

# CODES

ARC CENTRE OF EXCELLENCE IN ORE DEPOSITS

# ANNUAL REPORT

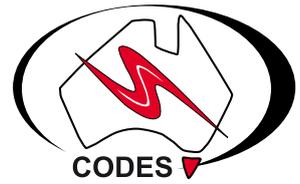
2011



Australian Government  
Australian Research Council



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# CODES

ARC CENTRE OF EXCELLENCE IN ORE DEPOSITS

# ANNUAL REPORT 2011

CODES  
ARC Centre of Excellence in Ore Deposits  
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ISSN 1440-6411  
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## Vision

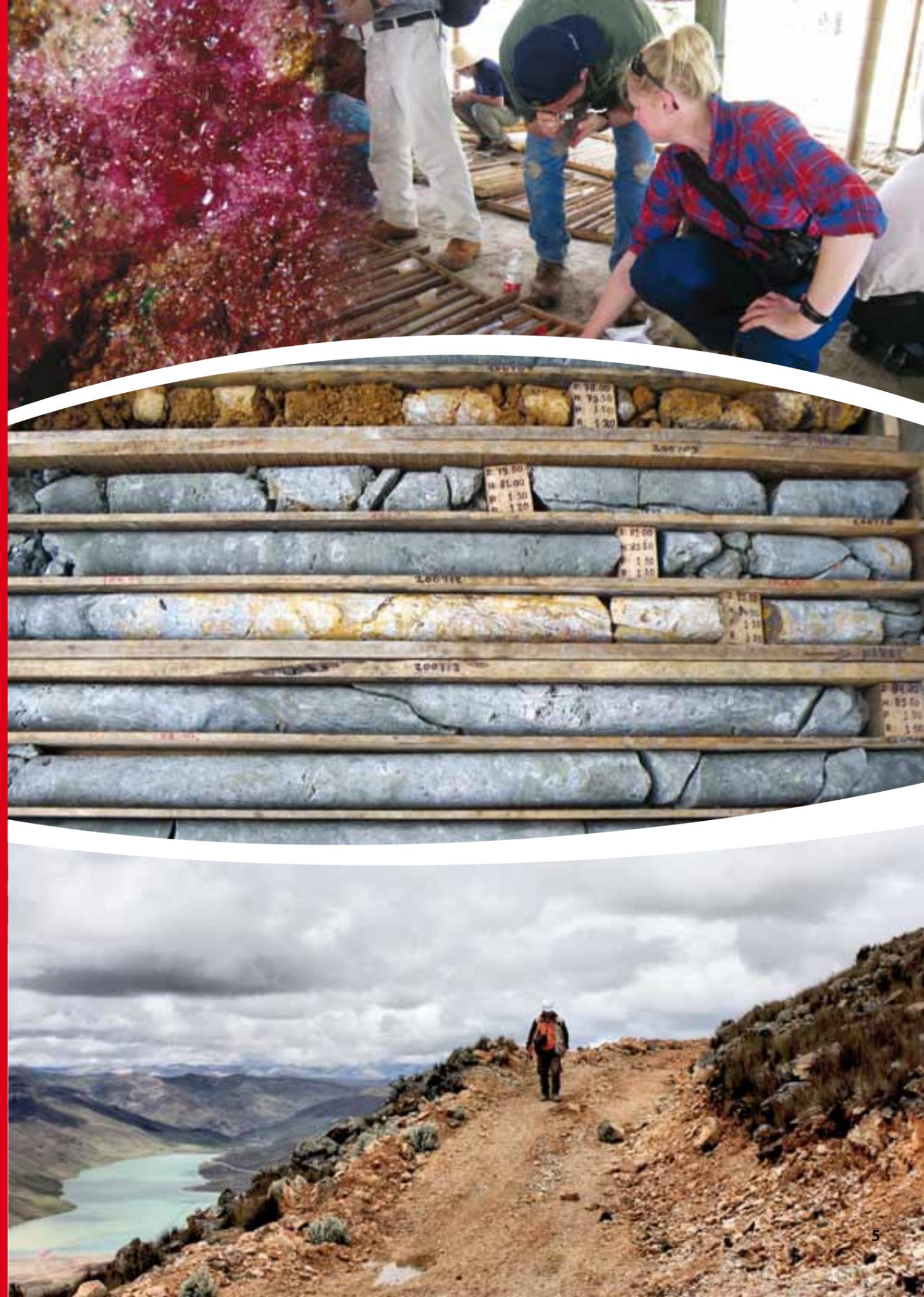
To be the premier international research centre in ore deposit geology.

## 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.



# Director's Report



ROSS R LARGE  
DIRECTOR AND CHIEF OPERATIONS OFFICER

Although there have been one or two disappointments in 2011, overall it has been another highly productive year that has produced successful outcomes in a variety of key areas.

CODES has built a reputation for fostering highly productive collaborations with its peers from the world's leading universities and institutes. These joint research initiatives have brought a host of groundbreaking findings over the years, and the past twelve months has seen that trend continue:

- » Research conducted by Dr Peter McGoldrick in collaboration with the University of California Riverside, the Chinese University of Geosciences and the University of Manitoba has revealed that the ancient deep ocean was not only devoid of oxygen but also rich in iron - a key biological nutrient - for nearly a billion years longer than previously thought. The results have been published in *Nature*.
- » Research Fellow, Dr Jacqui Halpin, was a primary investigator in a team that mapped the poorly understood Perth Abyssal Plain. During its voyage on the RV *Southern Surveyor*, the team found two plateaus that are believed to be remnants of the ancient Gondwana supercontinent. In addition to Jacqui, the team included staff from Sydney and Macquarie universities, plus international researchers.
- » Our collaboration with Professor Valeriy Maslennikov, from the Urals Branch of the Russian Institute of Mineralogy, has continued a very fruitful exchange of Western and Russian theories on ore genesis, leading to the production of an alternative model for the genesis of orogenic and Carlin-type gold deposits.

Our research success also manifested itself through a very good year in terms of publications output. The Centre had 66 papers published in refereed international journals during the year, which is well above our benchmark figure of 50, set by the ARC. Notable amongst these publications was a Special Issue of *Economic Geology* covering a series of papers on our collaborative international project with UBC MDRU on shallow and deep-level alkalic mineral deposits, which was led by Professors David Cooke and Dick Tosdal.

This year's publication figure is particularly pleasing for a Centre such as CODES, which has a high level of industry-focussed research activities. Therefore, it is also satisfying to report that, even with this relatively high publications figure, we also maintained a high level of output in terms of technology

transfer. During the year, we produced 166 reports to industry and conducted 29 workshops and short courses in 15 countries - spread across five continents. Our links to industry were further strengthened with the addition of Drummond Gold as one of our Corporate Partners, which now total 11.

A number of industry-linked projects were started, extended or enhanced over the period:

- » The AMIRA P1060 project commenced in June building on research carried out within AMIRA P765A, often referred to as the explorer's toolbox for porphyry and epithermal districts. The new project has the support of 21 industry sponsors and funding of over \$3 million, making it the largest exploration-based research project in AMIRA's history.
- » The two new industry-funded extension projects, Ore Deposits of South East Asia and Volcanic Architecture of Olympic Dam, got underway during the year, and these are also building on the successes of their precursor projects.
- » The AMIRA geometallurgy project, (P843A) GeM<sup>III</sup>, continued to build momentum, gaining a number of new major industry sponsors in Gold Fields, Boliden and MMG.
- » The embedded research activities at Newcrest in 'Exploring the Porphyry Environment' project have led to the uptake of CODES' research outcomes in exploration, and helped the company to advance mineral projects at several of its world class deposits.
- » An AngloGold Ashanti funded case study (in AMIRA P1041) on pyrite in the Carbon Leader Reef, Witwatersrand Basin, has made a significant impact on understanding gold-forming processes in the reef.

It was also a year which resulted in a number of awards and honours for our staff. I was pleased to see that Associate Professor Khin Zaw's input to the Asia Oceania Geological Society (AOGS) was rewarded with his election as President of its Solid Earth Section. This is an important role within the society, which has the most members of any geoscience organisation in the region. Professor Tony Crawford was elected a Fellow of the Geological Society of Australia (GSA). This is a prestigious honour, awarded to only a select number of eminent geologists.

It was also an excellent year for our HDR research activities. Fourteen students had their theses under examination, seven of whom graduated. Fifty students were enrolled on the program, which included 39 international students from 22 countries. However, while we are pleased with our ability to attract students from around the world, it remains a concern that there are not more Australian geoscientists pursuing postgraduate studies - although, the lure of attractive employment opportunities in the mining industry remains a mitigating factor. Four new PhD students commenced this year, and all were from overseas.

The Master of Economic Geology Program went through a challenging year, with a change of leadership and an announcement of a future cut-back in funding. Dr Tony Webster, who had done a fine job in building the program in recent years, left to take up a job in industry at the end of July.

However, we were fortunate to find a very worthy successor in Dr Rob Scott, who has been with us for 12 years as a Research Fellow, and also has a strong track record working in industry and other academic institutions. Late in the year, the Minerals Council of Australia (MCA) announced that it will cease its financial support for the program at the end of 2012. We were very disappointed with this announcement because its financial support has been critical to the development and management of this successful and industry-focussed program. While their support to date has been very much appreciated, there is no doubt that this decision presents major challenges for the program in the years ahead. Notwithstanding future challenges, enrolments in the program continued to grow during the year, with a strong participation figure of 44 active students, including eight new enrolments.

In 2011, CODES submitted a bid to become a CRC, which was ultimately unsuccessful. While that outcome was disappointing at the time, the bid has proved to be a catalyst that has allowed us to fine-tune our strategic plans and focus more on our strengths. The comprehensive CRC application process helped us realise that in any future plans we need to retain the core attributes on which our success has been built. It became evident that CODES would not fit into the narrower focus of the CRC model, unless we made substantial changes to our successful research structure; and any future CRC bid would be futile unless such changes were made. Subsequent feedback from our industry partners confirmed that they would not be happy if the core attributes on which the Centre was built were substantially changed.

As a result we have adjusted our plan, moving away from the CRC model and pursuing a way forward that builds on our strengths, while ensuring that we adapt and evolve to meet the changing needs of industry and our other stakeholders. A number of avenues are being pursued in this regard, but it would be premature to report on those in any detail at this stage. However, areas being examined are further developments in our LA-ICP-MS facility, expansion of our team of world-class researchers, and continued expansion of our collaborations with industry, both in the areas of exploration and geometallurgy. I look forward to reporting about those developments in more detail in 2012.

A handwritten signature in black ink, appearing to read 'Ross R Large', with a horizontal line extending to the right.

# Outcome-driven Research

~ BUILT ON STRONG TEAMWORK AND WORLDWIDE COLLABORATIONS

## OVERVIEW

CODES is the Australian Research Council Centre of Excellence in Ore Deposits, based at the University of Tasmania. Formed in 1989, the Centre has grown substantially over the years and is now widely regarded as a global leader in ore deposit research.

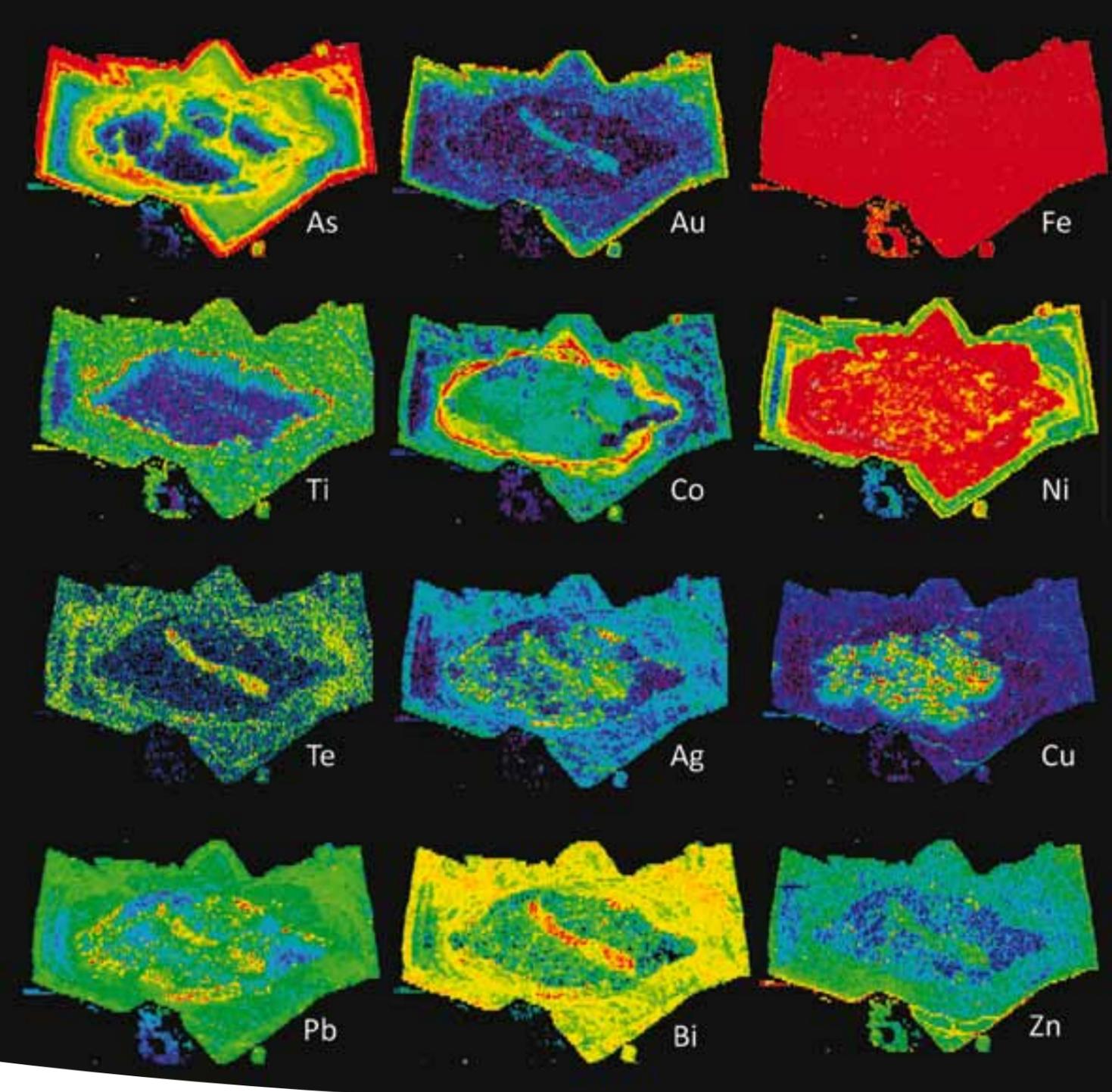
In 2011, it was home to 58 highly qualified research staff and 115 postgraduate students, further cementing its position as the largest university-based team of ore deposit researchers in the world.

Highly productive worldwide collaborations have been developed with approximately 70 industry companies, plus a host of joint research initiatives with 78 institutes and universities – 20 in Australia and 58 overseas. It currently has 46 major research projects spanning 29 countries, and is the leading academic group to publish in *Economic Geology*.

In 2011, it maintained its reputation for delivering excellence in technology transfer by producing 166 reports to industry and conducting 29 workshops and short courses in 15 countries, spread across five continents.

## KEY STATISTICS – 2011

Academic research staff	58
Postgraduate students	115
Major research projects	46
Publications in journals	66
Research reports to industry	166
Countries involved	29
Industry funding	\$2.9 million
ARC funding	\$3.0 million
UTAS funding	\$2.4 million
Worldwide collaborations:	
Industry	70
Institutes and universities	78



## FRAMEWORK FOR LEADING RESEARCH

CODES' research is built around five major programs that cover a wide spectrum of the geosciences including igneous petrology, geochemistry, melt/fluid inclusion research, volcanology, structural geology, tectonics, geophysics, ore petrology and geometallurgy.

The strategic focus of the Centre is based on a holistic, multidisciplinary approach that covers all elements of ore deposit research, from fundamental research through to applied research outcomes. Its modus operandi is to use advances in the fundamental research and technology programs to drive innovative team-based applied research, linked with industry. This is achieved through the five major research programs – Location, Formation, Discovery, Recovery and Technology.

» **Location** builds on expertise in magmatic, volcanic and tectonic processes in diverse tectonic settings – includes groundbreaking research into magmas associated with nickel-PGE mineralisation. The program provides a better understanding of the links between tectonic setting, magmatism, basin evolution, and ore deposit formation in modern and ancient terrains.

» **Formation** develops practical, process-based ore genesis models to help explorers understand the formation of deposits. CODES has built a fine reputation for its research into process-based exploration models for hydrothermal and magmatic ore deposits. This research is enhanced by employing an integrated approach to solving metal source-transport-trap problems and utilising targeted collaborations with other leading research institutes.

» **Discovery** focuses on the acquisition, processing and interpretation of scientific ore deposit data to assist in the

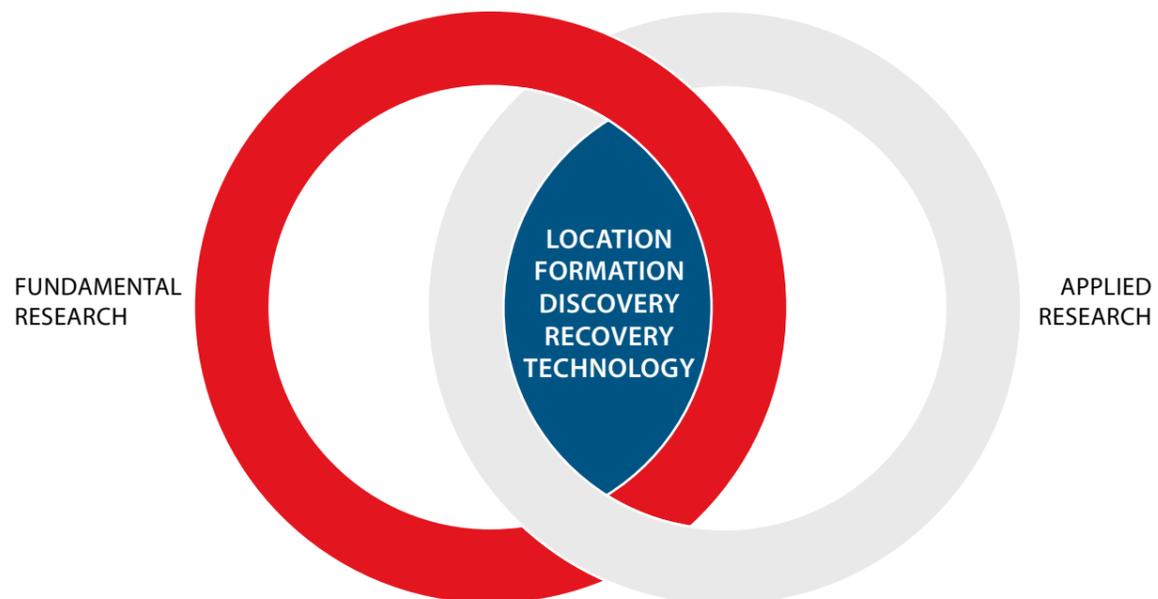
discovery of minerals. CODES' innovative work in the field of geology and geochemistry is augmented by its pioneering work in ore deposit geophysics. This research is strongly supported by the mining industry, which recognises that increasing efficiencies in the discovery of deep earth resources is essential to the long-term growth of the industry.

» **Recovery** is an integrated, cross-disciplinary field that seeks to enhance mineral processing techniques and optimise mineral recovery rates. CODES works in collaboration with the Julius Kruttschnitt Mineral Research Centre (JKMRC) at the University of Queensland, which is recognised as a world leader in metallurgical research. The alliance of these two benchmark organisations has created a synergy that has resulted in a number of innovative improvements to recovery methods that have provided wide ranging benefits throughout the industry.

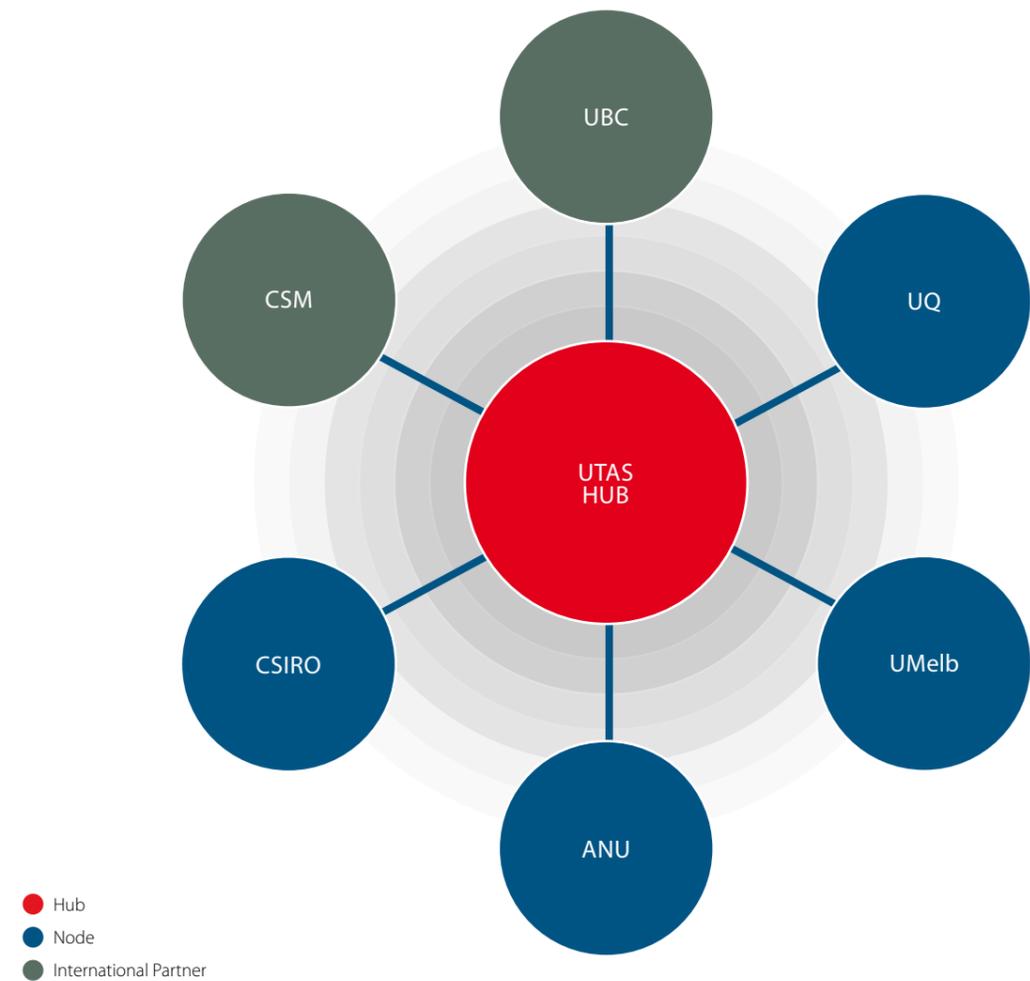
» **Technology** uses a combination of traditional and cutting-edge technological developments to improve the understanding and, subsequently, advance the exploration and exploitation of minerals. CODES is at the forefront of advances in spatially resolved, inductively coupled plasma mass spectrometry (ICP-MS), nuclear microprobe (NMP), and synchrotron-based non-destructive focused-beam spectroscopy and software development.

## TEAMWORK

The Centre continues to place a great emphasis on teamwork. Co-operation and collaboration is openly encouraged, both within CODES and in its interactions with a host of national and international organisations. This team approach is inherent in the five research programs, which foster teamwork through an overlapping and interlinked process that follows a logical progression from area selection through to exploration, discovery and recovery.



## NODES AND INTERNATIONAL PARTNERS



## 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 provides 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 include:

- » Metallurgy and mineral processing – JKMRC (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 are complemented by two strong partnerships with the University of British Columbia and the Colorado School of Mines, which provide an ideal platform for international research projects and augment the Centre's access to the latest technology.

Collaborations with these two international partners include:

- » Joint research projects in mineral deposits, geochronology and geophysics (University of British Columbia).

- » Joint research projects with Murray Hitzman and his team (Colorado School of Mines).

In addition to these international partnerships, CODES collaborates with 78 universities and institutes, plus approximately 70 industry companies worldwide.

# Staff and Management

## CENTRE DIRECTOR

Centre Director, Ross Large, is responsible for the scientific leadership and operational management of the Centre. He is supported in these duties by Bruce Gemmell (Deputy Director), the Advisory Board and the Executive Committee.

## ADVISORY BOARD

The Advisory Board meets annually 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 John Dow, a geologist with significant management experience in the minerals industry and a strong international reputation in economic geology.

## 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, 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.

## STAFF MOVEMENTS 2011

### Appointments

Rebecca Carey has returned to UTAS to take up a Postdoctoral Fellowship, working with Sharon Allen, Jocelyn McPhie and Vadim Kamenetsky on research aimed at furthering the understanding of magma ascent and degassing processes at subaqueous volcanoes. Rebecca graduated from UTAS in 2002 with BSc Honours, and then went on to attain her PhD in geology and geophysics from the University of Hawaii.

Nathan Fox has been appointed as a Postdoctoral Research Fellow, working with David Cooke on the AMIRA P1060 project – Enhanced geochemical targeting in magmatic-hydrothermal systems.

Nic Jansen has been appointed as a Postdoctoral Research Fellow, working with David Cooke on the P2B1A project – Exploring the porphyry environment.

Bernd Lottermoser was appointed as Professor in Environmental Geochemistry under the UTAS New Stars program. Bernd is leading the Predictive Environmental Indices theme in the GeM<sup>III</sup> project, in Program 4.

Deborah Macklin was appointed as PA to the Director, Ross Large.

Jay Thompson from Iowa, USA, was appointed as a Laboratory Analyst in the LA-ICP-MS facility.

Jennifer Thompson from Iowa, USA, was appointed as a Laboratory Analyst to work with David Cooke on the AMIRA P1060 project – Enhanced geochemical targeting in magmatic-hydrothermal systems.

Lejun Zhang has been appointed as a Postdoctoral Research Fellow, working with David Cooke on the AMIRA P1060 project – Enhanced geochemical targeting in magmatic-hydrothermal systems.

### Departures

Seven academic staff and three professional staff left CODES during the year.

Academic staff: Zhaoshan Chang, Sandrin Feig, Marcel Guillong, Anthony Harris, Emily Johnson, Steve Micklethwaite, and Tony Webster.

Professional Staff: Nilar Hlaing, Phil Robinson, Andy Wakefield.

## CODES' STAFF

Name		%	Name		%
Director, Professor Ross Large, BSc Hons (UTAS), PhD (UNE)	Volcanic-hosted and sediment-hosted base metal and gold ores	100	Deputy Director, Professor J Bruce Gemmell, BSc (UBC), MA, PhD (Dartmouth)	VHMS deposits and epithermal Au-Ag	50

### ACADEMIC/RESEARCH STAFF AT UTAS

Name		%	Name		%
Dr Sharon Allen, BSc (Massey), MSc (Auckland), PhD (Monash)	Volcanic facies analysis	50	Dr Maya Kamenetsky, PhD (UTAS)	MLA-SEM, geomaterials, petrology	80
Dr Mike Baker, BSc Hons (Sydney), PhD (UTAS)	Igneous petrology, mineral chemistry	100	Professor Vadim Kamenetsky, BSc Hons (Moscow), PhD (Vernadsky Inst.)	Petrology and geochemistry of melt inclusions	50
Associate Professor Ron Berry, BSc, PhD (Flinders)	Structure of mineralised provinces, CHIME dating, geomaterials	50	Associate Professor Khin Zaw, BSc (Rangoon), MSc (Queen's), PhD (UTAS)	Fluid inclusions, SE Asian metallogenesis	100
Dr Stuart Bull, BSc Hons, PhD (Monash)	Clastic and carbonate sedimentology and volcanology	85	Dr Lyudmyla Koziy, PhD (UTAS)	Fluid flow modelling	25
Dr Rebecca Carey, BSc Hons (UTAS), PhD (U Hawaii)	Volcanology	100	Professor Bernd Lottermoser, DipSc, PhD (Newcastle)	Environmental geochemistry	50
Dr Huayong Chen, BSc, MSc (PKU), PhD (Queen's)	IOCG, porphyry and epithermal deposits	100	Dr Peter McGoldrick, BSc Hons, PhD (Melbourne)	Ore deposits and their halos	50
Professor David Cooke, BSc Hons (Latrobe), PhD (Monash)	Porphyry Cu-Au, fluid-rock geochemistry	50	Associate Professor Andrew McNeill, BSc Hons, PhD (UTAS)	Petrology, VHMS deposits, mineral exploration	100
Professor Tony Crawford, BSc Hons, PhD (Melbourne)	Petrology, geochemistry and tectonics of volcanic arcs	50	Professor Jocelyn McPhie, BA Hons (Macquarie), PhD (UNE)	Volcanic facies architecture and volcanic textures	50
Professor Leonid Danyushevsky, PhD (Vernadsky Inst.)	Petrology, geochemistry, LA-ICP-MS analysis	100	Dr Sebastien Meffre, BSc Hons, PhD (Sydney)	Petrology and tectonics of the SW Pacific	100
Dr Garry Davidson, BSc Hons (ANU), PhD (UTAS)	Sulfur isotope geochemistry and Cu-Au ores	50	Dr Janina Micko, MSc (Birmingham), PhD (UBC)	Geology and genesis of hydrothermal ore deposits	10
Dr Paul Davidson, BSc Hons, PhD (UTAS)	Melt and fluid inclusions	25	Dr Karin Orth, BSc Hons (Monash), PhD (UTAS)	Volcanology	100
Dr Trevor Falloon, BSc Hons (Canterbury), BTeaching, PhD (UTAS)	Marine geoscience, petrology	35	Dr Anya Reading, BSc Hons (Edinburgh), PhD (Leeds)	Geophysics, seismology, computational methods	50
Associate Professor Jeff Foster, BSc Hons (City), MSc (Leicester)	Magmatic ore deposits, geomaterials	100	Dr Michael Roach, BSc Hons (Newcastle), PhD (UTAS)	Geophysical responses of ore deposits	50
Dr Nathan Fox, MSc Hons (Imperial), PhD (UTAS)	Porphyry Cu-Au and HS epithermal	100	Dr Ralf Schaa, MSc (Cologne), PhD (UTAS)	Remote sensing, approximate modelling and inversion of TEM	100
Dr Jacqui Halpin, BSc Hons (Melbourne), PhD (Sydney)	Metamorphic petrology, geochronology	70	Dr Rob Scott, BSc Hons, PhD (Monash)	Structural geology, gold deposits / MTEC Senior Lecturer and Masters Program Coordinator	50
Dr Julie Hunt, MSc (UBC), PhD (JCU)	Geomaterials, IOCG deposits	100	Dr Helen Thomas, MSc (Leicester), PhD (Manchester)	LA-ICP-MS trace elements	100
Dr David Hutchinson, HND (Camborne, Sch of Mines), BSc Hons, PhD (Cardiff)	Ni-Cu/PGE mineralisation, geomaterials	100	Dr Lejun Zhang, BSc, PhD (HFUT)	Porphyry Cu-Au and HS epithermal	100
Dr Nic Jansen, PhD (UTAS)	Porphyry Cu-Au and HS epithermal	100			

### ACADEMIC/RESEARCH STAFF BASED AT COLLABORATIVE INSTITUTIONS

Name	Institution	%	Name	Institution	%
Dr Stacey Borg	CSIRO	100	Mr Harri Kokkonen	Australian National University	20
Professor Deirdre Bradshaw	JKMRC, University of Queensland	16	Dr Jamie Laird	CSIRO	100
Mr Alan Cocker	WH Bryan Mining Geology Research Centre, University of Queensland	10	Dr Weihua Liu	CSIRO	10
Professor Stephen Cox	Node Leader: Australian National University	40	Dr Roland Maas	University of Melbourne	15
Professor Grant Garven	TUFTS	10	Dr Angus McFarlane	JKMRC, University of Queensland	88
Associate Professor Jeff Hedenquist	University of Ottawa	10	Dr Simon Michaux	JKMRC, University of Queensland	68
Associate Professor Janet Hergt	Node Leader: University of Melbourne	10	Dr Khoi Ke Nguyen	JKMRC, University of Queensland	92
Professor Murray Hitzman	Colorado School of Mines	20	Dr Italo Onederra	WH Bryan Mining Geology Research Centre, University of Queensland	30
Dr Luke Keeney	JKMRC, University of Queensland	29	Dr Bence Paul	University of Melbourne	100
			Dr Chris Ryan	Node Leader: CSIRO	19
			Mr Patrick Walters	JKMRC, University of Queensland	29
			Dr Yicai Wang	JKMRC, University of Queensland	20

(% in CODES)

# Student Projects

## TECHNICAL/ADMINISTRATIVE STAFF

Name	Title	%	Name	Title	%
Mr Steve Calladine	Communications Manager	100	Mrs Katie McGoldrick	Laboratory Assistant	40
Mrs Michele Chapple-Smith	Lapidary Technician	40	Mrs Karen Mollross	Finance Officer	100
Mr Peter Cornish	Laboratory Manager	50	Ms Caroline Mordaunt, BA Hons (King's College London)	Administrative Assistant	20
Mr Alex Cuison	Lapidary Technician	80	Ms June Pongratz	Publications	15
Ms Sarah Gilbert, BSc Hons (UTAS)	Laboratory Manager ICP-MS	100	Mrs Claire Rutherford	Finance Officer	70
Ms Christine Higgins, Grad.Cert. Management (UTAS)	Finance Manager	50	Miss Helen Scott, BSc Hons (UTAS), BEd (QUT)	Finance Officer	85
Mr Shaun Inglis	Research Technician	60	Mr Jay Thompson, BSc Hons, MSc (U Iowa)	Laboratory Analyst	100
Ms Erin Lawlis	Research Assistant	10	Mrs Jennifer Thompson, BSc (OSU), MSc (U Iowa)	Laboratory Analyst	100
Mr Ian Little, BSc Hons (UTAS)	Laboratory Analyst	100	Ms Isabella von Lichtan, BSc Hons (UTAS)	Curator / Website support	35
Mrs Deborah Macklin	Personal Assistant to the Director	100			

(% in CODES)

## ADVISORY BOARD

Name		Name	
Chair: John Dow	Consultant	Geoff Green	Mineral Resources Tasmania
Paul Agnew	Rio Tinto	Nick Hayward	Teck
Alexey Ariskin	Vernadsky Institute	Janet Hergt	University of Melbourne
Steve Beresford	MMG	John Holliday	Newcrest Mining
Margaret Britz	UTAS	Ross Large	CODES, UTAS
Graham Carr	CSIRO	Craig McEwan	Barrick Gold
Dean Collett	Newcrest Mining	Jocelyn McPhie	CODES, UTAS
Stephen Cox	Australian National University	Paddy Nixon	UTAS
Cathryn Dickins	St Barbara	Donna Sewell	AngloGold Ashanti
Kathy Ehrig	BHP Billiton	Steve Turner	Newmont Exploration
Bruce Gemmell	CODES, UTAS	Ian Willis	Anglo American
Alan Goode	AMIRA International		

## EXECUTIVE COMMITTEE

Name		Name	
Chair: Ross Large	Director, CODES	Bruce Gemmell	Deputy Director, CODES
Steve Calladine	Communications Manager	Christine Higgins	Finance Manager
David Cooke	Formation (2) Program Leader	Bernd Lottermoser	Environmental Geochemistry
Tony Crawford	Location (1) Program Leader	Andrew McNeill	Discovery (3) Program Leader
Leonid Danyushevsky	Technology (5) Program Leader	Jocelyn McPhie	Co-ordinator Graduate Research
Jeff Foster	Recovery (4) Program Leader	Helen Scott	Finance Officer

## SCIENCE PLANNING PANEL (also includes the Executive Committee and all CODES' research staff and students)

Name		Name	
Chair: Ross Large	Director, CODES	Geoff Green	Mineral Resources Tasmania
Paul Agnew	Rio Tinto	Nick Hayward	Teck
Steve Beresford	MMG	Paul Heithersay	PIRSA
Stacey Borg	CSIRO	Janet Hergt	University of Melbourne
Graham Carr	CSIRO	John Holliday	Newcrest Mining
Dean Collett	Newcrest Mining	Jamie Laird	CSIRO
Stephen Cox	Australian National University	Weihua Liu	CSIRO
Cathryn Dickins	St Barbara	Craig McEwan	Barrick Australia Pacific
John Dow	Consultant	Bence Paul	University of Melbourne
Mark Doyle	AngloGold Ashanti	Robbie Rowe	Barrick Australia Pacific
Kathy Ehrig	BHP Billiton	Donna Sewell	AngloGold Ashanti
Alan Goode	AMIRA International	Steve Turner	Newmont Exploration
David Green	Mineral Resources Tasmania	Ian Willis	Anglo American



## IN AUSTRALIA

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

1. **Agangi, Andrea.** SA  
Magmatic and volcanic evolution of a silicic large igneous province (SLIP): The Gawler Range Volcanic and Hiltaba Suite, South Australia.
2. **Best, Fiona.** QLD  
The petrogenesis of the Dido Tonalite, northern Queensland.
3. **Braniff, Victoria.** TAS  
The structure and deformational history of the Savage River magnetite orebodies and host rocks, NW Tasmania.
4. **Condon, Joanna.** WA (Masters)  
Mineralisation characterisation of the Doolgunna prospect: Implications for mining, milling and exploration.
5. **Cotterill, Jesse.** SA (Hons)  
Mafic dykes at Wirrda Well: Composition, timing, distribution and sources.
6. **Diemar, Glen.** SA (Masters)  
Geochronology of hydrothermal REE minerals and their relationships with economic mineralisation at the Olympic Dam breccia complex, South Australia.
7. **Doran, Daniel.** WA (Hons)  
Geology, geochemistry and mineralisation of the Handpump Gold Prospect, West Musgrave Province, WA.
8. **Ferguson, Paul.** Macquarie Island (Masters)  
Origins of large negative anomalies in oceanic crust, Macquarie Island.
9. **Fox, Nathan.** NSW  
Controls on alteration and mineralisation at the Cadia East alkalic porphyry Au-Cu deposit, NSW.
10. **Gill, Michael.** WA (Hons)  
The Youanmi Intrusion (Yilgarn Craton), Western Australia: Petrogenesis and FeTi-oxide accumulation.
11. **Gilmore, Phil.** NSW (Masters)  
An aspect of the geology of the Koonenberry Belt, NSW.
12. **Greene, Joshua.** QLD (Hons)  
Fluid and formational constraints of the Merlin Mo + Re deposit, Cloncurry.
13. **Gregory, Daniel.** WA  
Gold trace metal accumulation in diagenetic pyrite, from a present and Archean perspective.
14. **Hawke, Margaret.** WA (Masters)  
Geology of the DeGrussa prospect, WA: Implications for ore genesis and exploration.
15. **Jayathilaka, Dilani Singappuli.** TAS (Hons)  
Reducing the leaching of metals and acid from Mt Lyell mine wastes: Immobilisation with carbonate and silica coatings.
16. **Jensen, Torsten.** TAS (Hons)  
Geochronology and geochemistry of some Horodyskia-bearing shales, NW Tasmania.

17. **Jimenez Torres, Carlos Andres.** VIC  
Genesis of epithermal and porphyry deposits.
18. **Kay, Brian.** VIC (Masters)  
Combined economic and geologic evaluation of eastern Australian gold projects – selection of acquisition targets.
19. **Kyne, Roisin.** NSW  
Structural controls on mineralisation, including sulfide mineralogy, at the CSA mine, Cobar NSW.
20. **Lower, Chantelle.** SA (Masters)  
An aspect of the geology of the Olympic Dam deposit.
21. **Lygin, Alexey.** TAS  
The geology, geochemistry and genesis of the Avebury Ni deposit, Tasmania.
22. **Mackay, Wallace.** SA  
Structure and sedimentology of the Curdimurka Subgroup, northern Adelaide Fold Belt, South Australia.
23. **Maier, Rodney.** NT  
Pyrite trace element haloes to Northern Australian SEDEX deposits.
24. **McMillan, Nichola.** TAS (Hons)  
The deep alteration system at the Prince Lyell deposit, Mt Lyell, Tasmania.
25. **McNab, Sarah.** TAS (Hons)  
Effects of contamination on karst hydrogeology and hydrogeochemistry, Mole Creek, Tasmania.
26. **Miedecke, Kate.** TAS (Hons)  
The internal stratigraphy and provenance of the Mixed Sequence, Que-Hellyer Volcanics, Western Tasmania.
27. **Nolan, Nicholas.** NSW (Hons)  
Geophysical character of the Junction Reefs JV Area, Molong Belt, NSW: Applications for exploration of porphyry related Cu-Au mineralisation.
28. **Pereira da Fonseca, Pedro.** TAS  
Facies analysis and correlations in complex mineralised submarine volcanic successions: Mount Read Volcanics, western Tasmania.
29. **Perry, Owen.** TAS (Hons)  
A geophysical and geological study of the Arthur River Magnesite deposit, northwest Tasmania.
30. **Richardson, Steven.** TAS (Masters)  
The Fossey Zone, Hellyer Mine.
31. **Smith, Nicholas.** SA (Hons)  
Microtremor array method applied to minerals exploration under cover in Australia.
32. **Tomes, Kara.** TAS (Hons)  
The textures and geochemistry of the Hellyer Basalt, western Tasmania.
33. **Wu, Selina.** TAS  
Volcanic hosted massive sulfide deposits of the Que-Hellyer Volcanics, western Tasmania.



## LAB-BASED PROJECTS

### Bonnici, Natalee

The mineralogical and textural characteristics of Cu-Au deposits related to mineral processing attributes.

### Chauhan, Mitesh [JKMRC] (Masters)

Application of small scale flotation testing.

### Cracknell, Matthew

Innovative data inference from spatial datasets in earth science.

### Evans, Cathy [JKMRC]

The relationship between mineral characteristics or ores and the variation in their processing attributes.

### Gilbert, Sarah

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

### Hartner, Richard [JKMRC]

Integration and analysis of optical and MLA-based microscopy for optimisation of geometallurgical modelling and ore deposit characterisation.

### Hoschke, Terence (Masters)

Geophysical signatures of copper-gold porphyry and epithermal gold deposits, and implications for exploration.

### Kohnehsahri, Adel Vandoost

Automated petrophysical characterisation of drill core as a link to mineral processing attributes.

### McMahon, Claire

Controls on the major and trace elements content of pyrite in hydrothermal alteration envelopes.

### Paleri, Siddharth [UMelb] (Masters)

The application of copper isotopes and trace element geochemistry in revealing the temporal and spatial evolution of the Rainbow hydrothermal vent field and associated sediment.

### Parbhakar-Fox, Anita

Texture-based approaches to predictive geo-environmental modelling.

### Parra Galvez, Hector Ivan [BRC]

Quantifying the impact of blast induced fragment conditioning on leaching performance.

### Vasyukova, Olga

The origin of quartz and fluid inclusions in mineralised porphyries.

## 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 Minife and Lienetz Ore Zones, Ladolam gold deposit, Lihir Island, Papua New Guinea.
2. **Basori, Mohd Basril Iswadi Bin.** MALAYSIA  
Geology of volcanic hosted massive sulfide (VHMS) deposits in Central Belt, Peninsular Malaysia.
3. **Berkenbosch, Heidi.** NEW ZEALAND  
Geochemistry of hydrothermal mineral chimneys from Brothers volcano, Kermadec Arc.
4. **Chandler, William.** RUSSIA (Hons)  
Mineral chemistry indicators of solidification process within layered intrusion: EMPA and LA-ICPMS study of a cross-section through the Dovyren layered intrusion.
5. **Clark, Lindsey.** INDONESIA  
The geology and genesis of the Kencana epithermal Au-Ag deposit, Gosowong goldfield, Halmahera Island, Indonesia.
6. **Cobenas Benites, Gisela.** SW PACIFIC  
Metal and volatile contents of primitive subduction-related magmas (Hunter Ridge, SW Pacific): Assessing magmatic contributions to volcanic-hosted seafloor mineralisation.
7. **Croaker, Mawson.** ZAMBIA  
The geology of the Nkana-Mindola sediment-hosted copper-cobalt deposit, Zambian Copperbelt, Zambia.
8. **Galván-Gutiérrez, Víctor Hugo.** MEXICO  
Palmarejo carbonate-base metal epithermal Ag-Au district, Chihuahua, México.
9. **Goh, Kian Chee.** MALAYSIA (Hons)  
Geological setting and mineralisation characteristics of Au deposits in the Bau Mining District, Sarawak, East Malaysia.
10. **Guan, JianXiang.** CHINA, USA  
Origin of associated magnetite and sulfide mineralisation in large gabbroic intrusions: A LA-ICP-MS study of minerals and melt inclusions from the Panzhihua and Taihe intrusions in Emeishan LIP and Duluth Complex.
11. **Harris, Jarod.** SOUTH AFRICA (Hons)  
In-mine rock mass characterisation using active seismic monitoring.
12. **Harrison, Rachel.** INDONESIA (Masters)  
An aspect of the geology of the Tujuh Bukit Cu-Au porphyry-epithermal deposit, Java, Indonesia.
13. **Jansen, Nicholas.** MEXICO  
Geology and genesis of the Cerro la Mina porphyry – high sulfidation epithermal prospect, Mexico.
14. **Jutzeler, Martin.** NZ, JAPAN, USA  
Behaviour of submerged eruption plumes using data from facies analysis of a variety of submarine pyroclastic successions.

15. **Lai, Chun Kit.** CHINA  
Tectonics and metallogensis of ophiolites and volcanics in southwestern Yunnan, China.
16. **Leichtler, Stacey.** COLOMBIA (Masters)  
Gold deportment and geometallurgical recovery model for the La Colosa porphyry gold deposit, Colombia.
17. **Lim, Yungu.** CAMBODIA (Masters)  
Geological setting and mineralisation characteristics of the Steung Nambrai-Elephant Au-base metal system, eastern Cambodia.
18. **Makoundi, Charles.** MALAYSIA (Masters)  
Geology, geochemistry and metallogensis of selected orogenic gold deposits in the central gold belt, Peninsular Malaysia.

19. **Manaka, Takayuki.** VIETNAM  
Geology and mineralisation characteristics of the Phuoc Son goldfields, central Vietnam.
20. **McGee, Brendan.** ALGERIA  
The geology and mineralisation of Tala Hamza Pb-Zn deposit, Algeria.
21. **Orovan, Evan.** FIJI  
Geology and geochemistry of the Namosi porphyry Cu-Au district, southeastern Viti Levu, Fiji.
22. **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.
23. **Redi, Daniele.** [U Naples] ITALY  
Geochemistry of Plinian and Interplinian eruptions at Monte Somma Vesuvio.

24. **Rinne, Marc.** PNG  
Characteristics and relationships of the contrasting Wafi-Golpu Cu-Au porphyry-epithermal system, Papua New Guinea.
25. **Salam, Abhisit.** THAILAND  
A geological, geochemical and metallogenic study of the Chatree epithermal deposit, Phetchabun Province, central Thailand.
26. **Steadman, Jeffrey.** USA, CANADA  
The source of gold in gold deposits associated with banded iron formation (BIFs).
27. **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.





# Program One Location

1

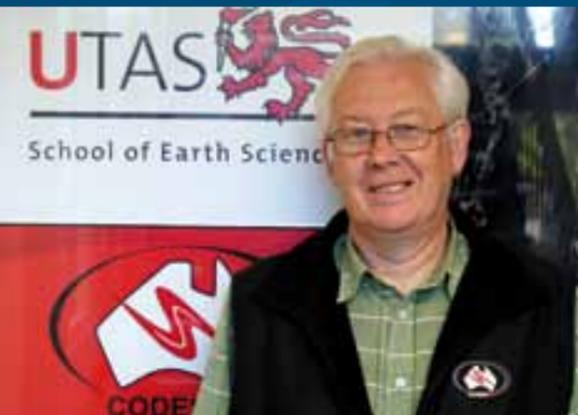
**Objective:** To better understand the links between tectonic setting, magmatism, basin evolution and ore deposit formation in modern and ancient settings.

## INTRODUCTION

The Location Program hosts the majority of fundamental research being carried out in CODES, with a strong emphasis on magmatic petrology and geochemistry, tectonics, and volcanology. Researchers within this program work across the scales from microscopic to mountain belt, and from laboratory- to field-based studies, attempting to better understand the major controls on the location, timing and size of key ore deposits, particularly those in arc-backarc settings and in continental rift basins. Current projects cover a diverse range of themes, from fundamental to more strategic in nature, and Team Members with a more fundamental science background are strongly encouraged to become involved in at least one industry- or mineralisation-related project.

## HIGHLIGHTS

- » Research conducted by Peter McGoldrick in collaboration with the University of California Riverside, the Chinese University of Geosciences and the University of Manitoba has revealed that the ancient deep ocean was not only devoid of oxygen but also rich in iron – a key biological nutrient – for nearly a billion years longer than previously thought. The results have been published in *Nature*. McGoldrick also held a lengthy live interview with ABC Radio.
- » Khin Zaw has been elected President of the Solid Earth Section of the Asia Oceania Geological Society (AOGS). The society has the most members of any geoscience organisation in the region.
- » Tony Crawford was elected a Fellow of the Geological Society of Australia (GSA). Currently, there are about 80 Fellows, who are elected by the GSA Executive on the basis of having made a significant contribution to the understanding of Australian geology.
- » A team of researchers, including CODES' Research Fellow Jacqui Halpin, discovered the remnants of the Gondwana supercontinent off the coast of Western Australia, during a research voyage on the RV *Southern Surveyor*. The discovery was covered by media worldwide, including the ABC, Fox News and Pravda Online. Halpin conducted an interview with the ABC.
- » Commencement of new industry-funded projects on SE Asia (led by Khin Zaw) and Olympic Dam (led by Jocelyn McPhie and Vadim Kamenetsky), building on the successes of their precursor projects.
- » Post-doctoral Fellow Rebecca Carey joins Program 1 to work with Jocelyn McPhie, Vadim Kamenetsky and Sharon Allen on submarine explosive volcanism.



**LEADER**  
**TONY CRAWFORD**

### TEAM MEMBERS

Sharon Allen, Mike Baker, Ron Berry, Stuart Bull, Rebecca Carey, Leonid Danyushevsky, Paul Davidson, Trevor Falloon, Sandrin Feig, Karsten Goemann, Jacqui Halpin, Janet Hergt, Emily Johnson, Maya Kamenetsky, Vadim Kamenetsky, Ross Large, Roland Maas, Peter McGoldrick, Andrew McNeill, Jocelyn McPhie, Sebastien Meffre, Karin Orth, Bence Paul, Anya Reading, Michael Roach, Phil Robinson, Khin Zaw

### PHD STUDENTS

Andrea Agangi, Mohd Basril Iswadi Bin Basori, Fiona Best, Gisela Cobenas, Quang Sang Dinh, Pedro Fonseca, Sarah Gordee, JianXiang Guan, Martin Jutzeler, Teera Kamvong, Chun Kit Lai, Alexey Lygin, Takayuki Manaka, Rod Maier, Daniele Redi, Abhisit Salam, Olga Vasyukova

### MASTERS STUDENTS

Glen Diemar, Yungu Lim, Charles Makoundi

### HONOURS STUDENTS

Will Chandler, Dan Doran, Michael Gill, Kian Chee Goh, Torsten Jensen, Kate Meidecke, Kara Tomes

### COLLABORATORS

AMERICAN MUSEUM OF NATURAL HISTORY, USA – James Webster  
ANGLO AMERICAN EXPLORATION – Paul Polito, Allan Kneeshaw, Tony Donaghy  
AUSTRALIAN NATIONAL UNIVERSITY – Richard Arculus, Hugh O'Neill  
BASS METALS – Kim Denwer  
BEADELL RESOURCES – Rob Watkins  
BHP BILLITON – Kathy Ehrig  
CHIANG MAI UNIVERSITY, THAILAND – Phisit Limtrakun, Sampan Singharajwarapan, Weerapan Srichan  
CHINESE ACADEMY OF GEOLOGICAL SCIENCE, CHINA – Zengqian Hou

COLORADO SCHOOL OF MINES, USA – Dave Broughton, Murray Hitzman

COLORADO STATE UNIVERSITY, USA – Holly Stein

CONSULTANT – Barney Stevens

CONSULTANT, THAILAND – Clive Burrett

DEPARTMENT OF MINERAL RESOURCES, THAILAND – Pol Chaodumrong, Somboon Khositantont

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GEOLOGICAL SURVEY OF JAPAN – Kenzo Sanematsu

GEOLOGICAL SURVEY OF QUEENSLAND – Ian Withnall

GEOSCIENCE AUSTRALIA – David Huston, Terry Mernagh

GFZ GERMAN RESEARCH CENTRE FOR GEOSCIENCES – Rainer Thomas

GUANGZHOU INSTITUTE OF GEOCHEMISTRY, CHINA – Weidong Sun

HANOI UNIVERSITY OF GEOLOGY AND MINING, VIETNAM – Hai Thanh Tran

IFM-GEOMAR, GERMANY – Armin Freundt

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INSTITUTE OF GEOLOGY OF ORE DEPOSITS, PETROGRAPHY, MINERALOGY AND GEOCHEMISTRY, RUSSIA – Alexander Borisov

INSTITUTE OF TECHNOLOGY, INDONESIA – Andri Subandrio

JAMES COOK UNIVERSITY – Bob Henderson

LAURIN TECHNIC – Michael Shelley

MACQUARIE UNIVERSITY – Nathan Daczko, Norm Pearson

MONASH UNIVERSITY – Reid Keays, Massimo Raveggi

MOSCOW STATE UNIVERSITY, RUSSIA – Pavel Plechov

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TARBIAT MOALLEM UNIVERSITY, IRAN – Zahra Bonyadi

UNITED STATES GEOLOGICAL SURVEY – Poul Emsbo

UNIVERSIDAD NACIONAL DE LA PATAGONIA, ARGENTINA – Marcelo Marquez

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UNIVERSITY OF CENTRAL MISSOURI, USA – Mark Dudley, John Nold

UNIVERSITY OF LISBON, PORTUGAL – Jorge Relvas

UNIVERSITY OF MALAYA – Azman Ghandi, Teh Guan Hoe

UNIVERSITY OF MELBOURNE – Jon Woodhead

UNIVERSITY OF NAPLES, ITALY – Benedetto De Vivo

UNIVERSITY OF NEW CALEDONIA – Dominique Cluzel, Christine Laporte-Magoni

UNIVERSITY OF OREGON, USA – Ilya Bindeman, Kathy Cashman, Paul Wallace

UNIVERSITY OF QUEENSLAND – Ben Cohen, Sue Golding, Paulo Vasconcelos

UNIVERSITY OF SCIENCE & TECHNOLOGY, CHINA – Yuling Xie

UNIVERSITY OF SYDNEY – Geoff Clarke

UNIVERSITY OF WESTERN SYDNEY – Lin Sutherland

UNIVERSITY OF TASMANIA – Donna Satterthwait

UNIVERSITY OF THE WITWATERSRAND, SOUTH AFRICA – Allan Wilson

UNIVERSITY OF WOLLONGONG – Chris Fergusson

VERNADSKY INSTITUTE, RUSSIA – Alexey Ariskin, Galina Barmina

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY, USA – Robert Bodnar, Rosario Esposito

## CORE PROJECTS

### Theme 1A – Geodynamic Controls on the Fertility of Foldbelts, Cratons and Sedimentary Basins

P1A1 Palaeoproterozoic magmatism and mineralisation

P1A2 Mafic magmatism in modern submarine SW Pacific settings

P1A3 Global ocean chemistry, marine basins and mineralisation

P1A4A Ore deposits of SE Asia

P1A6 Tectonic significance and mineralisation potential of volcano-plutonic belts and ophiolites at the northern end of the Tasman Line, N Queensland

### 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

P1B2 Ni-PGE potential of mafic and ultramafic magmas – a combined melt inclusions and numerical modelling approach (AMIRA P962)

P1B3B Melt-melt immiscibility and the origin of magnetite-apatite deposits

## PROJECT SUMMARIES

### P1A1 PALAEOPROTEROZOIC MAGMATISM AND MINERALISATION

**Leader:** Tony Crawford

**Team Member:** Mike Baker

**Collaborators:** Reid Keays, Roland Maas, Barney Stevens, Ian Withnall

This project was completed at the end of 2010.

### P1A2 MAFIC MAGMATISM IN MODERN SUBMARINE SW PACIFIC SETTINGS

**Leader:** Leonid Danyushevsky

**Team Members:** Tony Crawford, Trevor Falloon

**Student:** Gisela Cobenas

**Collaborators:** Andrew Berry, Robert Bodnar, Benedetto De Vivo, Hugh O'Neill, Pavel Plechov, Jon Woodhead

This project aims at improved understanding of magma generation and evolution processes in the complex settings of convergent plate margins in the Southwest Pacific and other regions worldwide. These tectonic settings are likely modern analogues of the geodynamic environments that existed during formation of paleo-magmatic sequences in the orogenic volcanic belts along eastern Australia, which host numerous types of ore deposits.

During 2011, the major outcomes were:

» Analysis of volcanic and intrusive rocks from the Hunter Ridge in the southwest Pacific, collected during the SS03/2009 research voyage on board RV *Southern Surveyor*, for major and trace element contents by XRF and solution ICP-MS. The analytical data obtained are currently being investigated with the aim of better constraining magma generation and evolution processes in the region.

» Analysis of major and trace elements in olivine, plagioclase and clinopyroxene from a set of comagmatic samples collected from an active volcano on the Hunter Ridge. These samples are from Gisela Cobenas's PhD project, the aim of which is to better understand the behaviour of metals during evolution of calc-alkaline arc magmas.

» Analysis of major and trace elements in olivine and clinopyroxene from a set of samples representing different eruption styles of Mt. Vesuvius, Italy, over the past 25,000 years. These samples are from Daniele Redi's PhD project, the aim of which is to better understand the causes of explosive eruptions at Mt. Vesuvius.

### P1A3 GLOBAL OCEAN CHEMISTRY, MARINE BASINS AND MINERALISATION

**Leader:** Peter McGoldrick

**Student:** Torsten Jensen

**Collaborators:** Tim Lyons, Donna Satterthwait

This project aims 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; and elucidate the role played by (micro-) organisms during seafloor venting of fluids responsible for forming Proterozoic sedimentary Zn mineralisation.

Work continued toward a manuscript describing the outcomes of Josh Guilliame's 2010 Honours research project. His thesis involved textural studies of bedding surface features from carbonaceous 'waste' at the Century Zn mine in NW Queensland. Many of these features were previously interpreted as stylolites, but Guilliame was able to conclusively demonstrate that they are various types of microbially induced sedimentary structures (MISS). Additional SEM work by Peter McGoldrick and Donna Satterthwait has revealed a remarkable array of fossil microorganisms in some of Guilliame's samples, and more SEM work is required to finalise the paper.

In the interim, Satterthwait and McGoldrick have completed a manuscript entitled *2.1 billion year old fossils from Gabon were placozoans*, which will be submitted for publication in *Biology Letters*. This publication arose out of the work on the Century fossil assemblages.

In September, a 'Letter to Nature' was published describing the results of work arising from McGoldrick's collaboration with Tim Lyons's group at University of California Riverside.

An Honours project by Torsten Jensen focussed on the lower Rocky Cape Group in NW Tasmania, which hosts rare 'string-of-beads' fossils (*Horodyskia* sp.). New monazite and zircon dates from the Balfour Subgroup indicate that these rocks are several hundred million years older than previously thought. Jensen presented the new dates at the 'Explore the Science' – GSA/AusIMM meeting held in Strahan in December.

Rod Maier graduated with a PhD in June.

### P1A4A ORE DEPOSITS OF SE ASIA

**Leaders:** Khin Zaw, Sebastien Meffre

**Team Members:** Tony Crawford, Jacqui Halpin, Ross Large

**Students:** Mohd Basril Iswadi Bin Basori, Quang Sang Dinh, Teera Kamvong, Chun Kit Lai, Charles Makoundi, Takayuki Manaka, Abhisit Salam

**Collaborators:** Clive Burrett, Pol Chaodumrong, Wan Fuad Wan Hassan, Azman Ghandi, Sue Golding, Teh Guan Hoe, Somboon Khositantont, Phisit Limtrakun, Mohd Rozi Umor, Sampan Singharajwarapan, Weerapan Srichan, Holly Stein, Hai Thanh Tran, Paulo Vasconcelos

A new project commenced in October that extends the research until at least 2014. The new initiative builds on the methods and techniques developed during previous work in the region, while expanding the research in terms of its geological scope and geographical footprint, which now includes the whole of mainland SE Asia and Sumatra.

The new project aims to:

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

The following volcanic/magmatic belts have been proposed for detailed study in relation to Cu-Au-Mo and Pb-Zn-Cu-Ag metallogeny:

- » Sibumasu (Si=Siam, Bu=Burma, Ma=Malaysia, Su=Sumatra) terrane.
- » Kratie-Dalat Fold Belt in Cambodia and Vietnam.
- » Northern and southern margin of Truong Son Fold Belt in Laos and Vietnam.
- » Martabe-Miwah-Monywa belt in west Myanmar and Sumatra.
- » Northern and southern extension of the Loei Fold Belt in Cambodia.
- » Sukothai and Chiang Mai Fold Belts in Thailand, Myanmar, the eastern part of Peninsular Malaysia, and Yunnan.
- » Song Ma (Ailaoshan) Suture in NW Vietnam and Yunnan.
- » Bentong-Raub Suture in Malaysia.
- » Borneo terrane in East Malaysia.

In 2011, reconnaissance field work and sampling were carried out at the Mount Popa volcano in the Monywa-Wuntho belt, Myanmar, to determine the episode and timing of volcanic eruption and mineralisation.

In addition, preliminary field programs were undertaken in Cambodia and East Malaysia.

### P1A6 TECTONIC SIGNIFICANCE AND MINERALISATION POTENTIAL OF VOLCANO-PLUTONIC BELTS AND OPHIOLITES AT THE NORTHERN END OF THE TASMAN LINE, N QUEENSLAND

**Leader:** Tony Crawford

**Student:** Fiona Best

**Collaborators:** Chris Fergusson, Bob Henderson, Reid Keays, Paul Polito, Ian Withnall

This project includes two overlapping strands. The first strand covers the geology, geochronology and geochemistry of diverse



Early Palaeozoic units at the northern end of the Tasman Line in the area around Greenvale, N Queensland, along the eastern margin of the Palaeo- and Mesoproterozoic Georgetown Block. Key outcomes include a study covering the geochronology, geochemistry and geological mapping of volcanic units east of Greenvale.

A paper documenting the tectono-magmatic setting of key lithostratigraphic units in the Broken River Province, including the Late Ordovician Carriers Well Formation, Everetts Creek Volcanics and dismembered volcanic slivers now structurally intercalated in the adjoining Wairuna Formation, was published in *Australian Journal of Earth Sciences* (Henderson et al., 2011). This publication marks the completion of the first strand of this project.

The second strand involves the PhD study by Fiona Best on the petrogenesis and mineralisation potential of the Dido Batholith, which is a tonalite-dominated major crustal feature west of Greenvale that sits astride the Tasman Line. This thesis is almost completed, and has shown that the Dido Batholith, formerly considered to be a single Late Silurian intrusive unit, also includes diorites and associated rocks of Early Ordovician age. Mafic and ultramafic rocks in the core of the batholith are shown to include both strongly Fe-enriched cumulates, and more typical, relatively Fe-poor cumulates. High precision PGE data and Nd isotope data have been collected and are being used to decipher relationships between the two cumulate packages and the more abundant dioritic rocks.

#### **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, Emily Johnson, Maya Kamenetsky, Sebastien Meffre, Karin Orth

**Students:** Andrea Agangi, Glen Diemar, Pedro Fonseca, Sarah Gordee, Martin Jutzeler, Olga Vasyukova

**Collaborators:** Kathy Ehrig, Richard Fiske, Yoshihiko Goto, Roland Maas, Marcelo Marquez, Terry Mernagh, Jorge Relvas, Carlos Rosa, Yoshihiko Tamura, Paul Wallace

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 determine

how degassing of felsic magmas affects eruption styles and products, as well as the influences of magmatic volatiles on related hydrothermal systems. The research is being conducted in the Gawler Range Volcanics (South Australia), Mount Read Volcanics (Tasmania), Taupo Volcanic Zone (New Zealand), Izu-Bonin arc (Japan), Southern Aegean Volcanic Arc (Greece), Cascade Range (Washington, USA) and a selection of porphyry Cu-Au districts.

Outcomes during the year included:

» Results of a melt-inclusion-based study of rhyolites in the Taupo Volcanic Zone were published in *Geology* (Johnson et al., 2011). The paper focusses on particularly high volatile contents of the rhyolitic magmas, and pressure and temperature conditions of crystallisation.

» Sharon Allen and co-authors published their research on subaqueous pumice-rich density current deposits generated by magmatic-volatile driven explosive eruptions in the *Bulletin of Volcanology*. The paper used experimental simulations to determine the links between deposit characteristics and current dynamics.

» Work on rhyolites in the Gawler SLIP indicates that fluorine played a key role in the concentration of U and REE into late magmatic-hydrothermal fluids. The results were published in *Lithos* (Agangi et al.). Andrea Agangi has a second manuscript under review in *Precambrian Research* that explores the influence of high magmatic fluorine on eruption styles.

» Two papers based on research at Olympic Dam were published in *Geology*. The first paper (McPhie et al.) presents a new interpretation of the architecture of the host succession, emphasising the evidence for the existence of a sedimentary basin at Olympic Dam at the time the breccia complex formed. The second paper (McPhie et al.) suggests that the Olympic Dam hydrothermal fluids were fluorine-rich and that the fluorine ultimately came from the F-rich Gawler SLIP rocks.

» Emily Johnson has submitted a manuscript to the *Journal of Petrology* showing the influence of crystallisation of hydrous phases on metal abundance in rhyolitic magmas that lack appropriate ligands, such as S or Cl.

» Martin Jutzeler submitted two manuscripts for review. The first (*Geological Society of America Bulletin*), is entitled 'A facies model for subaqueous deposits from pumice-rich density currents in a below wave-base basin: The Ohanapecosh Formation, Washington, USA'. The second (*Journal of Volcanology and Geothermal Research*) is entitled 'Grain-size distribution of consolidated pyroclastic rocks 1: Procedures and tests'.

» Two additional manuscripts were submitted to the *Journal of Volcanology and Geothermal Research*, one on the misidentification of peperite (Rosa, McPhie et al.) and another on submarine pillow lavas (Goto and McPhie).

» PhD candidates Andrea Agangi and Olga Vasyukova graduated, and Martin Jutzeler submitted his thesis for examination.

» New ARC Post-Doctoral Fellow, Rebecca Carey, joined the team late in the year. Rebecca will contribute to current research on the dynamics and products of submarine explosive eruptions involving felsic magmas.

#### **P1B2 (AMIRA P962) Ni-PGE POTENTIAL OF MAFIC AND ULTRAMAFIC MAGMAS – A COMBINED MELT INCLUSIONS AND NUMERICAL MODELLING APPROACH**

**Leader:** Leonid Danyushevsky

**Team Members:** Tony Crawford, Sandrin Feig, Andrew McNeill

**Student:** JianXiang Guan

**Collaborators:** Alexey Ariskin, Alexander Borisov, Allan Wilson

During 2011, research focussed on understanding the interplay between magnetite and sulfide crystallisation during solidification of large gabbroid intrusions. This work is part of JianXiang Guan's PhD project, focussing on the Panzhihua Intrusion in China, which is one of the world's largest magmatic magnetite deposits. Major and trace element contents in magnetite, sulfide, and major silicate rock-forming minerals were analysed in 40 samples collected from two vertical cross-sections through the intrusion. The main outcome to date is that there is very little variation in mineral chemistry across the intrusion, despite very significant changes in mineral proportions, from magnetite-rich ores, to wehrlite, gabbro, and olivine gabbro. This indicates that the intrusion was an open magma chamber, with minerals deposited from passing melts of similar compositions. Data collection for this project will finish in 2012.

Also during the year, a collaborative study (with Alexander Borisov) on understanding the mechanism of PGE solubility in silicate melts was published.

In collaboration with Allan Wilson from the University of the Witwatersrand, South Africa, a project is underway on the nature of primitive melts for the Bushveld and Great Dyke intrusions in southern Africa. The project focuses on drill-core samples from basal sections of both intrusions that contain

abundant high-magnesian olivine phenocrysts, which are likely to have formed during the earliest stages of the parental melt evolution. Allan Wilson made two trips to CODES in 2011 to prepare grain mounts of Bushveld Complex chilled margin olivines for electron microprobe and LA-ICP-MS microanalysis. Excellent compositional data for the trapped melts has been collected, and a paper detailing this study is in preparation.

#### **P1B3B MELT-MELT IMMISCIBILITY AND THE ORIGIN OF MAGNETITE-APATITE DEPOSITS**

**Leader:** Paul Davidson

**Team Member:** Leonid Danyushevsky

**Collaborators:** Mark Dudley, Neng Jiang, Mirsaleh Mirmohammadi, John Nold, Rainer Thomas, James Webster, Yuling Xie

Whether melt-melt immiscibility is a geologically important process in crustal differentiation, and ore-deposit formation, remains controversial. This study addresses the problem by examining selected ore deposits to determine if melt-melt immiscibility occurred during deposit formation, and establishing criteria that can be used to identify its former existence. Fe-Ti oxide melt-melt immiscibility will be examined directly, and silicate-silicate melt-melt immiscibility in the origin of pegmatites will be researched via collaborative studies.

The Fanshan magnetite-apatite deposit study is continuing. Extensive melt inclusion studies have been completed on the unheated apatites, resulting in the discovery of considerable evidence of melt-melt immiscibility with silicate, carbonate, sulfide, and Fe-Ti oxide components observed in various combinations in various melt inclusions. Samples were sent for high-pressure homogenisation at the GeoForschungsZentrum Potsdam, Germany. Once the samples are returned in 2012, it is hoped that homogenisation and rapid quenching will show positively what forms of melt-melt immiscibility were originally present in the Fanshan ore body.

With the submission to *Mineralium Deposita* of the paper titled 'Mineralogy, textures, chemistry and origin of the Pilot Knob magnetite deposit, St. Francois Mountains Terrane, southeast Missouri', the Pilot Knob study is nearing completion.

Research being carried out in collaboration with Rainer Thomas and James Webster into melt-melt immiscibility in the pegmatite area, has resulted in three published papers (Thomas et al. 2011a, b, c). Two more papers, including an invited review paper in *Ore Geology Reviews*, have been reviewed and are awaiting a final decision on publication.



# Outlook

- » Continue to investigate the secular change in Proterozoic ocean chemistry and its implications for sedimentary ores and early complex life.
- » Continue to expand the geographical footprint of the SE Asia project.
- » Finalisation of PhD studies of Fiona Best and Chun Kit Lai, and theses submission in Q1, 2012.





# Program Two Formation

# 2

**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

- » Textures in some fault breccias indicate that flow velocities up to several metres per second can occur transiently, immediately after fault rupture events where ruptures breach overpressured fluid reservoirs. Such high fluid velocities may be an important part of the ore formation process in many magmatic-hydrothermal systems.
- » Publication of special issue of *Economic Geology*, including articles on ore-forming processes in Philippine porphyry, epithermal and geothermal systems.
- » Embedded research activities have led to the uptake of CODES' research outcomes in exploration, and helped to advance mineral projects at several of Newcrest's world class deposits.
- » Field trip and workshop for the UTAS SEG Student Chapter to the Middle and Lower Metallogenic Belt of China.
- » Finalisation and acceptance of six manuscripts for the 2012 publication in the alkalic special issue of *Economic Geology*.
- » Publication of a paper in *Mineralium Deposita* by Huston, Relyas, Gemmell and Driberg, entitled 'The role of granites in volcanic-hosted massive sulfide ore-forming systems: An assessment of magmatic hydrothermal contributions'.



**LEADER**  
**DAVID COOKE**

### TEAM MEMBERS

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## HONOURS STUDENTS

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BGR GERMANY – Julia Rutkowski  
CONSULTANT – Noel White  
CSIRO – Adam Bath  
EMMERSON RESOURCES – Grant Osborne  
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GEOLOGICAL SURVEY OF NSW – Ian Percival  
GEOSCIENCE AUSTRALIA – Geoff Fraser, David Huston, Roger Skirrow  
GNS SCIENCE NEW ZEALAND – Cornel de Ronde, Kevin Faure, Andrew Rae  
GOLD FIELDS – Jacqueline Blackwell  
HANOI UNIVERSITY OF GEOLOGY AND MINING, VIETNAM – Hai Thanh Tran  
HARMONY GOLD – Mawson Croaker, Russell Dow  
HEFEI UNIVERSITY OF TECHNOLOGY, CHINA – Yu Fan, Fang Yuan, Taofa Zhou  
IMPERIAL COLLEGE LONDON – Clara Wilkinson, Jamie Wilkinson  
IMPERIAL METALS – Patrick McAndless, Chris Rees  
IOGLOBAL – Heidi Pass  
IVANHOE AUSTRALIA – Florinio Lazo, Rohan Wolfe  
JAMES COOK UNIVERSITY – Zhaoshan Chang, Nick Oliver  
LAURENTIAN UNIVERSITY, CANADA – Steve Piercey  
MAWSON WEST – Wojciech Zukowski  
MOROBE MINING JOINT VENTURE – Dave Finn, Chris Muller, Simon Shakesby, Betty Tekeve  
NEWCREST MINING – Benjamin Ackerman, Dean Collett, Anthony Harris, John Holliday, Jon Rutter  
NORTHERN TERRITORY GEOLOGICAL SURVEY – Masood Ahmad  
OZ MINERALS – Hamish Freeman  
QUEEN'S UNIVERSITY, CANADA – Dan Layton-Matthews  
RESEARCH SCHOOL OF EARTH SCIENCES ANU – Charlotte Allen, Ian Campbell  
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TECK – Kevin Byrne, Amber Henry  
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UNIVERSITY OF BRITISH COLUMBIA, CANADA – Thomas Bissig, Greg Dipple, Jim Mortensen, Dick Tosdal  
UNIVERSITY OF MALAYA – Azman Ghandi, Teh Guan Hoe  
UNIVERSITY OF OTTAWA, CANADA – Mark Hannington

## 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 Polymetallic mineralisation and associated magmatic and volcanic activity in Cretaceous volcano-sedimentary basins of eastern China

P2B1D Shallow and deep-level alkalic mineral deposits

P2B3B Genesis of volcanic-hosted Cu-Pb-Zn-Ag-Au massive sulfide deposits

P2B3C Hydrothermal event recognition and target vectoring in sedimentary strata

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

P2B4 Iron oxide copper-gold and related deposit types

## PROJECT SUMMARIES

### 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

**Collaborator:** Janos Urai

Fluid dynamics were applied in order to explore transient fluid flow rates associated with fault ruptures when they breach overpressured fluid reservoirs. Field studies of the Rusey (Cornwall) and Roamane faults (Porgera, PNG) have demonstrated that 'accretionary' fault breccias were formed by particle fluidisation during transiently fast flow rates immediately after fault rupture events. Particle sizes indicate that fluid velocities in excess of several metres per second were attained, and were associated with fluxes in excess of 100 l/s per metre strike length of fault rupture. Such flow rates are expected to be associated with substantial advective heat transport. These fast, episodic pulses of flow promoted severe chemical disequilibrium in the fluid. Ore formation involved markedly episodic, rather than steady state, flow processes. In 2012, the controls on spacing and thickness of veins in intrusion-related vein arrays will be examined in a collaboration with Professor Urai (Aachen University).

### P2A3

#### EFFICIENCY OF ORE-FORMING PROCESSES

**Leader:** David Cooke

**Team Members:** Mike Baker, Huayong Chen, Nathan Fox, Nic Jansen, Janina Micko, Lejun Zhang

**Student:** Carlos Jimenez

**Collaborators:** Andrew Rae, Noel White, Clara Wilkinson, Jamie Wilkinson, Rohan Wolfe

Following the departure of former project leader Zhaoshan Chang in 2011, research activities are being reinvigorated through new appointments and graduate recruitment. Carlos Jimenez commenced his PhD study in October, and has begun an investigation of hydrothermal alteration and mineralisation at the Unicorn porphyry Mo deposit in NE Victoria. During the coming year, the team plans to quantify metal compositions in fluid inclusions from Unicorn in order to constrain the effectiveness of likely ore forming processes that are being evaluated. Articles on the evaluation of likely ore forming processes at the Palinpinon geothermal field, Baguio epithermal Au-Ag and Dinkidi porphyry Cu-Au deposit (using chemical modelling, fluid inclusion and stable isotopic studies) were published as part of a *Special Issue of Economic Geology* in December 2011, which focussed on Philippine ore deposits.

### P2B1A

#### EXPLORING THE PORPHYRY ENVIRONMENT

**Leaders:** David Cooke, Janina Micko

**Team Members:** Tony Crawford, Nathan Fox, Nic Jansen

**Students:** Evan Orovan, Marc Rinne

**Collaborators:** Benjamin Ackerman, Charlotte Allen, Ian Campbell, Dean Collett, Robert Creaser, Mawson Croaker, Russell Dow, Kevin Faure, Dave Finn, Anthony Harris, John Holliday, Chris Muller, Ian Percival, Simon Shakesby, Betty Tekeve

The team is working in close collaboration with Newcrest Mining in order to maximise opportunities for the discovery of new porphyry-related gold resources in Australia and the South West Pacific region.

A combination of university-based research and in-house training has led to an improved understanding of Newcrest's porphyry and epithermal deposits in Australia, Papua New Guinea and Fiji, and advanced the conceptual models and exploration techniques applied at the relevant deposits and districts.

The close working relationship with Newcrest has resulted in the rapid uptake of knowledge arising from research activities, as well as the continued support from the company's leadership, both logistically and financially. Due to this, the company's exploration teams are now able to capitalise on epithermal and porphyry vectors developed in AMIRA research projects, past and present (P588, P765, P765A, and P1060), the findings of which have helped the team to develop sampling and analytical protocols. In most cases, these are now being routinely applied to exploration and advanced projects.

Current activities include intensive research via the PhD studies of Marc Rinne and Evan Orovan. These projects are aimed at gaining a better understanding of the geology of the Golpu-Wafi porphyry-epithermal deposits, PNG, and the Namosi porphyry deposits in Fiji, respectively.

Nic Jansen was appointed to the project as a postdoctoral research fellow late in the year, and will be focussing on lithocap exploration problems. Anthony Harris left CODES in June to take up a position with Newcrest. However, he maintains a very close working relationship with the Centre. Erin Lawlis will join the team in 2012 to undertake a PhD study of the Lihir gold mine (PNG), with a third postdoctoral research fellow also expected to be appointed in the forthcoming year, further enhancing the research capacity of the project group.



Top to bottom: Shallow rhodocrosite-cemented vein breccia (fragments mostly base metal sulfides including pyrite; WR397, 123.0m). Temporary core log shelter after wind and rain, Nine Mile camp, PNG.

### P2B1B POLYMETALLIC MINERALISATION AND ASSOCIATED MAGMATIC AND VOLCANIC ACTIVITY IN CRETACEOUS VOLCANO-SEDIMENTARY BASINS OF EASTERN CHINA

**Leader:** Taofa Zhou, David Cooke

**Team Members:** Huayong Chen, Sebastien Meffre, Lejun Zhang

**Students:** Fengjie Lin, Yanduan Ren, Zhi Ren, Cheng Tang, Shiwei Wang, Dayu Zhang, Guoxiong Zhong

**Collaborators:** Zhaoshan Chang, Yu Fan, Feng Yuan

This project continues to advance our understanding of polymetallic mineralisation and associated magmatic and

volcanic activity in the Luzong basin, middle and lower Yangtze River, eastern China.

Lejun Zhang completed his PhD study of the Nihe magnetite skarn in December, and has now joined CODES as a postdoctoral research fellow. Four journal articles and several conference presentations were generated by the research team during the year. The CODES SEG Student Chapter visited Hefei University of Technology in May, and conducted a one-week field excursion through the Luzong Basin and adjacent areas.

Further geochronological and mineralogical studies are planned in 2012, along with presentations of major findings at the IGC conference in Brisbane.

### P2B1D SHALLOW AND DEEP-LEVEL ALKALIC MINERAL DEPOSITS

**Leaders:** David Cooke, Thomas Bissig

**Team Member:** Janina Micko

**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. In 2011, several manuscripts were finalised for a special issue of *Economic Geology* summarising the results of the alkalic project, now scheduled for publication in mid-2012. This special issue will conclude the project.

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

**Leader:** Bruce Gemmell

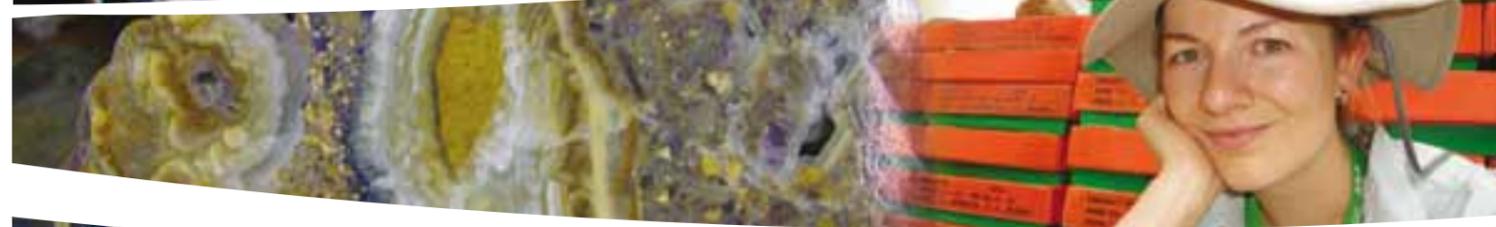
**Team Members:** Susan Belford, Garry Davidson, Ross Large, Andrew McNeill, Khin Zaw

**Students:** Mohd Basril Iswadi Bin Basori, Jo Condon, Paul Ferguson, Margy Hawke, Brendan McGee, Nichola McMillan, Kate Miedecke, Nathan Steeves, Selina Wu

**Collaborators:** Azman Ghandi, Teh Guan Hoe, Mark Hannington, David Huston, Jim Mortensen, Hai Thanh Tran, Wan Fuad Wan Hassan, Jamie Wilkinson

This project is investigating the spectrum of massive sulfide deposit types – from typical seafloor VHMS (zinc-lead-copper-silver-gold) deposits, through to sub-seafloor shallow-water, replacement gold-rich epithermal, and deep sub-volcanic intrusion-related copper-gold-rich styles.

In 2011, research was undertaken on deposits at Fossey-Hellyer-Que River-Mt Charter (Tasmania), Mt Lyell (Tasmania),



DeGrussa (Western Australia), Palmer (Alaska), Duc Bo (Vietnam), Tsik Chini (Malaysia) and Tala Hamza (Algeria). The team's new zircon age determinations for the Mount Read Volcanic Belt were presented publically for the first time. This work was conducted in collaboration with Jim Mortensen of UBC. A paper entitled 'The role of granites in volcanic-hosted massive sulfide ore-forming systems: An assessment of magmatic-hydrothermal contributions' was published in *Mineralium Deposita*, and was a collaboration with David Huston of Geoscience Australia.

#### P2B3C HYDROTHERMAL EVENT RECOGNITION AND TARGET VECTORIZING IN VOLCANO-SEDIMENTARY STRATA

**Leader:** Bruce Gemmell

**Team Member:** Ross Large

**Collaborators:** Wayne Goodfellow, Mark Hannington, Dan Layton-Matthews, Jan Peter, Steve Piercey

This CAMIRO (Canadian Mining Industry Research Organization-Exploration Division)-funded project aims 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 develop new tools (mineralogical, geochemical, isotopic) to discriminate potentially mineralised versus unmineralised horizons in many mineralised districts. A sponsors meeting was held at the PDAC meeting in Toronto in March.

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

**Leader:** Bruce Gemmell

**Student:** Heidi Berkenbosch

**Collaborators:** Cornel de Ronde, Julia Rutkowski

This project is investigating the ore and gangue mineralogy, textures, paragenesis, mineral chemistry and sulfur isotopes of the sulfide-sulfate chimneys.

Heidi Berkenbosch's PhD project at Brothers volcano, in the Tonga-Kermadec arc, continued in 2011. This is a collaborative project with GNS Science, New Zealand.

A paper detailing the mineralogy, textures and mineral chemistry of the chimneys was accepted and will be published in *Economic Geology*.

#### P2B4 IRON OXIDE COPPER-GOLD AND RELATED DEPOSIT TYPES

**Leader:** Garry Davidson

**Team Members:** Huayong Chen, David Cooke, Julie Hunt, Ross Large, Sebastien Meffre, Karin Orth, Bence Paul

**Students:** Josh Greene, Claire McMahon

**Collaborators:** Masood Ahmad, Zahra Bonyadi, Geoff Fraser, Hamish Freeman, Florinio Lazo, Behzad Mehrabi, Nick Oliver, Grant Osborne, Roger Skirrow, Derek Thorkelson, Rohan Wolfe

This project aims to improve the understanding of IOCG and related ore deposit systems.

Achievements in 2011 included:

» An Honours study, supported by Ivanhoe Australia, evaluated fluid inclusion and trace element characteristics of the Merlin Mo-Re deposit. Further development work on Mo stable isotopes was also undertaken.

» A new sulfur isotope investigation began at Prominent Hill, aimed at determining the 3D variability of the deposit.

» A summary of the Wernecke Breccia geology and IOCG mineralisation was published in the latest Porter volumes.

» Additional data was generated for the Northern Star and Warrego (Tennant Creek) deposits. A paper has been submitted for a special IOCG issue of *Mineralium Deposita*.

» A paper published in *Chemical Geology* shows that REE and alkali element metasomatism of apatite in Kiruna-style IOCG deposits occurs immediately before intense brecciation, and may be related to the development of high fluid pressures that are the agent of fragmentation.

# Outlook

» Efforts will be renewed to recruit a new research fellow for project P2A2A, which was not achieved in 2011, mainly due to the shortage of well-trained structural geologists. Work will focus on controls on vein geometries, spacing and distribution in porphyry systems, and exploring how evolution of vein systems impacts on fluid pathways and ore formation.

» Initiate research into a vertical section through a lithocap to evaluate metal transport and hydrothermal processes responsible for alteration and mineralisation.

» Publication of results from collaborative research with Newcrest in Australia and the southwest Pacific region in *Economic Geology*.

» Taofa Zhou, Shiwei Wang and Dayu Zhang to visit CODES to conduct LA-ICP-MS analyses in relation to project P2B1B. Research results to be presented at IGC in Brisbane.

» Publication of the alkalic special issue of *Economic Geology*.

» Publication of a paper outlining new detailed geochronology data for the Mount Read Volcanics.

» Publication of a paper in *Mineralium Deposita* on the Tennant Creek IOCG deposits.





# Program Three Discovery

# 3

**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 now structured around two key discovery themes: innovative techniques, and integrated exploration models.

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

## HIGHLIGHTS

- » 3DTEM inversion algorithms have been improved using a hybrid 'scheme', which now accounts for conductivity gradients.
- » The ambient seismic technique was successfully applied to finding the depth of cover to resolve ambiguities in geophysical modelling for mineral exploration target generation.
- » The team continued to develop innovative strategies for turning geophysical data into geological information.
- » AMIRA project P1060 (Enhanced geochemical targeting in magmatic-hydrothermal systems) commenced in June.
- » An invited keynote address on an alternative origin for gold in the Super-Giant Witwatersrand Reefs was delivered at the Geological Society of London Fermor Conference.
- » At the Savage River magnetite deposit, textures that were previously considered to be bedding were determined to be mylonitic fabrics, which affect all units in the mine host sequence.



**LEADER**  
**ANDREW McNEILL**

**TEAM MEMBERS**

Mike Baker, Ron Berry, Stuart Bull, Huayong Chen, David Cooke, Tony Crawford, Leonid Danyushevsky, Garry Davidson, Jeff Foster, Nathan Fox, Bruce Gemmell, Sarah Gilbert, Leon Graham, Dave Hutchinson, Shaun Inglis, Vadim Kamenetsky, Ross Large, Sebastien Meffre, Steve Micklethwaite, Anya Reading, Ralf Schaa, Robert Scott, Helen Thomas, Jennifer Thompson, Andrew Wakefield, Tony Webster, Lejun Zhang

**PHD STUDENTS**

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**MASTERS STUDENTS**

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**HONOURS STUDENTS**

Jarrold Harris, Nicholas Smith

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 CLUMP MOUNTAIN GEOSCIENCE – Pat Williams  
 CONSULTANT – Noel White  
 CSIRO – Rob Hough, John Walshe  
 EPIGENESIS CONSULTING – Marcus Tomkinson  
 FULLAGAR GEOPHYSICS – Peter Fullagar  
 GLASS EARTH EXPLORATION – Simon Henderson  
 GRANGE RESOURCES – Roger Hill  
 IMPERIAL COLLEGE LONDON – Clara Wilkinson, Jamie Wilkinson  
 INSTITUTE FOR MINE SEISMOLOGY – Richard Lynch  
 JAMES COOK UNIVERSITY – Tom Blenkinsop  
 LAKEHEAD UNIVERSITY, CANADA – Peter Hollings  
 MINERAL RESOURCES TASMANIA – Ralph Bottrill, Jafar Taheri  
 MMG – Todd McGilvray  
 MONASH UNIVERSITY – Michael Asten  
 OZ MINERALS – Mark Allen, Jorge Benavides, Hamish Freeman, Charles Funk, Kerrin Gale, Marcel Van Eck  
 RUSSIAN ACADEMY OF SCIENCE, URALS BRANCH – Valeriy Maslennikov  
 UNIVERSITY OF OTAGO, NEW ZEALAND – Dave Craw  
 UNIVERSITY OF SYDNEY – Patrice Rey

**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

**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 AMIRA P1041)

P3B3A Shales and carbonates – improved vectors for Rosebery and Hercules style VHMS

P3B5A The Tweefontein Sector of the Platreef, South Africa

P3B5B The characterisation of magmatic sulfide systems

P3B5C The geology, geochemistry 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

**PROJECT SUMMARIES**

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

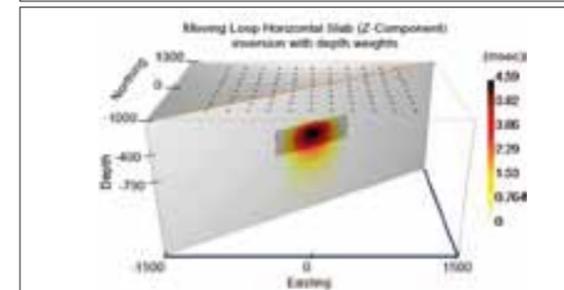
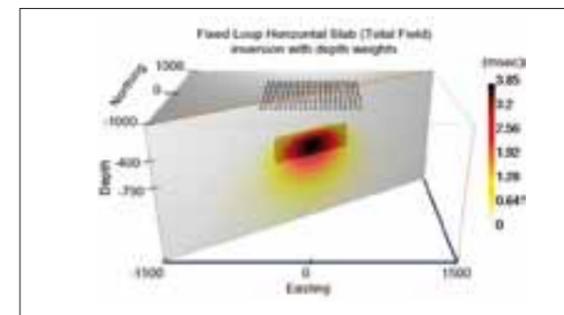
Leaders: Peter Fullagar, Jeff Foster

Team Member: Ralf Schaa

The aims of this project are to build on the results of Ralf Schaa's PhD research and further advance the development of rapid approximate 3D inversion of TEM data. The following work was completed during the year:

» The resistive limit forward modelling scheme was revised by imposing Faraday's Law. The purpose of this hybrid scheme is to ameliorate shortcomings of the original modelling scheme by taking conductivity gradients into account. The new algorithm is now being integrated into the VPmg potential field framework to expedite further development, including implementation of geometry inversion.

» The original VPem3D inversion scheme has been extended to permit inversion of moving- and fixed-loop TEM data, plus total field B and dB/dt data, including individual components.



The top panel shows a cross section through the model after inversion of synthetic total B-field data (TEM moment) for a fixed transmitter 500 x 500m loop. The bottom panel shows a cross-section of the same model but for moving-loop synthetic vertical component TEM moments. Colour denotes VPem3D inverted time constant distribution. True model is horizontal slab (shaded grey). Model dimensions are (3km X 2km X 2km) for east, north and depth, respectively. The model is discretised into 768,000 25 m cubic cells. Depth weighting applied to suppress shallow sources. Run time, respectively, was 2:38 and 3:24 min for fixed-loop and moving-loop on an Intel Processor i7 @ 1.60GHz.

» The original VPem3D inversion scheme was further extended to allow for homogeneous property inversion, which optimises the conductivity of a relatively small number of homogeneous bodies.

» Analytical solutions were derived for the horizontal and vertical TEM moments (time integrated B-field) produced underground in a uniform half-space by a rectangular loop on

or above the surface. The resulting formulae will be used to compute background response for downhole TEM surveys, and to extrapolate measured downhole transients to very early and very late times.

» The graphical user interface (VPview) is being improved by incorporating a more modern look and feel, and adding functionality to interrogate 3D VPem models.

**P3A2A  
AMBIENT SEISMIC ENERGY TECHNIQUES**

Leader: Anya Reading

Team Member: Leon Graham

Students: Jarrod Harris, Nicholas Smith

Collaborators: Michael Asten, Charles Funk, Richard Lynch, Nicholas Rawlinson

A new initiative has been established, in collaboration with Monash University and OZ Minerals, which has resulted in significant progress in relation to ambient seismic techniques aimed at constraining the depth to basement in the context of exploration under cover. Initial results are very positive, producing a good match between basement depths, determined using an ambient seismic technique, and a ground-truth value from a nearby borehole. Geophysical modelling is also being carried out to test the likely accuracy of the technique in practical situations.

In-mine seismic work, aimed at in-situ rock mass characterisation, was conducted in collaboration with the Institute for Mine Seismology. The work showed the potential for extracting useful information from source wavelets, from a highly repeatable piezoelectric source, in an underground mine setting. Variations in seismic velocity are a proxy for changing stress in the rock mass, with implications for extraction techniques and mine safety.

**P3A3A  
DATA INFERENCE TECHNIQUES APPLIED TO DIVERSE GEOSCIENTIFIC DATASETS**

Leader: Anya Reading

Team Member: Jeff Foster

Student: Matt Cracknell

Collaborator: Malcolm Sambridge

The main aim of this project is to explicitly investigate the application of innovative mathematical, geophysical and statistical approaches to diverse geoscience datasets. The focus is on alternate strategies that operate alongside currently used inversion techniques, with the aim of *maximising opportunity*, i.e. suggesting useful answers that may be missed using traditional techniques.

A highlight of the year was Anya Reading's feature article for the Australian Society of Exploration Geophysicists on the wider concepts behind turning geophysical data into geological information, which was published in the April issue of *Preview*.

Matthew Cracknell's work on using machine learning strategies to probe disparate, multilayered datasets has progressed well, with new algorithms being developed that enable linear features to be extracted from geophysical data. This work was presented at the IUGG meeting in Melbourne in July.

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

Leaders: Bruce Gemmell, David Cooke, Mike Baker

Team Members: Huayong Chen, Nathan Fox, Jennifer Thompson, Lejun Zhang

Students: Djohanne Celiz, Nic Jansen, Neil Macalalad, Jose Piquer, Leo Subang, Francisco Testa

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

This initiative commenced in June, 2011, building on research carried out within AMIRA P765A, often referred to as the explorer's toolbox for porphyry and epithermal districts, which concluded in late 2010. The project is being conducted in collaboration with Lakehead University and Imperial College London, and has the support of 21 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 analyses.

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 the analyses 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, Indonesia, Chile, Peru and Argentina. Sponsor meetings were held in June and December.

### **P3B1C LOW- AND HIGH- SULFIDATION EPITHERMAL MINERAL DEPOSITS**

Leaders: Bruce Gemmell, David Cooke

Team Member: Steve Micklethwaite

Students: Mathieu Ageneau, Lindsey Clark, Hugo Galvan, Daud Silitonga, Bronto Sutopo

Collaborators: Tom Blenkinsop, Patrice Rey, Jamie Wilkinson

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.

» Research continued on the Newcrest-funded deposit- to district-scale study of the Gosowong goldfield, Halmahera Island, Indonesia. Steve Micklethwaite finished his post-doctoral study on 'Enabling blind exploration – identifying hidden structure with faults, fractals and geomorphology'. This project utilised quantitative geomorphological technology to identify the location of mineralised faults and veins from subtle landscape signatures.

» Lindsey Clark's PhD project, investigating the geology and genesis of the Kencana epithermal Au-Ag deposit at Gosowong, is providing the first detailed study of the deposit via geological, structural, mineralogical and geochemical investigations. Masters of Economic Geology student, Daud Silitonga, continued his investigation of the Toguraci epithermal veins that crosscut the low grade Bora porphyry Cu-Au prospect in the district.

» Hugo Galvan's PhD project, funded by Coeur d'Alene, is investigating the geological and geochemical evolution of carbonate-base-metal Ag-Au epithermal veins in the Palmarejo District, Chihuahua, Mexico. The project is on track for completion in 2012 and first drafts of all chapters were completed in 2011.

» PhD student, Mathieu Ageneau, continued to study the low-sulfidation Ladolam Au deposit in Papua New Guinea, supported by Newcrest. During the year, research focused on the mineralogy of the Lienetz and Minifie ore bodies and, more specifically, the geochemistry of the main ore mineral – refractory pyrite. Fluid inclusion studies were completed, in collaboration with Jamie Wilkinson.

» Bronto Sutopo completed his PhD research on the high- and low- sulfidation mineralisation in the Martabe district, Indonesia. His thesis significantly improved the understanding of the geologic setting and ore genesis, as well as developing criteria for enhanced exploration in the district.



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

Leaders: Ross Large, Stuart Bull

Team Members: Leonid Danyushevsky, Garry Davidson, Sarah Gilbert, Shaun Inglis, Sebastien Meffre, Rob Scott, Helen Thomas

Students: Dan Gregory, Jeff Steadman

Collaborators: Dave Craw, Simon Henderson, Rob Hough, Valeriy Maslennikov, John Walshe

This project focuses on pyrite textures, geochemistry and isotopes in a wide range of gold deposits, to elucidate the origin, sources and timing of pyrite and gold using LA-ICP-MS analyses and mapping. A portion of this work forms AMIRA project P1041: The application of new technologies to gold deposits.

The following deposits were studied as part of this overall project in 2011:

- » Witwatersrand Carbon Leader Reef in the West Wits district (part of AMIRA P1041 – Research is addressing the question: “What are the potential sources of the various pyrite types and related gold?” A keynote address on the results of this research was delivered at the Fermor Conference.
- » Wafi high sulfidation epithermal gold deposit, PNG – The focus for this project with Newcrest is on the pyrite textures, mineralogy and timing of gold, and the geochemical fingerprint of the gold event.
- » McPhillamys volcanic/sediment hosted disseminated gold deposit in NSW – Work in collaboration with Newmont is determining the pyrite-gold mineralogy, timing of gold, S and Pb isotope characteristics of pyrite and the alteration mineralogy/geochemistry.
- » Kumtor gold deposit in Central Asia – In this collaboration with Valeriy Maslennikov, pyrite has been studied in both the black shale wall rocks and the ore zones. It has been discovered that nodular diagenetic pyrite in the carbonaceous shale host sequence is enriched in gold and tellurium, and may be the original source of these elements in the ores.
- » Bendigo gold mine, Victoria – S-isotope studies of sediment-hosted and vein pyrite have been written for publication.
- » Northern Carlin Trend, Nevada – Ross Large and Stuart Bull published a paper on the results from AMIRA P923 research.

» Otago Gold Province, New Zealand – In a collaboration with Dave Craw and Simon Henderson, a paper has been submitted for publication on the importance of diagenetic pyrite as a source for gold in the Otago Province.

» St Ives gold camp, Yilgarn, WA – This PhD study by Dan Gregory is a collaboration with the CSIRO MDU Flagship and Goldfields. The research, focussing on the Kapa Slate, demonstrated that early diagenetic pyrite is enriched in Au and Te, which could have been a factor in the genesis of the Au-Te deposits in the camp.

» Homestake gold mine, USA – PhD student, Jeff Steadman, is undertaking a study of the carbonaceous pyrrhotite-pyrite-bearing shales in the footwall of this deposit. His research is focused on understanding the metamorphic transition from pyrite to pyrrhotite in the shales, and how this may relate to the concentration of gold in the overlying carbonate facies BIF.

» Randalls gold-BIF deposits, Kalgoorlie District – PhD student, Jeff Steadman, is also studying the mineralogy, mineral chemistry and source of gold in the BIFs, hosted in sedimentary rocks equivalent to the Black Flag Beds.

» Hope Bay greenstone-hosted gold camp, Canada – Helen Thomas and Sebastien Meffre have been studying pyrite and gold paragenesis in the structurally controlled Madrid deposit (part of AMIRA P1041) to assist Newmont in the development of a model for the discovery of further deposits in the camp.

» Geita Hill BIF-hosted gold deposit, Tanzania – This study with AngloGold Ashanti is focused on pyrite-magnetite-gold relations and paragenesis in the complex lodes at Geita.

Research on sediment-hosted and greenstone-hosted gold has resulted in a new genetic model for Carlin type and orogenic gold deposits, which has major relevance in mineral exploration. A paper on the topic has been recently published in *Economic Geology*.

**P3B3A  
SHALES AND CARBONATES – IMPROVED VECTORS  
FOR ROSEBERY AND HERCULES STYLE VHMS**

Leaders: Andrew McNeill, Bruce Gemmell

Collaborator: Todd McGilvray

Exploration for VHMS deposits in the Mt Read Volcanics (MRV) is based on the concepts that all economic mineralisation occurs at a particular time horizon, and this horizon has been

adequately tested to a depth of 150–200 m. Therefore, from the exploration perspective, it is important to define the location and down-dip extent of the prospective horizon and to locate alteration envelopes that may be associated with VHMS mineralisation.

Studies on an initial sample set are complete. However, MMG has recently located host rocks with much higher TI-contents than the samples studied so far. The team have obtained samples from these rocks to analyse muscovites, and to confirm trends and correlations found in the initial sample set. Once these analyses are complete, the project will be written-up for publication.

**P3B5A  
THE TWEEFONTEIN SECTOR OF THE PLATREEF,  
SOUTH AFRICA**

Leader: Jeff Foster

Team Member: Dave Hutchinson

This industry sponsored project was designed to investigate the mechanisms and processes that led to the formation of Ni-Cu-Platinum-Group Element (PGE) mineralisation in the Tweefontein Sector of the Platreef, northern limb of the Bushveld Complex, South Africa. The project was completed in January 2011, after final report submission in late 2010.

**P3B5B  
THE CHARACTERISATION OF MAGMATIC SULFIDE  
SYSTEMS**

Leader: Jeff Foster

Team Member: Dave Hutchinson

The principal aim of this project was to investigate the mechanisms and processes that lead to the formation of Ni-Cu-Platinum Group Element (PGE) mineralisation. A sample encompassing the main mineralised portion of the Merensky Reef has been studied in detail, together with samples from the Platreef (both part of the Bushveld Complex, South Africa). Studies have also been conducted on samples of disseminated, globular and massive ore from Noril'sk-Talnakh, Russia. This project is now complete and a publication on the results is being prepared.

**P3B5C  
THE GEOLOGY, GEOCHEMISTRY AND GENESIS OF  
THE AVEBURY NI DEPOSIT – IMPLICATIONS FOR  
EXPLORATION**

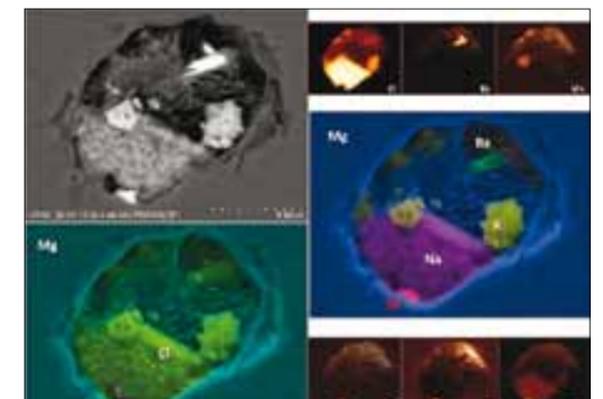
Leader: Jeff Foster

Team Members: Tony Crawford, Dave Hutchinson, Vadim Kamenetsky

Student: Alexey Lygin

The Awebury Ni deposit is hosted by serpentinised ultramafic rocks of the Mclvor Hill complex of western Tasmania. Data gathered during the year is confirming that the Ni mineralisation is related to the hydrothermal activity associated with emplacement of the Devonian Heemskirk granite:

- » Interpretative level plans (2000 and 1900 RL) show that metasomatic rocks (skarns) were developed mainly outside of the serpentinite body, while inner metasomatised ultramafics are localised along fractures. Although serpentinites contain disseminated sulfides, strongly mineralised rocks are clearly associated with contacts between country rocks, skarns and ultramafics.
- » Dating of Ni-bearing sphene from metasomatic rocks surrounding the ultramafic body yielded ages that were in accordance with the ages of red and white phases of the Heemskirk granite.
- » Fluid inclusions in olivine were found in a few samples of serpentinite. The inclusions are extremely saline, enriched in elements such as W, Sn, As, B, and Ni, and contain a range of chlorides, sulfides and Ni-arsenides.



Distribution of elements in exposed fluid inclusions in olivine. Maps based on BSE image. Pentlandite, nickeline, Ba-K-Cl, Pb-Na-Cl, NaCl, KCl.



**P3B6A**  
**STRUCTURE AND FORMATION OF THE SAVAGE RIVER  
MAGNETITE DEPOSIT**

Leader: Tony Webster

Team Members: Ron Berry, Rob Scott

Student: Victoria Braniff

Collaborators: Ralph Bottrill, Roger Hill, Jafar Taheri

The geology of the Savage River magnetite deposit is still very poorly understood, despite it being the largest metalliferous deposit in Tasmania. With the support of Grange Resources, a project was developed with the primary aim of understanding the structure of the highly strained rocks at the mine and the application of this knowledge to problems of slope stability management and near-mine exploration. Key findings in the past year included:

- » Mylonitic textures occur in all suites of rocks in the mine. Originally considered to be bedding, the microstructure shows strong foliation and mylonitic textures, and gives rise to the linear expression of the West, Host and East Wall assemblages.
- » Models, developed using 3DM Analyst photogrammetry, indicate brittle structures in the West and Host assemblages have similar orientations, while those in the East Wall assemblage have a completely different trend. This supports the concept that the structure of individual rock packages in the mine area is different.
- » Low temperature brittle features, often with some hematite infilling, dictate rock mass behaviour within the East Wall assemblage and have controlled recent pit wall failures.

**P3B7A**  
**IRON OXIDE COPPER-GOLD AND RELATED DEPOSIT  
TYPES**

Leader: Stuart Bull

Team Members: Garry Davidson, Sebastien Meffre

Collaborators: Mark Allen, Jorge Benavides, Hamish Freeman, Kerrin Gale, Marcus Tomkinson, Marcel Van Eck, Pat Williams

Phase one of the project conducted at Prominent Hill had the following aims:

- » Confirm the volcano-sedimentary architecture/ environments of the host rock succession by graphic core logging, with follow-up petrographic analysis of key samples.
- » Test the viability of using LA-ICP-MS analysis of U-bearing phases within this framework to establish a provisional chrono-stratigraphy.

This phase is now complete. Although the details of the outcomes remain confidential to OZ Minerals, it can be reported that the new chrono-stratigraphic framework for the host succession has significant implications for exploration for new IOCG deposits on the Gawler Craton.

Phase two, which commenced in October, involves applying the chrono-stratigraphic framework developed for the mine area to a number of regional prospects in the Mount Woods Inlier, and attempting to date the sulfide mineralisation.

# Outlook

- » Develop the ambient seismic method for determination of depth of cover in an exploration setting.
- » Develop a user-friendly software tool for the initial, automated extraction of linear features from geophysical data.
- » Preliminary interpretation of sponsors' site data, using the rapid EM inversion techniques being developed in AMIRA P1022.
- » Publication of new genetic model for Witwatersrand reefs.
- » Initiate new PhD projects on the geothermal aspects of the Ladolam deposit, PNG, and the Don Nicholas low to intermediate sulfidation deposit, Patagonia, Argentina.
- » Determine the age of the Prominent Hill sulfide mineralisation by dating co-precipitated U-bearing minerals, e.g. monazite.
- » Commencement of AMIRA project P1031: Copper, uranium, and precious metals in oxidising sedimentary basins: controls on ore formation and location.





# Program Four Recovery

# 4

**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 whole mine optimisation.

## INTRODUCTION

Geometallurgy is an exciting, cross-disciplinary activity that is having a significant economic impact on the mining industry. The ability to create and calibrate a geometallurgical 'toolkit' for an ore deposit at different stages in its life cycle leads to improved decision making and early recognition of processing options.

The three broad variables that control the economic viability and performance of an ore deposit are the amount of CAPEX required to put a deposit into production; cost per unit metal produced, net of by-products and co-products (C1 costs); and metals pricing. Of these variables, only CAPEX and C1 costs can be controlled.

The geometallurgical approach, developed in AMIRA P843 and P843A, utilises calibrated, small-scale tests to create proxies, which are used to define optimal processing domains within an economic envelope. The definition of an economic envelope is directly related to the conversion of resources to reserves, based on a series of modifying factors as defined by the JORC code or equivalent. This early detailed understanding of an ore body represents a significant leap forward from previous methods, which often relied on statistically insignificant bulk tests within a resource, defined on the basis of conventional grade-tonnage distribution.

The geometallurgical approach can be applied at a number of stages in the development of a mine, with maximum returns generated in relation to feasibility studies that precede development of new ore bodies or major expansions. The continuous application of geometallurgical protocols to extant ore bodies leads to performance optimisation and reduced C1 costs. The combination of reduced C1 costs and optimised CAPEX leads to superior economic performance.

The six principal themes of P843A, coupled with the case-study modules, effectively cover many of the major risk areas of mining and minerals recovery. Furthermore, the combined presence of Themes 1, 2 and 5 greatly enhances the probability of optimal cost curve solutions. As we move into a future further constrained by ever-rising energy and environmental costs, recognition of processing domains and routes can be used to more accurately and reliably establish the reserve base and, therefore, the amount of CAPEX required for a specific production rate.

## HIGHLIGHTS

- » A number of new major sponsors joined the project (Goldfields, Boliden and MMG).
- » A joint CRC ORE / GeM<sup>III</sup> MSc module was developed for the M.Econ.Geol. program at CODES / UTAS.

### Theme 1 (P4A1) – Predictive Environmental Indices

- » Prof Bernd Lottermoser has built the core of a world-class environmental facility at the UTAS Hub.

- » A major report – Predictive environmental indicators in mining: A review of the literature and best practice – was released to GeM<sup>III</sup> sponsors.

### Theme 2 (P4A2) – Integrated Blast Modelling

- » iFragX testing and evaluation completed.
- » Linking of iFragX to block model via 3DFrag completed.
- » An experimental method to assess the blast to leach concept has been proven successful.
- » The blast to size, sort to leach concept continues to evolve. A method has been identified to determine particle size from 3D imagery, which is a critical component of early sorting, upgrading and decision making.

### Theme 3 (P4A3) – Deterministic Comminution Modelling

- » Three labs have installed power meters leading to significant improvements in GeM<sup>III</sup> Ci.
- » A\*b express method confirmed and Bond proxy model complete. Final report issued.
- » It has been proven that the current A\*b express and GeM<sup>III</sup> Ci methods and indices are suited to rapid and high-volume hardness mapping.
- » The 'image analysis' approach to texture mapping is now highly advanced and ideal for the geometallurgical assessment of next generation core scanner output.

### Theme 4 (P4A4) – Texture-based Liberation and Recovery Modelling

- » The simulated fragments (Definiens) approach was used successfully.

### Theme 5 (P4A5) – Predictive Leaching Indices

- » A rapid tool for diagnostic selective leaching was developed and applied to samples from a major gold deposit.

### Theme 6 (P4A6) – Specialist Analytical and Support Software

- » Heap recovery factors were fully assessed and software is now under development that will combine both hydrology and chemical equilibrium.
- » A variety of software tools is under development and near completion. DomAln has developed further and can be readily used to convert complex geometallurgical processing proxies into mappable units.

### (P4A7) Case Studies and Technology Transfer

- » Nine sites with global significance have taken part in large-scale case studies. Three new case study sites are under active development.



### LEADER JEFF FOSTER

### TEAM MEMBERS

CODES – Ron Berry, Julie Hunt, Dave Hutchinson, Maya Kamenetsky, Lyudmyla Koziy, Andrew McNeill  
CRC ORE – Alan Bye  
CRC ORE / UTAS School of Earth Sciences – Bernd Lottermoser (partly CODES), Taryn Noble  
Parker Centre / CSIRO – Byron Benvie, Nicole Botsis, Goutam Das, Matthew Jeffrey, Dave Kelly, Nick Kelly, Laura Kuhar, Angus McFarlane, Bet Meakin, Patrick Merrigan, Dave Robinson, Nicole Turner  
UQ Sustainable Minerals Institute (SMI) – Dee Bradshaw, Alan Cocker, Mansour Edraki, Luke Keeney, Toni Kojovic, Angus McFarlane, Simon Michaux, Khoi Nguyen, Italo Onederra, Pat Walters  
UQ SMI / CRC ORE – Steve Walters

### PHD STUDENTS

CODES / UTAS – Natalee Bonnici, Anita Parbhakar-Fox, Ashish Sadhu, Adel Vatandoost  
UQ – Cathy Evans, Hector Parra Galvez, Richard Hartner, Kevin Pietersen,

### MASTERS STUDENTS

CODES / UTAS – Stacey Leichliter  
UQ – Mitesh Chauhan

## CORE PROJECTS

Project P4A (AMIRA P843A) – GeM<sup>III</sup> Geometallurgical 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

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

Leader: Bernd Lottermoser

Team Members: Mansour Edraki, Taryn Noble

Students: Anita Parbhakar-Fox, Ashish Sadhu

This theme provides early predictive information of intrinsic rock characteristics likely to impact on environmental performance and management during mineral processing, product manufacture and waste disposal. The underlying aim is to develop the foundations for a more predictive (and proactive) approach to early environmental characterisation that supports more effective management and valuation during mineral processing, and subsequent storage of waste. Ultimately, this will improve mine closure outcomes.

Significant outputs include the completion of a major literature review (Parbhakar-Fox, A., Lottermoser, B.G., 2011. Predictive environmental indicators in mining), which was released to sponsors.

Bulk sample materials (sulfide ore, plus sulfide and oxide waste rock) were obtained from operating and historic mines for accelerated static test work.

An experimental program has been initiated, focusing on evaluations of established rinse and paste pH procedures, and the use of microwaving in accelerated static test work.

A further experimental program has commenced, comparing the results of exploratory accelerated static tests with those of previously well characterised mine waste materials.

### THEME 2 (P4A2) INTEGRATED BLAST MODELLING

Leaders: Italo Onederra, Simon Michaux

Team Members: Ron Berry, Alan Cocker, Toni Kojovic, Steve Walters

Students: Hector Parra Galvez

Since the start of this project, blast fragmentation modelling has moved from single holes and local data to entire blasts and three dimensional geological data. An evaluation of different modelling techniques has shown that it is unlikely that any single parameter can provide a complete analytical description of fragmentation potential. However, the search for a means of directly associating fragmentation with mine-wide block models has great potential.

In the first step in trying to establish this association, the team considered fragmentation not as an output, but as a target to which standard blast 'templates' are applied in the search for the best engineering solution for any given rock mass. This was achieved by further extending iFragX to handle block model data and 3D visualisation. The embedded fragmentation model runs quickly enough to process batches of blast design templates in a few seconds. Currently, the approach is aimed at blast-sized volumes, where the engineer wants to know the best design template for the rock mass in a particular blast. This has the potential to become a useful tool for routine site use, as long as its data requirements are satisfied. In fact, it is the provision of fully qualified data that presents the greatest constraint on this approach. All efforts are currently aimed at validating iFrag protocols. Sensitivity analyses of iFrag's input parameters are already taking place, in order to guide future data collection campaigns.

### THEME 3 (P4A3) DETERMINISTIC COMMUNITION MODELLING

Leader: Toni Kojovic

Team Members: Julie Hunt, Simon Michaux, Pat Walters, Steve Walters

In 2011, the focus has been on improving the GeM<sup>III</sup> comminution index, use of non-core drilling products, and comminution blend response. The team has largely achieved its objectives and is now moving to a phase of applications support and method validation and refinement. New ideas, such as the A\*b Express concept, will be evaluated once a suitable prototype device is made available in 2012. The benefits and implications of the developments to date are covered in the text below.

The GeM<sup>III</sup> Ci has been shown to be ideally suited for high volume hardness mapping. With the addition of a simple power meter, the Ci test provides an enhanced level of information on the hardness of the core material, particularly in terms of the A\*b index in the harder samples, where the Ci was previously unable to resolve the difference between two samples. The improvement was not as significant when applied to Bond prediction, with the lowest error being around 10%. This is comparable with commercial ore hardness 'modified' tests.



A simple protocol has been defined for the integration of the ELF meter within the Ci test, which includes a no-load calibration at the key crusher gaps used in Ci testing for each machine. Power meter installations have been adopted by JKTech and external labs using the Ci test, and other laboratories are expected to follow. There are still limitations in dealing with friable core samples, and further work is required to investigate the most appropriate way of managing such cases.

The A\*b Express test concept has been confirmed as a rapid means of quantifying the impact resistance of core samples, using only one test at a single low RBT energy. Once calibrated to RBT Lite or full RBT test results, the A\*b Express method should be able to provide a robust mapping tool with a minimal sample requirement. This is ideally suited to hardness characterisation at the pre-feasibility level. Alternatively, integration with routine assaying of blast chips offers a number of potential applications suited to short-term planning.

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

Leader: Dee Bradshaw

Team Members: Ron Berry, Julie Hunt, Maya Kamenetsky, Steve Walters

Students: Natalee Bonnici, Mitesh Chauhan, Kevin Pietersen

The main objective is to develop an appropriate methodology to populate deposit block models, with recovery predictions that incorporate inherent geological variability. This is being achieved from mineralogical predictions (particularly those focused on obtaining texture indicators) and the development of a suitable small-scale test. In addition to this work, the team has been developing grain size measures and fractionation indicators as part of Theme 6, and is also playing a key role in the Prominent Hill case study, in which a recovery predictor for the block model is being developed, using an appropriate small-scale test.

Four pixel correlation analysers and one feature extraction system have been developed, incorporating new parameters to extract geological textures implicitly, or as distribution data.

Work is progressing towards the development of a robust, low cost, small-scale test that provides a mineral separability index, linked to potential flotation performance and variability, and comminution tests. The focus is on the sample preparation methods. Results to date indicate that a plain crush, or a planetary ball mill sample, displays similar mass distribution (below a certain size) to that produced using a typical grind calibration curve. Because of the small amount of mass required, and the unbiased nature of the sampling, the best sample preparation method for geometallurgical applications has been proven to be by using a planetary ball mill. The potential use of a small-scale batch test (500g ore in 1.5 L) is also being evaluated as an alternative to the 1 kg batch test.

The development of the GeM<sup>III</sup> MSI test for geometallurgical applications is continuing, with a focus on evaluating the

differences in behaviour obtained with ore from an IOCG deposit (Prominent Hill) relative to those obtained from porphyry ores (Cadia, Escondida and others). For the porphyry ores, the recovery by size obtained with the MSI test for each fraction was equivalent to that obtained either by batch flotation tests, or on an industrial scale. However, this correlation was not obtained with the ores from Prominent Hill.

#### THEME 5 (P4A5) PREDICTIVE LEACHING INDICES

Leader: Dave Robinson

Team Members: Byron Benvie, Nicole Botsis, Goutam Das, Matthew Jeffrey, Dave Kelly, Nick Kelly, Lyudmyla Koziy, Laura Kuhar, Angus McFarlane, Bet Meakin, Patrick Merrigan, Nicole Turner

This theme falls under two broad categories: Diagnostic/ Selective Leaching and Agglomeration/Coarse Particle Leaching.

The diagnostic and selective leaching study involves a small-scale leaching approach, comprising two distinct methodologies. Diagnostic leaching targets proxies for leach performance, while selective leaching aims to be a proxy for copper mineral speciation. Agglomeration largely concerns the hydrology of coarse particle leaching, thus a broader focus has been adopted to encompass additional rock characteristics pertaining to the 'leachability' of coarse particles.

Previous work identifying the non-selectivity of conventional diagnostic or partial leach methods has prompted exploration of new leaching matrices that are able to target copper minerals more discretely. This has resulted in numerous trials of documented and novel leaching conditions, many of which were unsuccessful, or only partially successful. However, while few matrices are completely selective, a number of the tested methods are sufficiently selective to allow quantification of the mineralogy of copper-oxides, chalcocite, bornite and chalcopyrite. Depending on the ore-body, some or all of these tests can be undertaken and an estimate of copper deportment determined via back-calculation from the various leach results. Further improvement is being sought to increase the precision of the various leaches and expand the testing regime to allow quantification of other copper minerals (covellite in particular).

Meanwhile, conventional diagnostic leaching methods remain an area for ongoing development. Since sulfuric acid and cyanide leaching tests are widely used, it may be that further understanding of the ore, and its hydrometallurgical response, can be obtained through measurement of a broader range of solution species. An example of this approach is a cyanide leach, whereby elements of significance to downstream processing (e.g. environmental disposal) were assayed in addition to the routinely measured Cu and Au. Exploratory work in this area is continuing.

Development of the agglomeration test, using a pelletisation method, has been advanced by trials on a series of crushed drill-core sections, including measurement of pellet

permeability and strength. Results appear to indicate that the agglomeration response will vary significantly between drill core sections, with clay mineral content showing a strong influence on both strength and permeability in the samples available. Other factors affect the pellet strength response (e.g. moisture-ore 'optimum') and further testing of a wider range of samples, preferably with associated data from columns or heaps, is needed to explore the significance and meaning of the results.

#### THEME 6 (P4A6) SPECIALIST ANALYTICAL AND SUPPORT SOFTWARE

Leader: Ron Berry

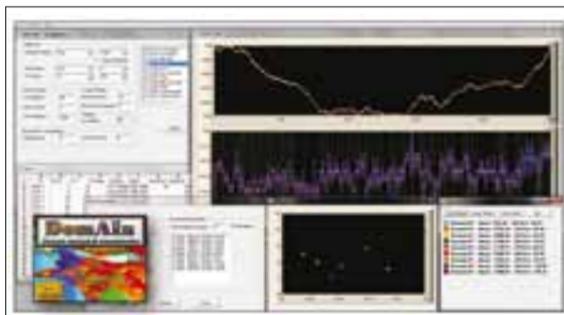
Team Members: Dave Hutchinson, Maya Kamenetsky, Luke Keeney, Khoi Nguyen, Steve Walters

UTAS has installed a Renishaw laser Raman fast mapping system with 4 lasers. The aim in GeM<sup>III</sup> is to use this machine to test the applicability of laser Raman mapping to geometallurgy. The configuration has been optimised for fast mapping and initial tests indicate high quality spectral data can be recorded at 3 micron pixel resolution and 50 milliSecs/pixel. Classification options will be fully tested over the next six months.

A program (STORC) has been developed to measure structure orientations using high quality photographs of oriented core. The program was released to the sponsors as a beta version in September, with the final version planned for release after it has been widely tested.

The ioGem program of additional geometallurgy features for ioGas was successfully completed with the release of version 4.3 in June. These features are now available in ioGas.

Spatial modelling within the project has largely been taken over by developments in CRC ORE. Where demand has developed within GeM<sup>III</sup>, this has been handled using DomAIn, with outcomes exported into block models using available software. Spatial modelling problems within GeM<sup>III</sup> have been relatively small scale because of the size of existing data. Non-linearity in parameters, such as A\*b, has been avoided by modelling more linear parameters such as throughput. Other possibilities suggested, but not yet tested, are transforms such as 1/x.



Screen chart from DomAIn software.

#### (P4A7) CASE STUDIES AND TECHNOLOGY TRANSFER

Leader: Steve Walters

Team Members: Ron Berry, Dee Bradshaw, Alan Bye, Julie Hunt, Toni Kojovic, Angus McFarlane, Andrew McNeill

Elective case studies aimed at creating large-scale, site-based validation and comparative benchmarking are a feature of GeM<sup>III</sup>. Their aims are to focus on tools and methodologies related to the project, and to support technology transfer through validation, enhancement and demonstration of outcomes. The studies play a key role in the difficult transition from research prototype to commercial product. The high level of engagement and collaboration with sponsor sites, involving a significant exchange of data and ideas, ensures that a process that requires a high degree of nurturing and investment is handled in a manner that enhances the chance of success.

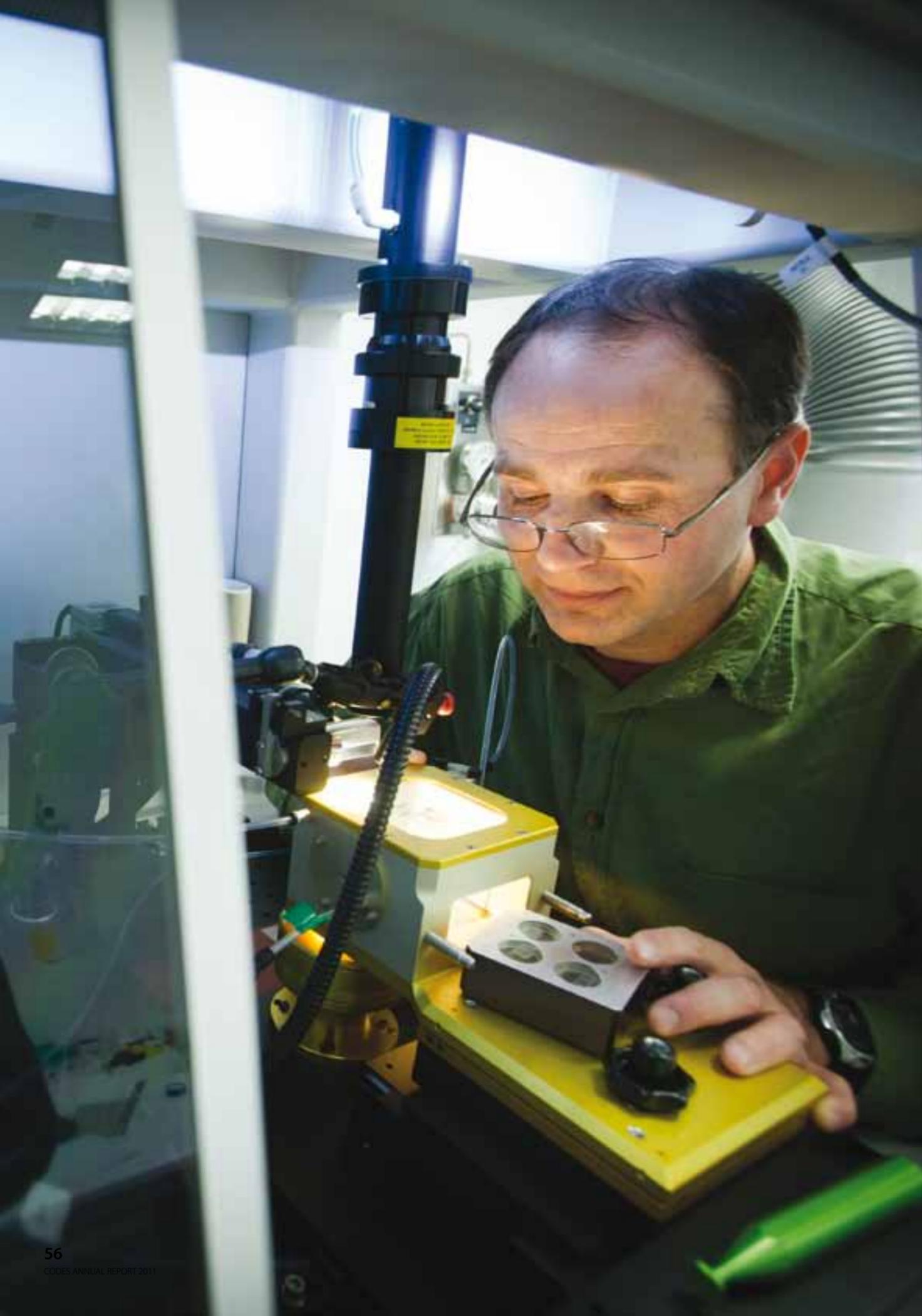
Of the 12 sites nominated for case studies at the beginning of the project, nine have progressed to full case study status, with three withdrawals. However, negotiations are underway to replace these three sites in the current round of case studies. Once this current round is completed, the next phase will involve site-based case study applications covering methodologies and techniques emerging from the project. Four case studies are nearing completion.

There is a geographic cluster of studies into Australia and South America, with a clear focus on bulk Cu-Au porphyry, epithermal and IOCG type deposits. Operational status ranges from feasibility to mature, with an emphasis on application of GeM<sup>III</sup> core scanning technologies, comminution testing tools and multivariate predictive modelling. The Chilean operations in particular represent mature, data-rich sites with a long history of geometallurgical programs, generally involving conventional testing methods. The Telfer case study involves retrospective analysis of concepts, methodologies and assumptions used during feasibility in 2002, prior to current concepts of geometallurgical integration. Ore type testing and definitions have been compared and reconciled against subsequent processing performance. Significant lessons are evident in this analysis, which can be applied to current geometallurgical programs. A significant issue is understanding the role of geometallurgy during the different phases of an operation, from discovery to mature production. Current debate regarding definition of geometallurgy as an overarching practice exacerbates problems of practical application.

For methods and technologies validated in the current case studies, the requirement is to provide commercially supported offerings. This involves emerging relationships with JKTech and other supplier sponsors associated with GeM<sup>III</sup>. Key areas include provision of in-house training and education to sponsors, laboratory testing services, specialised software and routine consulting services. It is of interest to note that two AngloGold Ashanti personnel for the La Colosa case study have been embedded into the research groups to assist with direct technology transfer to site.

# Outlook

- » Develop methods for the rapid assessment of dust, based around Raman optical microscopy.
- » Apply iFragx and 3DFrag to a large-scale case study test site. Apply 3D spatial analysis tools to determine particle size and link to blasting models.
- » Develop method for mapping of both sorting and blasting indices.
- » Complete current comminution program and investigate new and improved extant technologies able to deliver small-scale tests for A\*b and Bond.
- » Complete version one of textural analysis toolkit.
- » Continue to develop and improve sampling protocols for MSI.
- » Upscale diagnostic-selective leaching capability through application at deposit scale.
- » Develop software to link hydrology (fluid flow) with chemical equilibrium models in order to predict and plan development of heap/dump leach pads.
- » Investigate the potential of laser Raman spectroscopy to mineralogical mapping at a variety of scales.
- » Finalise current version of DomAIn and release to sponsors.
- » Develop case studies for the Environment, Blasting and Hydrometallurgy themes (1, 2, 4 & 5).
- » Complete, and report on, current round of case studies.



# Program Five Technology

# 5

**Objective:** Research activities within the Program are aimed at developing new analytical techniques, ensuring that research is driven by innovative technology, and 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 processing of analytical data. Many of the projects include close collaborations with Node partners, such as the University of Melbourne, CSIRO and the Australian National University.

## HIGHLIGHTS

- » Algorithms improved for gold particle size determination during LA-ICP-MS imaging of sulfide grains.
- » New work published on the Pb isotope compositions of melt inclusions, which refines the petrogenetic models of an archetypal OIB occurrence.
- » A large suite of hydrothermal sediments were analysed for Cu isotopes and the results are ready for publication.
- » Modifications made to a sulfate-in-carbonate extraction technique have been successfully trialled on experimental sulfide-sulfate mixes, and on natural vein-hosted samples.
- » Introduced state-of-the-art FPGA data collection system and beam control to aid PIXE and IL mapping.
- » The Maia 384 detector system received an R&D100 Award, presented annually to 100 of the world's most technologically significant products. It also received an Australian iAward.
- » XANES visualisation and stack processing in GeoPIXE implemented.
- » Petrolog 3.1, software for modelling magma crystallisation processes released.



**LEADER**  
**LEONID DANYUSHEVSKY**

### TEAM MEMBERS

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### PHD STUDENT

Sarah Gilbert

### MASTERS STUDENT

Siddharth Paleri

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## 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

### 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
- P5BN1 X-ray microanalysis development

### Theme 5C – Data Interpretation Tools

- P5C3 Modelling of crystallisation and melting processes

## PROJECT SUMMARIES

### P5A1 LA-Q-ICP-MS ANALYSIS DEVELOPMENT

**Leaders:** Sebastien Meffre, Leonid Danyushevsky

**Team Members:** Marcel Guillong, Ian Little, Jay Thompson

**Student:** Sarah Gilbert

**Collaborators:** Sergey Broude, Fred Fryer, 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 focus during the year was, once again, on improving the sensitivity, reliability and versatility of the LA-ICP-MS instrumental set-ups at the CODES analytical facility. Activities and successes included:

- » New particle trapping devices have resulted in improved Pb and S isotopic determinations.
- » Optimisation of the collision cell in the wet plasma mode has led to better signal/background ratio values for a range of light elements, such as Na, Mg, Fe, Ca and Al. This analysis has now become routine.
- » Optimisation of the purging system for the beam delivery unit on the RESOLUTION M50 laser probe has increased energy stability, while significantly decreasing instrument running costs.
- » A new type of nylon tubing is now being used for making the interface components that connect the laser probes and mass-spectrometers. This has significantly improved aerosol transport efficiency compared to the previously used FEP (fluorinated ethylene propylene) tubing, while maintaining low background levels for sulfur.

### P5A2 NEW LA-Q-ICP-MS APPLICATIONS

**Leaders:** Leonid Danyushevsky, Sebastien Meffre

**Team Members:** Marcel Guillong, Vadim Kamenetsky, Ian Little, Jay Thompson

**Student:** Sarah Gilbert

**Collaborators:** Jacob Hanley, Marc Norman, Norman Pearson, Massimo Raveggi, Dany Savard, Marcus Walle, Cora Wohlgemuth-Ueberwasser

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:

- » Apatite standards from a published apatite geochronology method were tested revealing subtle differences between U-Pb fractionation in different types of apatite, when analysed

in the spot mode. A number of data reduction methods are being compared to determine the method that yields the most accurate data.

- » Methods were developed for sizing gold particles that are much smaller than the laser spot. Particles down to 200 nm can now be identified under standard LA-ICP-MS operating conditions, and the chemistry of these gold particles can also be deconvoluted.

- » Following initial work in 2010, aimed at improving the accuracy and precision of S isotopic determination on the LA-ICP-MS, this year's focus was on finding ways to improve the washout of sulfur between analyses, and reduce signal errors for better precision of the isotopic measurements. Several sulfide standards were reanalysed at the UTAS Central Science Laboratory in order to better constrain the reference values and ensure the accuracy of the LA-ICP-MS isotopic measurements. The effects of changing laser parameters, such as spot size and energy, were investigated in both pyrite and pyrrhotite. This work will continue in 2012.

### P5A3 NEW LA-MC-ICP-MS APPLICATIONS

**Leaders:** Bence Paul, Janet Hergt

**Team Members:** Leonid Danyushevsky, Sebastien Meffre

**Collaborator:** Jon Woodhead

The aim 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. This will provide new spatially resolved information to help unravel processes involved in ore formation.

During the past year, the limits of in-situ laser ablation techniques have continued to be pushed, via the combined analysis of Pb isotope and trace element compositions in low-Pb material (melt inclusions), which provide insights into magmatic processes. Protocols have also been developed for creating images from Sr isotope and trace element data. In addition, the Lolite data reduction software developed within this project has seen a significant level of acceptance and usage by the analytical community.

### P5A4 NEW STABLE ISOTOPE MS APPLICATIONS

**Leaders:** Janet Hergt, Bence Paul

**Team Members:** Leonid Danyushevsky, Sebastien Meffre

**Student:** Siddharth Paleri

**Collaborators:** Chris German, Darryl Green, Nicole Lockhoff, Jon Woodhead, Feng Yuan

The aim 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.

Stable isotope work during 2011 was focussed on obtaining high quality Cu isotope results for a range of hydrothermal sediment samples, as well as mineral separates. Mineral

separates from Chinese basalts were analysed as part of a collaboration with Prof. Feng Yuan of the Hefei University of Technology.

A first class MSc thesis on Cu isotope and trace element systematics of hydrothermal sediments from the Rainbow vent field in the mid Atlantic Ocean was completed. The results of this study should be published next year.

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

**Leader:** Garry Davidson

**Team Members:** David Cooke, Sandrin Feig

**Collaborators:** James Cleverley, Mike Nugus, Nick Oliver, Heidi Pass

Redox conditions and isotopic sulfur composition are increasingly being used in studies of ore genesis, and for exploration in oxidised hydrothermal systems. Unfortunately, sulfate minerals are commonly not available in many ore deposits for the purposes of isotopic analysis. Therefore, this project explores the use of carbonate-substituted sulfate (e.g., from vein carbonate-sulfide mixes) as a tool for determining the isotopic composition of sulfate.

The twin objectives for the past year were to refine a chemical means of extracting and measuring the isotopic composition of carbonate-hosted sulfur at low levels; and work towards establishing which carbonate-forming ore environments are applicable for the technique.

The modified extraction technique was successfully applied to synthetic sulfide-sulfate mineral mixtures, and used to analyse a vein sample set from the alkalic porphyry copper-gold deposit at Mt Polley, Canada. These samples have previously been mapped for S, which showed that high levels of primary S are substituted into the veins. This result opens the way for publication of the technique in 2012. Vein carbonate samples from several levels in the orogenic Sunrise Dam gold deposit were also mapped, and were shown to contain only low levels of substituted sulfate.

**P5B1  
ION BEAM ANALYSIS DEVELOPMENT**

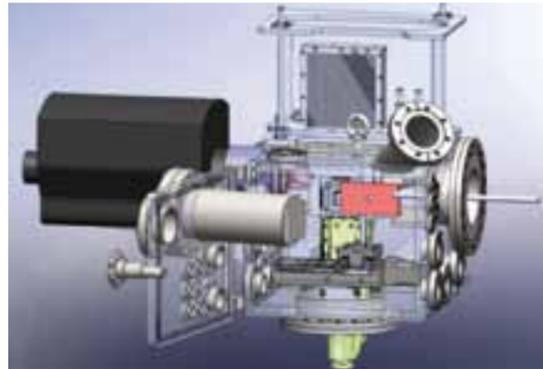
**Leader:** Jamie Laird

**Team Member:** Chris Ryan

**Collaborators:** Jeff McCallum, Roland Szymanski

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

The major outcomes this year were the completion of a new data collection system, entitled 'Mikrodaq', for PIXE and IL analysis of large mineral samples, and the design of a new chamber to accommodate the Maia rapid X-ray mapping system.



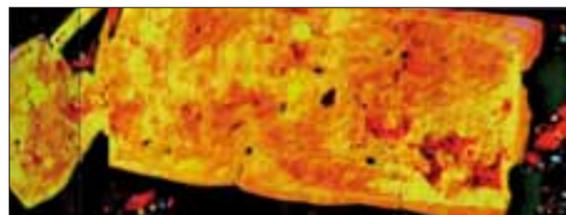
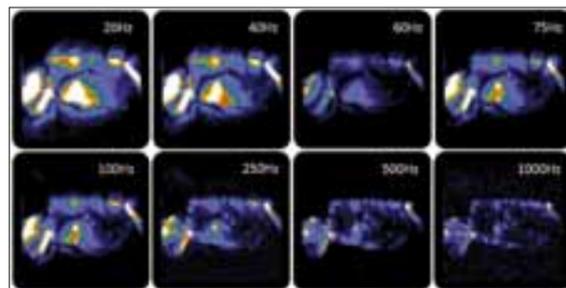
CAD schematic for the new CSIRO NMP chamber for the Maia X-ray mapping system.

**P5B2  
NEW ION BEAM APPLICATIONS**

**Leader:** Jamie Laird

**Team Members:** Stacey Borg, Chris Ryan

Understanding the role of metal sulfide semiconductivity on the genesis of precious metals requires methods for mapping electrical properties, such as the electric field in complex minerals. The major outcome this year was a correlation of LBIC mapping with PIXE on the same series of pyrite grains from Otago, New Zealand. However, comparison of the datasets is inconclusive and steps required to improve the understanding of LBIC in these minerals are in progress.



From top to bottom: Photograph of an Otago pyrite grain; frequency dependence of LBIC maps on the pyrite samples; and post-LBIC PIXE map (RBG composite) illustrating Fe/As and Au distributions.



### P5B3 SYNCHROTRON X-RAY PROBE DEVELOPMENT

**Leader:** Chris Ryan

**Team Members:** Stacey Borg, Weihua Liu

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

This project is developing new experimental equipment for probing samples of geological interest, using the following synchrotron radiation applications at the Australian Synchrotron:

- » The Maia detector – a high throughput, high definition fluorescence imaging system for the XFM beamline.
- » The mAESTRO system – a high pressure-temperature synchrotron spectroscopy cell for solution studies at the XAS beamline.

Hardware and software developed in 2011 address accurate quantification in images, and real-time display of element images. It also provides correction for scan irregularities, accurate dead-time and pileup corrections (consistent over wide count rate ranges, up to 10 M/s), which are ideal for wide-area trace element imaging, and as a platform for chemical state imaging using XANES absorption edge fine structure.

The mAESTRO system was hindered by the unavailability of the XAS beamline in 2011. However, further upgrades to the heating system were scheduled for early in 2012. Therefore, work is expected to start at the Australian Synchrotron, which will hopefully allow for mAESTRO experiments late in 2012.

### 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 development of new and existing synchrotron techniques for the study of metals and mineral species. Major outcomes for 2011 included:

- » Experimental procedures refined for the collection of XANES imaging datasets at the AS XFM beamline, including new kinetic stage mounts and stage movement protocols, which minimise sample drift and image artefacts in XANES stacks.
- » Data reduction and analysis tools for XANES stacks were incorporated into GeoPIXE.
- » XANES mapping experiments were conducted at the XFM beamline exploring Fe redox state and speciation in mineral and meteorite samples.
- » A HT/HP study of Au interactions with bromide, amine and carbonate bearing solutions was completed.

» Manuscripts submitted for HT/HP studies on Zn bromide and Mo chloride systems.

» Publication of Cu chloride manuscript in *RSC Advances*.

### P5BN1 X-RAY MICROANALYSIS DEVELOPMENT

**Leaders:** Karsten Goemann, Leonid Danyushevsky

This project was on hold in 2010, but recommenced in 2011. It encompasses hardware, software and analytical developments in the Electron Microscopy and X-ray Microanalysis Facility of the UTAS Central Science Laboratory (CSL).

A station to prepare standard materials for microanalysis has been set-up in the CSL, replacing the ageing standards blocks on the microprobe. This station will be permanently installed in the instrument on new holders, which will minimise user handling of the standard materials and increase their lifetime and reliability. The old blocks are still available, but will be used mainly for quantitative analysis on the new Hitachi FESEM.



Karsten Goemann using the new Hitachi FESEM.

### 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.

In 2011, work continued on improving the algorithms for modelling the behaviour of trace elements during crystallisation processes. Updated versions of Petrolog 3 were completed and are available at: <http://petrolog.web.ru>

These algorithms are continuously implemented in future versions of the 'Petrolog' software package.

# Outlook

- » Installation of a new large constant geometry ablation cell on the RESOLUTION M50 laser probe.
- » In-depth comparison of laser induced fractionation between different types of laser probes with the aim of increasing the accuracy of LA-Q-ICP-MS analysis.
- » Publish a new procedure for measuring Pb isotopes and trace elements in low-Pb melt inclusions.
- » Publish CAS extraction technique. In addition, evaluate the means to extend the technique to ultra-low S samples, and test its use for the first time on IOCG carbonate vein samples.
- » Attain a more detailed understanding of the correlation between LBIC and elemental mapping necessary to determine elemental distributions and textures related to gold precipitation via electrochemical analysis.
- » Introduce a highly integrated data collection and a new NMP chamber for large area mapping correlated with luminescence imaging.
- » Reintegration of the HT/HP mAESTRO system with fluorescence detection at the Australian Synchrotron.
- » Development of algorithms for magma and phenocrysts mixing calculations in Petrolog 3.

# 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 industry. HDR students have access to all of the Centre's equipment and facilities and are encouraged to take advantage of the wide range of expertise and experience offered by academic staff.

There were 50 students enrolled in the program during 2011 (46 PhD and 4 MSc), which included four new PhD students – Jose Piquer, Chile; Carlos Jimenez, Colombia; Evan Orovan, Canada; and Daniele Redi, Italy. Stacey Leichliter (USA) and Charles Makoundi (Republic of the Congo) began as MSc students. Twelve PhD students and two MSc students had theses under examination, seven of whom graduated: Andrea Agangi, Mawson Croaker, Terence Hoschke, Wallace Mackay, Rodney Maier, Olga Vasyukova, and Adel Vandoost.

Two PhD students suspended their candidature for part or all of the year, two chose to study part-time, and another two withdrew. Five students had their candidature terminated because they had ceased research activity and were not progressing. This reduced the effective PhD workforce to 36, which was lowered further to 24 by the number of thesis submissions and graduations.

The 2011 HDR cohort included 39 international students representing 22 nationalities, fourteen of whom were at least partly funded by Centre of Excellence scholarships. CODES' success in attracting HDR students from overseas is underpinned by its international reputation as a research training centre, and ability to invest ARC Centre funds in scholarships. In addition, the program is generously supported by UTAS in the form of international student tuition fee waivers. It is also worth noting that none of the five new students were Australian, and CODES is dependent on ongoing UTAS support to recruit internationally.

Many of CODES' HDR students are members of the UTAS Student Chapter of the Society of Economic Geologists (SEG). Pedro Fonseca and Jeff Steadman were co-presidents of the chapter for the first part of the year, while Dan Gregory took over the presidency in the latter part of the year, with Roisin Kyne and Chris Large as co-vice presidents. Supported by their committees, they organised a wide range of events that encompassed both professional development and recreational activities.

The highlight of the year was the 12-day field excursion in May to China's Middle and Lower Yangtze Mineral Belt. The visit included areas along the Yangtze River from the border between Hubei and Anhui provinces to Nanjing in Jiangsu province. This region contains a large-scale belt of polymetallic (Cu, Fe, Au, Mo, Zn, Pb) mineralisation with more than 260 economic deposits, making it one of the most important metallogenic belts in China. The trip was organised by the Student Chapter, led by David Cooke, Huayong Chen and Zhaoshan Chang, and sponsored by CODES, AngloGold Ashanti, and Data Metallogenica. Industry personnel from AngloGold Ashanti, Gold Fields, Rio Tinto, and OZ Minerals also participated in the excursion.

Other professional development events organised by the Chapter included a short course on the geology and mineral deposits of Tasmania, plus a successful speaker series that included Jim Mortenson, UBC; Glen Masterman, Kinross Gold; John Walshe, CSIRO; and Peter Hollings from Lakehead University. Another highlight was the inaugural Mike Solomon Lecture, which had Paul Kitto from Ampella Mining as its guest speaker. Paul was formerly a PhD student and Research Fellow at CODES.

The recreational program plays an important role in building team spirit and helping students from diverse cultural backgrounds settle in to life on campus. Once again, the committee did an excellent job in organising a broad range of activities from ice hockey, through to a quiz night, Australian rules football, wine and cheese tasting, barbecues and holiday parties.

Dan Gregory was successful in gaining an SEG Graduate Student Fellowship Award that will help fund his PhD studies.

## MASTER OF ECONOMIC GEOLOGY PROGRAM

The Master of Economic Geology Program continues to be one of CODES most successful activities. Participation remained strong in 2011, with a total of 44 active students, including eight new enrolments. It also continues to be the course of choice for an increasing number of international students, with the current cohort including participants from the UK, South Korea, the Philippines, Indonesia and Vietnam. Four students graduated during the year: Colin Carter, David Freeman, Bruce Whittaker and Paluku Batsotsi. Mr Batsotsi hails from the Democratic Republic of Congo, which epitomises the cosmopolitan composition of the student group.

The program forms part of the national Minerals Geoscience Masters (MGM), which is a collaborative initiative between UTAS, the University of Western Australia and James Cook University. Generous financial support from the Minerals Council of Australia (through the Minerals Tertiary Education Council) has been critical to the development and management of this successful and industry-focussed program. Therefore, it was very disappointing to learn in late 2011 that the MCA will cease financial support for the program at the end of 2012.

Universities participating in the MGM offer between three and six, two-week short courses, held in rotation over a two-year period. The program is aimed primarily at industry-based geoscientists, and is structured with a number of flexible options designed to enable the degree to be completed with minimal disruption to their working lives. These options include completion of the degree via coursework only, or coursework plus a research thesis.

Two short courses were held by CODES in 2011 as part of the Program. David Cooke and Bruce Gemmill led the Ore Deposits of South America course in March, which had 23 participants, comprised of ten MGM students, nine industry participants, and four CODES' staff and students. This field-based course was held in Chile and Peru and included visits to numerous mines and exploration projects that included IOCG, porphyry, epithermal, skarn and MVT deposits. The students also gained firsthand exposure to the remarkable regional geology and tectonic evolution of the Andes. In June, Anthony Harris led the Ore Deposit Geochemistry, Hydrology and Geochronology course, which had 24 participants, comprised of 13 MGM students, five industry participants, and six CODES' staff and students. The course was held at CODES' Hobart Hub and covered a range of geochemical and geochronological techniques used to interpret environments of ore formation and the processes of ore genesis.

The year also saw a change in the stewardship of the program at CODES. At the end of July, Tony Webster, who had done an admirable job in building the program over the past five and a half years, left the Centre to take up a position in industry. However, an excellent replacement was found in Rob Scott who has been with CODES as a research fellow for 12 years, and also has a strong track record working in industry and other academic institutions. Rob started his duties late in the

year and is using his extensive experience at the Centre to ensure a seamless transition.

The coming year promises to be the one of the busiest years in the history of the Master of Economic Geology program at CODES. In the past, the Centre has alternately run two and three courses per year. However, next year's schedule includes three of the well-established courses, plus a new course that expands the scope of the program by encompassing geometallurgy. This full schedule is further proof that the program is highly valued and continues to grow.

The program for 2012:

- » March – Geometallurgy.
- » April – Volcanology and Mineralisation in Volcanic Terrains.
- » June– Exploration in Brownfields Terrains.
- » October/November – Ore Deposit Models and Exploration Strategies.

## HONOURS PROGRAM

There were 12 Honours enrolments for the year, which was moderately down on the previous year's figure of 15. However, it should be noted that in addition to this figure there were four mid-year enrolments, which took the total up to about the optimum logistical size for an Honours year intake. Although these students formed part of the cohort for half of the year, they can only officially be counted in next year's figures.

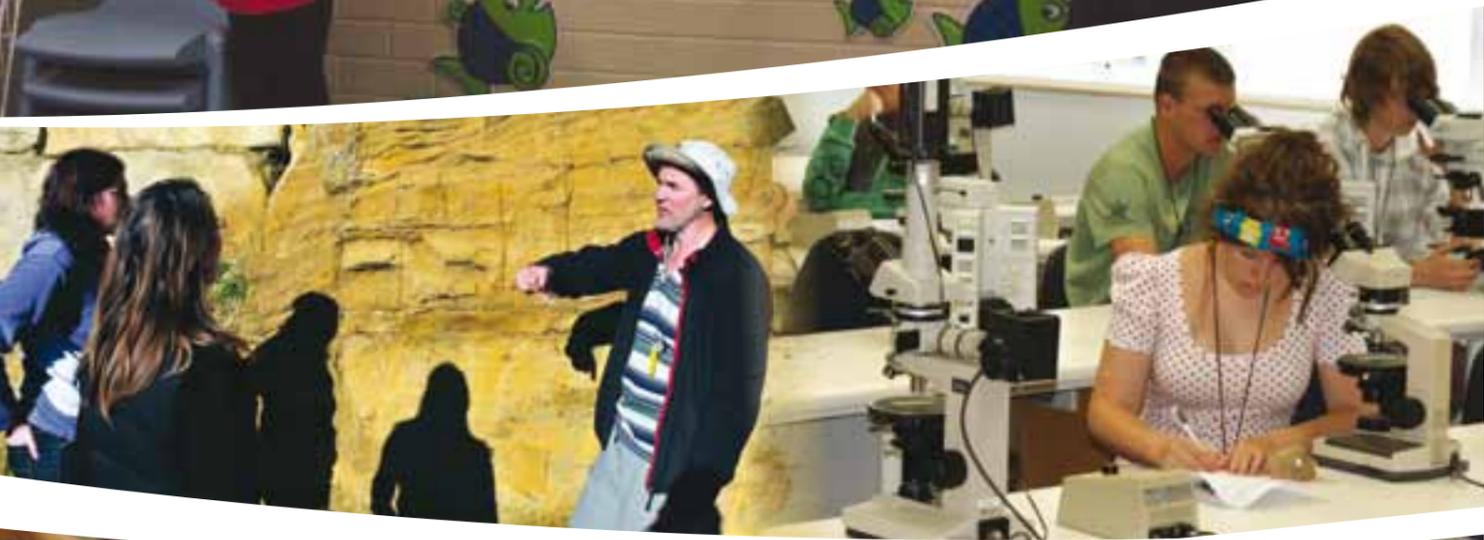
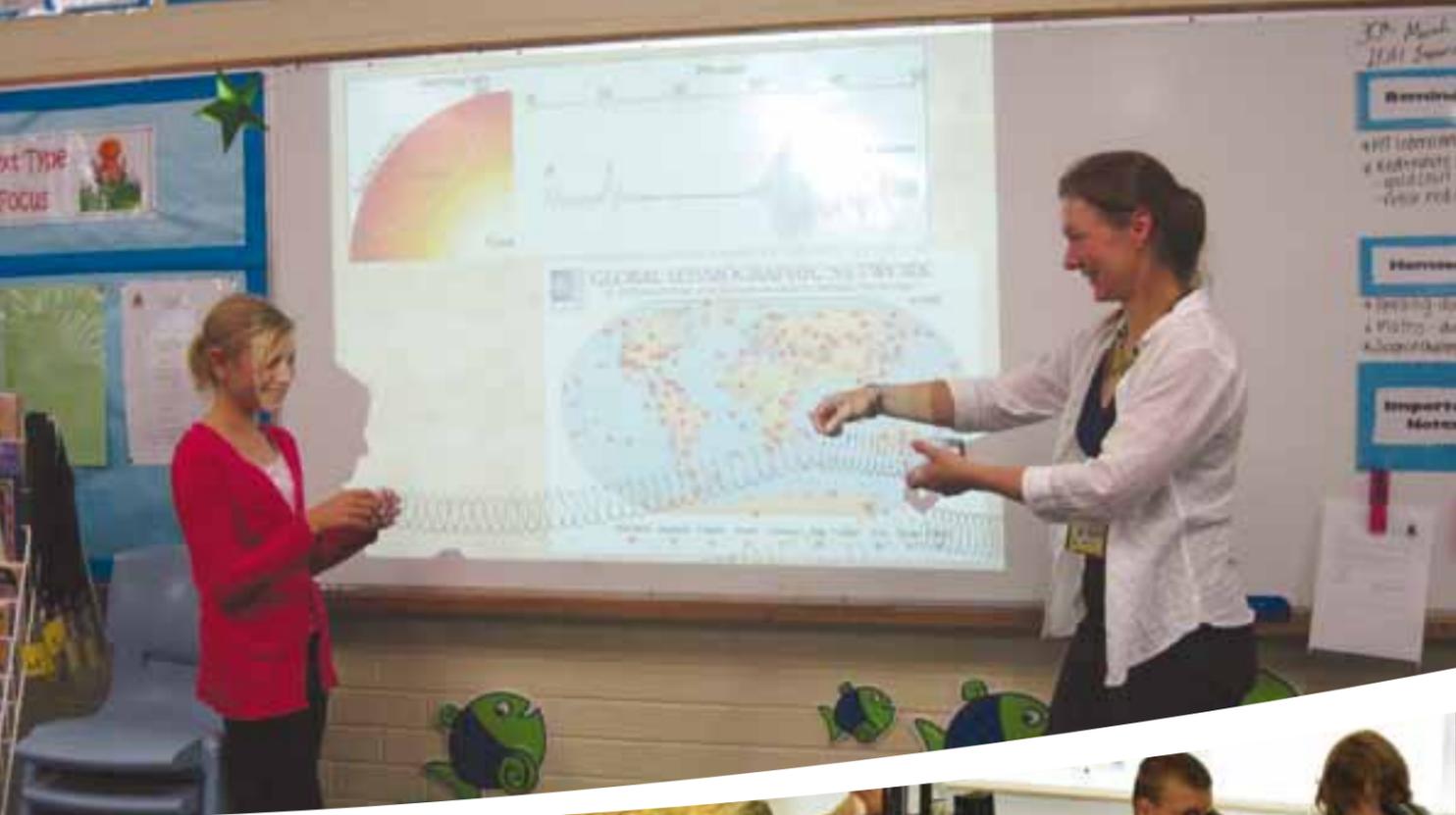
The year was unusual in that all the students that enrolled were following on directly from their bachelor degrees, there were no mid-year starters carried over from 2010, and the entire intake was sourced from UTAS.

Six students undertook projects based in Tasmania, with most other projects spread throughout Australia. An exception was a student that was evaluating in-mine seismic response in a gold mine on the world-famous Witwatersrand Basin in South Africa. The projects were typically spread across the disciplines in the following categories: economic geology (3), geophysics (3), igneous petrology (2), volcanology (2), sedimentology, and environmental geology. The projects were sponsored by Bass Metals, Copper Mines of Tasmania, Newcrest, Beadell Resources, Tasmania Magnesite, Institute of Mine Seismology and Ivanhoe.

The Honours year was administered by Garry Davidson, with Peter McGoldrick supervising the coursework aspects. Principal supervision was undertaken by Michael Roach (2), Andrew McNeill (2), Garry Davidson (2), Tony Crawford (2), Anya Reading, Peter McGoldrick, Leonid Danyushevsky, and Jocelyn McPhie. Additional co-supervision was provided by Jocelyn McPhie, Andrew McNeill, Anya Reading, Garry Davidson, Ross Large, Ron Berry, David Cooke, Jeff Foster and Michael Roach.

The Exploration and Skills Mapping Course was held twice during the year. The course was held once in the previous year, but this was increased to two courses in 2011 as a result of its growing popularity. Once again, the course attracted a high number of participants from UTAS and mainland universities, which has prompted the organisers to schedule a further two courses in 2012.





# Outreach

CODES places a high level of importance on its outreach program. It recognises that it is vital for the future of the profession that young people are encouraged to choose a career in the geosciences, and the wider community appreciates the significant contribution this field of science makes to the economic, environmental and social wellbeing of societies throughout the world.

Since its inception, CODES has worked closely with the UTAS School of Earth Sciences (SES) to develop an holistic program of activities to promote the geosciences within the community. Key elements of its strategy have been to ensure that all demographic areas are covered, while targeting specific groups to influence career choices, such as students up to Year 12, teachers and career advisors. This is of particular importance in Tasmania, where geology is no longer part of the school curriculum.

Once again, outreach activities were conducted predominantly by Michael Roach, but he was ably supported by a host of other staff including Al Cuisson, Garry Davidson, Bruce Gemmell, Ross Large, Andrew McNeill, Sebastien Meffre, Karin Orth, Anya Reading, Rob Scott, Simon Stephens, Helen Thomas, and Isabella (Izzy) von Lichten.

A number of schools visited the Centre during the year, with participants ranging from primary school students through to Year 12. One of the key aims when hosting visits of this nature is to make the participants' stay at the Centre both educational and enjoyable. The fact that a visit to CODES / SES has become a regular feature on a number of school calendars bears testament to how well this balance has been achieved.

The Centre continued its participation in the Science Experience initiative by hosting a workshop for Year 11 students in January. This program aims to inspire students to continue their science studies and is supported by the Science Schools Foundation, Rotary, and the Australian Science Teachers Association.

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

teachers. A further two workshops were held at the Centre during the year, which mixed interactive classroom and laboratory sessions with off-site field activities at local sites of geological interest.

In addition to the full agenda of outreach events held within the Hobart campus, staff also participated in a variety of activities out and about in the local community. Anya Reading visited Mount Carmel College, where she talked to Year 6 students about her career as a geophysicist, and fielded numerous questions about recent seismic events around the world. Garry Davidson gave a general talk on geology to Year 9 students at Taroona High School. Rob Scott returned to Montagu Bay Primary School where he has given a number of talks introducing preparatory and Year 1 students to the wonders of fossils and rocks. A little further afield, Izzy von Lichten, curator of the Centre's extensive rock collection, assisted Launceston's Queen Victoria Museum to establish a permanent exhibition on the geological history of Tasmania. In addition, Izzy provided information for a geological mural that was subsequently painted by the students at Kempton Park Primary School in the Southern Midlands. She also attended its opening in December.

The older age groups are catered for via a small pool of staff that delivers talks at various community events, via initiatives such as the School for Seniors and the University of the Third Age (U3A). Andrew McNeill delivered a talk at the Sorell School for Seniors in May. However, other talks had to be rescheduled for the coming year due to difficulties in aligning dates suitable to both parties.

In 2012, plans will come to fruition for an extensive upgrade to the rock and mineral displays and seismology exhibits adjacent to the main geology lecture theatre. These exhibits will be augmented by the opening of a bust of the late Professor Warren Samuel Carey, together with a model illustrating his pioneering theory of the Expanding Earth. Professor Carey is widely regarded as one of the key figures in establishing UTAS as one of the world's leading universities for the study of the earth sciences. This general upgrade will significantly enhance the facilities for visitors to CODES and the School of Earth Sciences.

# 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 will continue to be a key strategic focus, which will strengthen CODES' position as a premier centre for ore deposit research.

## INDUSTRY LINKS AND SYNERGIES

CODES has strong, enduring and mutually beneficial links with a large group of the 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 2011, Drummond Gold joined the group of CODES' industry partners, which now comprises eleven Australian and international mining companies: Anglo American, AngloGold Ashanti, Barrick Gold, BHP Billiton, Drummond Gold, MMG, Newcrest Mining, Newmont Mining, Rio Tinto, St Barbara Mines, and Teck.

Each of the partner companies provides support of \$20,000 to \$80,000 in cash per year to the research budget of the Centre. Senior representatives of these companies sit on the Science Planning Panel, along with other government and university researchers. This panel meets annually to discuss the results of CODES' research and the potential directions for new research.

CODES' industry partners benefit from sponsorship by having:

- » Association with, and first call on, a world-class research team in ore deposit science.
- » Membership of the CODES Science Planning Panel.
- » Access to scholarships for staff undertaking Masters degree courses.
- » Fee reductions on regular short courses and special in-house courses.
- » Branding exposure at national and international conferences and exhibitions.

## 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 2011, AMIRA funded these major projects for CODES:

- » P765A Geochemical and geological halos in green rocks and lithocaps – The explorer's toolbox for porphyry and epithermal districts.
- » P843A (GeM<sup>III</sup> 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 2011, CODES further cemented its reputation for cultivating research collaborations with other Australian and international research organisations. During the year, collaborative research was conducted with 58 international and 20 national organisations.

Collaborative research between international and Australian-based partners is also being facilitated by joint research appointments. The table below details each of the collaborating institutions with the joint researchers and their

funding source. These researchers are based at collaborating partner institutions and incorporate research visits to CODES throughout the term of their research projects.

CODES, together with UTAS, continues to attract high profile researchers to the Centre through the International Visitors Program and the Visiting Fellows / Scholars Program. In 2011, Associate Professor Jing Zhang from the Chinese University of Geosciences visited Professor David Cooke for a period of approximately six months, to collaborate on the sulfide geochemistry of porphyry Mo and orogenic gold deposits in China.

## 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 (5%), Alan Cocker (4%), Luke Keeney (9%), Angus McFarlane (27%), Simon Michaux (29%), Khoi Ke Nguyen (28%), Italo Onederra (11%), Yicai Wang (12%)	Simon Michaux (13%), Yicai Wang (8%)	Dee Bradshaw (11%), Alan Cocker (6%), Luke Keeney (20%), Italo Onederra (19%), Angus McFarlane (61%), Simon Michaux (26%), Khoi Ke Nguyen (64%), Patrick Walters (16%)	
University of Melbourne	Bence Paul	Roland Maas		Janet Hergt
Australian National University				Stephen Cox
CSIRO	Stacey Borg (50%), Jamie Laird (50%)	Stacey Borg (50%), Jamie Laird (50%)		Weihua Liu, Chris Ryan



# 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 2011, 165 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 Gifkins, W Herrmann and R Large (87 copies sold in 2011).
- » Basins, fluids and Zn-Pb ores – CODES Special Publication 2 (1999). Editors: O Holm, J Pongratz and P McGoldrick (6 copies sold in 2011).
- » Geophysical signatures of copper-gold porphyry and epithermal gold deposits, and implications for exploration (2011). Author: T Hoshcke (253 copies sold in 2011).
- » Giant ore deposits: Characteristics, genesis and exploration (2002). CODES Special Publication 4. Editors: D Cooke and J Pongratz (14 copies sold in 2011).

- » New developments in Broken Hill-type deposits (1996). CODES Special Publication 1. Editors: J Pongratz and G Davidson (6 copies sold in 2011).
- » Ore Geology Reviews – Special Issue (April 2007): Mineral deposits of South China. Editors: Khin Zaw, S Peters, N Cook and Z Hou (3 copies sold in 2011).
- » The geology and origin of Australia's mineral deposits (2000). Authors: M Solomon and D Groves (10 copies sold in 2011).
- » The geology of the Broken Hill Pb-Zn-Ag deposit, NSW, Australia (2006). Author: A Webster (7 copies sold in 2011).
- » 24ct Au workshop (2004). CODES Special Publication 5. Editors: D Cooke, C Deyell and J Pongratz (12 copies sold in 2011).
- » Volcanic environments and massive sulfide deposits (2000). Editors: JB Gemmell and J Pongratz (10 copies sold in 2011).
- » Volcanic textures: A guide to the interpretation of textures in volcanic rocks (1993). Authors: J McPhie, M Doyle and R Allen (97 copies sold in 2011).

## COMMERCIAL PRODUCTS AND PROCESSES

Geometallurgical research in Program 4, in collaboration with JKMR 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 29 courses were held at various locations around the world. This included venues in 15 countries on five continents, including Argentina, Chile, Colombia and Peru in South America; the USA and Canada in North America; China, Indonesia, Myanmar, the Philippines and PNG in the Asia Pacific region; and Germany, Italy and the Czech Republic in Europe.

Total attendance by industry geologists, academic researchers and postgraduate students was 1249, with 20 presenters from the CODES' Hub, plus a number of students, involved in delivering the lectures.

## 2011 SHORT COURSES/WORKSHOPS/CONFERENCES LED BY CODES

TITLE	PRESENTERS*	NO**	LOCATION	DATE
Porphyry Cu-Au Systems	<b>David Cooke</b> , Jeff Hedenquist	150	Lima, Peru	7–8 Jan
Volcanic Hazards and Eruption Styles	Alexander Belousov, Marina Belousova, <b>Takayuki Manaka</b> , <b>Khin Zaw</b>	26	Yangon, Myanmar	23 Jan
Ores in Sediments	<b>Stuart Bull</b> , David Leach, Wayne Goodfellow, Jean Cline, Gema Olivo, Dave Burrows, Paul Spry, Rich Goldfarb, Andre Becker, Jan Peter	120	University of Ottawa, Canada	19–26 Feb
Felsic Domes and Breccias	<b>Jocelyn McPhie</b>	25	Minera IRL, Argentina	13 Mar
AMIRA P765A Workshop	<b>David Cooke</b> , <b>Bruce Gemmell</b>	40	CODELCO, Santiago, Chile	28 Mar
Characteristics and Genesis of Porphyry and Epithermal Deposits	<b>David Cooke</b> , <b>Anthony Harris</b>	35	Lae, Papua New Guinea	Apr
Sediment-hosted Gold Deposits	<b>Ross Large</b> , <b>Rob Scott</b> , <b>Stuart Bull</b>	8	Drummond and Unity Mining, Hobart	2–3 May
UTAS SEG Student Chapter – Middle and Lower Metallogenic Belt of China: Workshop	<b>David Cooke</b> , <b>Zhaoshan Chang</b> , <b>Huayong Chen</b> , Taofa Zhou	58	Hefei University of Technology, China	14–25 May
Porphyry Ore Deposit Exploration: New and Existing Models	<b>David Cooke</b> , <b>Garry Davidson</b> , <b>Bruce Gemmell</b> , <b>Mike Baker</b> , <b>Janina Micko</b> , <b>Huayong Chen</b>	25	CODES, Hobart	Jun
Porphyry-Epithermal Workshop	<b>David Cooke</b>	20	Barisan, Indonesia	8–9 Jul
Structural Processes and Controls on the Formation of Lode Gold Systems	Stephen Cox	40	Kalgoorlie	20–21 Jul
Porphyry Copper Workshop	<b>David Cooke</b>	10	Archer Resources, Brisbane	31 Jul
Volcanoes and Their Products	<b>Jocelyn McPhie</b>	20	Freeport McMoRan, Philippines	2–5 Aug
Iolite Workshop	Bence Paul, Chad Paton, Jon Woodhead	43	Prague, Czech Republic	14 Aug
AMIRA P1060 Workshop	<b>David Cooke</b> , <b>Huayong Chen</b> , <b>Mike Baker</b>	20	PT Freeport, Indonesia	17–18 Aug
Geometallurgical Mapping and Mine Modelling Annual Review	Nicole Botsis, Laura Kuhar, Angus McFarlane, Bet Meakin, Patrick Merrigan, Dave Robinson, Nicole Turner, Dee Bradshaw, Alan Cocker, Luke Keeney, Toni Kojovic, Angus McFarlane, Simon Michaux, Khoi Nguyen, Italo Onederra, Pat Walters, Steve Walters, <b>Ron Berry</b> , <b>Jeff Foster</b> , <b>Julie Hunt</b> , <b>Lyudmyla Koziy</b> , <b>Bernd Lottermoser</b> , <b>Andrew McNeill</b> , Taryn Noble	100	Brisbane	8–9 Sep
AMIRA P1060 Workshop	<b>David Cooke</b> , Jamie Wilkinson	20	Bingham Canyon, Utah, USA	12 Sep
AMIRA P1060 Workshop	<b>Mike Baker</b>	10	AngloGold Ashanti, Colombia	Oct
Low and Intermediate Sulfidation Epithermal Deposits	<b>Bruce Gemmell</b>	10	La Zanja mine, Peru	10 Oct
Rhyolitic Volcanoes and Their Products	<b>Jocelyn McPhie</b>	25	Minera IRL, Argentina	11 Oct
Structure, Permeability and Fluid Flow at Depth in the Earth's Crust	Stephen Cox	35	Aachen, Germany	11–13 Oct
Fluids in the Earth	<b>Leonid Danyushevsky</b> , Robert Bodnar, Jim Webster	25	University Of Naples, Italy	25–29 Oct
Submarine Volcanoes and Their Products	<b>Jocelyn McPhie</b>	10	Nautilus Minerals, Brisbane	1–2 Nov
Ore Deposit Models	<b>Huayong Chen</b> , Noel White	250	Beijing, China	1–6 Nov
Low, Intermediate and High Sulfidation Epithermal Deposits	<b>Bruce Gemmell</b>	18	Aceh, Indonesia	2–3 Nov
GeoPIXE XFM Workshop	Chris Ryan	36	Melbourne	6–7 Dec
AMIRA P765A Workshop	<b>David Cooke</b> , <b>Bruce Gemmell</b> , <b>Mike Baker</b> , <b>Huayong Chen</b> , Peter Hollings, Noel White	30	CODES, Hobart	8 Dec
Maar Volcanism in Western Victoria	<b>David Cooke</b>	9	Western Victoria	12–15 Dec
Current Research on Mineral Deposits in SE Asia	<b>Khin Zaw</b> , Kenzo Sanematsu, <b>Takayuki Manaka</b>	31	Yangon, Myanmar	22 Dec

\* CODES PRESENTERS IN BOLD

\*\* NUMBER OF ATTENDEES

# Performance Indicators

PERFORMANCE MEASURE	TARGET	2011
<b>RESEARCH FINDINGS</b>		
Publications in international journals	50pa	66
Percentage of publications in A/A* journals	70%	55%
Reports to industry collaborators	80pa	166
Special Issues and/or research monographs	1 per 2 years	1
Invitations to give keynote conference presentations	10pa	9
Papers at national/international meetings	70pa	91
<b>INVESTIGATORS</b>		
Average percentage of CIs research in Centre	70%	80%
Average percentage of PIs research in Centre	15%	15%
Percentage of team-based projects	80%	85%
Percentage of Australian cross institutional projects	30%	43%
<b>RESEARCH TRAINING AND PROFESSIONAL EDUCATION</b>		
Percentage of RHD students attracted from interstate	40%	20%
Percentage of RHD students attracted from overseas	40%	68%
Honours students in Centre programs	10	14
RHD students in Centre programs	45	50 PhD, 6 MSc
Percentage of students in projects linked with industry	50%	75%
Professional short courses/workshops for industry	5pa	23
<b>INTERNATIONAL, NATIONAL AND REGIONAL LINKS AND NETWORKS</b>		
Centre national or international conferences /workshops	1 per 2 years	1
Registrants at Centre's conferences/workshops	100pa	1249
International and national visitors per year	50pa	104
Collaborative projects with other global centres/groups	10pa	13
External collaborators using Centre's equipment	10pa	10

PERFORMANCE MEASURE	TARGET	2011
<b>END-USER LINKS</b>		
Frequency of meetings with industry representatives	15pa	25
End-user representatives to Science Planning Panel and Advisory Board	20% / 50%	40% / 56%
Frequency of meetings with AMIRA Research Co-ordinator	10pa	12
Number of industry visitors to Centre	80pa	72
<b>ORGANISATIONAL SUPPORT</b>		
Annual cash contributions from UTAS	\$1,800,000	\$2,366,074
Annual cash support from other collaborating universities & CSIRO	\$205,000	\$190,000
Annual cash support from industry	\$2,000,000	\$2,947,458
Number of new organisations recruited to or involved in the Centre	1pa	1 (Drummond Gold)
<b>GOVERNANCE</b>		
Joint post-doctoral appointments between collaborating institutions/organisations	5	6 (2 CSIRO, 1 UMelb, 3UQ)
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
<b>NATIONAL BENEFIT</b>		
Centre research has input into a major mineral discovery	1 per 5 years	Nil
Employment of Centre's graduates by minerals industry	>65%	72%

# 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 covers five years of 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 Finance Manager and 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 is meeting the income and expenditure requirements of the current agreement.

## 2011 INCOME

Total CODES income was \$9.3 million (see Table 1). This was derived principally from industry (32%), the ARC (32%) and UTAS (25%) (see Figure 1). The main income streams over time are compared in Figure 2, demonstrating that ARC funding continues to be exceeded by other funding at a ratio of approximately 2:1 (the original CoE agreement with the ARC was 1:1). Therefore, non-ARC funding has consistently exceeded expectations since the start of the CoE, with industry funding showing the strongest growth.

## 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. All agreed cash funding from the collaborators/contributors (except that of the ANU Node and some Industry Partners) was up to date at the end of 2011 (see explanation in the 'CoE node income' and 'industry income' sections on page 75 regarding this deficit). It should be noted that, in total, CODES has received \$23.8 million more to-date towards CoE projects than was specified in the original agreement. This is 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 has extended into the CoE period.

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

In addition to the abovementioned cash income, the CoE receives 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 2011:

- » **ARC income:** ARC income received in 2011 comprised primarily of the CoE ARC Grant (\$2.9 million), with the addition of one Discovery Grant (\$0.1 million). Despite this additional grant, total ARC funding decreased by approximately \$130k compared to 2010. This decrease is as a result of the CoE Grant being reduced by approximately 20% for the extension period.

- » **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 is reported annually to CODES.

All but one of the nodes have received their agreed 2011 ARC income from CODES and contributed their matching funds to the Centre. ANU is unable to contribute its matching funds until the Extension Agreement is finalised, due to internal policy. It is anticipated that this Agreement will be executed early in 2012, and these transactions will be included in the accounts for that year.

- » **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 2011 was \$2.9 million. Industry funding decreased by 14% (\$0.5 million) in 2011, mainly due to the following factors:

- » Completion of a large AMIRA project in the middle of the year
- » Late signing of a new AMIRA project, which commenced mid-year
- » Late signing of contracts for the extension of the SE Asia Project, which finished at the end of 2010
- » A temporary \$200k shortfall in Industry Partner income for the elapsed extension period (July 2010 to December 2011), due to late finalisation of the CoE Extension Agreement - this will be rectified in 2012 upon full signing of the agreement
- » Funds amounting to \$680k from the AMIRA GeM Project were transferred to UQ and will be counted as income to UQ (see Notes to the Financial Statements).

As demonstrated by the abovementioned points, there are a number of mitigating factors for this year's decrease in industry funding. However, over the life of the Centre, this funding remains well above the CoE Agreement target of \$700k to \$1.5 million per year.

- » **Host institution support:** UTAS increased its core cash funding by 12% to \$2.4 million, continuing an upward trend. This funding relates primarily to research salaries, PhD scholarships and income earned by the Centre from research output. UTAS also provided approximately \$1.5 million in in-kind support in 2011.

## 2012 INCOME ESTIMATES

Subsequent to the downturn in industry and ARC funding in recent years, both of these major funding streams are now showing some signs of improvement. Agreements for several new research projects were signed in 2011, and two more are in the contract negotiation phase. Although this positive trend is encouraging, CODES takes a conservative view of the level of funding in 2012. Nevertheless, overall funding to the Centre is expected to increase.

## 2011 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 2011 were salaries, research and field travel, student scholarships and laboratory analyses. As predicted, most expenditure was lower than in previous years as a result of decreased ARC funding. Although ARC funding showed signs of improvement in 2011 (via a Discovery Grant), its overall funding is substantially down on the level prior to the extension agreement.

The 2011 combined ARC CoE income and carry-forward of \$3.2 million was offset by expenditure of \$2.6 million. This leaves a carry-forward surplus of \$652k. However, it should be noted that more than half of this amount is currently held at the ANU Node due to the late start-up of its research projects, and to facilitate funding of relevant staff via the CoE ARC Grant.

## 2012 EXPENDITURE ESTIMATES

Expenditure in 2012 is expected to be similar to 2011.

TABLE 1  
CASH INCOME FINANCIAL STATEMENT 2005–2011

	(half year) 2005	2006	2007	2008	2009	2010	2011
<b>ARC - CENTRE OF EXCELLENCE GRANT</b>							
CoE agreed core funding* – 2005 grant indexation (not received until 2006)	0	31,500	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
	<b>1,500,000</b>	<b>3,152,698</b>	<b>3,184,402</b>	<b>3,248,088</b>	<b>3,313,864</b>	<b>3,097,230</b>	<b>2,856,123</b>
<b>COE NODES MATCHING FUNDS (AGREED MATCHING FUNDS HELD AT NODE INSTITUTIONS)</b>							
CoE agreed core funding*	0	295,000	255,000	250,000	237,500	242,500	190,000
Additional funding (pre-existing or new)	0	0	0	0	0	0	0
	<b>0</b>	<b>295,000</b>	<b>255,000</b>	<b>250,000</b>	<b>237,500</b>	<b>242,500</b>	<b>190,000</b>
<b>OTHER ARC GRANTS</b>							
CoE agreed core funding*	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
	<b>328,791</b>	<b>397,325</b>	<b>394,338</b>	<b>471,524</b>	<b>403,889</b>	<b>0</b>	<b>106,655</b>
<b>OTHER COMMONWEALTH GOVERNMENT</b>							
CoE agreed core funding*	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
	<b>7,184</b>	<b>19,649</b>	<b>24,666</b>	<b>62,680</b>	<b>2,046</b>	<b>87,856</b>	<b>4,364</b>
<b>STATE GOVERNMENT</b>							
CoE agreed core funding*	200,000	200,000	200,000	0	0	0	0
Additional funding (pre-existing or new)	68,000	852	4,000	8,000	2,500	2,396	3,556
	<b>268,000</b>	<b>200,852</b>	<b>204,000</b>	<b>8,000</b>	<b>2,500</b>	<b>2,396</b>	<b>3,556</b>
<b>LOCAL GOVERNMENT</b>							
CoE agreed core funding*	0	0	0	0	0	0	0
Additional funding (pre-existing or new)	0	0	0	0	0	0	0
	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>INDUSTRY/PRIVATE</b>							
CoE agreed core funding*	868,646	1,582,507	1,825,010	2,158,677	2,182,472	1,298,919	716,463
Additional funding (pre-existing or new)	444,803	909,552	938,913	1,487,935	2,268,323	2,117,721	2,230,995
	<b>1,313,448</b>	<b>2,492,059</b>	<b>2,763,923</b>	<b>3,646,611</b>	<b>4,450,795</b>	<b>3,416,640</b>	<b>2,947,458</b>
<b>CONTRACTS/CONSULTANCIES/REVENUE RAISING</b>							
CoE agreed core funding*	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
	<b>143,787</b>	<b>286,675</b>	<b>306,743</b>	<b>368,160</b>	<b>383,012</b>	<b>411,097</b>	<b>841,397</b>
<b>UNIVERSITY OF TASMANIA - HOST INSTITUTION SUPPORT</b>							
CoE agreed core funding*	343,744	1,334,728	1,147,471	1,128,759	1,430,393	2,107,854	2,366,074
Additional funding (pre-existing or new)	383,623	678,064	566,682	468,267	589,489	0	0
	<b>727,367</b>	<b>2,012,792</b>	<b>1,714,152</b>	<b>1,597,026</b>	<b>2,019,881</b>	<b>2,107,854</b>	<b>2,366,074</b>
<b>OTHER INCOME SOURCES/INTEREST</b>							
CoE agreed core funding*	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
	<b>4,348</b>	<b>60,006</b>	<b>53,000</b>	<b>131,585</b>	<b>25,147</b>	<b>84,795</b>	<b>22,726</b>
<b>TOTAL ANNUAL INCOME</b>	<b>4,292,926</b>	<b>8,917,056</b>	<b>8,900,226</b>	<b>9,783,674</b>	<b>10,838,635</b>	<b>9,450,368</b>	<b>9,338,352</b>
<b>GRAND TOTAL OF ALL INCOME TO DATE</b>							<b>61,521,237</b>

\* CORE FUNDING LISTED IN THE COE AGREEMENT AND MATCHED TO THE ARC FUNDS

FIG 1

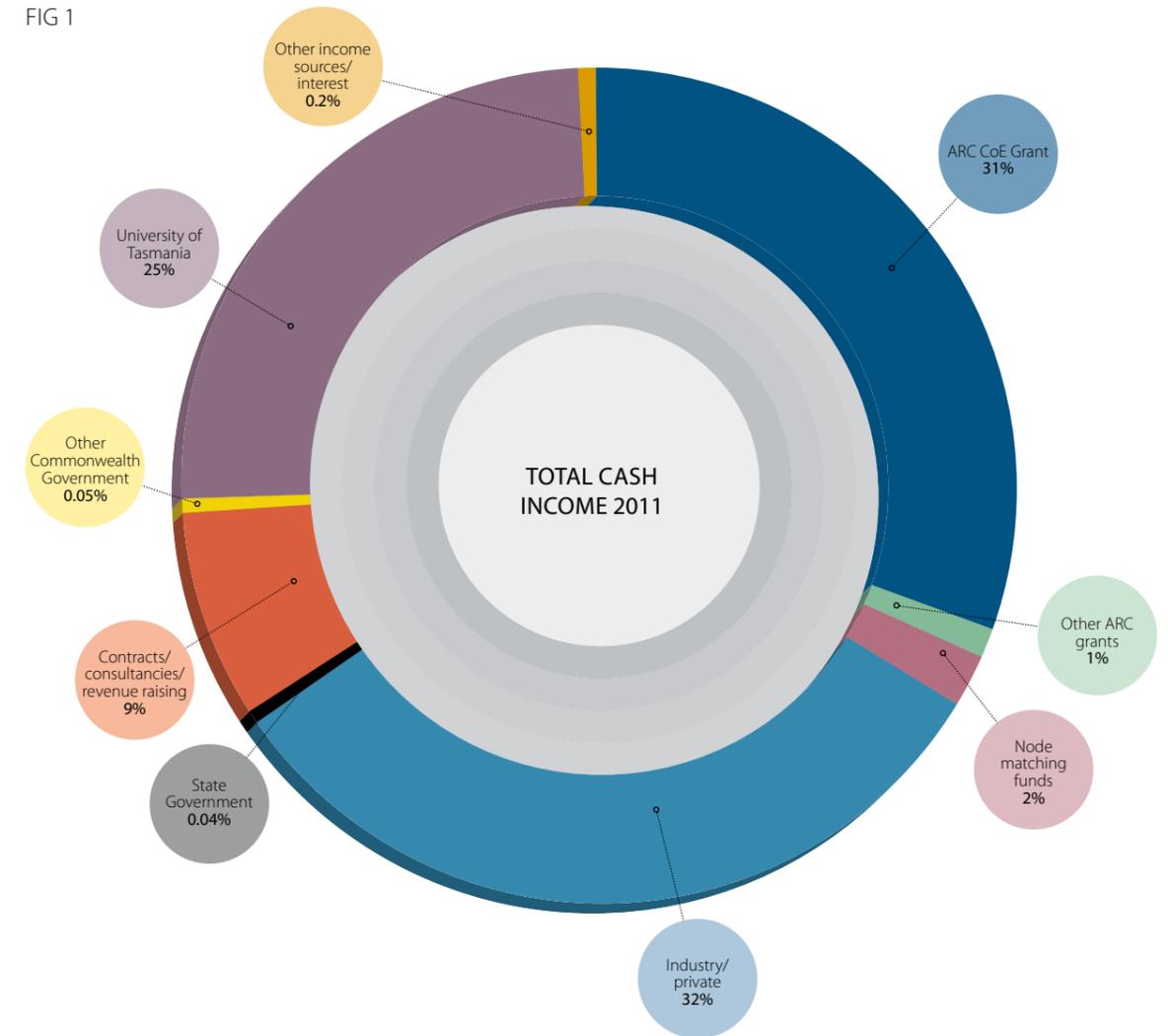
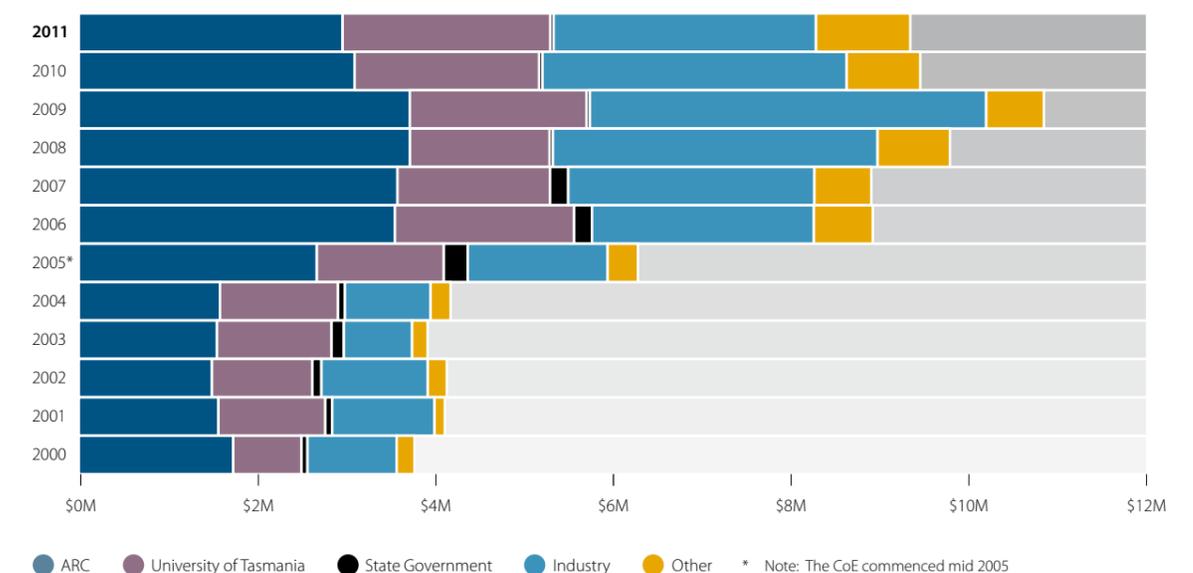


FIG 2  
COMPARISON OF CODES' MAIN INCOME STREAMS 2000 – 2011



## NOTES TO, AND FORMING PART OF, THE FINANCIAL STATEMENTS FOR 2011

The financial pages of this Annual Report were prepared by Helen Scott (Finance Officer) in collaboration with Christine Higgins (Finance Manager). 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 2011, 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.

» \$680k of AMIRA GeM Project funds were deposited into a UTAS account, but were later transferred to UQ for a joint research project. These funds will be listed as AMIRA income to UQ, therefore they cannot also 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.

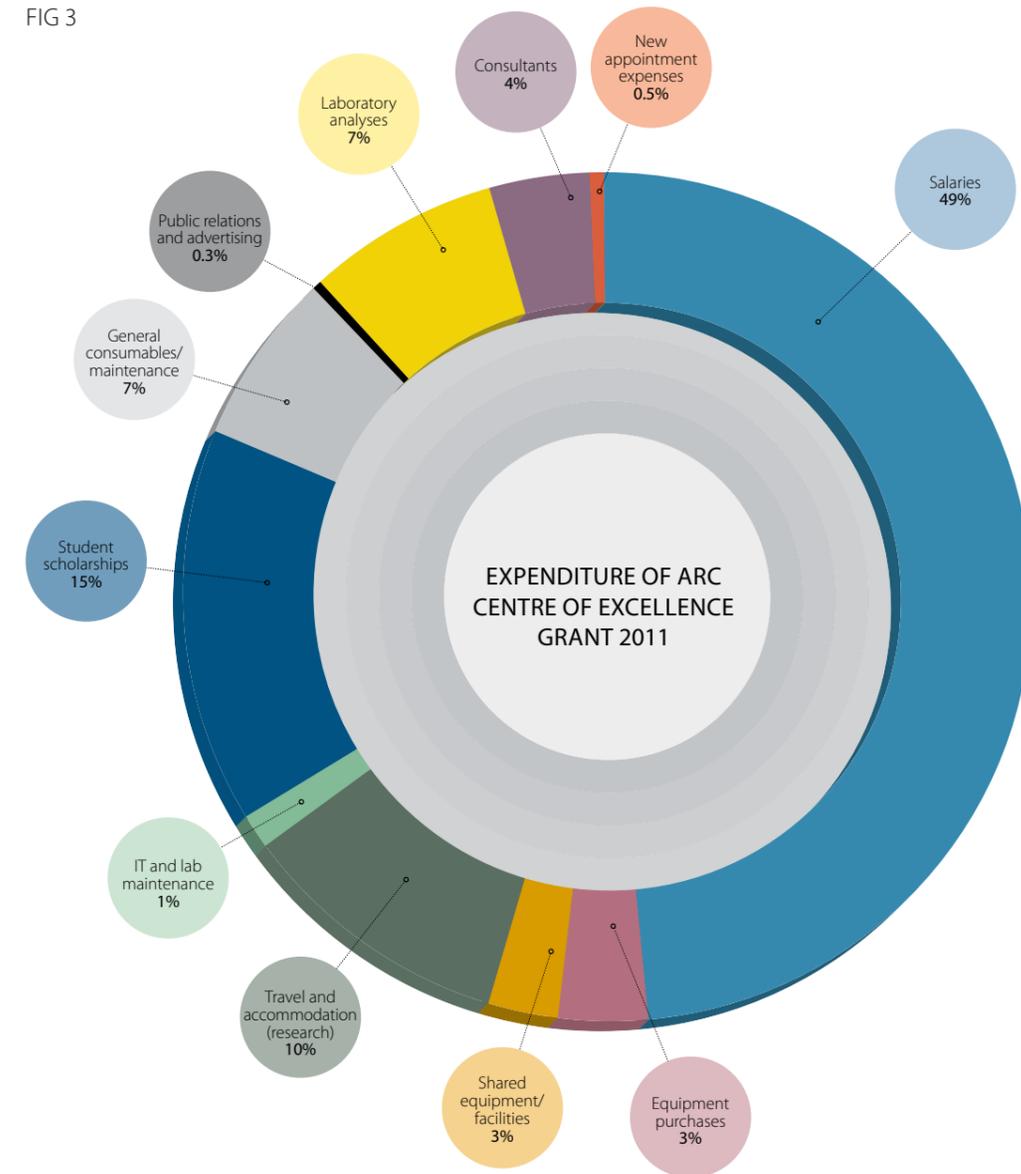
In 2008, there was a minor retrospective amendment made to the 2005 industry/private income figure, which has increased the 2005 income total by \$20,000. This relates to \$20,000 of CoE agreed 2005 income, which was paid in advance by Teck

TABLE 2  
EXPENDITURE OF ARC CENTRE OF EXCELLENCE GRANT 2005–2011 (CODES PLUS ITS NODES)

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

\* FROM 2010 ONWARDS, VISITING ACADEMIC EXPENDITURE IS NO LONGER ITEMISED SEPARATELY

FIG 3



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).



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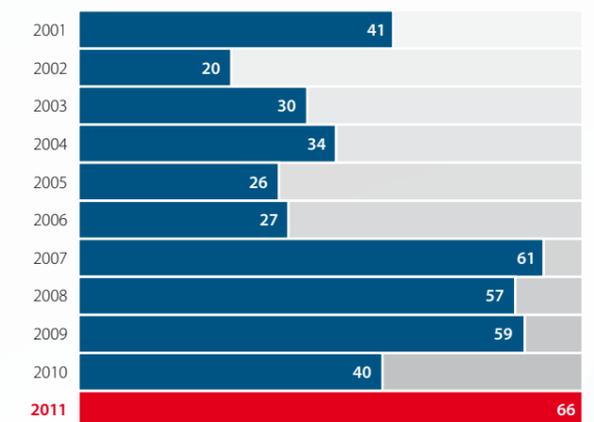
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# Appendices

## CODES' POSTGRADUATE STUDENTS 2011



### BACHELOR OF SCIENCE (HONOURS) (16)

Student	Supervisor(s)	Project	Support
William Chandler*	Danyushevsky, McNeill	Mineral chemistry indicators of solidification process within layered intrusion: EMPA and LA-ICPMS study of a cross-section through the Dovyren layered intrusion	
Jesse Cotterill	McPhie, Kamenetsky	Mafic dykes at Wirrda Well: Composition, timing, distribution and sources	BHP Billiton
Daniel Doran*	Crawford, Large	Geology, geochemistry and mineralisation of the Handpump Gold Prospect, West Musgrave Province, W.A.	Beadell Resources
Michael Gill*	Crawford, Foster	The Youanmi Intrusion (Yilgarn Craton), Western Australia: Petrogenesis and FeTi-oxide accumulation	
Kian Chee Goh	Zaw	Geological setting and mineralisation characteristics of Au deposits in the Bau Mining District, Sarawak, East Malaysia	SE Asia project, Olympus Pacific Minerals
Joshua Greene*	G.Davidson, Cooke	Fluid and formational constraints of the Merlin Mo + Re Deposit, Cloncurry	Ivanhoe
Jarod Harris*	Reading, Roach	In-mine rock mass characterisation using active seismic monitoring	Institute of Mine Seismology
Dilani Singappuli Jayathilaka	Lottermoser	Reducing the leaching of metals and acid from Mt Lyell mine wastes: Immobilisation with carbonate and silica coatings	Copper Mines of Tasmania
Torsten Jensen*	McGoldrick, Berry	Geochronology and geochemistry of some Horodyskia-bearing shales, NW Tasmania	
Nichola McMillan*	McNeill, G.Davidson	The Deep alteration system at the Prince Lyell Deposit, Mt Lyell, Tasmania	Copper Mines of Tasmania
Sarah McNab*	Kiernan (Geog), G.Davidson	Effects of contamination on karst hydrogeology and hydrogeochemistry, Mole Creek, Tasmania	
Kate Miedecke*	McNeill, McPhie	The internal stratigraphy and provenance of the Mixed Sequence, Que-Hellyer Volcanics, Western Tasmania	Bass Metals
Nicholas Nolan*	Roach, Reading	Geophysical character of the Junction Reefs JV Area, Molong Belt, NSW: Applications for exploration of porphyry related Cu-Au mineralisation	Newcrest Mining
Owen Perry*	Roach, Reading	A geophysical and geological study of the Arthur River Magnesite deposit, northwest Tasmania	Tasmania Magnesite
Nicholas Smith	Reading, Roach, Asten (Monash)	Microtremor array method applied to minerals exploration under cover in Australia	OZ Minerals
Kara Tomes*	McPhie, McNeill	The textures and geochemistry of the Hellyer Basalt, western Tasmania	Bass Metals



### MASTER OF ECONOMIC GEOLOGY (44)

Student	Supervisor(s)	Project	Support
Abdul Arbi		coursework only	Ivanhoe
Fabian Baker	Cooke	Thesis topic not yet determined	Lydian International Ltd
Paluku Batsotsi^		coursework only	African Mining Consultants
Lynelle Beinke		coursework only	Heathgate Resources
John Brewster		coursework only	Newcrest Mining Limited (Cracow GM JV)
Mark Burdett		coursework only	Monash University
Adrian Byass		coursework only	Ironbark Gold Limited
Colin Carter^		coursework only	Bluestone Tin

Student	Supervisor(s)	Project	Support
Chloe Cavill		Thesis topic not yet determined	Xstrata Copper, Mount Isa
Djohanne Celiz		coursework only	Freeport-McMoran Exploration Corporation
Corrie Chamberlain		coursework only	Minera IRL Patagonia S.A.
Joanna Condon	Gemmell	Mineralisation characterisation of the Doolgunna prospect: Implications for mining, milling and exploration	Sandfire Resources NL
Glen Diemar	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
Stephen Fox		coursework only	Copper Mines of Tasmania
David Freeman^		coursework only	AngloGold Ashanti Australia Limited
Phil Gilmore		An aspect of the geology of the Koonenberry Belt, NSW	Geological Survey of NSW
Rachel Harrison		An aspect of the geology of the Tujuh Bukit Cu-Au porphyry-epithermal deposit, Java Indonesia	Intrepid Mines Limited
Margaret Hawke	Gemmell	Geology of the DeGrussa prospect, WA: Implications for ore genesis and exploration	Sandfire Resources NL
Alexander Johnston		coursework only	Private contractor
Brian Kay	Foster	Combined economic and geologic evaluation of eastern Australian gold projects – selection of acquisition targets	Northgate Australian Ventures
Chris Large		coursework only	Cam Bow
Xuan Truong Le	Zaw	Thesis topic not yet determined	Hanoi University of Mining and Geology
Yungu Lim	Zaw	Geological setting and mineralisation characteristics of the Steung Nambrai-Elephant Au-base metal system, eastern Cambodia	Korea Resources Corporation
Chantelle Lower		An aspect of the geology of the Olympic Dam deposit	BHP Billiton
Thomas Lucas		coursework only	Ivanhoe Australia
Neil Macalalad		coursework only	Anglo American Exploration Philippines Inc
Imam Malik		coursework only	
Kane Maxwell		coursework only	Peabody Energy Australia
David Meade		coursework only	Bluestone Tin
Matthew O'Neill		coursework only	
Anna Price		coursework only	Silver Lake Resources Limited
Michelle Puskas		coursework only	Rex Minerals (South Australia)
Scott Randall		coursework only	AngloGold Ashanti Beijing Rep Office
Steven Richardson	Gemmell, McNeill	The Fossey Zone, Hellyer Mine	Bass Metals
Alan Riles		coursework only	Riles Integrated Resource Management Pty Ltd / AMC
Jonathan Robbeson		coursework only	Signature Gold
Daud Silitonga		coursework only	PT. Nusa Halmahera Minerals (Newcrest Mining Group)
Linda Sprigg		coursework only	

Student	Supervisor(s)	Project	Support
Leonardo Subang		coursework only	Freeport-McMoran Exploration Corporation
Edward Summerhayes		coursework only	Silver Lake Resources Limited
Jason Triffitt		coursework only	
Bruce Whittaker^		coursework only	OZ Minerals
Yong Zhang		coursework only	Anglogold Ashanti (Tropicana JV)
Stanley Zutah		coursework only	Goldfields

#### MASTER OF EXPLORATION GEOSCIENCE (1)

Student	Supervisor(s)	Project	Support
Terence Hoschke^	Large, Roach	Geophysical signatures of copper-gold porphyry and epithermal gold deposits, and implications for exploration	

#### MASTER OF SCIENCE (5)

Student	Supervisor(s)	Project	Support
Mitesh Chauhan (JKMRC)	Napier-Munn (UQ)	Application of small scale flotation testing	GeM project
Paul Ferguson	G.Davidson, Roach	Origins of large negative anomalies in oceanic crust, Macquarie Island	SEG
Stacey Leichter	Hunt, Berry	Gold deportment and geometallurgical recovery model for the La Colosa porphyry gold deposit, Colombia	AngloGold Ashanti
Charles Makoundi*	Khin Zaw, Large	Geology, geochemistry and metallogenesis of selected orogenic gold deposits in the central gold belt, Peninsular Malaysia	Selinsing Gold Mine
Siddharth Paleri (UMelb)^	Hergt (UMelb), Paul (UMelb)	The application of copper isotopes and trace element geochemistry in revealing the temporal and spatial evolution of the Rainbow hydrothermal vent field and associated sediment	UMelb

#### DOCTOR OF PHILOSOPHY (50)

Student	Supervisor(s)	Project	Support
Andrea Agangi^	Kamenetsky, McPhie, Allen	Magmatic and volcanic evolution of a silicic large igneous province (SLIP): The Gawler Range Volcanic and Hiltaba Suite, South Australia	TPRS co-fund, CoE, PIRSA
Mathieu Ageneau	Cooke, Gemmell, Danyushevsky	Geology of the Kapit Ore Zone and comparative geochemistry with Minifie and Lienetz Ore Zones, Ladolam Gold Deposit, Lihir Island, Papua New Guinea	Lihir Gold Ltd, Newcrest, SEG, UTAS
Mohd Basril Iswadi Bin Basori	Khin Zaw, Large	Geology of volcanic hosted massive sulfide (VHMS) deposits in Central Belt, Peninsular Malaysia	Malaysian Govt, CoE, Ore deposits of SE Asia Project
Heidi Berkenbosch	Gemmell, McNeill, de Ronde (GNS)	Geochemistry of hydrothermal mineral chimneys from Brothers volcano, Kermadec Arc	CoE, GNS Science, UTAS
Fiona Best	Crawford, Foster	The petrogenesis of the Dido Tonalite, northern Queensland	CoE, Anglo American, UTAS, SEG
Natalee Bonnici*	Walters, Berry	The mineralogical and textural characteristics of Cu-Au deposits related to mineral processing attributes	GeM project, TGRS
Victoria Braniff	Scott, Berry, Webster	The structure and deformational history of the Savage River magnetite orebodies and host rocks, NW Tasmania	Grange Resources Ltd
Kirill Bychkov\$	Danyushevsky, McNeill	Numerical modelling of sulfide precipitation from mafic magmas with implications for the formation of layered intrusions	CoE, UTAS
Lindsey Clark	Gemmell, Cooke, Micklethwaite	The geology and genesis of the Kencana epithermal Au-Ag deposit, Gosowong goldfield, Halmahera Island, Indonesia	Newcrest, SEG
Gisela Cobenas Benites	Danyushevsky, Falloon	Metal and volatile contents of primitive subduction-related magmas (Hunter Ridge, SW Pacific): Assessing magmatic contributions to volcanic-hosted seafloor mineralisation	UTAS, CoE

Student	Supervisor(s)	Project	Support
Matthew Cracknell	Reading, Foster	Innovative data inference from spatial datasets in earth science	UTAS, CoE
Mawson Croaker^	Selley, McGoldrick, Bull	The geology of the Nkana-Mindola sediment-hosted Copper-Cobalt Deposit, Zambian Copperbelt, Zambia	AMIRA, TPRS
Quang Sang Dinh§	Crawford, Berry	Geochronology and geological evolution of the northern margin of the Kontum massif, central Vietnam	Vietnamese Govt., CODES
Cathy Evans (JKMRC)^	Walters (UQ), Johnson (UQ), Manlapig (UQ), Kojovic (UQ)	The relationship between mineral characteristics or ores and the variation in their processing attributes	GeM project
Nathan Fox*	Cooke, Harris	Controls on alteration and mineralisation at the Cadia East Alkalic Porphyry Au-Cu Deposit, NSW	Newcrest
Víctor Hugo Galván-Gutiérrez	Cooke, Gemmell, McPhie	Palmarejo carbonate-base metal epithermal Ag-Au district, Chihuahua, México	IPRS, Coeur d Alene
Sarah Gilbert	Danyushevsky, Guillong, Large	Development of analytical methods and standard reference materials for determination of trace element concentrations and isotopic ratios in sulphur-rich minerals and silicate glasses	CoE, CODES
Sarah Gordees§	McPhie, Allen	Characteristics of submarine volcanic facies in oceanic arc depocentres	TPRS co-fund, CoE
Daniel Gregory	Large, Bull	Gold trace metal accumulation in diagenetic pyrite, from a present and Archean perspective	CSIRO, CoE, UTAS
JianXiang Guan	Danyushevsky, Crawford	Origin of associated magnetite and sulfide mineralisation in large gabbroic intrusions: A LA-ICP-MS study of minerals and melt inclusions from the Panzihua and Taihe intrusions in Emeishan LIP and Duluth Complex	CoE, UTAS
Richard Hartner (JKMRC)	Nguyen (UQ)	Integration and analysis of optical and MLA-based microscopy for optimisation of geometallurgical modelling and ore deposit characterisation	UQ
Nicholas Jansen*	Gemmell, Chang	Geology and genesis of the Cerro la Mina porphyry – high sulfidation epithermal prospect, Mexico	AMIRA P765A, Kinross
Carlos Andres Jimenez Torres	Cooke, White, Baker	Genesis of epithermal and porphyry deposits	UTAS Foundation
Benjamin Jones§	Large, Crawford	Tectonic setting and magmatic evolution of the Antapaccay porphyry copper-gold and skarn deposit, Peru	BHP, APA Scholarship
Martin Jutzeler*	McPhie, Allen	Behaviour of submerged eruption plumes using data from facies analysis of a variety of submarine pyroclastic successions	CoE, USGS, UTAS
Teera Kamvong§	Khin Zaw, Meffre	Geology and genesis of porphyry-skarn Cu-Au deposits at the northern Loei fold belt, Northeast Thailand and Laos	IPRS, ARC Linkage, CoE, SEG, Pan Australian
Roisin Kyne	Berry, Gemmell	Structural controls on mineralisation, including sulfide mineralogy, at the CSA mine, Cobar NSW	UTAS, Cobar Management Ltd
Chun Kit Lai	Crawford, Meffre, Khin Zaw	Tectonics and metallogenesis of ophiolites and volcanics in southwestern Yunnan, China	CoE, Ore Deposits of SE Asia project, UTAS
Alexey Lygin	Foster, Crawford	The geology, geochemistry and genesis of the Avebury Ni deposit, Tasmania	CoE, UTAS, MMG
Wallace Mackay^	Selley, Bull	Structure and sedimentology of the Curdimurka Subgroup, northern Adelaide Fold Belt, South Australia	APA-I, AMIRA
Rodney Maier^	McGoldrick, Large	Pyrite trace element haloes to Northern Australian SEDEX deposits	Anglo American
Takayuki Manaka	Khin Zaw, Meffre	Geology and mineralisation characteristics of the Phuoc Son goldfields, central Vietnam	CoE, UTAS, Ore Deposits of SE Asia project, SEG, Olympus Pacific Minerals
Brendan McGee	McNeill, Gemmell	The geology and mineralisation of Tala Hamza Pb-Zn, Algeria	Terramin Australia, UTAS
Claire McMahon	G.Davidson	Controls on the major and trace elements content of pyrite in hydrothermal alteration envelopes	ARC
Robert Josephus Moye Jr§	Cooke, Scott	Genesis and chemical and kinematic evolution of the late Proterozoic Ridgeway gold deposit in the Carolina terrane of the central South Carolina piedmont, USA	CoE, Kennecott Minerals, Kennecott Exploration Inc, SEG, TPRS Scholarship
Evan Orovan	Cooke, Micko	Geology and geochemistry of the Namosi porphyry Cu-Au district, southeastern Viti Levu, Fiji	Newcrest, UTAS
Anita Parbhakar-Fox,	Lottermoser, Walters (UQ), Edraki (UQ)	Texture-based approaches to predictive geo-environmental modelling	SEG, GeM Project
Hector Ivan Parra Galvez (BRC)	Onederra (BRC)	Quantifying the impact of blast induced fragment conditioning on leaching performance	GeM project

Student	Supervisor(s)	Project	Support
Pedro Pereira da Fonseca	McPhie, McNeill	Facies analysis and correlations in complex mineralised submarine volcanic successions: Mount Read Volcanics, western Tasmania	Portuguese Govt, CoE
Kevin Pietersen (JKMRC) §	Walters (UQ), Berry, Bradshaw (UQ)	Geological and geometallurgical texture discrimination	GeM Project
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
Daniele Redi (U Naples)	Danyushevsky, De Vivo (U Naples), Lima (U Naples)	Geochemistry of Plinian and Interplinian eruptions at Monte Somma Vesuvio	University of Naples, CoE
Marc Rinne	Cooke, Harris, Micko	Characteristics and relationships of the contrasting Wafi-Golpu Cu-Au porphyry- epithermal system, Papua New Guinea	Newcrest, Harmony Gold, Morobe Mining Joint Venture, UTAS
Abhisit Salam*	Khin Zaw, Meffre, McPhie	A geological, geochemical and metallogenic study of the Chatree Epithermal Deposit, Phetchabun Province, central Thailand	Kingsgate Consolidated Ltd, IPRS, SEG, ARC Linkage, CoE
Blackwell Singoyi§	G.Davidson, Khin Zaw, Large	Controls on the geochemistry of magnetite in hydrothermal fluids	IPRS, CODES, TGMS, SEG
Jeffrey Steadman	Large, Bull, G.Davidson	The source of gold in gold deposits associated with banded iron formation (BIFs)	CoE, UTAS, SEG, CSIRO
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 Corporation
Olga Vasyukova^	Kamenetsky, G.Davidson, Danyushevsky	The origin of quartz and fluid inclusions in mineralised porphyries	CoE, IPRS
Adel Vatandoost Kohnehshahri^	Roach, Walters, Fullagar	Automated petrophysical characterisation of drill core as a link to mineral processing attributes	GeM project
Selina Wu	McNeill, Gemmell, Large	Volcanic hosted massive sulphide 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 2011

### NATIONAL COLLABORATIONS (IN ADDITION TO NODES)

Institution	Researcher(s)	CODES Collaborator(s)	Project / Research Focus
Australian Museum	Lin Sutherland	Sebastien Meffre	LA-Q-ICP-MS analysis development
Australian National University	Charlotte Allen, Ian Campbell	Evan Orovan, Marc Rinne	Exploring the porphyry environment
Australian National University	Richard Arculus, Hugh O'Neill	Leonid Danyushevsky	SW Pacific magmatism
Australian National University	Marc Norman	Sarah Gilbert	New LA-Q-ICP-MS applications
Australian National University	Nicholas Rawlinson	Anya Reading	Ambient seismic energy techniques
Australian National University	Malcolm Sambridge	Anya Reading, Matt Cracknell	Data inference techniques applied to diverse geoscientific datasets
Australian Synchrotron	Daryl Howard, Martin de Jonge, David Paterson, Kathryn Spiers	Chris Ryan, Stacey Borg, Weihua Liu	New synchrotron-based applications; Synchrotron X-ray probe development
CSIRO	Charles Butt	Bruce Gemmill	Genesis of volcanic-hosted Cu-Pb-Zn-Ag-Au massive sulfide deposits
CSIRO	Paul Dunn, Simon James, Murray Jensen, Robin Kirkham, Gareth Moorhead, James Cleverley, Rob Hough, Mel Lintern	Chris Ryan, Stacey Borg	Synchrotron X-ray probe development
CSIRO	Rob Hough, John Walshe	Ross Large, David Cooke	Sediment-hosted gold-arsenic-tellurium deposits: genesis & exploration models
Geological Survey of New South Wales	Ian Percival	David Cooke, Janina Micko	Exploring the porphyry environment
Geological Survey of Queensland	Ian Withnall	Tony Crawford	N Qld tectonics and magmatism
Geoscience Australia	David Huston	Bruce Gemmill	Genesis of volcanic-hosted Cu-Pb-Zn-Ag-Au massive sulfide deposits
Geoscience Australia	David Huston, Terry Mernagh	Khin Zaw	VHMS deposits
Geoscience Australia	Terry Mernagh	Vadim Kamenetsky	Kimberlites
Geoscience Australia	Roger Skirrow, Geoff Fraser	Garry Davidson	Iron oxide copper-gold and related deposit types
Institute for Mine Seismology	Richard Lynch	Anya Reading	Ambient seismic energy techniques
James Cook University	Tom Blenkinsop	Steve Micklethwaite	The rapid approximate inversion of TEM data
James Cook University	Zhaoshan Chang	Huayong Chen, David Cooke	Polymetallic mineralisation and associated magmatic and volcanic activity in Cretaceous volcano-sedimentary basins of eastern China
James Cook University	Bob Henderson	Tony Crawford	Fold belt tectonics, N Qld
James Cook University	Nick Oliver	Garry Davidson	Cracking the sulfate isotopic composition problem in ancient hydrothermal systems: application of the Carbonate-Associated Sulfate (CAS) method
Macquarie University	Nathan Daczko	Jacqui Halpin	Metamorphic PTT studies
Macquarie University	Norman Pearson	Sarah Gilbert	New LA-Q-ICP-MS applications

Institution	Researcher(s)	CODES Collaborator(s)	Project / Research Focus
Mineral Resources Tasmania	Ralph Bottrill, Jafar Taheri	Tony Webster, Rob Scott	Structure and formation of the Savage River magnetite deposit
Monash University	Michael Asten	Anya Reading	Ambient seismic energy techniques
Monash University	Reid Keays	Tony Crawford	PGE geochemistry
Monash University	Massimo Raveggi	Leonid Danyushevsky	New LA-Q-ICP-MS applications; LA ICP-MS methodologies
Northern Territory Geological Survey	Masood Ahmad	Garry Davidson	Iron oxide copper-gold and related deposit types
Primary Industries and Resources South Australia	Martin Fairclough	Jocelyn McPhie, Sharon Allen	Gawler Range Volcanics
University of Adelaide	Joel Brugger, Barbara Etschmann	Chris Ryan, Stacey Borg, Weihua Liu	New synchrotron-based applications; Synchrotron X-ray probe development
University of Adelaide	Cristiana Ciobanu, Nigel Cook	Leonid Danyushevsky	Sulfide mineral chemistry
University of Melbourne	Prof J.C. McCallum, Roland Szymanski	Jamie Laird, Chris Ryan	Data collection system for NMP and beamline upgrade
University of Queensland	Ben Cohen, Paulo Vasconcelos	Tony Crawford	Ar-Ar dating
University of Queensland	Sue Golding	Khin Zaw	Stable isotope studies
University of South Australia	Erica Donner, Enzo Lombi	Chris Ryan, Stacey Borg	Synchrotron X-ray probe development
University of Sydney	Patrice Rey	Steve Micklethwaite	The rapid approximate inversion of TEM data
University of Wollongong	Chris Fergusson	Tony Crawford	Tasman Fold Belt tectonics

### INTERNATIONAL COLLABORATIONS (IN ADDITION TO NODES)

Institution	Researcher(s)	CODES Collaborator(s)	Project / Research Focus
American Museum of Natural History	James Webster	Paul Davidson	Pegmatites and melt-melt immiscibility
Brookhaven National Laboratory, USA	Gianluigi De Geronimo, Tony Kuczewski, Zhi Yong Li, Peter Siddons	Chris Ryan, Stacey Borg	Synchrotron X-ray probe development
Chiang Mai University, Thailand	Phisit Limtrakun, Sampan Singharajwarapan, Weerapan Srichan	Tony Crawford, Khin Zaw, Sebastien Meffre	Geology of Thailand
Chinese Academy of Geological Science	Zengqian Hou	Khin Zaw, David Cooke	Ore deposits in China
Colorado School of Mines, USA	Dave Broughton, Murray Hitzman	Stuart Bull, Peter McGoldrick	Central African Copperbelt
Colorado School of Mines, USA	Thomas Monecke	Bruce Gemmill, Ross Large	Hydrothermal event recognition and targeting in volcano-sedimentary strata
Colorado State University, USA	Holly Stein	Khin Zaw	Re-Os dating
Curt-Engelhorn-Zentrum Archäometrie, Germany	Nicole Lockhoff	Bence Paul, Janet Hergt	New stable isotope MS applications
Department of Mineral Resources, Thailand	Pol Chaodumrong, Somboon Khositanon	Khin Zaw	Geology of Thailand
ETH Zurich, Switzerland	Marcus Walle	Leonid Danyushevsky	New LA-Q-ICP-MS applications
Geological Survey of Canada	Jan Peter	Bruce Gemmill, Ross Large	Hydrothermal event recognition and target vectoring in sedimentary strata
GFZ German Research Centre for Geosciences	Rainer Thomas	Paul Davidson	Melt-melt immiscibility

Institution	Researcher(s)	CODES Collaborator(s)	Project / Research Focus
Guangzhou Institute of Geochemistry, China	Weidong Sun	Vadim Kamenetsky	Mantle-derived magmas
Hanoi University of Geology and Mining, Vietnam	Hai Thanh Tran	Jacqui Halpin, Khin Zaw	SE Asian tectonics
Hanoi University of Geology and Mining Vietnam	Hai Thanh Tran	Khin Zaw	Genesis of volcanic-hosted Cu-Pb-Zn-Ag-Au massive sulfide deposits
Hefei University of Technology, China	Feng Yuan	Bence Paul, Janet Hergt	New stable isotope MS applications
Hefei University of Technology, China	Taofa Zhou, Fan Yu, Feng Yuan	David Cooke, Huayong Chen, Lejun Zhang	Polymetallic mineralisation and associated magmatic and volcanic activity in Cretaceous volcano-sedimentary basins of eastern China
IFM-GEOMAR, Germany	Armin Freundt	Sharon Allen, Jocelyn McPhie	Explosive degassing of felsic magmas
Imperial College London, UK	Andrew Berry	Leonid Danyushevsky	SW Pacific mafic magmatism
Imperial College London, UK	Jamie Wilkinson, Clara Wilkinson	David Cooke, Bruce Gemmill, Mike Baker, Huayong Chen	Enhanced geochemical targeting in magmatic-hydrothermal systems
Imperial College London, UK	Jamie Wilkinson, Clara Wilkinson	David Cooke, Andrew McNeill	Efficiency of ore-forming processes; Hydrothermal event recognition and target vectoring in sedimentary strata
Institute for Frontier Research on Earth Evolution, Japan	Yoshihiko Tamura	Jocelyn McPhie, Sharon Allen	Felsic magmas in arcs
Institut Neel and European Synchrotron Radiation Facility, France	Jean-Louis Hazemann, Denis Testemale	Weihua Liu, Stacey Borg	New synchrotron-based applications
Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry, Russia	Alexander Borisov	Leonid Danyushevsky	Geochemistry of platinum group elements
Lakehead University, Canada	Peter Hollings	David Cooke, Bruce Gemmill, Mike Baker, Huayong Chen	Enhanced geochemical targeting in magmatic-hydrothermal systems
Lakehead University, Canada	Peter Hollings	Ross Large	Sediment-hosted gold-arsenic-tellurium deposits: genesis & exploration models
Memorial University, Canada	Steve Piercy	Bruce Gemmill, Ross Large	Hydrothermal event recognition and target vectoring in sedimentary strata
Mineral Deposits Research Unit, University of British Columbia, Canada	Thomas Bissig, Dick Tosdal, Elizabeth Stock	David Cooke, Janina Micko	Shallow and deep-level alkalic mineral deposits; Sulfur isotopic signature of the Red Dog Au-deposit
Moscow State University, Russia	Pavel Plechov	Leonid Danyushevsky	Modelling of crystallisation and melting processes; Numerical petrology
Muroran Institute of Technology, Japan	Yoshihiko Goto	Jocelyn McPhie	Volcanic facies, submarine volcanism
National Laboratory of Energy and Geology, Portugal	Carlos Rosa	Jocelyn McPhie	Iberian Pyrite Belt
National Oceanography Centre, UK	Darryl Green	Bence Paul, Janet Hergt	New stable isotope MS applications
Queen's University, Canada	Dan Layton-Matthews	Bruce Gemmill, Ross Large	Hydrothermal event recognition and target vectoring in sedimentary strata
Russian Academy of Science	Valery Maslennikov	Ross Large, Helen Thomas	Sediment-hosted gold-arsenic-tellurium deposits: genesis & exploration models
RWTH Aachen University, Germany	Janos Urai	Stephen Cox	Fracture arrays in intrusion-related ore systems – controls on the dynamics of fluid flow, vein formation and the generation of giant deposits
Simon Fraser University, Canada	Derek Thorkelson	Garry Davidson	Iron oxide copper-gold and related deposit types
Smithsonian Institution, USA	Richard Fiske	Sharon Allen	Submarine explosive volcanism
State Key Laboratory in Ore Deposit Geochemistry, China	Xieyan Song, Ruizhong Hu, Bi Xianwu, Wei Xie	Tony Crawford	Tien Shan magmatism and fold belt studies

Institution	Researcher(s)	CODES Collaborator(s)	Project / Research Focus
St Mary's University, Canada	Jacob Hanley	Sarah Gilbert	New LA-Q-ICP-MS applications
Tarbiat Moallem University, Iran	Zahra Bonyadi	Garry Davidson, Sebastien Meffre	Iranian ore deposits
Tarbiat Modares University, Iran	Majit Ghaderi, Hossein Kouhestani, Fardin Mousivand	Khin Zaw, Sebastien Meffre	Iranian ore deposits
United States Geological Survey	Poul Emsbo	Peter McGoldrick, Rob Scott	Global ocean chemistry, marine basins and mineralisation
Universidad Nacional de la Patagonia, Argentina	Marcelo Marquez	Jocelyn McPhie	Patagonian felsic magmatism
Universiti Kebangsaan, Malaysia	Wan Fuad Wan Hassan	Khin Zaw	Genesis of volcanic-hosted Cu-Pb-Zn-Ag-Au massive sulfide deposits
Universiti Kebangsaan, Malaysia	Wan Fuad Wan Hassan, Mohd Rozi Umor	Khin Zaw	Malaysian ore deposits and geology
University College of Science, School of Geology, Iran	Mirsaleh Mirmohammadi	Paul Davidson	Origin of magnetite-apatite deposits
University du Quebec a Chicoutimi, Canada	Dany Savad	Sarah Gilbert	New LA-Q-ICP-MS applications
University of Alberta, Canada	Robert Creaser	Marc Rinne, David Cooke	Exploring the porphyry environment
University of Bern, Switzerland	Thomas Pettke	Leonid Danyushevsky	New LA-Q-ICP-MS Applications
University of British Columbia, Canada	Jim Mortensen, Greg Dipple	Bruce Gemmill, Andrew McNeill, Janina Micko	Genesis of volcanic-hosted Cu-Pb-Zn-Ag-Au massive sulfide deposits; Shallow and deep-level alkali minerals deposits
University of California Riverside, USA	Tim Lyons, Noah Planavsky	Peter McGoldrick	Chemistry of Earth's early oceans
University of Central Missouri, USA	Mark Dudley, John Nold	Paul Davidson	Origin of magnetite-apatite deposits
University of Johannesburg, South Africa	Cora Wohlgegemuth-Ueberwasser	Sarah Gilbert	New LA-Q-ICP-MS applications
University of Lisbon, Portugal	Jorge Relvas	Jocelyn McPhie	VHMS deposits
University of Malaya, Malaysia	Azman Ghandi, Teh Guan Hoe	Khin Zaw	Genesis of volcanic-hosted Cu-Pb-Zn-Ag-Au massive sulfide deposits; Malaysian ore deposits and geology
University of Naples, Italy	Benedetto De Vivo	Leonid Danyushevsky	Melt inclusions in Italian lavas
University of New Caledonia	Dominique Cluzel, Christine Laporte-Magoni	Sebastien Meffre, Tony Crawford	SW Pacific tectonics
University of Oregon, USA	Paul Wallace	Emily Johnson, Jocelyn McPhie, Vadim Kamenetsky	Felsic lava volatiles
University of Otago, New Zealand	Dave Crow	Ross Large	Sediment-hosted gold-arsenic-tellurium deposits: genesis & exploration models
University of Ottawa, Canada	Mark Hannington	Bruce Gemmill, Ross Large	Hydrothermal event recognition and target vectoring in sedimentary strata
University of Science & Technology, China	Yuling Xie	Paul Davidson	Magnetite-apatite deposits
University of the Witwatersrand, South Africa	Allan Wilson	Leonid Danyushevsky	Bushveld Complex melt inclusions
Vernadsky Institute, Russia	Alexey Ariskin, Galina Barmina	Leonid Danyushevsky	Numerical petrology
Virginia Polytechnic Institute & State University, USA	Robert Bodnar, Rosario Esposito	Leonid Danyushevsky	Melt inclusion studies
Woods Hole Oceanographic Institution, USA	Chris German	Bence Paul, Janet Hergt	New stable isotope MS applications

## VISITORS TO CODES 2011

### INDUSTRY VISITORS

Name	Company	Name	Company
Paul Agnew	Rio Tinto	Anthony Harris	Newcrest Mining
Michael Banks	Olympus Pacific Minerals	Mary Harris	Rio Tinto
Marc Bardoux	Newmont	Zaidi Harun	Monument Mining
Steve Beresford	MMG	Nick Hayward	Teck
Mike Blake	Consultant Geologist	Roger Hill	Grange Resources
David Braxton	Anglo American	John Holliday	Newcrest Mining
Rob Burnett	AngloGold Ashanti	Tony Hope	Consultant Geologist
Paul Burrell	MMG	Terry Hoschke	Newmont Asia Pacific
Cameron Cairns	Pan Australian	Bruce Hutchison	Grange Resources
Chris Campbell	Newmont	Marcello Imaña	Pyhäsalmi-GSF working group/ProMine
Djohanne Celiz	Freeport McMoRan	Tim Ireland	Mawson West
Corrie Chamberlain	Minera IRL, South America	Eric Laurio	Vale
Genesio Circosta	Issara Mining/Kingsgate	David Lawie	ioGlobal
Dean Collett	Newcrest Mining	Stacey Leichter	AngloGold Ashanti
Donna Copolov	AMIRA International	Clyde Leys	Freeport McMoRan
Jun Cowan	Prestologic	Richard Lindsay	Consultant Geologist
Shawn Crispin	G-Resources	Neil Macalalad	Anglo American
Paul Cromie	Tigers Realm Minerals	Glen Masterman	Kinross
Vladimir David	MMG	Toshiaki Matsuda	Agilent, Japan
Cathryn Dickins	St Barbara	Craig McEwan	Barrick Australia Pacific
John Dow	Consultant	David Meade	Indochine Mining Limited
Mark Doyle	AngloGold Ashanti	Mark Miller	Newcrest Mining
Kathy Ehrig	BHP Billiton	James Patterson	MMG
David First	Freeport McMoRan	Aubrey Paverd	Compania de Minas
Fred Fryer	Agilent, Australia	Rachmat Pratiwinda	Vale
Charles Funk	OZ Minerals	Amelia Rainbow	Gold Fields
Alan Goode	AMIRA International	Robbie Rowe	Barrick Australia Pacific
Michael Hamel	Resonetics, USA	Thomas Sant	Eldorado Gold

Name	Company	Name	Company
Donna Sewell	AngloGold Ashanti	Bronto Sutopo	PT Antam Mining
Adele Seymon	AMIRA International	Marcus Tomkinson	MMG
Michael Shelley	Laurin Technic, Australia	Steve Turner	Newmont
Stuart Smith	G-Resources	Mario Valdez	BHP Billiton
Gary Snow	Intrepid Mines	Le Van Hai	Olympus Pacific Minerals
Friedrich Speidel	Inmet Mining	David Wallace	MMG
Wayne Stange	AMIRA International	Ian Willis	Anglo American
Kathryn Stewart	Newcrest Mining	Andrew Wurst	Gold Fields

### NATIONAL ACADEMIC AND GOVERNMENT VISITORS

Name	Institution	Name	Institution
Michael Asten	Monash University	Janet Hergt	University of Melbourne
Stacey Borg	CSIRO	Jamie Laird	CSIRO
Graham Carr	CSIRO	Weihua Liu	CSIRO
Stephen Cox	Australian National University	Richard Lynch	Institute for Mine Seismology
Kim Creak	Mineral Resources Tasmania	Roland Maas	University of Melbourne
Miles Davies	DMITRE, South Australia	Alexander Mendecki	Institute for Mine Seismology
David Green	Mineral Resources Tasmania	Bence Paul	University of Melbourne
Geoff Green	Mineral Resources Tasmania	Nicholas Rawlinson	Australian National University
Stephen Guigni	CSIRO	Malcolm Sambridge	Australian National University
Paul Heithersay	PIRSA	Tonguac Uysal	(QGECE)/University of Queensland
		John Walshe	CSIRO

### INTERNATIONAL ACADEMIC AND GOVERNMENT VISITORS

Name	Institution	Name	Institution
Alexey Ariskin	Vernadsky Institute, Russia	Jim Mortenson	University of British Columbia, Canada
Jon Blundy	FRS University of Bristol, UK	Pavel Plechov	Moscow State University, Russia
Yoshi Goto	Muroran Institute of Technology, Japan.	Jamie Wilkinson	Imperial College London, UK
Brian Hoal	SEG, USA	Allan Wilson	University of Witwatersrand, South Africa
Pete Hollings	Lakehead University, Canada	Jing Zhang	Chinese University of Geosciences (Beijing)
Nicole Lockhoff	Curt-Engelhorn-Zentrum Archäometrie, Germany		

## MAJOR EXTERNALLY FUNDED RESEARCH PROJECTS\*

AMIRA-ARC CENTRE OF EXCELLENCE PROJECTS 2011 <sup>†</sup>								
Investigator(s)	Project	Industry Partners	Period	COE-ARC Funding For 2011	AMIRA Funding For 2011	Misc Funding For 2011	Additional AMIRA Funding For 2011	Case Study Funding For 2011
Foster, Walters (consultant), Lottermoser, Berry, Kojovic <sup>‡</sup> , Michaux <sup>‡</sup> , Onederra <sup>‡</sup> , Bradshaw <sup>‡</sup> , Robinson (CSIRO) ( <sup>‡</sup> 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	July 2009 – 2013	\$500,000	\$670,282	\$0	\$396,956 (Parker Centre) \$718,393 (CRC Ore- UQ)	\$157,383
Cooke, Gemmell, Baker, Chen, White, Fox, Zhang, Thompson, 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	\$60,000	\$478,800	\$13,587	\$0	
Cooke, Gemmell, Chang, Baker, Chen	AMIRA P765A. Geological and geochemical halos in green rocks and lithocaps	Anglo American, AngloGold Ashanti, Barrick Gold, Cia De Minas Buenaventura, Codelco, CVRD, Dundee Precious Metals, Equinox Resources, Freeport McMoran, Gold Fields, Kinross Gold, MMG, Newcrest Mining, Newmont Mining, Rio Tinto, St Barbara, Teck, Xstrata	2008 – 2011	\$114,000	\$169,250	\$11,046	\$8,700 (Lakehead University)	
Large, Thomas, Bull, Meffre, Danyushevsky, Scott, G. Davidson	AMIRA P1041. Application of new technologies to gold deposits	AngloGold Ashanti, Newcrest Mining, Newmont Mining, G-Resources, Issara Mining, Sipa Exploration	2010 – 2013	\$45,000	\$157,600	\$33	\$0	
Foster, 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	\$45,000	\$144,000	\$0	\$0	

## ARC DISCOVERY GRANTS 2011<sup>^</sup>

Investigator(s)	Project	Period	ARC Funding For 2011	Misc Funding For 2011
Allen	Discovery Grant: Submarine explosive eruptions of silicic magma: constraints on products and processes from modern sea-floor examples, ancient successions and experiments	2004 – 2012	**	\$0

\* Projects with greater than \$2,000 external (non-CoE-ARC) funding per year

<sup>†</sup> ARC funding for these projects comes from the CoE-ARC Grant

<sup>^</sup> ARC funding for these projects comes directly from the ARC Discovery or Linkage programs

\*\* All project funding received, project still active

<sup>‡</sup> Full project funding received in one year

# Protect income received in 2011 for 2012 student project

## INDUSTRY AND OTHER EXTERNALLY FUNDED RESEARCH GRANTS 2011

Investigator(s)	Project	Funding Body	Period	Funding For 2011	Misc Funding For 2011
McPhie, V.Kamenetsky, Orth	Setting, age and architecture of the Olympic Dam Au-Cu-U deposit, South Australia	BHP Billiton	July 2010 – 2012	\$569,860 <sup>‡‡</sup>	\$744
Cooke, Micko, Jansen, Harris (Newcrest)	Exploring the porphyry environment	Newcrest Mining Limited	July 2009 – 2013	\$363,057	\$6,096
Khin Zaw, Meffre, Salam, Large, Crawford, Lai, Khositantong (DMR Thailand), Tran (Hanoi), Rosana (Padjajaran), Subandrio (ITB, Bandung)	Ore Deposits of SE Asia (extension)	East Asia Minerals, Indochine Resources Ltd, Issara Mining, MMG, Monument Mining, Olympus Pacific, Phu Bia Mining, PT Antam (Persero), Tigers Realm Minerals	2011 – 2014	\$400,000	\$0
Bull, Meffre, G.Davidson	Volcano-sedimentary and chrono-stratigraphic architecture for the host rock succession at Prominent Hill, South Australia	OZ Minerals	2011 – 2012	\$78,171	\$0
Gemmell, Clark (student)	Deposit to district-scale study of the Gosowong Goldfield	Newcrest Mining Limited	2007 – 2011	\$74,154	\$0
McNeill, Wu (student)	Volcanic hosted massive sulphide deposits of the Que-Hellyer Volcanics, western Tasmania	Bass Metals	2010 – 2013	\$56,500	\$0
Scott, Berry, Braniff (student)	The structure & deformational history of the Savage River Magnetite orebodies	Grange Resources (formerly Australian Bulk Minerals)	2008 – 2012	\$55,000	\$0
Berry, Kyne (student)	Structural controls on mineralisation, including sulfide mineralogy, at the CSA mine, Cobar NSW	Cobar Management Pty Ltd	2009 – 2013	\$45,000	\$0
G.Davidson	Geochemical controls on gold, Sunrise Dam	James Cook University	2010 – 2011	\$21,500	\$0
McNeill, McGee (student)	The Geology and Mineralisation of the Tala Hamza Pb-Zn deposit, Algeria	Terramin Australia Ltd	2010 – 2013	\$16,000	\$0
Lottermoser, Jayathilaka (student)	Leaching characteristics of Mt Lyell mine wastes	Copper Mines of Tasmania	2011 – 2012	\$13,636	\$0
Cooke, Gemmell, Ageneau (student)	Geology of the Kapit ore zone and comparative geochemistry with Minifie and Lienetz ore zones, Ladolam gold deposit, Lihir Island, Papua New Guinea	Newcrest Mining Limited (formerly Lihir Gold Ltd)	2009 – 2011	\$10,000	\$990
McPhie, Cotterill (student)	Mafic dykes at Wirrda Well: composition, timing, distribution and sources	BHP Billiton	2011 – 2012	\$10,000	\$0
Roach, Reading, Perry (student)	The geology and geophysics of a new magnesite prospect, NW Tasmania	Tasmania Magnesite	2011	\$10,000	\$0
Roach, Reading, Smith (student)	Geophysical investigation of a minerals prospect under cover, Prominent Hill, South Australia	OZ Minerals	2011 – 2012	\$10,000	\$0
G.Davidson, Cooke, Greene (student)	Characteristics of the fluids that formed the Merlin Mo-Re-Cu deposit (Cloncurry, Australia) and their implications for exploration	Ivanhoe	2011	\$9,250	\$0
Crawford, Large, Doran (student)	The geology and mineralisation of the Handpump Gold Prospect, West Musgrave Province, Central Australia	Beadell Resources	2011	\$7,000	\$0
Zaw, Manaka (student)	Geology and mineralisation characteristics of the Phuoc Son goldfields, central Vietnam	Olympus Pacific Minerals	2011	\$7,000	\$0
McNeill, McPhie, Meidecke (student)	The stratigraphy, volcanology of the mixed sequence, Que-Hellyer Volcanics, Tasmania	Bass Metals	2011	\$6,000	\$0
McPhie, McNeill, Tomes (student)	The volcanology of the hangingwall basalt at Hellyer	Bass Metals	2011	\$5,000	\$0
McNeill, G.Davidson, McMillan (student)	The Deep alteration system at the Prince Lyell Deposit, Mt Lyell, Tasmania	Copper of Mines Tasmania	2011	\$5,000	\$0
Reading, Roach, Harris (student)	In-mine rock mass characterisation using active seismic monitoring	Institute of Mine Seismology	2011	\$5,000	\$0
Roach, Reading, Nolan (student)	Geophysics of the Cadia deposit, NSW	Newcrest Mining	2011	\$5,000	\$0
G.Davidson, Bull, TBA (student)		Tasmanian Museum and Art Gallery	2012 #	\$3,556	\$0

# Activity Plan 2012

PROGRAM 1		
Project	Leader(s)	Activity Plan
P1A2	Leonid Danyushevsky	Submit Gisela Cobenas's PhD thesis on Hunter Ridge arc magmatism, SW Pacific.
P1A3	Peter McGoldrick	Submit papers deriving from the Guiliamse and Jensen Honours theses on Precambrian life forms and implications for global atmospheric oxygen.
P1A4A	Khin Zaw, Sebastien Meffre	Hold further negotiations to secure two additional sponsors for the Ore Deposits of SE Asia (2011–2014) extension project. Appoint two post-doctoral fellows – one full-time, one part-time.
P1B1	Jocelyn McPhie, Vadim Kamenetsky	Conduct ALS synchrotron microanalytical study of submarine giant pumice clasts to constrain volatile exsolution and mechanisms of foam rupture. Submit manuscripts on submarine eruption-fed density current deposits. Submit manuscripts on volcanic-influenced basins. Publish a paper on the behaviour of metals during degassing and crystal fractionation of Taupo Volcanic Zone rhyolites. Conduct structural and facies analysis of bedded sedimentary facies at Olympic Dam.
P1B2	Leonid Danyushevsky	Complete analysis of melt inclusions in olivine from the Bushveld Complex.
P1B3B	Paul Davidson	Complete the Fanshan magnetite-apatite project and submit manuscript detailing results.

PROGRAM 2		
Project	Leader(s)	Activity Plan
P2A2A	Stephen Cox	Complete microstructural work on 'accretionary' fault breccias and submit paper. Conduct detailed microstructural studies of how cohesion during vein sealing impacts on the style of vein systems. Perform fieldwork, optical microscopy, SEM cathodoluminescence, and element mapping in veins.
P2A3	David Cooke	Undertake analyses of metal contents in fluid inclusions from Unicorn. Initiate a study of a vertical transect through a lithocap in Mongolia.
P2B1A	David Cooke, Janina Micko	Marc Rinne to complete PhD field work at Wafi-Golpu, PNG, including sample collection and analysis. Nic Jansen to initiate spectral and geochemical analysis of the lithocap. Evan Orovan to complete PhD field work at Namosi, Fiji, including sample collection and analysis, and begin thesis write-up. Janina Micko to continue sample collection at Cadia, NSW, for pathfinder minerals, and apply and advance pathfinder mineral toolbox. Andrew Beattie to initiate Honours field work at Gooleys Creek (one or two trips), including sample collection and analysis. Erin Lawlis to initiate PhD field work (one or two trips) at Lihir, PNG, including sample collection and analysis. Janina Micko and Nic Jansen to initiate spectral and geochemical analysis, conduct sample collection for pathfinder minerals, and apply and advance the pathfinder mineral toolbox.
P2B1B	Taofa Zhou, David Cooke	Continue fieldwork in Luzong basin. Submit a Cooperation Research Agreement grant application for a collaboration with Hefei University of Technology on 'The ore-forming system of intra-continental porphyry-skarn copper-gold and magnetite-apatite iron deposits in the Middle-Lower Yangtze River Valley metallogenic belt in eastern China'. Funding from 2013 – 2017. Taofa Zhou, Shiwei Wang and Dayu Zhang to visit CODES to conduct LA-ICP-MS analyses. Present research results at IGC in Brisbane.

Project	Leader(s)	Activity Plan
P2B1D	David Cooke, Thomas Bissig	Publication of the alkalic special issue of <i>Economic Geology</i> .
P2B3A	John Walshe	Complete the sulfur isotopic study on the ore and stockwork veins of the Lombador orebody, Neves Corvo.
P2B3B	Bruce Gemmell	Continue research on the Fossey-Hellyer-Que River-Mt Charter (Tasmania), DeGrussa (Western Australia), Palmer (Alaska), Duc Bo (Vietnam), Tasik Chini (Malaysia) and Tala Hamza (Algeria) deposits. Initiate a PhD project into the geology and genesis of the ore bodies at Greens Creek, Alaska (project funded by Hecla Mining). Begin a study of the supergene and weathering geology above the Doolgunna VHMS deposits in Western Australia. This will be a two-year post-doctoral study, funded by Sandfire Resources. Margy Hawke will convert her Master of Economic Geology project at DeGrussa, WA into a PhD study. Publish results from the initial age dating throughout the Mount Read Volcanics.
P2B3C	Bruce Gemmell	Hold a sponsors review meeting at the PDAC meeting in Toronto, during March.
P2B3D	Bruce Gemmell	Publish a paper in <i>Economic Geology</i> on the Brothers Volcano black smoker chimneys.
P2B4	Garry Davidson	Publish a paper in <i>Mineralium Deposita</i> on the Tennant Creek IOCG deposits.

PROGRAM 3		
Project	Leader(s)	Activity Plan
P3A1C	Peter Fullagar, Jeff Foster	Generalise the hybrid scheme for arbitrary vertical cell dimensions and for moving loop configurations. Modify VPview v2 to enable it to reproduce all VPview v1 functions (except create new model), read and display TEM data (including downhole TEM), convert TEM decays to moments using existing RS routines, and create a data file in VPem3D format. Commence preliminary interpretation of sponsors' site data.
P3A2A	Anya Reading	Carry out sensitivity testing for ambient seismic determination of depth of cover. Process field data collected in November/December 2011. Prepare manuscript(s) on using the ambient seismic method in an exploration setting.
P3A3A	Anya Reading	Submit manuscript on linear feature detection to a geophysical journal. Matthew Cracknell to present PhD research at American Geophysical Union meeting, San Francisco.
P3B1B	David Cooke, Bruce Gemmell, Mike Baker	Conduct an intensive program of field campaigns in the Americas and SW Pacific, coupled with a major analytical program, including reporting at two sponsors meetings, scheduled for the USA in July and Hobart in December.
P3B1C	Bruce Gemmell, David Cooke	Initiate a new PhD study at Ladolam, Lihir Island, PNG. Hold further discussions with Almaden Resources on a potential PhD study on the Ixtaca low-intermediate sulfidation deposits in Mexico. Lindsey Clark to complete her PhD study on the Kencana deposit, Indonesia. Mathieu Ageneau to complete his PhD study on the Ladolam deposit, PNG. Hugo Galvan to complete his PhD study on the Palmarejo deposit, Mexico.
P3B2A	Ross Large, Stuart Bull	Report to AMIRA and hold AMIRA P1041 sponsors meetings in February and August on the results from pyrite-gold case studies at Chatree, Thailand; Geita, Tanzania; Matarbe, Indonesia; Golpu, PNG; and Hope Bay, Canada. Complete sulfur isotope study on CLR, West Wits. Write-up Kapai Slate and Randalls studies in the Yilgarn, for publication. Commence collaboration with University of Johannesburg in relation to the Witwatersrand reefs. Compile database on background pyrite chemistry in black shales.

Project	Leader(s)	Activity Plan
P3B3A	Andrew McNeill, Bruce Gemmell	Analyse muscovites and sulfides in highly (200–600ppm) TI-enriched samples to confirm trends evident in previously analysed samples. Submit manuscript on alteration halo at Rosebery.
P3B5C	Jeff Foster	Alexey Lygin to complete his PhD study on the Avebury Ni deposit, Tasmania.
P3B6A	Rob Scott	Attempt to determine the sense of shear in the mylonitic fabrics that occur throughout the Savage River host sequence.  Complete structural mapping of the Oonah formation, immediately east of the Savage River Mine, and attempt to relate the structural pattern in these rocks to that of the East Wall assemblage.
P3B7A	Stuart Bull	Apply the chrono stratigraphic framework developed for the mine area to a number of regional prospects in the Mount Woods inlier.  Determine the age of the Prominent Hill sulfide mineralisation by dating co-precipitated U-bearing minerals e.g. monazite.

PROGRAM 4		
Project	Leader(s)	Activity Plan
General activities	Jeff Foster	Aid development of 'Road Map for Geometallurgy' with AMIRA. Focus on developing theme cross-links, such as blast-to-size, sort-to-leach.  Build optimisation capabilities and ensure geometallurgical outputs and indices are mappable through an ore body and suitable for optimisation methods.
P4A1	Bernd Lottermoser	Develop links with HydroMet group. Investigate and link HydroMet protocols with environmental indices. Develop dust analysis protocols and investigate potential of laser Raman system. Develop case studies, where appropriate.
P4A2	Italo Onederra, Simon Michaux	Identify site for MWD data calibration. Complete IFragX and 3DFrag test and develop reliable geometallurgical proxies.  Finalise results of synthetic blast-to-leach experiment. Analyse results from 3D photography and particle size analysis – comparison with HSBM and real data. Complete UCS and tensile strength measurements.
P4A3	Toni Kojovic	Complete reporting of current procedures and finalise blend response modelling. Investigate alternate methods for A*b and Bond.
P4A4	Dee Bradshaw	Continue to develop sampling protocols for batch flotation. Reassess role of JKMSI equipment and investigate alternate experimental methods. Fully develop software tools for textural measurement and data extraction.
P4A5	Dave Robinson	Finalise small-scale diagnostic leaching tools, protocols and proxies. Develop large-scale, integrated case study. Develop software that combines fluid-flow and chemical equilibrium models for dump/heap leach performance prediction and planning. Develop scoping study for agglomerate porosity and hydrology test.
P4A6	Ron Berry	Monitor laser ablation developments and investigate incorporation into geometallurgical models. Investigate potential of laser Raman system for the analysis of dust and general rapid mineralogical mapping. Investigate methods for particle size analysis from 3D imagery – link to sorting potential and ore upgrading. Finalise DomAln software. Monitor, and continue to develop, education and short-course modules.
P4A7	Steve Walters	Finalise and report findings from active case studies. Aid the development of case studies in themes 1, 2 and 5.

PROGRAM 5		
Project	Leader(s)	Activity Plan
P5A1	Sebastien Meffre, Leonid Danyushevsky	Install a new large-volume constant geometry ablation cell.
P5A2	Leonid Danyushevsky, Sebastien Meffre	Gain an in-depth understanding of laser-induced fractionation. Complete the analytical technique for S isotope measurements in sulfides. Improve the apatite U-Pb dating technique.
P5A3	Bence Paul, Janet Hergt	Complete new procedure for melt inclusion analysis, and publish. Publish spatial imaging software paper. Conduct another international Iolite workshop.
P5A4	Janet Hergt, Bence Paul	Publish results of hydrothermal sediment Cu isotope/trace element study. Publish paper describing new double spike deconvolution software. Finish Mo isotopes in ore deposit samples study.
P5A4A	Garry Davidson	Produce and submit methods and applications manuscript.  Undertake trials of large volume, ultra-low sulfate samples, using Sn chloride reagent to improve extraction efficiency.  Undertake CAMECA mapping of S in an IOCG carbonate vein set, and then apply the CAS technique to these samples.  Collaborate with Tony Crawford, and an Honours student, to extract whole-rock sulfur from a range of ultramafic rock samples from Anglo American.
P5B1	Jamie Laird	Perform 3D TCAD simulations of a series of pyrite structures, progressively moving from simple to more complex assemblages.  Adapt a detector system for Photoluminescence (PL) imaging to the LBIC system – to enable direct mapping and identification of minerals and their intrinsic defects/microstructure.  Install a series of 5µm pitch 40point probes on a separate XYZ stage to perform micro-resistivity/thermoelectric measurements required to electrically characterise some of the smaller grains.  Work on finalising the Scanning Electrochemical Microscope. Perform rudimentary experiments later in the year, utilising a laboratory glove box for chemically treating the pyrite surface prior to electrochemical experiments.
P5B2	Jamie Laird	Commission the new nuclear microprobe chamber, which will enable additional simultaneous techniques to be performed on very large samples.  Integrate the beamline control and software, developed in 2011, with the Maia data collection and control software to enable rapid large area PIXE and IL mapping.  Ionoluminescence mapping system to include NIR spectroscopy for mapping sulfides.
P5B3	Chris Ryan	Upgrade Maia 384 to improve noise performance, energy resolution, safety and reliability. For implementation in the Nuclear Microprobe for PIXE imaging.  Analyse Maia characterisation results from October 2011, finalise new quantitative methods and corrections, and submit a detailed Maia methods paper.  Reintegrate the HT/HP mAESTRO system in the second hutch at the XAS beamline of the Australian Synchrotron with fluorescence detection capability.
P5B4	Stacey Borg	Further develop XANES imaging methods and software platform to allow routine species identification and mapping.  Complete analysis of XANES imaging data collected in 2011. Collect XAS data on Ni, Zn and Pd using the mAESTRO system.
P5C3	Leonid Danyushevsky	Add mixing calculations to Petrolog 3.

# Image Details

SEQUENCE OF IMAGES ARE FROM TOP TO BOTTOM, LEFT TO RIGHT ON INDICATED PAGE

## COVER

- Front: Dan Gregory and Selina Wu studying Huangshan granite at Yellow Mountain, China.  
Back: Core samples from Andina mine, Chile.

## INTRODUCTORY PAGES

- Page 5: David Cooke and Roisin Kyne inspect Mo porphyry samples at Shapinggou Mo deposit, China.  
Core samples from Colquijirca silver mine in Peru.  
View from Tomorocho porphyry copper mine, Peru.

## OUTCOME-DRIVEN RESEARCH

- Page 8: Laser images of 'super pyrite' from Bendigo.  
Dredge samples of pillow lavas and volcanic glass.

## STUDENT PROJECTS

- Page 15: Huayong Chen, Jeff Steadman, David Cooke, Chris Large, Chun Kit Lai, Dan Gregory, Bruce Whittaker and Lejun Zhang at Baohe Park, Hefei, China.  
Chun Kit Lai and Huayong Chen looking at magnetite skarn samples from Nihe, China.  
Jeff Steadman, Selina Wu, Chris Large, Bruce Whittaker, Chun Kit Lai, Lejun Zhang and Dan Gregory at Zhonghua Gate, Nanjing, China.  
Bruce Whittaker and students from Hefei University at drill site near Shapingou, China.

## PROGRAM ONE: LOCATION

- Page 20: Old Chinkuashih Au deposit area, Taiwan.  
Page 25: RV *Southern Surveyor*.  
Khin Zaw (centre) leads group at 8000-year-old fresh pyroclastic flow, Mt Popa, Myanmar.  
Page 26: Tertiary basalts, northwest Tasmania.  
Page 27: Tertiary basalts, northwest Tasmania.  
Page 28: Researchers from the Ore Deposits of SE Asia project at the Kratie North gold deposit, Cambodia.  
Newly appointed Research Fellow, Rebecca Carey, at Kilauea volcano, Hawaii.  
Agate sample from Brazil.

## PROGRAM TWO: FORMATION

- Page 30: Cun Yu (Gold Fields) studying massive sulfide mineralisation at Xin Qiao mine, China.  
Page 35: Jie Xie, Lejun Zhang, Roisin Kyne, and Taka Manaka at Xin Qiao mine, China.  
Agate with fluorite.  
Janina Micko in core yard, Namosi, Fiji.  
Heidi Berkenbosch with seafloor black smoker samples.  
Page 36: Dan Gregory and Selina Wu studying Huangshan granite at Yellow Mountain, China.  
Some of the participants in the SEG Student Chapter trip to China at the Xinqiao polymetallic (Cu-Au-Pb-Zn-S) open pit mine.  
Core laid out at a temporary core yard at Wafi Camp, PNG.  
Participants in the SEG Student Chapter trip to China at the Fushan Geopark.  
Namosi exploration camp, Fiji.

## PROGRAM THREE: DISCOVERY

- Page 38: Seismometers being transported for use in ambient seismic sounding fieldwork.  
Page 43: Core yard at Prominent Hill.  
Attendees at AMIRA P1060 meeting at CODES in December, 2011.  
Page 44: Core yard at Prominent Hill.  
Page 46: Compact passive seismic monitoring equipment.  
Prominent Hill.  
Victoria Braniff examining outcrop of the West Wall Assemblage at Savage River.  
Prominent Hill (both the remaining images on this page).

## PROGRAM FOUR: RECOVERY

- Page 48: Core samples from Noel White's trip to Peru.  
Page 52: Julie Hunt (centre) at Escondida mine, Chile.  
GeM<sup>III</sup> meeting, Brisbane.  
Ernest Henry Mill.  
Aerial view of Escondida mine, Chile.  
Core samples from Andina mine, Chile.

## PROGRAM FIVE: TECHNOLOGY

- Page 56: Sebastien Meffre using the Resonetics M50 laser ablation system. (image courtesy of Peter Mathew).  
Page 61: Leonid Danyushevsky and Sebastien Meffre in the rock reference store at the CODES Hub. (image courtesy of Peter Mathew).  
The CODES custom designed laser ablation cell on the New Wave solid state laser.

## GRADUATE RESEARCH & TRAINING

- Page 64: Graduates Rodney Maier, Mawson Croaker and Adel Vatandoost with Ross Large (centre) and Pat Quilty (far right).

## OUTREACH

- Page 66: Anya Reading conducts a hands-on geophysics exercise for Year 6 students at Mount Carmel College.  
Michael Roach leading a field excursion as part of a Teacher Earth Science Education Program (TESEP) workshop.  
Year 11 students participating in the Science Experience workshop at the CODES Hub.  
Helen Thomas (far right) guiding students from Fahan School for girls through an interactive exercise using rock samples from around the world.

## PUBLICATIONS

- Page 80: Janina Micko and Evan Orovan at the Morococha epithermal polymetallic deposit, central Peru.  
Page 95: Taocun apatite/magnetite mine, China.  
View east from the Cerro De Papas to the central Andes in Chile.  
Chris Large examining rock specimens at Taocun apatite/magnetite mine, China.  
Roisin Kyne at Xinqiao copper-gold mine, China.

## APPENDICES

- Page 96: Two of the new recruits for 2011; lab analysts Jennifer and Jay Thompson, from Iowa, USA.  
Bernd Lottermoser delivering a presentation at the Science Planning Meeting.

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

