carey, Sharon Allen	Explosive eruptions and volatiles
Piton De La Fournaise Observatory, Reunion	Andrea Di Muro	Rebecca Carey, Jocelyn McPhie	Piton de la Fournaise explosive eruptions
Queen's University, Canada	Dan Layton-Matthews	Bruce Gemmell, Ross Large	Hydrothermal event recognition and target vectoring in volcano-sedimentary strata
Royal Holloway University of London, UK	Ian Watkinson	Khin Zaw	Ore deposits of SE Asia
Russian Academy of Science	Valeriy Maslennikov	Jacqueline Halpin, Ross Large, Leonid Danyushevsky, Stuart Bull, Elena Lounejeva, Peter McGoldrick, Daniel Gregory	Trace elements and oxygen in the ocean through time
Smithsonian Institution, USA	Richard Fiske	Rebecca Carey, Sharon Allen, Jocelyn McPhie	Submarine volcanoes
St Petersburg State University, Russia	Anatoly Zaitsev	Vadim Kamenetsky	A melt inclusions pursuit into identity of carbonatite magmas and their economic potential
Universidad Catolica del Norte, Chile	Hans Niemeyer	Sebastien Meffre	Links between tectonic setting, magmatism, basin evolution and ore deposit formation in modern and ancient settings
Universiti Kebangsaan, Malaysia	Mohd Rozi Umor, Wan Fuad Wan Hassan	Khin Zaw	Ore deposits of SE Asia

INSTITUTION	RESEARCHER(S)	CODES COLLABORATOR(S)	PROJECT/RESEARCH FOCUS
University College of Science, Iran	Mirsaleh Mirmohammadi	Paul Davidson	Melt-melt immiscibility and the origin of magnetite-apatite deposits (Qareaghaj study)
University of Barcelona, Spain	Amaia Castellano, Marc Campeny, Joan Carles Melgarejo	Vadim Kamenetsky	A melt inclusions pursuit into identity of carbonatite magmas and their economic potential
University of Bonn, Germany	Chris Ballhaus, Raul Fonseca, Alexander Hauser	Vadim Kamenetsky	Unmixing in magmas: Melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
University of Bremen, Germany	Wolfgang Bach, Janis Thal	Sharon Allen	North Su volcano, PACMANUS Hydrothermal Vent Field
University of British Columbia, Canada	Jim Mortensen	Bruce Gemmell, Andrew McNeill	Genesis of volcanic-hosted copper-lead-zinc-silver-gold massive sulfide deposits
University of California Riverside, USA	Tim Lyons	Jacqueline Halpin, Ross Large, Leonid Danyushevsky, Stuart Bull, Elena Lounejeva, Peter McGoldrick, Dan Gregory	Trace elements and oxygen in the ocean through time
University of California Riverside, USA	Tim Lyons	Peter McGoldrick	Proterozoic ocean redox evolution
University of Canterbury, New Zealand	Hamish Cattell, Jim Cole	Sharon Allen	Sublacustrine volcanism of the Middle Huka Falls Formation, TVZ
University of Central Missouri, USA	John L. Nold, Mark Dudley	Paul Davidson	Melt-melt immiscibility and the origin of magnetite-apatite deposits (Pilot Knob iron oxide orebody study)
University of Hawaii, USA	Bruce Houghton	Rebecca Carey	Eruption dynamics
University of Johannesburg, South Africa	Andrea Agangi	Vadim Kamenetsky, Jocelyn McPhie	Felsic magmas in volcanic arcs and intraplate volcanic provinces – eruption style, degassing processes, fluid evolution and links to mineralisation
University of Johannesburg, South Africa	Nic Beukes, Bradley Guy	Ross Large	Links between tectonic setting, magmatism, basin evolution and ore deposit formation in modern and ancient settings
University of Köln, Germany	Maria Kirchenbaur, Carsten Münker	Vadim Kamenetsky	The supergiant Olympic Dam uranium-copper-gold rare earth element ore deposit: towards a new genetic model
University of Lisbon, Portugal	Jorge Relvas, Carlos Rosa	Jocelyn McPhie	Submarine volcanology, Iberian Pyrite Belt
University of Malaya, Malaysia	Azman Ghandi, Teh Guan Hoe	Khin Zaw	Ore deposits of SE Asia
University of Manitoba, Canada	Anton Chakhmouradian, Ekaterina Reguir	Vadim Kamenetsky	Kimberlites and flood basalts: linking primary melts with mantle and crustal sources
University of Missouri, USA	Ray Coveney	Ross Large	Trace elements in the ocean
University of New Caledonia	Dominique Cluzel	Sebastien Meffre	Links between tectonic setting, magmatism, basin evolution and ore deposit formation in modern and ancient settings
University of Notre Dame, USA	Wei Chen, Tony Simonetti	Vadim Kamenetsky	A melt inclusions pursuit into identity of carbonatite magmas and their economic potential
University of Oregon, USA	Paul Wallace, Ilya Bindeman	Vadim Kamenetsky	The distribution of volatile and metallic elements in oceanic glasses and melt inclusions: Implications for fractional crystallisation and degassing during seafloor basaltic magmatism
University of Otago, New Zealand	James White	Jocelyn McPhie	Seafloor lavas
University of Ottawa, Canada	Mark Hannington	Bruce Gemmell, Ross Large	Hydrothermal event recognition and target vectoring in volcano-sedimentary strata
University of Oulu, Finland	Eero Hanski	Vadim Kamenetsky	Kimberlites and flood basalts: linking primary melts with mantle and crustal sources
University of Oxford, UK	Kate Kiseeva	Vadim Kamenetsky	A melt inclusions pursuit into identity of carbonatite magmas and their economic potential
University of Padjadjaran, Bandung, Indonesia	Mega Rosana	Khin Zaw	Ore deposits of SE Asia
University of Padova, Italy	Andrea Marzoli, Lina Serrano	Vadim Kamenetsky, Jocelyn McPhie	Felsic magmas in volcanic arcs and intraplate volcanic provinces – eruption style, degassing processes, fluid evolution and links to mineralisation

INSTITUTION	RESEARCHER(S)	CODES COLLABORATOR(S)	PROJECT/RESEARCH FOCUS
University of Pisa, Italy	Paolo Fulignati, Paola Marianelli	Vadim Kamenetsky	Unmixing in magmas: Melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
University of Science and Technology, China	Yuling Xie	Paul Davidson	Melt-melt immiscibility and the origin of magnetite-apatite deposits (Fanshan magnetite-apatite study)
University of Witwatersrand, South Africa	Rais Latypov	Vadim Kamenetsky	Kimberlites and flood basalts: linking primary melts with mantle and crustal sources
Victoria University of Wellington, New Zealand	John Creech	Bence Paul, Janet Hergt	New stable isotope MS applications
VS Sobolev Institute of Geology and Mineralogy, Russia	Victor Sharygin, Alexander Golovin, Lyudmila Zhitova	Vadim Kamenetsky, Maya Kamenetsky	Kimberlites and flood basalts: linking primary melts with mantle and crustal sources
VS Sobolev Institute of Geology and Mineralogy, Russia	Sergei Smirnov	Vadim Kamenetsky, Ross Large	Phase and chemical composition of high-temperature hydrothermal systems undergoing interaction between silicate rocks/magmas and aqueous fluid
Woods Hole Oceanographic Institution, USA	Noumichi Shimizu	Leonid Danyushevsky	New LA-Q-ICP-MS applications
Yale University, USA	Noah Planavsky	Peter McGoldrick	Proterozoic ocean redox evolution
Yukon Geological Survey, Canada	Patrick Sack	Jacqueline Halpin, Ross Large, Leonid Danyushevsky, Stuart Bull, Elena Lounejeva, Peter McGoldrick, Daniel Gregory	Trace elements and oxygen in the ocean through time



Opposite: Karin Orth demonstrating to student Aukje Benedictus during the Master of Economic Geology Geometallurgy short course.

MAJOR EXTERNALLY FUNDED RESEARCH PROJECTS*

AMIRA-ARC CENTRE OF EXCELLENCE PROJECTS 2013†

INVESTIGATORS	PROJECT	INDUSTRY PARTNERS	PERIOD	COE-ARC FUNDING FOR 2013	AMIRA FUNDING FOR 2013	MISC FUNDING FOR 2013	ADDITIONAL FUNDING FOR 2013	CASE STUDY FUNDING FOR 2013
Berry, Hunt, Lottermoser, Nguyen ¹ , Bradshaw ¹ , Keeney ¹ , Kojovic ¹ , Cocker ¹ , Robinson (CSIRO), Kuhar (CSIRO), P.Walters ¹ , S.Walters ¹ (¹ UQ-SMI)	AMIRA P843A. GeM Geometallurgical Mapping and Mine Modelling (extension)	Anglo American, AngloGold Ashanti, ALS, Barrick Gold, BHP Billiton, Boliden, Codelco, Datamine, Gold Fields, ioGlobal, Metso, Minera San Cristobal, MMG, Newcrest Mining, OZ Minerals, Quantitative Geoscience, Rio Tinto, Teck, Vale Inco, Xstrata Copper/Mt Isa Mines	2009–2013	\$250,000	\$649,651	\$0	\$305,431 (Parker Centre)	\$52,865
Cooke, Gemmell, Baker, White, Fox, Zhang, Thompson, Lounejeva, 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	\$150,000	\$968,000	\$24,487	\$40,000 (Lakehead University)	
Roach, Schaa, Fullagar (Fullagar Geophysics)	AMIRA P1022. The applied rapid constrained inversion of TEM data	AngloGold Ashanti, Gold Fields Australia, Rio Tinto, Mira Geoscience	2010–2013	\$0	\$108,000	\$2,000	\$0	
Large, Thomas, Bull, Meffre, Danyushevsky, Scott, Davidson	AMIRA P1041. Application of new technologies to gold deposits	AngloGold Ashanti, Newcrest Mining, Newmont Mining, G-Resources, Issara Mining, Sipa Resources	2010–2013	\$0	\$39,400	\$0	\$0	

ARC DISCOVERY GRANTS 2013^

INVESTIGATOR	PROJECT	PERIOD	ARC FUNDING FOR 2013	MISC FUNDING FOR 2013
Carey	Submarine volcanoes: degassing of silicic magma with implications for ascent and eruption processes	2011–2014	\$93,183	\$0

INDUSTRY AND OTHER EXTERNALLY FUNDED RESEARCH GRANTS 2013

INVESTIGATORS	PROJECT	FUNDING BODY	PERIOD	FUNDING FOR 2013	MISC FUNDING FOR 2013
Khin Zaw, Salam, Large, Burrett, Lai, Khositanont (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	\$450,000	\$0
Large, Danyushevsky	Research and development in mineral deportment and exploration	Newcrest Mining Limited	2012–2016	\$330,000	\$0
Cooke, Jansen, Selley, Harris (Newcrest)	Exploring the porphyry environment	Newcrest Mining Limited	July 2009–2016	\$322,554	\$1,428
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	\$249,996	\$0
Orth	Carson Volcanics-Hart Dolerite Large Igneous Province project	Geological Survey of Western Australia	2012–2014	\$81,475	\$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
G.Davidson	Geochemical controls on gold, Sunrise Dam (extension)	AngloGold Ashanti Australia Ltd	2012–2013	\$40,000	\$361
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	\$35,000	\$0

INVESTIGATORS	PROJECT	FUNDING BODY	PERIOD	FUNDING FOR 2013	MISC FUNDING FOR 2013
Scott, Berry, Braniff (student)	The structure and deformational history of the Savage River magnetite orebodies and host rocks, NW Tasmania	Grange Resources (formerly Australian Bulk Minerals)	2008–2013	\$27,500	\$0
Meffre	Toward at site whole rock LA-ICPMS analyses	Deep Exploration Technologies CRC	2012–2013	\$25,000	\$0
G.Davidson, Fox, Cross (student)	A geochemical assessment of the prospectivity of the Fletchers Awl region, Queensland	Signature Gold	2013	\$17,208	\$0
Sanematsu (visitor)	Granite geochemistry and related REE deposits in Southeast Asia	Japan Society for the Promotion of Science	2013–2015	\$10,000	\$0
G.Davidson, Meffre, Officer (student)	Stable isotope (S +/- C-O) and pyrite trace element anatomy of the Henty Gold Deposit, Tasmania, with emphasis on the zonation around the high grade Read Zone	Unity Mining	2013	\$9,905	\$0
Scott, Halpin, Thomas (student)	Geochronology and metamorphism of the magmatic Ni-Cu Nova deposit, Albany-Fraser Range, WA	Sirius Resources	2013	\$7,000	\$0
Berry, Hunt, Arnold (student)	Spatial variability of sphalerite composition in W lens, Rosebery Mine, Western Tasmania	MMG Australia	2013	\$6,000	\$0
Carey, Scott, Chadraprasert (student)	Stratigraphy, structure and volcanology between the Mount Black Fault and the Rosebery Fault in the north-end of Rosebery Mine, Western Tasmania	MMG Exploration	2013–2014	\$5,100	\$0
Gemmell, Calderon-Tipiani (student)	Chanca low sulfidation deposit, Peru	Buenaventura	2012–2014	\$5,000	\$0
G.Davidson, Cavill (student)	Geochemical classification of orebearing/metalliferous fluids of the Costerfield region	Mandalay Resources	2013	\$5,000	\$0
Roach, Reading, Phythian (student)	Geophysical investigation of Mt. Weld carbonatite, Laverton Western Australia	Lynas Corporation	2013	\$4,000	\$282
Roach, Reading, Rowlands (student)	Petrophysical properties and geophysical response of the Benambra (VHMS) deposits, Victoria	Stockman Project	2013	\$4,000	\$0
Berry, Gemmell, Scott, Kyne (student)	Structural controls on mineralisation, including sulfide mineralogy, at the CSA mine, Cobar NSW	Cobar Management Pty Ltd	2009–2013	**	\$1,000
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
Gemmell, Large, Wu (student)	Volcanic hosted massive sulphide deposits of the Que-Hellyer Volcanics, western Tasmania	Bass Metals	2010–2013	**	\$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
Reading, Bombardieri	A geophysical investigation of western Tasmania	Mineral Resources Tasmania	2012–2014	**	\$0
Crawford, Large, Ferguson (student)	Mineral paragenesis and geometallurgical characteristics of the Karlawinda deposit, WA	Independence Group NL	2012–2013	**	\$0

* Projects with greater than \$2,000 external (non-CoE-ARC) funding per year
† ARC funding for these projects comes from the CoE-ARC Grant
^ ARC funding for these projects comes directly from the ARC Discovery or Linkage programs
** All project funding received, project still active

VISITORS TO CODES 2013

INDUSTRY VISITORS

NAME	INSTITUTION
Ben Ackerman	Newcrest Mining
Paul Agnew	Rio Tinto
Conrad Alderton	G-Resources Group
Debora Araujo	Rio Tinto
Steve Beresford	First Quantum Minerals
Jeffrey Bigelow	Newmont
Dave Braxton	Anglo American
Paul Burrell	MMG
Dean Collett	Newcrest Mining
Paul Cromie	Anglo American
Ken Cross	Menninnie Metals
Joe Cucuzza	AMIRA International
Iain Dalrymple	Teck Resources
Andrew Davies	Teck Resources
Cathryn Dickins	St Barbara
Mary Doherty	Newmont Mining
Kathy Ehrig	BHP Billiton
David First	Freeport McMoRan Australasia
Nicholas Fitzpatrick	Newcrest Mining
Fred Fryer	Agilent Technologies
Hannah Goswell	First Quantum Minerals
Joshua Greene	Newcrest Mining
Scott Halley	Mineral Mapping
Anthony Harris	Newcrest Mining

NAME	INSTITUTION
Zaidi Harun	Monument Mining
John Holliday	Consultant
Raul Hollinger	Unity Mining
Tony Hope	GHD
Rohan King	GHD
Toni Kojovic	Simsage
Gerhard Krummei	Maydena Sands
Richard Malysiak	BHP Billiton
Toshiaki Matsuda	Agilent Technologies
Robert Moye	Consultant
Ashley Norris	Norris Software
Nick Oliver	HCO Associates
Javier Ortuzar	Anglo American
Aubrey Paverd	Buenaventura
Adele Seymon	AMIRA International
Trevor Shaw	Glencore Xstrata
Michael Shelley	Laurin Technic
Nick Smith	OZ Minerals
Kathryn Stewart	Newcrest Mining
Steve Turner	Newmont Exploration
Mario Valdez	BHP Billiton
Mike Whitbread	MMG

INTERNATIONAL ACADEMIC AND GOVERNMENT VISITORS

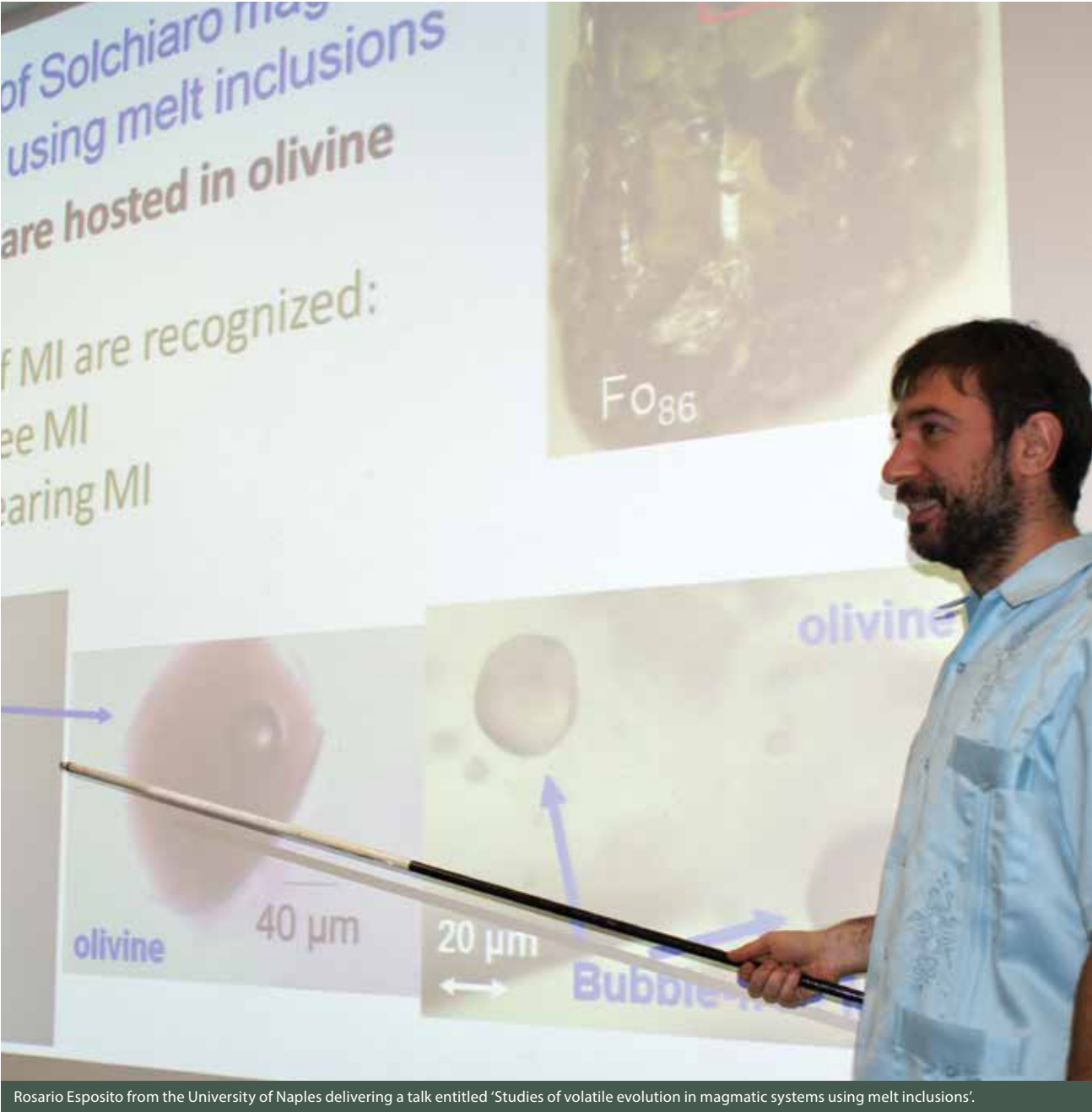
NAME	INSTITUTION
Andrea Agangi	University of Johannesburg, South Africa
Shaun Barker	University of Waikato, New Zealand
Marc Campeny	University of Barcelona, Spain
Amaia Castellano	University of Barcelona, Spain
Julien Collot	Geological Survey of New Caledonia
Rosario Esposito	University of Naples, Italy
Fang Feng Hu	Chinese Academy of Sciences
Martin Jutzeler	University of Otago, New Zealand
Kate Kiseeva	University of Oxford, UK
Chengbiao Leng	Chinese Academy of Sciences
Zhanke Li	China University of Geosciences

NAME	INSTITUTION
Fabre Maud	Geological Survey of New Caledonia
Martin Patriat	IFREMER, New Caledonia
Pavel Plechov	Moscow State University, Russia
Hong Rei Fan	Chinese Academy of Sciences
Masayuki Sakakibara	Ehime University, Japan
Kenzo Sanematsu	Geological Survey of Japan
Stephen Self	Nuclear Regulatory Commission, USA
Lina Serrano	University of Padova, Italy
Wenyan Sun	China University of Geosciences
Hongzuo Wang	Nanjing University, China
Allan Wilson	University of the Witwatersrand, South Africa

NATIONAL ACADEMIC AND GOVERNMENT VISITORS

NAME	INSTITUTION
Phil Blevin	Geological Survey of NSW
Dee Bradshaw	JKMRC, University of Queensland
Graham Carr	CSIRO
Ray Cas	Monash University
Naomi Clear	CSIRO
Stephen Cox	Australian National University
Kim Creak	Mineral Resources Tasmania
Nathan Daczko	Macquarie University
Andrea Giuliani	University of Melbourne
David Green	Mineral Resources Tasmania
Paul Heithersay	DMITRE-Geological Survey of SA
Mark Kendrick	University of Melbourne

NAME	INSTITUTION
Robin Kirkham	CSIRO
Roland Maas	University of Melbourne
Andrew McNeill	Mineral Resources Tasmania
Geoff Nichols	DSTO
Mark Pearce	CSIRO
Craig Proctor	CSIRO
Jess Robertson	CSIRO
Wayne Stange	JKMRC, University of Queensland
Lesley Wyborn	Geoscience Australia
Greg Yaxley	Australian National University



Rosario Esposito from the University of Naples delivering a talk entitled ‘Studies of volatile evolution in magmatic systems using melt inclusions’.

CODES

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