

CODES

*ARC Centre of Excellence in Ore Deposits
Annual Report 2008*



CODES

ARC Centre of Excellence in Ore Deposits
Annual Report 2008



Location

Formation

Discovery

Recovery

Technology



Australian Government
Australian Research Council

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CODES

ARC Centre of Excellence in Ore Deposits

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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.

Centre 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

The major highlight of 2008 was the successful three-year review held by the ARC in November. As part of our Centre of Excellence agreement, a panel of independent experts, selected by the ARC, conducted a rigorous examination of our performance against all the key elements of our strategic plan.

I am very pleased to report that CODES emerged with a very positive scorecard, which is reflected in the following extracts from the ARC's review report:

The Review Panel considers that the ARC Centre of Excellence in Ore Deposits has strongly pursued its objectives, as set out in the original proposal, and is achieving outstanding levels of success in many of these.

The Centre has created a world-class reputation and good visibility both within Australia and across the world. Centre staff have strong links with industry and students and staff are working directly with industry partners on a range of projects. The Technology Program within the Centre is also providing strong benefits for industry, with new technology providing strong scope for new mineral location and recovery. The collaboration of researchers between CODES and industry in the area of geometalurgy is already benefiting industry and is likely to provide further national benefit in the future.

The result of this highly successful performance review is that the ARC has agreed to extend its funding for CODES by a further 3.5 years to December 2013, with an additional grant of approximately \$9.5 million. This ensures the future of CODES through what may be a very difficult period for the minerals industry.

In our third year of operations as an ARC Centre of Excellence, CODES has continued to increase its complement of world-class research staff and postgraduate students. Seven postdoctoral research fellows were hired during the year, which brings our total research staff to 69 across all six nodes and the UTAS hub. In addition, our PhD group comprises 48 students and the specialised Master of Economic Geology Program has achieved a healthy enrolment figure of 37.

Another significant highlight was the completion of our AMIRA-ARC P872 project on the sediment-hosted copper deposits of the Central African Copperbelt, led by David Selley and Murray Hitzman. This successful four-year project has provided the industry sponsors with a new and innovative model for the generation of these major deposits, within the context of basin evolution and metalliferous brine fluid flow. Over 100 geoscientists attended the final meeting in the Democratic Republic of Congo and Zambia, where the outcomes of the project were discussed and 13 scientific papers on the results of the research were presented.

It is always extremely satisfying to see industry success emanate from our collaborative research and, once again, this was achieved in 2008 – on this occasion via the 'District- to deposit-scale structural and geochemical study of the Cadia porphyry Au-



Cu deposits'. This project, led by Anthony Harris and David Cooke in close collaboration with Newcrest geologists, commenced in 2005 and is aimed at unravelling the architecture and volcanic-magmatic evolution of the Cadia Valley. Drill testing of a conceptual model developed by the research team has resulted in a significant Au-Cu intersection, which is being followed up by Newcrest for potential exploitation.

In another exciting development, a team that includes Leonid Danyushevsky has had research published in *Nature* that provides conclusive evidence that Archaean komatiites were formed by the melting of a very hot mantle. Combining synchrotron-based X-ray and FTIR measurements of the oxidation state and H₂O contents of silicate melt inclusions in olivine phenocrysts from 2.7 Ga Belingwe komatiites, Zimbabwe, they have shown that the komatiite parental melts contained low water (~ 0.3 wt%) and, therefore, were formed at temperatures much higher than the current mantle temperature. It is also pleasing to report that Leonid, along with David Cooke and Dima Kamenetsky, were deservedly promoted to full Professor late in the year. All three are Chief Investigators who started with CODES over ten years ago and have been very major contributors to the growth and success of the Centre.

Other successes in the area of fundamental research include Sharon Allen's EPSL paper on the dynamics of subaqueous explosive eruptions, conducted in conjunction with collaborators from the Smithsonian Institution and the University of Oregon. Ralf Schaa developed a rapid inversion technique for geophysical interpretations, and Dima Kamenetsky and Olga Vasyukova continued their groundbreaking work on hydrosilicate precursors to quartz crystals and veins in porphyritic intrusions.

Looking to the future, several new research projects commenced in 2008, which will form the backbone of our research program for the next few years:

- Khin Zaw and Sebastien Meffre are leading a project in SE Asia on tectonics and metallogensis of several volcano-plutonic fold belts, covering Thailand, Malaysia, Vietnam, Cambodia, Laos and southern Yunnan. This project is sponsored by eight minerals companies.
- In collaboration with the CSIRO, we have initiated an ion-beam electrochemistry project on the nuclear microprobe, which is aimed at better understanding the depositional mechanisms of gold in sulfide minerals. The project is led by Chris Ryan and new postdoctoral fellow Jamie Laird.
- Anya Reading is leading a project to test the application of ambient seismic energy, which will provide information on basin architecture, in part of the Tasmania basin.
- Anglo American is supporting a project, led by Jeff Foster and new postdoctoral fellow David Hutchinson, on the geology, mineralogy and evolution of the Tweefontein PGE deposit in South Africa.
- Jocelyn McPhie, Dima Kamenetsky and new postdoctoral fellow Isabelle Chambefort are collaborating with BHP geoscientists to better understand the host succession of the giant Olympic Dam Cu-U-Au deposit.
- Bendigo Mining is supporting a project, led by Ross Large, Stuart Bull and new postdoctoral fellow Helen Thomas, on the application of pyrite laser mapping and sediment geochemistry to predicting the presence of gold-rich reefs.
- Bruce Gemmell and new research fellow Steve Micklethwaite are working with Newcrest to study structure and epithermal fluid flow in the Gosowong gold district, Indonesia.
- Dima Kamenetsky, Jocelyn McPhie and new postdoctoral research fellow Emily Johnson began a project examining the evolution and metal and volatile budgets of rhyolitic magmas in the Taupo Volcanic Zone, New Zealand.

The highly successful collaboration between CODES and JKMRC on the AMIRA P843 GeM^{III} project, led by Steve Walters, has continued to attract major interest from industry, with over 150 participants attending the two major review meetings in 2008. This project finishes in mid-2009 and preparations for an extension project are well advanced. The proposed research programs include a broader scope of geometallurgical research topics and commodities, plus new collaborations, particularly in the areas of hydrometallurgy and environmental geometallurgy.

It was an exceptional year for CODES researchers' involvement in running short courses and workshops for academic and industry geologists. Twenty-two courses, attended by over 900 registrants, were run at various global locations, including Hobart, Vancouver, Johannesburg, Bangkok, Melbourne, Gosowong, Reykjavik, Perth, Brisbane, Golden Grove and Rosebery.

There is no doubt that the sudden downturn in the minerals industry related to the global financial crisis will impact on our operations. However, we believe that through our high-quality research staff, team-based approach, and technology-driven

research initiatives, we are well-placed to provide support to the industry through these difficult times. As orebodies become harder to find, and increasingly difficult to extract, we need to increase our knowledge of the fundamentals of orebody genesis, and find new, smarter, more cost-effective ways to maximise their recovery. Through our five programs, covering fundamental and applied research, we believe that we have the structure and skills in place to continue to provide research results that are both appropriate for the needs of industry and will significantly enhance the base of knowledge in our field of the earth sciences.

Finally, I wish to express my sincere thanks to the ARC, UTAS, collaborating institutions, industry partners, AMIRA International and our staff for your contributions to what has been an exceptional year for CODES on so many fronts.



Ross R Large
Director and Chief Operations Officer

CODES at a Glance 2008

<i>Academic Research Staff</i>	54
<i>Postgraduate Students</i>	97
<i>Major Research Projects</i>	48
<i>Publications in Journals</i>	55
<i>Research Reports to Industry</i>	149
<i>Countries Involved</i>	20
<i>Industry Funding</i>	\$3.6 million
<i>ARC Funding</i>	\$3.2 million
<i>UTAS Funding</i>	\$1.6 million
<i>Collaborating Nodes</i>	
<i>CSIRO E&M, University of Queensland, University of Melbourne, Australian National University, University of British Columbia, Colorado School of Mines</i>	

CODES – Synergy, Teamwork and Collaboration

About Us

CODES is an Australian Research Council Centre of Excellence that is widely regarded as a global leader in ore deposit research. Formed in 1989, the Centre has grown substantially over the years and is now home to 54 highly-qualified research staff and 97 postgraduate students, which makes it the largest university-based team of ore deposit researchers in the world.

Highly productive worldwide collaborations have been developed with approximately 60 industry companies, plus a host of joint research initiatives with 57 institutes and universities – ten in Australia and 47 overseas. It currently has 48 major research projects spanning 20 countries.

Four hundred and sixty-eight research reports have been issued to industry in the past three years, and it is the leading academic group to publish in *Economic Geology*.

Strategic Research Framework

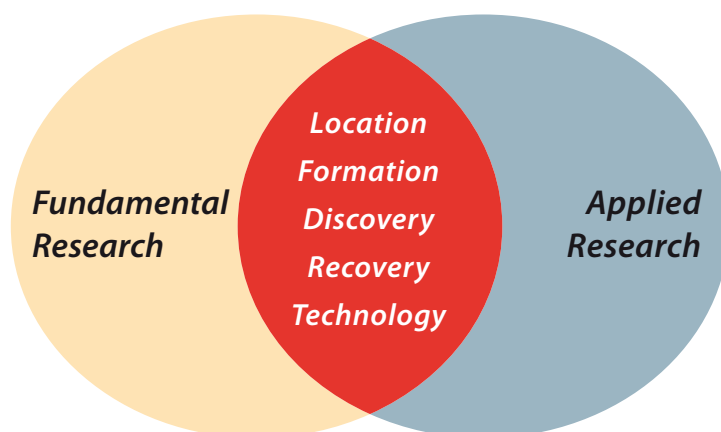
The strategic focus of the Centre is based on a holistic, multidisciplinary approach that covers all elements of ore deposit research, from fundamental research through to applied research outcomes. Its modus operandi is to use advances in fundamental research and the technology programs to drive innovative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

This is achieved through five major research programs – Location, Formation, Discovery, Recovery and Technology, which encompass igneous petrology, geochemistry, melt/fluid inclusion research, volcanology, structural geology, tectonics, geophysics, ore petrology and geometallurgy.

- **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 (ICPMS), nuclear microprobe (NMP), and synchrotron-based non-destructive focused-beam spectroscopy and software development.

These five programs have formed the foundation of CODES' strategy to provide a seamless transition between fundamental and applied research.



Teamwork – A Foundation for Success

The Centre continues to place a great emphasis on teamwork. Cooperation 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.

Structure – Greater Than the Sum of its Parts

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, CSIRO Exploration and Mining, the University of British Columbia (Canada) and the Colorado School of Mines (USA).

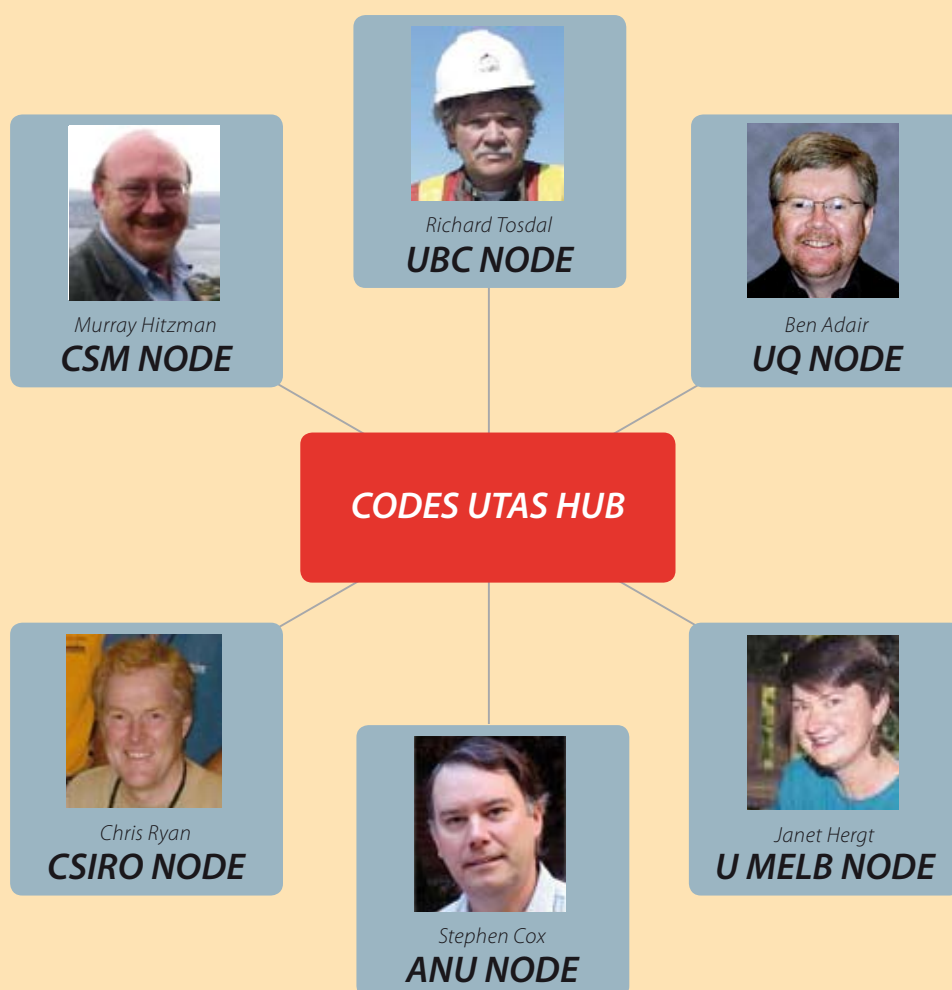
This structure provides an exceptionally strong mix of skills and facilities by combining the research strengths of CODES' UTAS hub, with the diverse range of expertise available through the nodes. The nodes' strengths include:

- 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 Exploration and Mining)

The strengths of these Australian nodes are complemented by the overseas nodes, which provide an ideal platform for international research projects and augment the Centre's access to the latest technology. Our collaborations with the international nodes 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)

Nodes and Node Leaders



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 major industry sponsors, 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 sponsor 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 Appointments in 2008

Dr Mike Baker returned to CODES after spending a year with the Northern Territory Geological Survey in Darwin. He is currently working on the AMIRA P765A project with David Cooke and Bruce Gemmell. Mike completed his PhD at CODES.

Dr Isabelle Chambeft has been recruited to work with Jocelyn McPhie and Vadim Kamenetsky on the Olympic Dam deposit, South Australia. Isabelle has previously held research positions at Oregon State University (USA) and the University of Geneva.

Dr Huayong Chen has joined the Discovery Program, working with Dave Cooke and the P765A team on epithermal porphyry systems. Huayong graduated from Peking University (China) with an MSc, and attained his PhD from Queen's University (Canada).

Dr David Hutchinson has joined the Discovery Program team to work as a research fellow sponsored by Anglo American on platinum-group element and sulfide mineralisation in the



Advisory Board Members.

Northern Limb of the Bushveld Complex, South Africa. David completed his PhD at Cardiff University (UK).

Dr Emily Johnson has joined the Location Program, where her focus is on a melt inclusion-based study of the genesis of rhyolites in the Taupo Volcanic Zone, New Zealand. Emily completed her PhD at the University of Oregon.

Dr Steven Micklethwaite has joined the team to work with Bruce Gemmell on the Gosowong epithermal Au-Ag deposit, Indonesia. Steve completed his PhD at Leeds University (UK) and then worked for five years with Professor Stephen Cox at the Australian National University.

Dr Helen Thomas has joined the Discovery and Technology programs, where she will work with Ross Large and Leonid Danyushevsky, focusing on pyrite geochemistry and texture at Bendigo, Victoria. Helen completed her PhD at the University of Manchester (UK).

Professor Jamie Wilkinson is a Visiting Research Professor from Imperial College, London, who will be working on the P765A porphyry-epithermal project and the development and application of LA-ICPMS, PIXE and transition metal isotope techniques.

Shaun Inglis has been appointed as a research assistant for the Director, Ross Large, and as a member of the P765A AMIRA project. Shaun, who completed an Honours degree in physics at UTAS, specialises in inductively coupled plasma mass spectrometry (ICP-MS) analysis.

Terrie Sawyer has joined CODES as a laboratory assistant. Terrie, who previously worked in marine geochemistry at the Scottish Association for Marine Science, is working with Leonid Danyushevsky and Sarah Gilbert in the running of the solution and laser ablation ICP-MS facility.

Steve Calladine has been appointed Communications Manager. Steve has extensive experience in marketing and communications, including a number of years as a public relations manager for Anglo Platinum.

Nilar Hlaing has been appointed as PA to the Director, Ross Large. Nilar has a broad range of experience in administration and technical positions within UTAS, including CODES.



Right: Jim Mortensen from the UBC node delivering a presentation at the Science Planning Panel meeting.

Jeff Foster, Program 3 Leader, addresses the Science Planning Panel meeting.



Staff and Management

% in CODES		
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		
Dr Sharon Allen, BSc (Massey), MSc (Auckland), PhD (Monash)	Volcanic facies analysis	50
Dr Mike Baker, BSc Hons (Sydney), PhD (UTAS)	Igneous petrology, mineral chemistry	100
Associate Professor Ron Berry, BSc, PhD (Flinders)	Structure of mineralised provinces, CHIME dating, geometallurgy	50
Dr Stuart Bull, BSc Hons, PhD (Monash)	Clastic and carbonate sedimentology and volcanology	75
Dr Isabelle Chambefort, MSc (Clermont-Ferrand), PhD (U Geneva)	Petrology	100
Dr Zhaoshan Chang, BSc (PKU), PhD (PKU, WSU)	Skarn, porphyry and epithermal deposits; LA-ICPMS zircon dating	100
Dr Huayong Chen, BSc, MSc (PKU), PhD (Queen's)	IOCG, porphyry and epithermal deposits	100
Professor David Cooke, BSc Hons (Latrobe), PhD (Monash)	Fluid-rock geochemistry, porphyry Cu-Au	50
Professor Tony Crawford, BSc Hons, PhD (Melbourne)	Petrology, geochemistry and tectonics of volcanic arcs	50
Professor Leonid Danyushevsky, PhD (Vernadsky Inst.)	Petrology, geochemistry, application of melt inclusions	100
Dr Garry Davidson, BSc Hons (ANU), PhD (UTAS)	Sulfur isotope geochemistry and Cu-Au ores	50
Dr Paul Davidson, BSc Hons, PhD (UTAS)	Melt and fluid inclusions	100
Dr Mark Duffett, BSc Hons, PhD (UTAS)	Regional geophysics	75
Dr Trevor Falloon, BSc Hons (Canterbury), BTeaching, PhD (UTAS)	Marine geoscience, petrology	50
Dr Sandrin Feig, MSc, PhD (Hannover)	Petrology	100
Associate Professor Jeff Foster, BSc Hons (City), MSc (Leicester)	Magmatic ore deposits	100
Dr Jacqui Halpin, BSc Hons (Melbourne), PhD (Sydney)	Metamorphic petrology, geochronology	100
Dr Anthony Harris, BSc Hons, PhD (UQ)	Ore deposit geology/geochemistry	100
Dr Julie Hunt, MSc (UBC), PhD (JCU)	Geometallurgy, IOCG deposits	100
Dr David Hutchinson, HND (Camborne, Sch of Mines), BSc Hons, PhD (Cardiff)	Ni-Cu/PGE mineralisation	100
Dr Emily Johnson, BSc (Michigan), PhD (Oregon)	Petrology, physical volcanology	100
Dr Maya Kamenetsky, PhD (UTAS)	MLA-SEM, geometallurgy, petrology	100
Professor Vadim Kamenetsky, BSc Hons (Moscow), PhD (Vernadsky Inst.)	Petrology and geochemistry of melt inclusions	50
Associate Professor Khin Zaw, BSc (Rangoon), MSc (Queen's), PhD (UTAS)	Fluid inclusions, SE Asian metallogensis	100
Dr Lyudmyla Koziy, PhD (UTAS)	Fluid flow modelling	100
Dr Peter McGoldrick, BSc Hons, PhD (Melbourne)	Geochemistry of ore deposits and their halos	50
Dr Andrew McNeill, BSc Hons, PhD (UTAS)	Petrology, VHMS deposit, mineral exploration	100
Professor Jocelyn McPhie, BA Hons (Macquarie), PhD (UNE)	Volcanic facies architecture and volcanic textures	50
Dr Sebastien Meffre, BSc Hons, PhD (Sydney)	Petrology and tectonics of the SW Pacific	100
Dr Steven Micklethwaite, BSc, PhD (Leeds)	Structural geology	100
Dr Karin Orth, BSc Hons (Monash), PhD (UTAS)	Volcanology	50
Dr Anya Reading, BSc Hons (Edinburgh), PhD (Leeds)	Geophysics, seismology, computational methods	50
Dr Michael Roach, BSc Hons (Newcastle), PhD (UTAS)	Geophysical responses of ore deposits	50
Dr Rob Scott, BSc Hons, PhD (Monash)	Structural geology, gold deposits	100
Dr Dave Selley, BSc Hons (Adelaide), PhD (UTAS)	Structural geology/basin analysis, sedimentary Cu	100
Dr Michael Soloman, MSc, PhD (UTAS), DSc (London)	Geochemistry and genesis of mineral deposits	20
Dr Helen Thomas, MSc (Leicester), PhD (Manchester)	Geochemistry, geochronology	100
Professor Steve Walters, BSc Hons, PhD (Sheffield)	Node Leader: geometallurgy, applied mineralogy, exploration technologies	50
Dr Tony Webster, BSc Hons (Latrobe), BA (UNE), MSc (JCU), PhD (UTAS)	MTEC Senior Lecturer and Masters Program Coordinator	50
Professor Jamie Wilkinson, BA Hons (Cambridge), PhD (Southampton)	Geochemistry and isotopes of ore fluids	100
Academic/research staff based at collaborative institutions		
Professor Ben Adair	University of Queensland	19
Dr Stacey Borg	CSIRO Exploration & Mining	35
Professor Deirdre Bradshaw	University of Queensland	50

Professor Alan Bye	WH Bryan Mining Geology Research Centre, University of Queensland	20
Professor Stephen Cox	Node Leader: Australian National University	20
Dr Nenad Djordjevic	University of Queensland	10
Dr Barbara Etschmann	CSIRO Exploration & Mining	100
Dr Peter Fullagar	Fullagar Geophysics Pty Ltd	30
Professor Grant Garven	Johns Hopkins University	10
Dr Angela Halfpenny	Australian National University	100
Associate Professor Jeff Hedenquist	Colorado School of Mines	10
Associate Professor Janet Hergt	Node Leader: University of Melbourne	10
Professor Murray Hitzman	Colorado School of Mines	20
Dr Toni Kojovic	JKTech, University of Queensland	20
Dr Jamie Laird	CSIRO Exploration & Mining	100
Dr Weihua Liu	CSIRO Exploration & Mining	15
Dr Roland Maas	University of Melbourne	15
Dr Simon Michaux	University of Queensland	100
Dr Rob Morrison	University of Queensland	10
Dr Khoi Ke Nguyen	University of Queensland	100
Dr Chad Paton	University of Melbourne	100
Dr Chris Ryan	CSIRO Exploration & Mining	50
Dr Kirstie Simpson	Geoscience BC	50
Miss Esther Soden	University of Queensland	100
Dr Richard Tosdal	University of British Columbia	30
Professor Steve Walters, BSc Hons, PhD (Sheffield)	Node Leader: University of Queensland	50
Dr Yicai Wang	University of Queensland	100
Dr Jon Woodhead	University of Melbourne	15
Technical/administrative staff		
Mr Steve Calladine	Communications Manager	100
Mr Ruben Chan, BComp (UTAS)	Database and Website Manager	100
Mrs Michele Chapple-Smith	Lapidary Technician	40
Mr Peter Cornish	Laboratory Manager	50
Mr Alex Cuisson	Laboratory Technician	80
Ms Grace Cumming	Research Assistant	50
Mr Keith Dobson	IT Support Manager	50
Ms Sarah Gilbert, BSc Hons (UTAS)	Senior Technician ICP-MS	100
Ms Christine Higgins, Grad.Cert.Management (UTAS)	Finance Manager	50
Mrs Nilar Hlaing, BSc (Rangoon)	Personal Assistant to the Director	100
Mr Christopher Hollitt	Senior Technical Officer	100
Mr Shaun Inglis	Research Technician	100
Mr Christopher Lees	Lapidary Technician	30
Dr Roman Leslie, PhD	Research Assistant	20
Mrs Ruth Lowe	Laboratory Technician	50
Mrs Katie McGoldrick	Laboratory Assistant	50
Ms Claire McMahon	Research Assistant	30
Mr Zen Miles	IT Support Assistant	50
Ms Caroline Mordaunt, BA Hons (King's, London)	Administrative Assistant	100
Ms June Pongratz	Publications and Media Resource Centre Manager	50
Mr Philip Robinson, BSc Hons (Nottingham)	Analytical Services Manager	100
Ms Terrie Sawyer	Laboratory Analyst	100
Miss Helen Scott, BSc Hons (UTAS), BEd (QUT)	Finance Officer	75
Ms Dianne Steffens	Finance Officer	100
Mr Simon Stephens, BSc (UTAS)	Lapidary Services Manager	50
Ms Isabella von Lichten, BSc Hons (UTAS)	Curator/MTEC Administrative Officer	50

Staff and Management

Advisory Board	
Chair: John Dow	Consultant
Ben Adair	Director, JKMRC
Tony Brown	Executive Director, Mineral Resources Tasmania
Graham Carr	CSIRO
Stephen Cox	Australian National University
Lynda Daley	Newmont Exploration
Ed Eshuys	Managing Director & CEO, St Barbara Limited
Bruce Gemmell	Deputy Director, CODES
Alan Goode	Research Director, AMIRA International
Janet Hergt	University of Melbourne
John Holliday	General Manager, Property Generation, Newcrest
Ross Large	Director, CODES
John Larson	VP Exploration, Zinifex
Jo Laybourn-Parry	Pro-Vice Chancellor Research, UTAS
Jocelyn McPhie	Coordinator Graduate Research, CODES
Jim Reid	Dean, Faculty of Science, Engineering and Technology, UTAS
Steve Walters	Recovery Program Leader, CODES
Noel White	Consultant
Ian Willis	VP Exploration, Anglo American
Shu Zhan	Chief Geologist, Zeehan Zinc
Executive Committee	
Chair: Ross Large	Director, CODES
Bruce Gemmell	Deputy Director, CODES
Tony Crawford	Location (1) Program Leader
David Cooke	Formation (2) Program Leader
Jeff Foster	Discovery (3) Program Leader
Steve Walters	Recovery (4) Program Leader
Leonid Danyushevsky	Technology (5) Program Leader
Jocelyn McPhie	Coordinator Graduate Research
Christine Higgins	Finance Manager
Nilar Hlaing	Personal Assistant to the Director
June Pongratz	Publications and Media Resource Centre Manager
Steve Calladine	Communications Manager
Science Planning Panel (includes the Executive Committee and all CODES research staff)	
Chair: Ross Large	Director, CODES
Paul Agnew	Rio Tinto
Trevor Beardsmore	Barrick Gold
Rex Brommecker	Barrick Gold
Tony Brown	Mineral Resources Tasmania
Allan Canty	UTAS
Graham Carr	CSIRO
Mike Cawood	Teck Cominco
Stephen Cox	Australian National University
Lynda Daley	Newmont Exploration
John Dow	Consultant
Ed Eshuys	St Barbara Limited
David First	Freeport
Alan Goode	AMIRA International
David Green	Mineral Resources Tasmania
Geoff Green	Mineral Resources Tasmania
Angela Halfpenny	Australian National University
Janet Hergt	University of Melbourne

John Holliday	Newcrest Mining Limited
Jamie Laird	CSIRO
John Larson	Zinifex
Jo Laybourn-Parry	UTAS
Adrian McArthur	St Barbara Limited
Jim Mortensen	University of British Columbia
Chad Paton	University of Melbourne
Chris Ryan	CSIRO
Donna Sewell	AngloGold Ashanti
Stuart Smith	Oxiana Limited
Ned Stolz	Geoscience Australia
Steve Turner	Newmont Exploration
Noel White	Consultant
Ian Willis	Anglo American
Shu Zhan	Zeehan Zinc



Student Projects in Australia

Field- and lab-based projects

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

- 1 **Agangi, Andrea, SA**
Magmatic and volcanic evolution of giant intraplate felsic igneous provinces and associated ore deposits: Gawler Range Volcanics and Hiltaba Suite, South Australia
- 2 **Andrews, Darren, Tas**
Geophysical monitoring of acid mine drainage at Savage River Mine, northwestern Tasmania
- 3 **Belford, Susan, WA**
Genetic and chemical characterisation of the Archaean Jaguar VHMS deposit
- 4 **Bowden, Bryan, SA**
Geology, geochemistry and genesis of the Prominent Hill IOCG Deposit, South Australia
- 5 **Chmielowski, Reia, Tas**
The metamorphic history of Tasmania
- 6 **Cuison, Ana Liza, NSW**
Geology and genesis of the Ridgeway porphyry Au-Cu deposit, NSW
- 7 **Davidson, Mark, Tas (Hons)**
Sedimentology and provenance of the Burnie Formation
- 8 **Evans, Lee, Tas**
Ground waters in wet, temperate sulfide mining districts: delineation of modern fluid flow and predictive modelling to improve management after mine closure (Rosebery, Tasmania)
- 9 **Farran, Michelle, WA (Hons)**
Volcanic, metamorphic and structural architecture of the Prospero-Tapinos nickel sulfide host succession
- 10 **Ferguson, Paul, Macquarie Is (MSc)**
Origin of large negative magnetic anomalies in oceanic crust, Macquarie Island
- 11 **Fox, Nathan, NSW**
Controls on alteration and mineralisation in the Cadia East Au-Cu porphyry copper deposit, NSW, Australia
- 12 **Goh, Hilary, Tas (Hons)**
Properties of rocks in northeastern Tasmania for geothermal exploration
- 13 **Keeney, Luke (JKMRC), NSW**
Integrated geomettallurgical modelling of the Cadia East deposit
- 14 **Kuhn, Stephen, WA (Hons)**
Potential field geophysical interpretation of the Cave Rocks Region, WA
- 15 **Mackay, Wallace, SA**
Sedimentology and structure of the Curdimurka Subgroup, Willouran Range, South Australia
- 16 **Maier, Rodney, NT**
Pyrite and base metal trace-element halos in the northern Australia Zn-Pb-Ag deposits
- 17 **Methorst, Thomas, Tas (Hons)**
Gravity survey of Flinders Island
- 18 **Robson, Lee, Tas**
Application of remote sensing for geological mapping in western Tasmania
- 19 **Zukowski, Wojciech, NSW**
Geology and mineralisation at Lake Cowal district, NSW, Australia

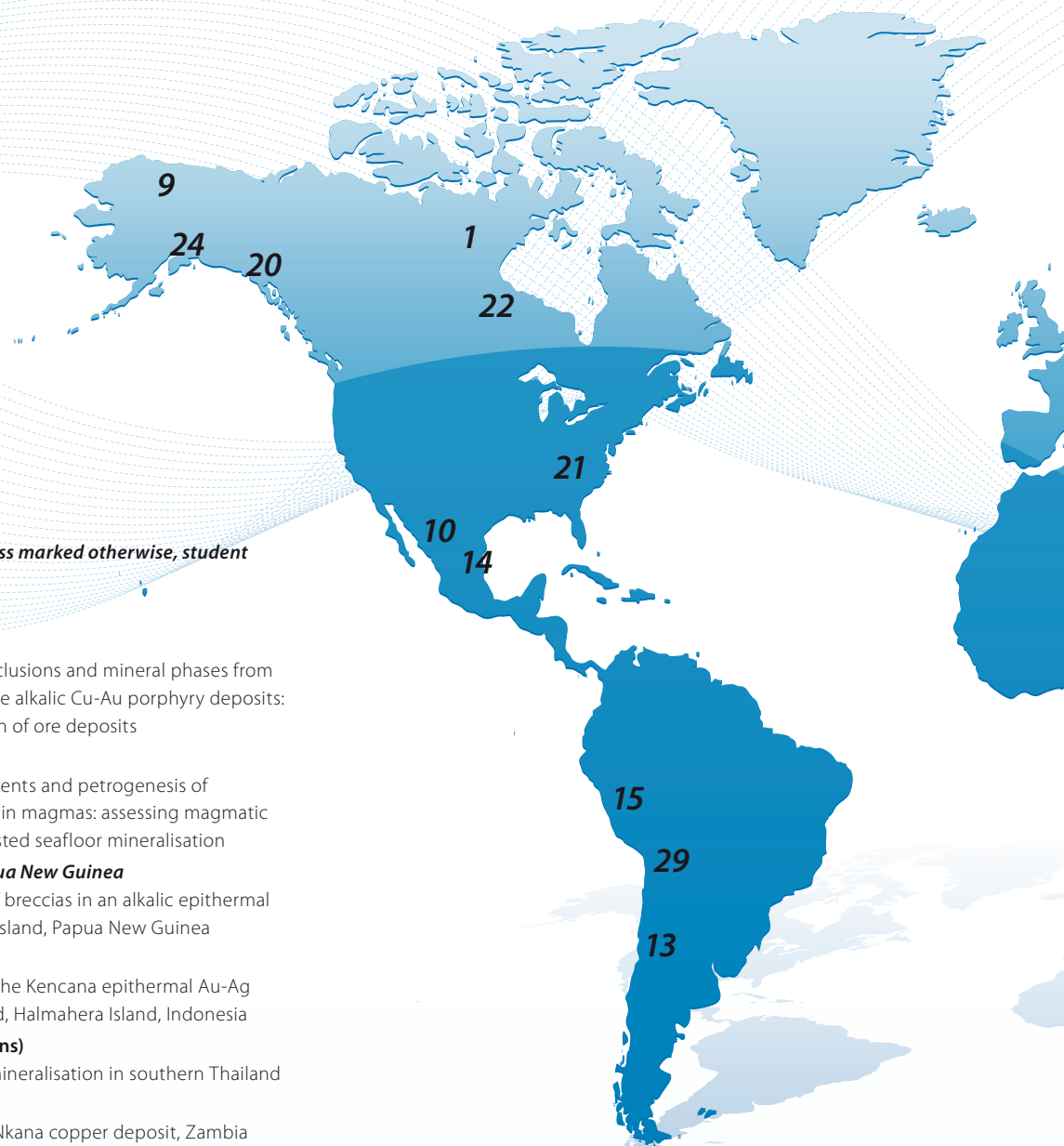
Lab-based only projects

- Bonnici, Natalee**
Textural and mineralogical characterisation of Cu-Au systems in relation to process mineralogy
- Bychkov, Kirill**
Numerical modelling of sulfide precipitation from mafic magmas with implications for the formation of layered intrusions
- Evans, Cathy (JKMRC)**
The relationship between mineral characteristics of ores and the variation in their processing attributes
- Hoschke, Terence (MExpGeo)**
Geophysical signatures of gold-copper porphyry systems
- Leigh, George (JKMRC)**
Multi-resolution image analysis for process mineralogy
- McMahon, Claire**
Controls on the major and trace elements content of pyrite in hydrothermal alteration envelopes
- Parbhakar, Anita**
Predictive environmental mineralogy and geochemical techniques: a new approach to integrated acid rock drainage characterisation
- Schaa, Ralf**
Rapid approximate imaging of electromagnetic data acquired using distributed multichannel data acquisition systems
- Singoyi, Blackwell**
Controls on the geochemistry of magnetite in hydrothermal fluids
- Vasyukova, Olga**
The origin of quartz and fluid inclusions in mineralised porphyries
- Vatandoost Kohneshahri, Adel**
Automated petrophysical characterisation of drill core as a link to mineral processing attributes



10

Student Projects Outside Australia



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

- 1 **Bath, Adam, Canada**
The geochemistry of melt inclusions and mineral phases from the Mount Polley and Lorraine alkalic Cu-Au porphyry deposits: implications for the formation of ore deposits
- 2 **Best, Fiona, Fiji**
Chalcophile and volatile contents and petrogenesis of primitive arc and backarc basin magmas: assessing magmatic contributions to volcanic-hosted seafloor mineralisation
- 3 **Blackwell, Jacqueline, Papua New Guinea**
Characteristics and origins of breccias in an alkalic epithermal gold deposit: Ladolam, Lihir Island, Papua New Guinea
- 4 **Clark, Lindsey, Indonesia**
The geology and genesis of the Kencana epithermal Au-Ag Deposit, Gosowong Goldfield, Halmahera Island, Indonesia
- 5 **Cooper, Traci, Thailand (Hons)**
Origin and features of MVT mineralisation in southern Thailand
- 6 **Croaker, Mawson, Zambia**
Geology and genesis of the Nkana copper deposit, Zambia
- 7 **Cromie, Paul, Laos**
Geological setting, geochemistry and genesis of the Sepon Mineral District, Laos PDR
- 8 **Dinh, Sang Quang, Vietnam**
Geochronology and geological evolution of the northern margin of the Kontum massif, central Vietnam
- 9 **Fulton, Russell, United States**
Geology and geochemistry of the hanging wall argillite, Greens Creek VHMS deposit, Alaska: implications for ore genesis and exploration
- 10 **Galvan, Victor, Mexico**
Palmarejo carbonate base-metals silver-gold epithermal deposit, Trogon Project, Chihuahua, Mexico
- 11 **Geard, Amanda, Thailand (Hons)**
Geology of the Klaeng Region (SE Thailand): lithology, structure and geochronology
- 12 **Gordee, Sarah, Greece, Japan**
Characteristics of submarine volcanic facies in oceanic arc depocentres
- 13 **Ireland, Timothy, Chile**
Geological framework of porphyry and epithermal mineralisation in the Collahuasi District, Tarapac á, Chile
- 14 **Jansen, Nicholas, Mexico**
Geology and geochemistry of the Ixhuatan Lithocap, and its relationships to porphyry and epithermal mineralisation
- 15 **Jones, Benjamin, Peru**
Tectonic setting and magmatic evolution of the Antapaccay porphyry copper-gold and skarn deposit, Peru
- 16 **Jutzeler, Martin, New Zealand, Japan**
Behaviour of submerged eruption plumes using data from facies analysis of a variety of submarine pyroclastic successions
- 17 **Kamvong, Teera, Thailand**
Geology and genesis of porphyry-skarn Cu-Au deposits at the northern Loei Fold Belt, Northeast Thailand and Laos
- 18 **Maloney, Sam, Laos (Hons)**
Mineralisation characteristics of Ang Noi Prospect, Century tenement, Lao PDR



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| <p>19 Manaka, Takayuki, Laos (MExpGeo)
Geological setting and mineralisation characteristics of the Long Chieng Track and Ban Houayxai deposits, Lao PDR</p> <p>20 Micko, Janina (MDRU), Canada
The hydrothermal genesis of the alkalic Cu-Au porphyry deposit Galore Creek, Northwestern British Columbia</p> <p>21 Moye, Robert (Joe), United States
Genesis and chemical and kinematic evolution of the late Proterozoic Ridgeway gold deposit in the Carolina Terrane of the central South Carolina piedmont, USA</p> <p>22 Pass, Heidi, Canada
Chemical and mineralogical zonation patterns in alkalic mineral systems – Implications for ore genesis and mineral exploration</p> <p>23 Pollington, Nicole, Zambia
Sedimentology, mineral paragenesis and geochemistry of the Konkola North copper deposit, Zambia</p> <p>24 Sack, Patrick, United States
Characterisation of the footwall lithologies, Greens Creek VHMS deposit, Admiralty Island, southeast Alaska</p> | <p>25 Salam, Abhisit, Thailand
Geology and genesis of the Chatree Deposits, Phetchabun Province, central Thailand</p> <p>26 Srichan, Weerapan, Thailand
Petrochemistry, geochronology and tectonic implications of Chiang Khong-Lampang-Tak Volcanic Belt, Northern Thailand</p> <p>27 Sutopo, Bronto, Indonesia
The Martabe Au-Ag high-sulphidation epithermal mineralisation in the Tapanuli Selatan District, North Sumatra Province, Indonesia: implications for ore genesis and exploration</p> <p>28 Tetroeva, Sofia, South Pacific
Petrology and geochemistry of adakites and related rocks from the Hunter Ridge, Southwest Pacific</p> <p>29 Urzua, Felipe, Chile
Regional geology of the Escondida district, northern Chile</p> <p>30 Wilkinson, Alice, Thailand (Hons)
Geological setting and mineralisation characteristics of sedimentary rock-hosted Langu Au deposit, Satun district, southern Thailand</p> |
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Program 1

Objective

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

Leader

Tony Crawford

Team Members

Sharon Allen, Alexei Ariskin (Vernadsky Institute), Ron Berry, Stuart Bull, Isabelle Chambefort, Grace Cumming, Leonid Danyushevsky, Paul Davidson, Trevor Falloon, Sandrin Feig, Jeff Foster, Cathryn Gifkins, Carsten Goemann (UTAS Central Science Laboratory), Jacqui Halpin, Maya Kamenetsky, Vadim Kamenetsky, Khin Zaw, Eduard Konnikov (IEM), Emily Johnson, Peter McGoldrick, Andrew McNeill, Jocelyn McPhie, Sebastien Meffre, Anya Reading

PhD Students

Andrea Agangi, Adam Bath, Susan Belford, Fiona Best, Kirill Bychkov, Sang Quang Dinh, Sarah Gordee, Martin Jutzeler, Teera Kamvong, K Kiseeva (ANU), Somboon Khositantont, Rodney Maier, Abhisit Salam, Weerapan Srichan, Sofia Tetroeva, Olga Vasyukova



Tony Crawford, Program Leader

Masters Students

Y Lee, Takayuki Manaka

Honours Students

Traci Cooper, Sam Maloney, Derek Marshall (UWA), Alice Wilkinson

Collaborators

Academia Sinica (Taiwan) – George Zellmer

Anglo American Exploration – Paul Polito

Australian National University – R Arculus, Hugh O'Neill, D McPhail, G Yaxley

BHP Billiton – Kathy Ehrig, Nick Green

Chiang Mai University (Thailand) – W Srichan, P Limtrakun

Colorado State University (USA) – H Stein

CSIRO Melbourne – Chris Ryan

Department of Mineral Resources (Thailand) – Somboon Khositantont, P Chaodumrong

FrogTech (Australia) – Nick Direen

Geological Survey of Denmark and Greenland – T Neilsen

Geological Survey of NSW – Barney Stevens, Dick Glen

Geomarine Research, New Zealand – Bruce Hayward

Geological Survey of Queensland – Ian Withnall

Geoscience Australia – Terry Mernagh

Ghent University (Belgium) – Marlina Elburg



Guangzhou Institute of Geochemistry (China) – Weidong Sun
 Hanoi University of Mining and Geology (Vietnam) – Hai Thanh Tran
 Hebrew University of Jerusalem (Israel) – Oded Navon, Y Weiss
 Indian School of Mines (India) – Deepanker Asthana
 Institute of Experimental Mineralogy (IEM), (Russia) – O Safonov, E Konnikov
 Institute for Frontier Research on Earth Evolution (Japan) – Yoshihiko Tamura
 Institute of Geological and Nuclear Sciences (New Zealand) – K Faure
 Institute of Geology and Mineralogy Novosibirsk (Russia) – A Golovin, V Sharygin, Sergei Smirnov, L Zhitova
 Jabiru Metals Ltd – Neil Martin
 James Cook University – Bob Henderson
 Lakehead University (Canada) – Roger Mitchell
 Max Planck Institute for Geochemistry (Germany) – D Kuzmin, A Gurenko
 Monash University – Reid Keays
 Moscow State University (Russia) – Pavel Plechov
 National Taiwan University – Sun-lin Chung
 Primary Industry and Resources South Australia – Martin Fairclough, Stacey Curtis
 Shizuoka University (Japan) – Kenichi Kano
 Smithsonian Institution (USA) – Richard Fiske
 State Key Laboratory for Ore Deposit Geochemistry, Guiyang (China) – Xieyan Song
 Universiti Kebangsaan Malaysia – W Hassan
 University of California Riverside (USA) – Tim Lyons
 University of Lisbon (Portugal) – Jorge Relvas
 University of Malaya (Malaysia) – A Ghandi
 University of Manitoba (Canada) – A Chakhmouradian

University of Melbourne – Roland Maas, David Phillips, Chad Paton, Jon Woodhead
 University of Oregon (USA) – Cathy Cashman
 University of Oulu (Finland) – Eero Hanski
 University of Queensland – S Golding
 University of Wollongong – Chris Fergusson
 United States Geological Survey – Poul Emsbo
 Vernadsky Institute of Geochemistry (Russia) – Valeria Batanova, Alex Sobolev, Vlad Naumov
 Woods Hole Oceanographic Institution (USA) – Andrei Gurenko

Highlights

- Successful start of the new SE Asia metallogenesis –tectonics project with eight industry sponsors.
- New Pb isotope data support a magmatic-hydrothermal model for the Broken Hill Pb-Zn mineralisation.
- Parental high-Mg adakitic magmas described for first time, from Kadavu (Fiji).
- Evolution and volcanic architecture of the Gawler Range Volcanics documented in two publications.
- BHP Billiton-supported research on Olympic Dam breccias commences.
- Leonid Danyushevsky and Vadim Kamenetsky promoted to full Professor.
- Public release of Petrolog3, a sophisticated, but user-friendly, magmatic modelling program.



Program 1: Location

Outlook

For 2009, the SE Asian project will expand into Yunnan (including a new PhD project), and two new initiatives (linked with Program 3) will commence. One of these focuses on Neoproterozoic magmatism and gold mineralisation in the Dharwar and Bastar cratons in India, the other on the southeast margin of the Yilgarn Craton and the adjacent Fraser Complex of the Albany Fraser Orogen. A third research cruise of the R/V *Southern Surveyor* to the submarine Hunter Ridge arc between Vanuatu and Fiji is scheduled for the middle of the year, and a major project examining the nature and significance of breccias at the giant Olympic Dam Cu-Au-U-REE deposit in South Australia will get underway.

Introduction

The Location Program plays a vital role in enhancing our understanding of the broad-scale processes that form major ore deposits, encompassing a significant proportion of our fundamental research in igneous petrology, geochemistry, volcanology and geochronology. It addresses fundamental questions of why ore deposits occur where they do and what conjunctions of geological and geochemical factors may be responsible for their formation, location, nature, timing and size.

Core projects

Project P1.F1 Geodynamic controls on fertility of fold belts and cratons

Project P1.F2 Modern magmatism in the Southwest Pacific

Project P1.F3 Felsic magmas: volatile and metal budgets during magma evolution – a combined melt inclusion and volcanological approach

Project P1.F4 Ni-PGE potential of mafic and ultramafic magmas – a combined melt inclusion and numerical modelling approach (AMIRA P962)

Project P1.F5 Global ocean chemistry, marine basins and mineralisation

Project P1.F6 ARC Discovery Project and Australian Professorial Fellowship (DP0555984) – Unmixing in magmas: melt and fluid inclusion constraints on identity, timing, and evolution of immiscible fluids, salt and sulfide melts

Project P1.L2 Ore deposits of SE Asia

(F prefix denotes fundamental research project. L prefix denotes industry-linked project.)

Project P1.F1 Geodynamic controls on fertility of fold belts and cratons

Leader: T Crawford

Team Members: S Allen, R Berry, S Bull, J Halpin, V Kamenetsky, R Maas, S Meffre, P McGoldrick, A McNeill, J McPhie, J Woodhead

Student: S Belford

Collaborators: D Asthana, N Direen, P Emsbo, C Fergusson, D Glen, R Henderson, R Keays, S Khositantont, T Lyons, N Martin, D McPhail, P Polito, J Relvas, B Stevens, I Withnall

The aims of this project are to investigate and better understand the conjunction of geological factors that are responsible for the location, timing and scale of ore deposit formation linked directly or indirectly to magmatism. A number of discrete, but thematically overlapping, sub-projects constitute this project, and these are summarised below.

Project P1.F1.1 Palaeoproterozoic mafic magmatism in the Broken Hill Block, and in the Georgetown Block and Mt Isa Eastern Succession in northern Queensland: a role in mineralisation?

A model for the origin of the world-class Broken Hill Zn-Pb deposits suggests that the ore metals and S derive ultimately from advanced synkinematic fractionation of typical 1685Ma rift tholeiites along a major crustal scale extensional shear zone, now defined by the line of lode. In 2008, a comprehensive Pb and Nd isotope analytical program, using both wholerocks and mineral separates, was completed using the MC-ICPMS facility at UMelbourne, in collaboration with Roland Maas and Jon Woodhead. The Nd isotopic data shows that the most evolved, granophyric sections of many of the large tholeiitic metagabbro sills across the Broken Hill Block are either identical to the mafic gabbros ($\sim +4$, and thus derived via closed system fractionation), or have lower initial ϵ_{Nd} values (0–3), indicating significant crustal contamination preceding, or during, sill solidification. Stepwise dissolution of wholerocks and plagioclase separates has shown that the component hosting Pb is indeed plagioclase, and not a labile, interstitial sulfide component. Apart from the contaminated felsic sections of some sills, the Pb isotopic data for the gabbros (both wholerocks and mineral separates) matches the well established values for Broken Hill galenas, and supports the model that Broken Hill ore metals derived from highly evolved, extremely Fe-rich gabbroic rocks.

We hypothesise that the well known Potosi Gneiss, which occurs in close association with both the ores and the major sills along the Broken Hill Line of Lode, may represent the granophyric section of one or more contaminated thick sills that escaped from the sill into adjacent sediments. Typically, strongly Fe-enriched tholeiitic basalt magmas undergo unmixing to produce immiscible very Fe-, Ti- and P-rich, and felsic Al- and alkali-rich melt fractions, and it is possible that such liquid immiscibility was



Susan Belford and Ross Large at work on drill core from the Jaguar VHMS deposit, Western Australia.

involved in the formation of the Potosi Gneiss protolith. Rocks compositionally, texturally and spatially between the gabbros and the Potosi Gneiss (known to the miners and mappers as 'potobolites') may represent the frozen record of the escape of such felsic melt fractions from the thicker sills.

A paper deriving from Mike Baker's 2007 PhD thesis on the geochemistry of the Georgetown Block Palaeoproterozoic mafic rocks, in which these rocks are compared with those in the Broken Hill Block, has been submitted to Precambrian Research.

Project P1.F1.2 Geodynamic evolution and metallogenesis of the Ordovician Macquarie Arc, Lachlan Orogen, New South Wales

Project completed.

Project P1.F1.3 Tectonic and volcanological studies of 'fertile' submarine volcanic successions that host massive sulfide ore deposits

Within this project are a number of independent but thematically linked studies of the volcanology, geochemistry and tectonic setting of volcanic host packages to significant massive sulfide mineralisation. Current study areas include the Cambrian Mt Read Volcanics in western Tasmania, the 2.6 Ga Archaean rocks that host the Teutonic Bore and Jaguar massive sulfide deposits, and the Iberian Pyrite Belt.

Mafic rocks (Sterling Valley Volcanics) previously interpreted to be at or near the base of the Mt Read Volcanics in western Tasmania, and similar basaltic lavas and dolerites forming the nearby Henty Dyke Swarm and Henty Fault Wedge sequences, are the focus of a geochemical program involving Tony Crawford, Andrew McNeill and Cathryn Gifkins. New work suggests that the Sterling Valley Volcanics may be separated from the older Central Volcanic Complex by a hidden fault, and are more likely to be a relatively

late magmatic unit within the Mt Read Volcanics. To better understand the magmatic evolution and tectonic significance of the Mt Read Volcanics, we have collected a suite of felsic rocks from across the stratigraphic and spatial distribution of the Mt Read Volcanics, and we aim to commence a Nd and zircon Hf isotopic study of these rocks (in collaboration with Jon Woodhead and Roland Maas at University of Melbourne) in 2009.

PhD student, Susan Belford, made significant progress in her research on the origin and setting of the Archaean Jaguar VHMS deposit in Western Australia. The project is conducted in collaboration with Neil Martin of Jabiru Metals Ltd. The Jabiru deposit occurs in a thick submarine volcanic succession mainly composed of basaltic and andesitic lavas and shallow intrusions. Susan has successfully subdivided the succession into stratigraphic units using textural and lithofacies characteristics. She has also shown that the footwall and hangingwall lavas differ substantially in their lithogeochemistry, supporting the idea that formation of the ore deposit coincided with a major change in magma sources, and probably also in tectonic setting. This result also suggests that lithogeochemistry could be used to identify and pinpoint the same stratigraphic interval, and potential VHMS deposits, elsewhere in the district.

Carlos Rosa and Jocelyn McPhie continued their research on the volcanic setting of the massive sulfide deposits in the Iberian Pyrite Belt in Portugal and Spain. This project is funded by a grant from the Portuguese Science and Technology Fund and the INETI. A paper on the submarine felsic volcanic succession that hosts the giant Neves Corvo massive sulfide ore deposit was published in *Mineralium Deposita* (Rosa et al. 2008). Results of regional facies analysis are the subject of a manuscript currently in preparation. Carlos presented papers on the volcanic setting of Neves Corvo

Guardiana River outcrops of the volcanic host succession to massive sulfide deposits in the Iberian Pyrite Belt, Portugal (Jocelyn McPhie and Carlos Rosa pictured).



Program 1: Location

at the Society of Economic Geologists Joint Conference (Quebec, May 2008) and on the types of volcanoes in the Iberian Pyrite Belt at the General Assembly of the International Association for Volcanology and Chemistry of the Earth's Interior (IAVCEI) in Iceland (August, 2008).

A publication deriving from Kate Bull's 2007 PhD thesis on the Ural Volcanics in western NSW was published in the *Journal of Volcanology and Geothermal Research* (Bull et al. 2008).

Project P1.F1.4 Geological and tectonic evolution of the Greenvale region, Northern Queensland

The project focuses on the geological evolution of the northern termination of the Tasman Line. It aims to compare the tectono-magmatic development of the area with better known sections of the Tasman Line in western New South Wales, Victoria and Tasmania, and to refine the metallogenetic framework of the region. Detailed geochemical studies and LA ICP-MS dating of the key Early Palaeozoic magmatic units by Tony Crawford has been complemented by regional mapping (including the Anakie Inlier) by Bob Henderson (JCU), Ian Withnall (GS-Qld) and Chris Fergusson (UWoolongong). This work forms the basis of a synthesis, currently in preparation, of the tectonic development of this part of the Tasman Line.

One important magmatic unit in the region is the Dido Tonalite. This large, zoned mafic to felsic Silurian intrusive complex west of Greenvale is the focus of a collaborative project involving Tony Crawford, D McPhail (ANU) and Anglo American (Paul Polito). It will also include two Honours students in 2009.

Project P1.F1.5 Geological evolution of south-east Asian terranes

This project was incorporated into the new SE Asian project (see P1.L2) in 2008.

Project P1.F1.6 The ultimate source of gold in the Palaeozoic turbidite-hosted central Victorian gold deposits

The ultimate source of the 2500 tonnes of gold won from Victorian goldfields, particularly from the most productive regions around Ballarat and Bendigo, has been a controversial theme for many years. One hypothesis for the origin of this gold is that it derives from abnormally gold-rich greenstones in the fold belt basement of this section of the western Lachlan Fold Belt. In collaboration with R Keays (Monash), Tony Crawford has compiled a comprehensive dataset, including many new analyses, of the precious metal contents of modern and ancient boninites and picrites, including the Late Neoproterozoic and Cambrian greenstones from western Victoria. The data demonstrate that such high-Mg lavas in modern settings do indeed have significantly higher Au and platinum group element (PGE) abundances than, for example, typical mid-ocean ridge basalts.

Basement greenstones have either similarly high Au and PGE to their modern counterparts, or are significantly depleted in Au, but not PGE, supporting the notion that Victorian turbidite-hosted Au may be derived from the abnormally high-Mg lava packages assembled in the fold belt basement.

Project P1.F2 Modern magmatism in the Southwest Pacific

Leaders: L Danyushevsky, T Crawford

Team Member: T Falloon

Students: F Best, S Tetroeva

Collaborators: R Arculus, P Plechov, J Woodhead

This project aims at improved understanding of magma generation and evolution processes in the complex region of convergent plate margins in the Southwest Pacific. This tectonic setting is considered to be the likely modern analogue of the geodynamic environments that existed during formation of paleomagmatic sequences in the orogenic volcanic belts along the Eastern Australian Margin, which host numerous types of ore deposits. Understanding the processes, products and key elements involved in the construction of continental crust is fundamental to developing a better interpretation of where and why major ore deposits form, and devising smarter regional exploration philosophies.

The project has four long-term inter-related aims:

- To assess variations in the initial magma volatile and chalcophile element contents among closely spatial and temporally associated arc magmas on the Hunter Ridge, whose geochemical signatures cover a remarkable spectrum from boninite-tholeiite-calc-alkaline to adakite.

This spectrum most likely results from the addition of variable subduction-related components (i.e., various H₂O-rich fluids, sediment melt, basaltic crust melt) to the mantle source of these magmas. Close spatial and temporal association of different magma types on the Hunter Ridge allows for assigning all differences in their volatile and chalcophile budgets to these subduction components, as other factors, such as regional and temporal differences in the composition of the mantle can be eliminated.

- To understand the behaviour of volatile and chalcophile elements during differentiation (basalt-andesite-dacite-rhyolite) of a single geochemical magma type.

Samples collected from a single volcano on the Hunter Ridge record the entire differentiation history of a mantle-derived magma from a high-magnesian picrite to rhyolite. Detailed study of mineralogy and melt/fluid inclusions from this series will allow a better understanding of the degassing history of the magma and its effects on the magmatic metal budget.

- To compare volatile and chalcophile element contents in the initial magmas erupted at backarc basin spreading centres spatially and temporally associated with diverse arc magmatism.

The Hunter Ridge is unique in the sense that both arc and backarc magmas have been erupted contemporaneously within a few kilometres of each other. Our preliminary data indicate that the area is also characterised by a large range of backarc magma chemistry, from a mid-ocean ridge basalt-like magma, to a magma with strong subduction-related signature. The samples available to this project thus allow for comparison of metal budgets between different types of backarc magmas and also between closely associated arc and backarc magmas.

- To evaluate the importance of magma generation conditions above subduction zones for the metal and volatile budget of magmas.

The large amount of primitive, high-magnesian samples recovered from the Hunter Ridge enables assessment of magma generation conditions of all geochemical types sampled. This information can be used to understand the importance of magma generation conditions for the metal and volatile budget of subduction-related magmas.

Highlights for 2008 include:

- The successful application for beam time on the Australian Synchrotron infrared beam line (96 hours of beam time in October 2008). This was the first granted merit-based application by UTAS staff to use any of the beam lines at the Australian Synchrotron.
- The release of Petrolog 3.0, a unique user-friendly software package developed by LVD for modelling processes of magma crystallisation and melt inclusion evolution.

Using the FTIR microscope at the Australian Synchrotron, over 50 melt inclusions in olivine from different types of subduction-related lavas from the study area have been analysed for their H₂O and CO₂ contents. This data is crucial for our understanding of the volatile regime of different magma types in the area.

Also during 2008, working through our existing research plan, research has focused on continued analysis of samples from the SS10/2004 and SS08/2006 Hunter Ridge voyages of R/V *Southern Surveyor*. This work constitutes a significant part of Fiona Best's PhD project, which commenced in May 2008. Samples have been submitted for major, trace and isotope analyses with the results expected to be available early in 2009.

Mineral compositions have been studied in detail in eight samples, representing different magma types within the study area. Over a hundred experiments with melt inclusions in olivine phenocrysts have been performed in 2008 and these are in the process of being analysed for major and trace elements, using the electron microprobe and LA-ICPMS.

Research voyage SS08/2008 has been postponed due to a funding shortfall to the Marine National Facility, and is currently

scheduled for funding in the 2009/2010 financial year, pending the funding announcement by the Australian Government.

Several publications resulting from our previous research in the Tongan arc–Lau backarc region were published (Regelous et al. Falloon et al.). Also, a paper describing the important high-Mg adakitic parental magmas from Kadavu, at the northern end of the Hunter Ridge, was published in *Geology* (Danyushevsky et al.).

Project P1.F3 Felsic magmas: volatile and metal budgets during magma evolution – a combined melt inclusion and volcanological approach

Leaders: V Kamenetsky, J McPhie

Team Members: S Allen, I Chambeftort, E Johnson, M Kamenetsky

Students: A Agangi, S Gordee, M Jutzeler, O Vasyukova

Collaborators: C Goemann, T Mernagh, C Ryan, M Fairclough and S Curtis, K Ehrig and N Green, Y Tamura, A Gurenko, W Sun, K Kano, R Fiske, K Cashman

This project examines the role played by magmatic volatiles in the formation of metal-rich hydrothermal systems in felsic igneous provinces. By combining melt inclusion research and physical volcanology, we can examine the stages, mechanisms and products of degassing events affecting felsic magmas. Two major felsic igneous provinces are being studied (Gawler Range Volcanics, South Australia; Taupo Volcanic Zone, New Zealand), as well as selected felsic porphyries and felsic pyroclastic successions in the circum-Pacific region.

Martin Jutzeler (left) with Richard Fiske from the Smithsonian Institution working at Mount Rainier, Washington State, USA.



Program 1: Location

Volcanological and geochemical research underway on the Mesoproterozoic Gawler Range Volcanics in South Australia is conducted in collaboration with Martin Fairclough and Stacey Curtis of Primary Industries and Energy South Australia. This felsic igneous province covers a large area (~25000 km²) of the Gawler Craton and extends under cover to the east where it hosts the Olympic Dam U-Cu-Au-REE deposit. Two papers (Allen et al. 2008; McPhie et al. 2008) were published in the *Journal of Volcanology and Geothermal Research*, giving an overview of the architecture of the province and new geophysical data (anisotropy of magnetic susceptibility) on the source locations of extremely widespread felsic lavas.

Andrea Agangi's PhD research on the lower Gawler Range Volcanics has produced important results relating to the nature and abundance of magmatic volatiles. Andrea discovered well-preserved, glassy melt inclusions in some quartz-phyric volcanic units, and has measured high fluorine and low water contents in the inclusions. Volatile components play an important role in eruption and emplacement processes: their abundance in the melt reduces viscosity, allowing high discharge rates and effusion as lavas, and their sudden exsolution can increase viscosity to the point where explosive eruptions are inevitable. As well as high-F melt inclusions, fluorine-bearing minerals, such as fluorite, topaz and REE fluorocarbonates are ubiquitous in the groundmass and in micro-miarolitic cavities and vesicles in the rhyolites. This association strongly indicates that fluorine and some trace elements were mobile in late-stage fluids under near-solidus conditions.

A new two-year project examining aspects of the magmatic and hydrothermal events at Olympic Dam, sponsored by BHP Billiton, began in mid-2008. This collaborative project involves Isabelle Chambeftort, Vadim Kamenetsky and Jocelyn McPhie from CODES, and Kathy Ehrig and Nick Green from BHP Billiton.

Aerial view of Olympic Dam, South Australia: a new two-year project examining aspects of magmatic and hydrothermal events.

Isabelle has research experience and training in igneous petrology, hydrothermal alteration and volcanology, and is also skilled in a wide range of analytical techniques. An initial site visit for sampling, drill core logging, and follow-up analytical work has been completed. A second site visit late in the year provided another set of samples, currently being analysed.

Postdoctoral Research Fellow, Emily Johnson, joined CODES in mid-2008, bringing additional expertise in melt inclusion research and igneous petrology to the felsic magmas project. The focus of her efforts is the Taupo Volcanic Zone, New Zealand, one of the largest and most active modern felsic igneous provinces. Emily has sampled a selection of young rhyolitic pyroclastic units and lavas mainly from the Okataina Volcanic Centre. This centre is dominantly rhyolitic, although the most recent eruption (1886) was basaltic, and basaltic magmas have been involved in several other eruptions. There are numerous geothermal areas within, or close to, Okataina that record the presence of hydrothermal systems at depth.

All the rhyolites sampled are quartz-phyric and unaltered, and ideal for melt inclusion and geochemical analyses. These rhyolites are typical of felsic magmas at convergent margins in the circum-Pacific region. We found that the rhyolites are significantly degassed, and thus cannot be used to characterise primary magmatic abundances of volatile and metallic elements. On the other hand, the pristine quartz-hosted melt inclusions, trapped at pressures >3 kb, are significantly enriched in H₂O (7–8 wt %). The aqueous bubbles in melt inclusions, formed during natural cooling or during heating experiments, can be enriched in chloride, and are significant repositories for copper and other metals (e.g. Pb and Zn). Formation of Cu-rich aqueous fluid bubbles in H₂O-rich melts, and loss of bubbles in magma degassing processes, can be linked to the Cu enrichment observed in volcanic gases and magmatic-hydrothermal solutions associated with subduction-related magmas.



Olga Vasyukova's PhD project involves a detailed geochemical and textural study of quartz in a number of circum-Pacific mineralised porphyry intrusions. Quartz phenocrysts in these intrusions provide a surprising amount of information on magmatic and magmatic-hydrothermal processes. Olga has examined the internal structure of quartz using cathodoluminescence images, finding distinct and complex zonation patterns. She has determined the chemical composition of associated inclusions in the quartz, including concentrations of chlorides, metals and silica, their spatial distribution within quartz, and behaviour during thermometric experiments. Olga's results have been presented at three international conferences – the European Geophysical Union General Assembly (Vienna, Austria), Goldschmidt 2008 (Vancouver, Canada) and the PACRIM Congress (Queensland).

We are also interested in achieving a better understanding of explosive outgassing events and the pyroclastic facies they produce, especially in submarine settings. These pyroclastic facies are extremely common on the modern seafloor and in ancient volcanic successions, but are relatively poorly understood because they are difficult to study. Our research involves collaborations with colleagues from Japan (Yoshi Tamura, Institute for Frontier Research on Earth Evolution; Kenichi Kano, Shizuoka University), and the USA (Richard Fiske, Smithsonian Institution; Kathy Cashman, University of Oregon).

Samples from the seafloor south of Japan have provided new data on the physical properties of rhyolitic pumice. These samples have formed by exsolution of magmatic volatiles in a situation where explosive outgassing is suppressed by the high confining pressure. Nevertheless, the pumice vesicularity is identical to that of subaerial pyroclastic pumice, implying that the eruption style is strongly influenced by the vent setting. These results were published in *Earth and Planetary Science Letters* (Allen et al. 2008).

PhD student Sarah Gordee has been studying a well-exposed, texturally diverse, Neogene submarine volcanic succession on the south coast of Izu Peninsula, Japan, with a goal of developing a comprehensive and realistic model for the volcanic facies architecture of submarine arc successions. Her fieldwork is complete and ongoing laboratory-based research involves compilation of graphic logs from the field, textural and componentry studies, thin section petrography and geochemistry. Sarah presented the results of one portion of the study at the General Assembly of the IAVCEI in Iceland (August 2008). She is now focusing on writing her thesis, due for submission in late 2009.

Martin Jutzeler has focused his PhD research on the subaqueous pyroclastic facies deposited by eruption-fed density currents. The pumice clasts in these facies clearly indicate that the explosive eruptions feeding the currents were driven by the exsolution of magmatic volatiles. The challenge is to distinguish whether source vents were subaerial or subaqueous, because the outgassing behaviour contrasts markedly in these two settings. Three well-exposed, young successions have been

chosen for the field-based part of the project: a unit in the Manukau Subgroup (New Zealand), part of the Shirahama Group (Dogashima, Japan), and the Ohanapecosh Formation (Washington, USA). Fieldwork on the sections in New Zealand and Japan was completed in 2007. Martin presented part of his research on the Shirahama Group at the General Assembly of the IAVCEI in Iceland (August, 2008). Martin's fieldwork in the Ohanapecosh Formation was guided by Richard Fiske (Smithsonian Institution) who was the first to recognise the pumice-rich density current deposits in the succession. Preliminary results suggest that both eruption-fed and resedimented pumice-rich density current facies are present, and that they are distinguishable on the basis of componentry and sorting. Further fieldwork in the Ohanapecosh Formation may be required in 2009, depending on the outcome of ongoing data analysis and compilation.

Emily Johnson sampling rhyolitic pumice lapilli fall deposits in the Taupo Volcanic Zone, New Zealand (P1.F3).



Program 1: Location

Project P1.F4 Ni-PGE potential of mafic and ultramafic magmas – a combined melt inclusion and numerical modelling approach (AMIRA P962)

Leader: L Danyushevsky

Team Members: A McNeill, S Feig, T Crawford

Student: K Bychkov

Collaborators: A Ariskin, E Konnikov

The main objectives of this AMIRA/CODES(ARC)-funded project include:

- A better understanding of the potential of various mafic/ultramafic magmas to form magmatic sulfide deposits. Can any mantle-derived magma produce a deposit providing other requirements are met, or are there some magmas that cannot, and how can these be differentiated?
- An improved understanding of the S-saturation histories of mafic magmas and their effect on the ability of magmas to form deposits of economic grade and size.
- A better understanding of the processes during magma evolution that are responsible for the formation of sufficient mass of sulfide to form a deposit, if all other conditions are met. In other words, what processes are required for a Ni-rich magma to form a major sulfide Ni deposit?
- A better understanding of when, and why, sulfides are concentrated during magma evolution.
- Improved criteria for the Ni-PGE fertility of mafic/ultramafic complexes in different tectonic settings.

The project has three modules:

- The study of sulfide micro-inclusions in olivine phenocrysts in about 30 basalt samples from a range of tectonic settings.
- A field and laboratory (bulk rock geochemistry, mineralogy, isotopic, silicate and sulfide micro-inclusion) study of well-preserved, volcanic-intrusive complexes with known Ni-Cu-PGE mineralisation (the Dovgyren complex in eastern Siberia and the Duluth complex in the USA).
- The numerical modelling of magma evolution. An existing software package (COMAGMAT) will be expanded to allow the modelling of fertile mafic complexes that have complex crystallisation histories.

Sponsors' meetings were held in Hobart in April and November, during which the progress of the project was discussed and the future research program was approved. Three presentations describing non-confidential results of the project were made at the Goldschmidt Conference in Vancouver in July.

A field season was carried out in the Duluth magmatic complex in September, in cooperation with the Minnesota Geological Survey. The fieldwork has achieved all approved aims of the project and

samples are now in Hobart undergoing investigation.

Work continued on the samples collected previously from the Dovgyren magmatic complex in Siberia.

PhD student Kirill Bychkov commenced his candidature. His project involves an investigation of the role of S solubility in basaltic magma crystallisation. Kirill worked with collaborators A Ariskin and E Konnikov, who visited CODES for three and two months, respectively, during the year.

Planned work was undertaken in all three modules of the project, which is on track to fulfill its aims.

Project P1.F5 Global ocean chemistry, marine basins and mineralisation

Leaders: P McGoldrick, S Bull

Students: R Maier, D Marshall

Collaborators: P Emsbo, T Lyons

The aims of the project are:

- to decipher processes that controlled the sulfur chemistry and redox state of oceans that existed in northern Australia approximately 1.65 billion years ago, and
- to understand how coeval ocean water interacted with hydrothermal fluids responsible for forming the giant northern Australian Proterozoic sedex Zn-Pb-Ag deposits.

The main outcomes from new work in 2008 were:

- Carbonate-associated sulfur (CAS) sulfur isotope measurements and C/O isotope analyses have been completed for samples from the Paradise Creek Formation and part of the Lady Loretta Formation.
- Peter McGoldrick helped supervise an Honours project carried out by Derek Marshall (UWA), on the Citronen Fjord Sedex Zn deposit in Greenland. A manuscript based on this work is nearing completion.
- Some results from this project, pertaining to the origin of giant geochemical halos associated with Australian Proterozoic Sedex Zn deposits, were presented at the PACRIM Conference in Queensland, in November, as part of an SEG Sedex Zn workshop.
- Body fossils of an early eukaryote (*Grypania spiralis*) have been identified in a sample from the Century deposit. This is the fifth known locality and first Australian occurrence.
- Rod Maier completed a manuscript describing the Bluebush prospect for the 'Ores in Sediments' Special Issue of *Mineralium Deposita*, being co-edited by Peter McGoldrick and Ray Coveney.

**Project P1.F6 ARC Discovery Project
and Australian Professorial Fellowship
(DP0555984) – Unmixing in magmas: melt
and fluid inclusion constraints on identity,
timing, and evolution of immiscible fluids,
salt and sulfide melts**

Leader: V Kamenetsky

Students: A Agangi, A Bath, O Vasyukova, K Kiseeva

Collaborators: A Crawford, J Foster, K Goemann, M Kamenetsky, J McPhie, S Meffre, R Maas, C Paton, D Phillips, G Yaxley, T Mernagh, S-L Chung, A Golovin, V Sharygin, S Smirnov, L Zhitova, V Batanova, V Naumov, A Sobolev, A Gurenko, D Kuzmin, K Faure, M Elburg, WD Sun, O Navon, Y Weiss, A Chakhmouradian, O Safonov, R Mitchell, E Hanski, T Nielsen, G Zellmer

Exsolution of volatile-rich phases (fluids, salt and sulfide melts) from cooling and crystallising silicate magmas is critical for element transport from the Earth's interior into the atmosphere, hydrosphere, crustal hydrothermal systems, and for the formation of magmatic ore deposits. Unmixing is an inherently fugitive phenomenon and melt inclusions provide the most robust evidence of this process. This project applies melt inclusion studies and modern microanalytical techniques to directly address the impact of melt/fluid unmixing on the chemical evolution of some typical magmatic systems.

Research into immiscible melts and fluids entrapped as melt inclusions in kimberlitic olivine was complemented by detailed study of olivine compositional zoning and origins (publication in *Journal of Petrology*). The Udachnaya-East pipe kimberlites contain large amounts of olivine (up to 50 vol.%) in a chloride-carbonate groundmass. Olivine is represented by two populations (olivine-I and groundmass olivine-II) differing in morphology, colour and grain size, and trapped mineral and melt inclusions. The kimberlite melt is argued to have originated in the mantle as a chloride-carbonate liquid, devoid of ultramafic or basaltic aluminosilicate components, but became olivine-laden, and olivine-saturated, by scavenging olivine crystals from the pathway rocks and dissolving them en route to the surface. During emplacement, the kimberlite magma changed progressively towards an original alkali-rich, chloride-carbonate melt by extensively crystallising groundmass olivine and gravitational separation of solids in the pipe.

An important example of natural immiscible silicate and non-silicate melts is represented by melt inclusions in Cr-diopside from the gemstones deposit of the alkaline ultramafic Inagli massif in Yakutia, Russia (publication in *Geochemistry*

International). Primary polyphase inclusions in Cr-diopside are dominated by crystal phases, and contain an aqueous phase and a gas phase. Daughter minerals are represented by silicates (e.g. potassium feldspar, pectolite $[\text{NaCa}_2\text{Si}_3\text{O}_8(\text{OH})]$, and phlogopite) and abundant sulfates: glaserite (aphthitalite) $[\text{K}_3\text{Na}(\text{SO}_4)_2]$, glauberite $[\text{Na}_2\text{Ca}(\text{SO}_4)_2]$, aluminum sulfate, anhydrite (CaSO_4), gypsum ($\text{CaSO}_4 \times 2\text{H}_2\text{O}$), barite (BaSO_4), bloedite $[\text{Na}_2\text{Mg}(\text{SO}_4)_2 \times 4\text{H}_2\text{O}]$, thenardite (NaSO_4), polyhalite $[\text{K}_2\text{Ca}_2\text{Mg}(\text{SO}_4)(4 \times 2\text{H}_2\text{O})]$, arcanite (K_2SO_4), and celestite (SrSO_4). Chlorides are also present, as shown by elevated Cl content in crystalline aggregates (up to 10.3 wt%). The parental silicate melt contained a salt component of dominantly sulfate composition. Salt globules immiscibly separated as an emulsion in the denser silicate melt, from which the Cr-diopside crystallised.

Immiscible carbonate-chloride globules in a melt inclusion in nepheline from active natrocarbonatite Oldoinyo Lengai volcano, Tanzania.



Program 1: Location

Project P1.L2 Ore deposits of SE Asia

Leaders: Khin Zaw, S Meffre

Team Members: J Halpin, G Cumming, T Crawford, R Large

Students: T Kamvong, A Salam, S Quang Ding, T Manaka, Y Lee

Collaborators: S Khositanont, P Chaodumrong, P Limtrakun, W Srichan, A Ghandi, W Hassan, Hai Thanh Tran, S Golding, H Stein

'Ore deposits of SE Asia' commenced in January 2008. This project builds on the successful, three-year Loei ARC Linkage Project 'Geochronology, metallogensis and deposit styles of Loei Fold Belt (LFB) in Thailand and Laos PDR'. This project extends the methods and techniques developed in the previous project to encompass the other mineralised fold belts and suture zones of mainland SE Asia. The primary aims are to study:

- The timing of formation of Cu, Au, Pb and Zn deposits relative to magmatic and tectonic events in mainland SE Asia.
- The style, metal and hydrothermal fluids sources for the deposits in the region.

The project team conducted detailed investigations into the following fold belts and suture zones, and their related ore deposits in SE Asia:

- Northern and southern extensions of the Loei Fold Belt in Laos and Cambodia.
- Truongson Fold Belt in Laos and Vietnam.
- Sukothai and Chiang Mai fold belts in Thailand, Yunnan and east Malaysia.
- Kontum Massif and Phuoc Son-Tamky Suture region of central Vietnam.

The following fieldwork was completed:

- A detailed field program (including core logging and reconnaissance sampling), from 9 February to 1 March, in western and northern Thailand, covering the Chiang Mai Fold Belt and Nan Suture zone.
- Regional sampling, fieldwork and supervision of an Honours student at the Ang Noi Au deposit, Laos PDR, in February to March.
- Regional field sampling and supervision of a Masters study at the Bong Mieu Au deposit, central Vietnam, from March to early April.
- Regional field sampling in Cambodia from late April to early May.
- Regional sampling and fieldwork in eastern Thailand, and supervision of two Honours students for their theses on geotectonic development of the eastern part of the Shan-Thai Terrane and mineralisation characteristics of Langu sedimentary rock-hosted Au deposit, southern Thailand, from 8 September to 30 September.

Analytical and geochronological work in the Central Highlands, Vietnam (Kontum Massif northern margin – Tamky Suture zone), which constitutes Sang's PhD.

Altogether, 102 LA ICP-MS U-Pb zircon ages were completed. Most of the dated rocks were compiled into the geochronological and geochemical atlas. Approximately 20 Pb-Pb isotopic determinations were completed on galena and granites from Thailand and Laos. Sixty sulfur isotopes were determined on sulfides from five deposits, and 80 fluid inclusions from three deposits were measured.

The project has provided comprehensive spatial and temporal relations of magmatic, volcanic and hydrothermal events, and improved conceptual and genetic models for the formation of copper-gold, lead-zinc and other mineral resources in mainland SE Asia. Deposit-scale studies were completed to characterise the orogenic/mesothermal Au-W-Zn-Pb deposits at Bong Mieu, sedimentary shale-hosted Phuoc Son Au deposits in Vietnam, and an orogenic/mesothermal Au deposit at Penjom in Malaysia.

In addition, three student projects associated with this project have been completed in 2008:

Takayuki Manaka (CODES MSc) on LCT and BHX gold deposits, Laos.

Somboon Khositanont (UChiang Mai PhD) on gold and iron mineralisation in the Sukothai and Loei-Phetchabun fold belts.

Sam Maloney (CODES Hons) on the intrusive-related Ang Noi Au deposit, Laos PDR.

***Opposite:** Jacqueline Halpin (CODES postdoctoral Research Fellow), Takayuki Manaka (CODES PhD student) and Khin Zaw (CODES) take a closer look at xenoliths within granite north of Danang, central Vietnam.*



Program 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

Leader

David Cooke

Team Members

Ron Berry, Thomas Bissig (MDRU), Stuart Bull, Zhaoshan Chang, Huayong Chen, Stephen Cox (ANU), Tony Crawford, Leonid Danyushevsky, Garry Davidson, Greg Dipple (MDRU), Bruce Gemmell, Sarah Gilbert, Angela Halfpenny (ANU), Jacqui Halpin, Anthony Harris, Janet Hergt (UMelb), Chris Hollitt, Julie Hunt, Vadim Kamenetsky, Khin Zaw, Lyudmyla Koziy, Ross Large, Peter McGoldrick, Jocelyn McPhie, Sebastien Meffre, Karin Orth, Chris Ryan (CSIRO), Rob Scott, David Selley, Kirstie Simpson, Mike Solomon, Dick Tosdal (MDRU), Clara Wilkinson, Jamie Wilkinson, Noel White (UMelb), Jon Woodhead (UMelb)

PhD Students

Adam Bath, Sue Belford, Jacqueline Blackwell, Bryan Bowden, Zahra Bonyadi (Tarbiat Moalem University, Iran), Ana Liza Cuisson, Paul Ferguson, Nathan Fox, Russell Fulton, Ben Jones, Claire McMahon, Janina Micko (MDRU), Fardin Mousivand (Tarbiat Modares University, Iran), Heidi Pass, Patrick Sack, Blackwell Singoyi, Felipe Urzua, Victoria Vry (Imperial College, London), Lejun Zhang (Hefei University) Wojciech Zukowski

Masters Students

Kevin Byrne (MDRU), Amber Henry (MDRU), Meghan Jackson

(MDRU), Paul Jago (MDRU), Yansan Jamyambaatar, Neil Macalalad, Malissa Washburn (MDRU)

Collaborators

Adelaide University – John Foden

Anglo American Philippines – David Braxton, Paddy Waters

ANU – Charlotte Allen, Ian Campbell, G Fraser

Barrick Gold of Australia Pty Ltd (Porgera Operations)

Chinese Academy of Geological Sciences – Zhiming Yang, Zengqian Hou, Shihong Tian

Colorado School of Mines – Murray Hitzman

Consultants, Portugal – Orlando C Gaspar, Alfredo Ferreira

CSA Australia Pty Ltd – Mal Wilson

CSIRO – John Walshe

Geoscience Australia – Terry Mernagh, Roger Skirrow

Geological Survey of Canada – Jan Peter

Hefei University (China) – Taofa Zhou, Feng Yuan, Yu Fan

IFM-GEOMAR (Germany) – Sven Petersen

IGM (Portugal) – Carlos Inverno

IGNS (New Zealand) – Kevin Faure

Laurentian University (Canada) – Steve Piercey

Nanjing University (China) – Lianxing Gu

Newcrest Mining Ltd – Dean Collett, John Holliday, Colin McMillan, Geoff Smart, Ian Tedder



Northparkes Mines

NTGS – M Ahmad

OZ Minerals – Stuart Smith, P Williams

PIRSA – Paul Heithersay

Primary Industries NSW – Ian Percival

Queen's University (Canada) – Dan Layton-Matthews

Russian Academy of Science – Svetlana Maslennikova, Valery Maslennikov

Simon Fraser University (Canada) – Derek Thorkelson

Somincor (Portugal) – Nelson Pacheco

Tarbiat Moalem University (Iran) – B Mehrabi

Teck – Andrew Davies

Tufts University (USA) – Grant Garven

University of British Columbia (Canada) – Jim Mortensen

United States Geological Survey – Poul Emsbo

University of Huelva (Spain) – Manuel Toscano, Reinaldo Saéz

University of Alberta (Canada) – Robert Creaser

University of Malaya (Malaysia) – Azman Ghandi, Teh Guan Hoe

University of Ottawa (Canada) – Mark Hannington, Thomas Monecke

University of Science and Technology, Beijing – Yuling Xie

Highlights

- New hydrological models for the African Copperbelt highlight the importance of repeated cycles of fluid overpressuring and seal breaching by residual bittern brines to promote copper mineralisation (P2.F2).
- Magmatic volatile input from a degassing magma chamber demonstrated for the Palinuro submarine hydrothermal system, Tyrrhenian Sea, Italy (P2.F3).
- Completion of a major field campaign at the Coronation Hill Au-PGE deposit, Northern Territory (P2.F4).
- Drilling success in the Cadia district related to CODES–Newcrest Mining Ltd research collaboration (P2.L1).
- Successful completion of the alkalic project, with final sponsors' field meetings held in Williams Lake (British Columbia) and Orange (NSW) (P2.L3).
- Breakthrough in understanding the importance of seawater sulfur in the genesis of sediment-hosted gold-arsenic deposits (P2.L4).
- Five publications stemming from research into Fe-Cu-Au mineralisation in the Luzong basin, China (P2.N3).



David Cooke, Program Leader



Program 2: Formation

Outlook

It is planned to expand Program 2 activities into sediment-hosted uranium resources in 2009. The development of process-based genetic models requires detailed and integrated evaluation of the structural, sedimentary, volcanic, hydrothermal and magmatic processes fundamental to high-grade ore formation in these diverse geological environments. This research is being enhanced by collaborations between CODES staff and world-renowned researchers at the UBC, University of Ottawa, Imperial, GSC and the United States Geological Survey, and several other groups.

Significant project milestones scheduled to be achieved in the coming year include: (1) complete our structural analysis of the Porgera gold deposit; (2) publish our results of hydrological modelling for sediment-hosted Cu deposits; (3) initiate a new student-focused project on the genesis of a Cloncurry IOCG deposit; (4) complete the Cadia Valley project; and (5) prepare a special issue for *Economic Geology* from the results of the alkalic project.

Introduction

Success in exploration for ore deposits in fertile provinces depends on accurate and practical scientific models of ore formation. Such models are used by mining companies to decide where to explore and what methods to use. Hence, research focusing on the formation of ore deposits (Program 2) provides a further predictive dimension that is critical in mineral exploration – because it is only with a thorough understanding of the formation process that techniques can be developed to enhance the discovery levels of new orebodies.

CODES has earned an international reputation for research into the formation of copper, gold, zinc, lead and silver deposits that form in sedimentary basins, volcanic arcs and fold belts. Our research has led to significant breakthroughs with regard to understanding controls on metal transport and depositional processes, and provides a basis for improving exploration success for deep-earth resources. Our research efforts are primarily directed to porphyry copper-gold and related epithermal systems, magmatic nickel-PGE, sediment-hosted gold and base metal deposits, polymetallic VHMS systems, and IOCG deposits.

Reflected light photomicrograph of colloform banded, arsenic-rich marcasite rimming framboidal pyrite in a late-ore-stage sulfide vein, Gold Quarry mine, Carlin Trend, Nevada (Project P2.L2).

Core projects

Project P2.F1 Porphyry copper-gold-(molybdenum) deposits

Project P2.F2 Base metal and gold mineralisation in sedimentary basins

Project P2.F3 Volcanic-hosted massive sulfide deposits

Project P2.F4 Iron oxide copper-gold and related deposits

Project P2.L1 District to deposit scale structural and geochemical evolution of the Cadia porphyry Au-Cu deposits, NSW

Project P2.L2 Controls on the Formation and Sulfide Trace Element Signatures of Sediment-Hosted Gold Deposits (AMIRA P923)

Project P2.L3 Shallow and deep-level alkalic mineral deposits

Project P2.L4 Genesis of the giant Sukhoi Log gold deposit, Siberia

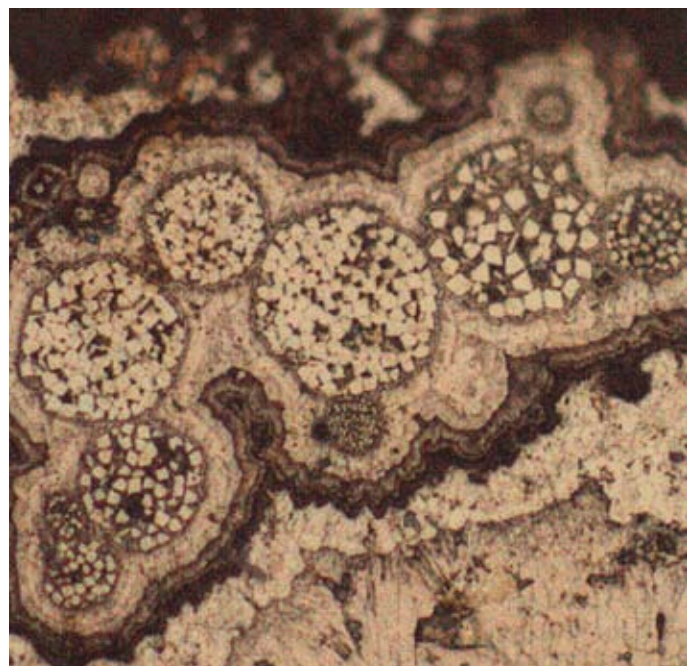
Project P2.N2 Zn and Au mineralisation in the Caijiaying deposit: geologic characteristics and genesis

Project P2.N3 Polymetallic mineralisation and associated magmatic and volcanic activity in the Luzong basin, middle and lower Yangtze River, eastern China

Project P2.N4 Breccia textures

Project P2.N5 T-P-X evolution of carbonatite melt-fluids and REE ore-forming processes in the Mianning-Dechang REE metallogenic belt

(F prefix denotes fundamental research project. L prefix denotes industry-linked project. N prefix denotes new initiative project.)





Anthony Harris talks to industry and academic geologists during a field trip to an outcrop of the Goonumbla Volcanics adjacent to the Northparkes Mines porphyry Cu-Au mine in NSW (P2.F1).

Project P2.F1 Porphyry copper-gold-(molybdenum) deposits

Leaders: Stephen Cox, David Cooke

Team Members: Angela Halfpenny, Zhaoshan Chang, Tony Crawford, Anthony Harris, Vadim Kamenetsky, Ross Large, Noel White, Jamie Wilkinson, Clara Wilkinson

Students: Yansan Jamyambaatar, Ben Jones, Neil Macalalad, Felipe Urzua, Victoria Vry

Collaborators: Barrick Gold of Australia Pty Ltd (Porgera Operations), Paddy Waters, David Braxton, Northparkes Mines, Ian Campbell, Charlotte Allen

This project encompasses two sub-projects: 1 – Fracture arrays in intrusion-related systems – controls on the dynamics of fluid flow, vein formation and the generation of giant deposits; 2 – Characterisation of porphyry deposits and their environments.

Sub-project 1 aims to document geometries and styles of vein systems and their overprinting relationships around several different styles of mineralised intrusion complexes. Within the framework of our developing understanding of the dynamics of stress and fluid pressure regimes in contemporary magmatic systems, we are exploring how stress states, stress field orientations and fluid pressures evolve during the development of intrusion-related hydrothermal systems. These results are helping to improve our understanding of the evolution of fracture-controlled hydrothermal fluid pathways and reactions, and allowing the impacts on the distribution of economic mineralisation in intrusion-related hydrothermal systems to be determined.

Project postdoctoral fellow Angela Halfpenny arrived at ANU early in 2008. Initial fieldwork involved structural, microstructural and alteration studies to analyse the progressive evolution of stress and fluid pressure states associated with the development of vein systems and faults associated at the Porgera gold deposit, Papua New Guinea (PNG). Porgera has two major gold-bearing vein stages, together with three other paragenetic stages, which are not known to host economic mineralisation.

The development of the richest vein-hosted gold (Stage 2) is associated with the growth of several low-displacement faults, which exhibit a complex kinematic evolution involving both dextral and normal slip histories during mineralisation. Stage 1 mineralisation comprises distributed veins that are not related to faulting. The transition from Stage 1 to Stage 2 is contemporaneous with the development of several faults (including the Roamane Fault) that appear to have grown across the active hydrothermal system and provided a short-circuit fluid pathway between a deep magmatic fluid reservoir and shallow crustal levels. Ongoing work is focusing on defining the architecture of major ore-producing fluid pathways and exploring the implications of dynamic competition between permeability creation and destruction processes; and consequent episodic flow regimes for ore genesis. Stephen Cox conducted a three-day structural geology training workshop at Porgera for experienced site geologists, junior geologists, and students from the University of Papua New Guinea (UPNG) students. A similar program will be undertaken at Porgera in 2009, supported by a teaching visit to UPNG to assist in training of PNG national geoscientists.

Sub-project 2: Felipe Urzua submitted his PhD thesis on the regional geology of the Escondida porphyry Cu-Mo district, Chile. Anthony Harris and colleagues published a paper demonstrating a three-million-year history of ore-forming and alteration events at Bajo de la Alumbrera, Chile. In late 2008, Jamie and Clara Wilkinson joined CODES and commenced work on detailed microanalyses of fluid inclusions from several porphyry deposits. Vicky Vry, a PhD student from Imperial College, London, spent three months at UTAS collaborating on her PhD research into El Teniente, Chile. Ben Jones continued to work towards completion of his PhD study of the Antapaccay porphyry copper-gold deposit, Peru. Yansan Jamyambaatar made significant progress towards the completion of his MEconGeol study of the E48 porphyry Cu-Au deposit in NSW, and a new MEconGeol student (Neil Macalalad) will be undertaking research into the Aisaijue porphyry copper-gold discovery in western Papua. Several CODES staff presented porphyry-related research results at the PACRIM 2008 conference.

Program 2: Formation

Project P2.F2 Base metal and gold mineralisation in sedimentary basins

Leader: S Bull

Team Members: D Cooke, L Koziy, R Large, P McGoldrick, D Selley, J Wilkinson

Collaborators: P Emsbo, G Garven, M Hitzman

This project investigates the nature of fluid flow in the formation of sedimentary ore deposits, with particular emphasis on the role of evaporates and associated brines. Districts studied include the Central African Copperbelt, the Kufershiefer District in Europe, the northern Australian Zinc Belt and modern analogues such as the Red Sea hydrothermal systems. The project is attempting to resolve whether ore-forming brines in sediment-hosted base-metal systems have a common heritage, and why we see such remarkably diverse alteration styles and metal associations. It is also endeavouring to determine whether residual brines or evaporite dissolution brines are involved in ore formation, and whether the different observed metal tenors in different provinces are a function of brine evolution, basin fill composition, varied depositional processes or some combination thereof. Another important question under consideration is whether there have been important stages of brine evolution that control the development of fertile versus infertile basin systems.

Investigations of the Red Sea hydrothermal systems were not continued in 2008 because of the departure of postdoctoral fellow Christian Schardt and Grant Garven's move to Tufts University. Instead, our research efforts were refocused onto the Central African Copperbelt, in collaboration with Project P3.L3.

The outcomes of a Cl-Br study of fluid inclusions from the Central African copper ores by Poul Emsbo has fundamentally changed our understanding of the origin of saline mineralising fluids in this system. Measured solute ratios clearly indicate that the basinal fluids were dominated by residual bittern brines, and there is no evidence of the widespread evaporite dissolution that was originally envisaged. As a result of this new insight, we supplemented our original numerical modelling for the Copperbelt with three new models that better characterise hydrological processes operating in this complex and long-lived ore forming system. These models have been applied to the extended Katangan section, which incorporates a thick peripheral basin. We also attempted to reconcile our modelling results with the current interpretation of stratiform copper mineralisation in the White Pine ore district, which advocates single pass dewatering of the basal aquifer sandstones. Our simulations, on the contrary, showed that density effects dominate fluid flow, impeding focused discharge from red bed packages. The presence of dense brine also seems to be an effective mechanism driving the basinal fluids into the metamorphic basement, thereby suggesting an alternative source of base metals.

Overall, our simulations show that once the salt seal in a basin is breached, potential metal-enriched fluid originating below the salt sheet is expelled into the upper stratigraphy for a relatively short period of time (approximately one million years). The mechanism that drives this expulsion appears to be fluid overpressure after sealing by evaporites. Crude estimates of the potential transfer of metal arising from this event, to an ore-position located above the breach, are far below ore grade values of copper. This suggests that repeated episodes of breaching and sealing may be necessary to produce an economic stratiform copper deposit.

Project P2.F3 Volcanic-hosted massive sulfide deposits

Leaders: B Gemmell, M Solomon

Team Members: R Large, Khin Zaw, G Davidson, L Danyushevsky, C Ryan

Students: R Fulton, P Sack, S Belford, P Ferguson, F Mousivand

Collaborators: A Ferreira, J Foden, O Gaspar, A Ghandi, Teh Guan Hoe, L Gu, M Hannington, Z Hou, C Inverno, D Layton-Matthews, S Maslennikova, V Maslennikov, T Mernagh, T Monecke, J Mortensen, N Pacheco, J Peter, S Petersen, S Piercey, R Saéz, M Toscano, J Walshe

This project encompasses four sub-projects: 1 – The nature and origin of fluids that form high-salinity, volcanic-hosted massive sulfide deposits; 2 – The nature, diversity and genesis of volcanic-hosted, Cu-Pb-Zn-Ag-Au, massive sulfide deposits; 3 – Hydrothermal event recognition and target vectoring in sedimentary strata for volcanic-hosted and sedex massive sulfide deposits; 4 – Active base and precious metal-rich massive sulfide-sulfate deposition associated with submarine volcanism.

Sub-project 1, led by Mike Solomon, investigates the genesis of the Lombador orebody, Neves Corvo, through comparisons with Sn granite systems. Additional sulphur isotopic data from Lombador have confirmed the narrow, mantle-like range of values. Similarly, new Nd and C isotope data for Sn granites at Renison and Ardlethan have confirmed mantle involvement in the generation of Sn granite magmas. Comparisons are currently being made between the base metal compositions of Sn-granite fluids and those of the Neves Corvo orebodies to further test genetic associations.

Sub-project 2 investigates the complete spectrum of massive sulfide deposit types. In 2008, we developed a three-fold tectonic classification for VHMS deposits: rifted arc (Hokuroku), arc-continent-collision (Mount Read), and continent-continent collision (IPB and BMC). Work has also continued on improving geochronological constraints on the Mount Read Volcanic Belt (MRV), in collaboration with Jim Mortensen (UBC), with an additional 23 samples collected during 2008. Deposit-specific research was undertaken at Jaguar (Western Australia), Greens Creek (Alaska), Yaman-Kasy (Russia), Baiyinchang (China), Tasik Chini (Malaysia) and Chahgaz (Iran).

Sub-project 3, led by Steve Piercey (Laurentian University), investigates the sulfide-bearing, carbonaceous (graphitic), argillaceous sedimentary rock horizons that are a minor, but ubiquitous, feature of marine volcanic successions in ancient greenstone belts and modern seafloor environments. It will provide an improved understanding of trace metals associated with volcanic-hydrothermal processes in marine sedimentary and volcano-sedimentary successions, and will develop new tools (mineralogical, geochemical, isotopic) to discriminate potentially mineralised versus unmineralised horizons. This Canadian Mining Industry Research Organization (CAMIRO) – Exploration Division project is funded to commence, but is still seeking additional industry support. The research team includes Bruce Gemmell, Mark Hannington, Wayne Goodfellow, Jan Peter and Dan Layton-Matthews.

In **sub-project 4**, Bruce Gemmell and Robina Sharpe have analysed the mineral chemistry and sulfur isotope characteristics of pyrite from seafloor massive sulfide mineralisation at Palinuro Seamount in the Tyrrhenian Sea, Italy. The massive sulfide body contains a number of unusual minerals, including enargite-famatinite, tennantite-tetrahedrite, stibnite, bismuthinite, and Ag-sulfosalts, which are not commonly encountered in mid-ocean ridge massive sulfides. By analogy with terrestrial epithermal deposits, the



occurrence of these minerals and the abundance of native sulfur suggest an intermediate to high sulfidation state for the hydrothermal fluids. This implies that the mineralising fluids were acidic and oxidised, rather than the near-neutral pH reduced fluids that typically form base metal-rich massive sulfides along mid-ocean ridges. Oxidised conditions during sulfide deposition are most likely related to magmatic volatiles derived from a degassing magma chamber below the Palinuro volcanic complex.

Project P2.F4 Iron oxide copper-gold and related deposits

Leader: G Davidson

Team Members: R Berry, H Chen, A Harris, J Hunt, R Large, S Meffre, K Orth, Khin Zaw

Students: S Blackwell, B Bowden, C McMahon, Z Bonyadi

Collaborators: M Ahmad, G Fraser, P Hiethersay, B Mehrabi, R Skirrow, S Smith, D Thorkelson, P Williams

The aim of the IOCG research project is to improve the understanding of the origin of this puzzling ore deposit type and related systems. The past year has seen an increase in IOCG-related research activities at CODES, due in part to new appointments and collaborations. We are currently undertaking IOCG-related research at Prominent Hill (Gawler Craton; PhD student B Bowden), Wernecke Breccias (Alaska; follow-up of PhD studies by J Hunt), Chilean and Peruvian Iron Belts (H Chen; follow-up of PhD studies), Nico (Great Bear Magmatic Province; PhD research of C McMahon), Tennant Creek (PhD research of S Blackwell), and the Sechalun magnetite-apatite deposit (Iran; PhD student Z Bonyadi, and B Mehrabi, in collaboration with G Davidson and S Meffre).

A larger project, funded by a 1–2-year Linkage project (Davidson, partnered with NTGS), is being undertaken on a related ore deposit type at Coronation Hill, with Karin Orth as the key researcher (fractional appointment). This site is considered to be a PGE-Au-rich variant of unconformity-style U mineralisation. Our project aims to establish the source of different ore components using stable and radiogenic isotope tracers, and also to determine the age of the mineralisation relative to the main Northern Territory (NT) uranium event in the East Alligator River region. A critical aspect is to understand why Coronation Hill is so PGE-rich compared to other examples in the NT. This is intended to assist exploration for similar orebodies in the future. An orebody model was provided by the NTGS, which was reviewed together with a large number of openfile reports, prior to the completion of a major field campaign. The laboratory work will be undertaken in 2009.

Bedded pyrite and sphalerite from Rosebery, Tasmania.

Program 2: Formation

Project P2.L1 District- to deposit-scale structural and geochemical evolution of the Cadia porphyry Au-Cu deposits, NSW

Leaders: A Harris, D Cooke

Team Members: R Berry, J McPhie

Students: A L Cuison, N Fox, M Washburn

Collaborators: C Allen, I Campbell, D Collett, R Creaser, K Faure, J Holliday, C McMillian, Ian Percival, G Smart, I Tedder, R Tosdal

CODES and industry partner Newcrest Mining Limited are working towards a better understanding of the architecture of Australia's premier porphyry gold-copper district. Newcrest's Cadia Valley Operations in central New South Wales is currently one of Australia's largest gold-producing districts. The district contains some of the world's most significant alkalic porphyry ore deposits (including Cadia East and Ridgeway). Our team is working to deconstruct the temporal and geometrical evolution of the district.

PhD candidate, Ana Liza Cuison, is characterising the Ridgeway and Ridgeway Deeps deposits. Her research aims to constrain the mechanisms of porphyry emplacement and space creation at Ridgeway by developing an improved understanding of the intrusion and vein geometries, including detailed microtextural studies of quartz veins. Ana Liza's research is proving critical in the development of an improved 3D model of Ridgeway. Her results have implications for our understanding of how fractures and veins develop in porphyry ore deposits globally.

PhD student Nathan Fox is investigating the lithological and structural controls on alteration assemblages in the giant Cadia East deposit. Field and laboratory investigations have focused on extending the knowledge of alteration assemblage in the upper parts of the Cadia East systems. Stable isotopic studies (in part with collaborators at

Cadia Hill Au-Cu open pit mine, New South Wales – Project P2.L1.



Pyritized sponge spicules and early diagenetic pyrite, Upper Mud member, Devonian Popovich Formation, Goldstrike Property, Carlin Trend, Nevada.

GNS) have attempted to trace the source of the causative metal-bearing hydrothermal fluids, and preliminary results were presented at the IGC conference (Oslo) in August 2008.

Malissa Washburn (MDRU MSc student) has completed her Masters thesis investigating the Silurian rocks that cover the Ordovician porphyry ore deposits in the Cadia Valley. Malissa's work has provided new insights into the post-mineral deformation that partially dismembered the district and juxtaposed different levels of the porphyry copper-gold systems. Reconstruction of the Silurian succession, plus recognition of the hierarchy of faults, has provided a predictive tool to infer basement structures at depth. Her research has aided in constraining the rotation and dismemberment of the Cadia Hill orebody.

Anthony Harris has been unravelling the architecture and evolution of the Cadia Valley. His study adopts aspects of structural and economic geology, volcanology, geochronology, and geochemistry, and has led to the development of an integrated district-scale structural model, improving the understanding of the geometry of the deposits and the rocks that host them. This newly developed model was presented to the industry sponsors at the Cadia Valley Structure Workshop in Orange, NSW, in April 2008. Outcomes are now being integrated into a district-scale 3D model being commissioned by Newcrest.

Throughout the life of this project, CODES researchers have sought to actively contribute to Newcrest's exploration and mining efforts in the Cadia Valley. A recent technical success made by Newcrest geologists was in part aided by our research findings. Drill testing of a conceptual model developed in close partnership between Newcrest and CODES has resulted in an intersection of 146 m with an average grade of 0.46g/t Au and 0.39% Cu. Newcrest is planning to follow up this encouraging result.

Project P2.L2 Controls on the formation and sulfide trace element signatures of sediment-hosted gold deposits (AMIRA P923)

Leaders: R Large, R Scott

Team Members: S Bull, S Meffre, J Halpin, S Gilbert, C Hollitt, L Danyushevsky

Collaborators: P Emsbo, V Maslennikov

This project was completed in late 2007 and a final confidential report and extensive pyrite LA-ICPMS geochemistry database were distributed to the AMIRA sponsor companies in early 2008. The report included a new and controversial ore deposit model for black-shale-hosted Au-As deposits that has major implications related to exploration for Carlin and orogenic gold-arsenic deposits. Several papers relating to criteria to enable distinction between syngenetic and epigenetic gold mineralisation in the Carlin district were prepared for publication during 2008.

Project P2.L3 Shallow and deep-level alkalic mineral deposits

Leaders: D Tosdal, D Cooke

Team Members: Z Chang, G Davidson, B Gemmell, V Kamenetsky, J McPhie, K Simpson

Collaborators: Dick Tosdal, Thomas Bissig, Greg Dipple

Students: A Bath, J Blackwell, K Byrne, A Henry, M Jackson, P Jago, J Micko, H Pass, W Zukowski

The 'alkalic' research project involved collaborative research between staff and students of the Mineral Deposit Research Unit at the University of British Columbia (Canada) and CODES. The

project was divided into 'porphyry' and 'epithermal' modules. Research was undertaken to improve our understanding of the characteristics and genesis of the alkalic porphyry deposits of British Columbia and alkalic epithermal deposits of PNG and Australia. The project was supported by nine industry sponsors: Amarc Resources Ltd, AngloGold Ashanti Ltd, Barrick Gold Corp, Imperial Metals Corp, Lysander Minerals Corp, Newcrest Mining Ltd, Newmont Mining Corp, Novagold Resources Inc and Teck Cominco Ltd. Additional financial support was obtained via grants from the Natural Sciences and Engineering Research Council of Canada (NSERC) and Geoscience BC.

This year saw the official conclusion of the alkalic project, culminating in final sponsors' meetings and field excursions in Williams Lake, British Columbia (September), and Orange, NSW (November). Two volumes of final reports were provided to sponsors at those meetings, summarising our major research outcomes. Work is underway to convert those reports into manuscripts for publication in a special issue of *Economic Geology*, scheduled for publication in 2010. Two MDRU students (Janina Micko and Kevin Byrne) spent one month at CODES undertaking analyses and participating in a thermodynamic modelling workshop. PhD student Jacqueline Blackwell completed her final field season, and presented research results for the Lihir gold deposit at the IAVCEI conference in Iceland. MSc student Kevin Byrne presented the results of his work on Galore Creek at the PACRIM conference in Queensland. Heidi Pass, Janina Micko and Jacqueline Blackwell all won SEG Canada Foundation awards, and Jacqueline Blackwell also won a Newmont Student Research Grant. Kevin Byrne won an SEG Hugo McKinstry Grant. Three MSc students at UBC (Jago, Jackson and Henry) completed their theses. The remaining students at CODES and UBC are working towards thesis completion, scheduled for 2009.

Endeavour 42 deposit, part of the P2.L3 project that concluded during the year.



Program 2: Formation

Project P2.L4 Genesis of the giant Sukhoi Log gold deposit, Siberia

Leaders: R Large, V Maslennikov

Team Members: Z Chang, L Danyushevsky, J Hergt, S Meffre, R Scott, J Woodhead

This project was completed in 2008, with a detailed study of S-isotope patterns in pyrite from the Sukhoi Log ores and adjacent sediments (Chang, Large and Maslennikov). Our research concluded that the overall mean value and the significant variability in early syngenetic and diagenetic gold-bearing pyrite (-6.5 to +19.3 permil) indicates that the sulfur was from the reduction of seawater sulfate. The later generations of hydrothermal and metamorphic sulfide at Sukhoi Log have $\delta^{34}\text{S}$ values in successively smaller ranges, coincident with the mode that is around the median value of the whole data set (+10.4 permil). Together with textural evidence, sulfide trace element data, and gold occurrence, the data demonstrate that metamorphism has gradually homogenised the early sulfur, accompanied by the segregation of quartz and the release of Au from the lattice of early pyrite and its re-precipitation as inclusions in later pyrite. This study has demonstrated that the S isotopic compositions of sulfides in Sukhoi Log, and many other major orogenic Au deposits hosted in sedimentary rocks of various ages, show a pattern generally parallel to the seawater sulfate curve through geologic time. This indicates that the sulfur in most sediment-hosted orogenic Au deposits also originally resulted from the reduction of seawater sulfate. Our research strongly suggests that sulfidation and gold mineralisation in many sediment-hosted orogenic gold deposits occurred early during basin evolution when seawater was the principal active fluid; rather than later during, or post, basin inversion, as proposed in current models. This research was published in the December 2008 issue of *Geology*.

Project P2.N2 Zn and Au mineralisation in the Caijiaying deposit: geologic characteristics and genesis

Leader: Z Chang

Team Members: N White, D Cooke, B Gemmell

Collaborator: M Wilson

The Caijiaying Zn-Au deposit is complicated, hosted in Proterozoic high-grade metamorphic rocks, yet with features typical of both skarns and low sulfidation epithermal deposit at different locations within the deposit. This project was established to investigate the deposit's geological characteristics and understand its origin, which will facilitate further exploration.

Considerable emphasis was placed on laboratory work during the year, with the completion of 966 SWIR spectral interpretations, 68 microprobe analyses, 116 LA-ICP-MS analyses, and 26 whole rock multi-element analyses. An additional six days of fieldwork were completed, during which 12 drill holes were logged (total 1,434 m), and 40 samples collected. Two

samples were submitted to the University of British Columbia for TIMS U-Pb dating, and one sample for Ar-Ar dating. Results are pending.

The project has now defined the extent of white mica alteration at Caijiaying, and the variation of SWIR spectral features with respect to proximity to the orebodies. We have also completed investigations of variations in whole rock geochemistry in the volcanic cover rocks above and away from the orebodies. The various modes of gold occurrences have been placed in a paragenetic context, and the unusual W anomaly is currently under investigation. This project will be completed in early 2009.

Project P2.N3 Polymetallic mineralisation and associated magmatic and volcanic activity in the Luzong basin, middle and lower Yangtze River, eastern China

Leader: T Zhou

Team Members: Z Chang, S Meffre

Student: L Zhang

Collaborators: Y Fan, F Yuan

This project aims to improve our understanding of the volcanic and intrusive evolution of the Luzong volcanic basin in China. New data have been generated that provide insights into the relationships between alkalic magmatism (both intrusive and extrusive), porphyry deposits, iron deposits and massive polymetallic sulfide mineralisation in this basin, and into the controlling geodynamic processes.

Highlights for 2008 include the publication of five journal articles and two conference abstracts in international and Chinese journals. Taofa Zhou attended six national and international conferences, including three as a keynote speaker, two as a session chair, one as a special invited speaker and one as leader of a post-conference field trip to the mineralisation belt of the middle and low reaches of the Yangtze River area.

Our application for funding as a key China NSFC project was ratified, which has allowed our research to expand to cover the whole belt, including several ore deposits not previously studied. New field programs were completed, allowing major deposits both in the Luzong and Ningwu volcanic basins to be investigated. We also completed geochemical analyses of volcanic and intrusive rocks, and Taofa Zhou completed an academic study visit to the University of Hong Kong to work with Dr Guochun Zhao.

Project P2.N4 Breccia textures

Leader: K Simpson

Team Members: D Cooke, J McPhie, B Gemmell

Collaborator: A Davies

CODES staff and collaborators are preparing a new book entitled *Breccia Textures*, which will provide a practical, systematic approach to dealing with fragmental rocks in mineralised environments. This book is based on the highly successful short course that has been taught at the Cordilleran Roundup meeting in Vancouver since 2006. The structure of the book has been finalised and several first drafts of chapters have been completed and edited. A major highlight of the year was the publication of two papers from Andrew Davies' PhD thesis on the Kelian breccia complex. Andrew's work forms the basis of parts of the breccia book, and key information contained within these papers will be integrated into the CODES publication. Kirstie Simpson, who had been leading the project, finished working for CODES at the end of November.

Project P2.N5 T-P-X evolution of carbonatite melt-fluids and REE ore-forming processes in the Mianning-Dechang REE metallogenic belt

Leader: Y Xie

Team Members: D Cooke, L Danyushevsky, V Kamenetsky, Z Chang

Collaborators: Z Hou, S Tian, Z Yang

This project investigates the characteristics of fluorite-hosted melt and fluid inclusions from REE-enriched carbonatites in the Mianning-Dechang REE metallogenic belt in China. Insights from the project will be used to develop a new model for REE mineralisation in carbonatite melts. Commencement of this project was delayed; project leader Yuling Xie arrived at CODES in mid-December 2008, and has commenced sample preparations. Most of the work on this project will be conducted in the first half of 2009.

Jigsaw-fit, monomictic breccia with base metal sulfide cement, Kelian breccia complex, Kalimantan, Indonesia – Project P2.N4.



Program 3

Objective

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

Leader

Jeff Foster

Team Members

Mike Baker, Stuart Bull, Huayong Chen, Dave Cooke, Tony Crawford, Leonid Danyushevsky, Mark Duffett, Peter Fullagar (Fullagar Geophysics), Bruce Gemmell, Sarah Gilbert, Jacqueline Halpin, Murray Hitzman (Colorado School of Mines), Dave Hutchinson, Shaun Inglis, Lyudmyla Koziy, Peter McGoldrick, Andrew McNeill, Sebastien Meffre, Steve Micklethwaite, Anya Reading, Mike Roach, Robert Scott, Dave Selley, Helen Thomas, Noel White (University of Melbourne), Jamie Wilkinson

PhD Students

L Clark, V Galvan, N Heckscher (ANU), T Ireland, N Jansen, R Schaa, B Sutopo

Masters Students

C Chamberlain, G Sweet (Lakehead University)

Honours Student

R Kyne (Lakehead University)

Collaborators

Australian National University – Nicholas Rawlinson, Malcolm Sambridge

Colorado School of Mines – Murray Hitzman, Nick Harris, Jeff Hedenquist

CSIRO – Steve Barnes

Geoscience Australia – Erdinc Saygin

Lakehead University (Canada) – Peter Hollings

Monash University – Reid Keays

Otago University (New Zealand) – Dave Craw

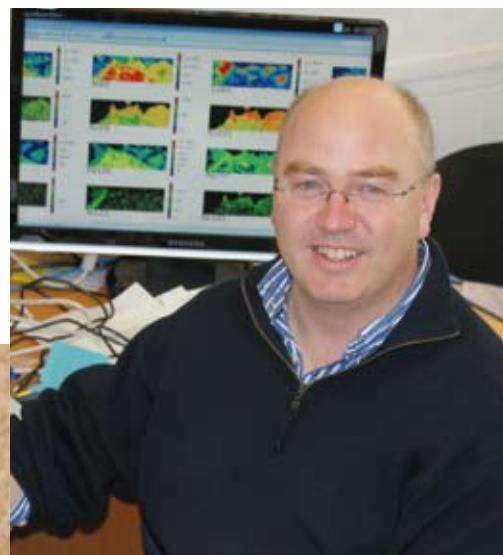
Southern Mineral Exploration Geophysics – Phil Muir

United States Geological Survey – Poul Emsbo

University of British Columbia (Canada) – Richard Freidman

University of Lubumbashi (DRC) – Stanislas Sebagenzi

Jeff Foster, Program Leader



Highlights

- A high-quality, internally consistent model for the formation of Congolese-type sediment-hosted Cu deposits was developed.
- The algorithms developed for the rapid inversion of TEM data yield reliable results 100 times faster than the conventional approach.
- LA-ICPMS mapping of the pyrite revealed the presence of early diagenetic Au in a number of world-class ore systems.
- Active research continues on high- and low-sulfidation epithermal deposits across three countries.
- LA-ICPMS mapping of magmatic sulfides from Noril'sk-Talnakh and the Merensky Reef revealed the distribution of the PPGE relative to Ni, Cu, Fe and the semi-metals.
- Base and precious metal data from a number of world-class magmatic sulfide deposits indicate sulfide undersaturated melts are not a prerequisite for the formation of a giant ore system.
- Fourteen major porphyry copper districts from eight countries were sampled as part of AMIRA P765A.
- An ambient seismic energy test array was deployed in eastern Tasmania.
- Co and Ni in pyrrhotite, along with Co, As and Zn concentrations in pyrite, potentially yield proximity indices for Rosebery-style VHMS mineralisation.

Outlook

A new framework for the Discovery Program was developed for the ARC Centre of Excellence Review. In the future, the R&D for Program 3 will focus on two principal themes:

Theme 3A: Innovative techniques for discovery

P3.A1 3D inversion of potential field and EM data.

P3.A2 Ambient seismic energy techniques and computational geophysics.

P3.A3 Advanced integrated techniques for discovery.

Theme 3B: Integrated exploration models for discovery, incorporating geophysics and petrophysics

P3.B1 Magmatic-hydrothermal Cu-Au ore deposits.

P3.B2 Sediment-hosted base and precious metal deposits.

P3.B3 Volcanic-hosted massive sulfide deposits.

P3.B4 Fe-oxide Cu-Au deposits.

P3.B5 Magmatic Ni-Cu-PGE deposits.

P3.B6 Hydrothermal and sedimentary U-PGE deposits.



Program 3: Discovery

Introduction

The Discovery Program leverages off CODES' extensive, broad-based research expertise to enhance the development of geophysical, geochemical and geological models for specific, first-rate ore deposit types and their alteration halos. This is achieved through the measurement, modelling and inversion, and interpretation of ore deposit data in a 3D geological setting.

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

Core projects

Project P3.F2 Sediment-hosted gold-arsenic deposits: genesis and exploration models

Project P3.F3 The characterisation of magmatic sulfide ores

Project P3.F4 The petrophysical characterisation of ore deposits

Project P3.L1 The rapid approximate inversion of TEM data

Project P3.L2 Geochemical and geological halos in green rocks and lithocaps – The explorer's toolbox for porphyry and epithermal districts (AMIRA P765A)

Project P3.L3 Origin and setting of Congolese-type copper deposits (AMIRA P872)

Project P3.L4 3D geophysical inversion evaluation

Project P3.L7 Shales and carbonates – Improved vectors for Rosebery-Hercules-style VHMS in the central Mt Read Volcanics, Tasmania

Project P3.L8 Low- and high-sulfidation epithermal mineral deposits, Australia and Pacific region

Project P3.L9 The Tweefontein Sector of the Platreef, South Africa

New Initiatives:

Ambient seismic energy techniques

GLODISC module A2 (AMIRA P1022): The applied rapid constrained inversion of TEM data

The geology, geochemistry and genesis of the Avebury Ni deposit, Tasmania: implications for exploration

(F prefix denotes fundamental research project. L prefix denotes industry-linked project.)

Project P3.F2 Sediment-hosted gold-arsenic deposits: genesis and exploration models

Leaders: R Large, S Bull

Team Members: L Danyushevsky, S Gilbert, S Inglis, S Meffre, R Scott, H Thomas

Collaborator: D Crow

This project focuses on understanding the mechanisms of gold concentration in black shale-hosted orogenic gold deposits, and how this understanding can be used to develop improved models for exploration. Three study sites are under investigation: Bendigo in the Victorian Goldfield, Spanish Mountain in British Columbia and the Otago Schist in New Zealand.

Our previous work on the giant Sukhoi Log deposit in Siberia and the Carlin district in Nevada demonstrates that gold is concentrated in organic-rich black shales, along with a particular suite of elements termed VAMSNZ: vanadium, arsenic, molybdenum, selenium, nickel, silver and zinc. These elements combined (plus gold and rarely PGE) are typical of metal concentration during sedimentation and diagenesis in a strongly euxinic and organic-rich sedimentary environment. Our working hypothesis is that Carlin-style and orogenic gold deposits can develop during deformation and metamorphism of VAMSNZ-bearing black shale.

Whole rock, multi-element analyses of selected shale intersections in the turbidite sequence at Bendigo indicate the presence of thin, organic-rich shale units showing the characteristic VAMSNZ signature of enrichments in V, As, Mo, Se, Ni, Ag and Zn. These units carry diagenetic and over-growth metamorphic pyrite, enriched in gold and arsenic. Detailed LA-ICPMS pyrite mapping shows that gold is enriched in both the early diagenetic stage of pyrite growth along with Ag, Mo, As, Ni, V, Pb, Te, Bi, and in the latest stage of metamorphic pyrite growth with As, Ni and Co.

Our research at Bendigo also demonstrates the value of laser trace element mapping and spot analyses of pyrite in helping to discriminate between high- and low-grade gold reefs in adjacent anticline positions. Ongoing allied research includes analysis of the background gold content of sedimentary rocks across the Bendigo district, and Pb-Pb dating of pyrite crystals.

Spanish Mountain, in British Columbia, is a black-shale-hosted disseminated gold deposit with many features similar to Sukhoi Log. Petrography and laser mapping have revealed that some of the gold concentrated very early, and occurs as 'invisible' gold dissolved in cores of diagenetic pyrite.

Project P3.F3 The characterisation of magmatic sulfide ores

Leaders: J Foster, D Hutchinson

Team Members: S Gilbert, S Inglis

Collaborator: S Barnes

A detailed LA-ICPMS and SEM study was undertaken on the lower contact of the Merensky Reef – the world's most renowned platinum-group element (PGE) orebody. This stratiform and stratabound horizon forms part of a cyclic sequence within the Bushveld Complex, South Africa, which is the world's largest layered mafic-ultramafic intrusion.

Many models and mechanisms have been proposed to explain the formation of the Merensky Reef. However, most have focused on a limited number of aspects in what now appears to have been a very complex ore-forming and depositional magmatic system.

The study confirms the presence of multiple chromitite layers along the contact with, and in, the footwall rocks, which together appear to form a single layer. Each of the petrologically distinctive zones, which occur on a millimetre to centimetre scale, host distinctive sulfide and platinum-group mineral assemblages.

These observations are not adequately explained by current models for the formation of the Merensky Reef. Instead of multiple episodes of in-situ crystallisation from new injections of magma, or element remobilisation due to chromotagraphic processes, a new model will be generated that incorporates entrainment of early formed ore minerals that were subsequently transported to, and deposited in, their current location.

P3.F4 The petrophysical characterisation of ore deposits

Leaders: J Foster, M Roach

Team Member: P Fullagar

Collaborator: P Muir

Work has commenced on the development and implementation of a database for the physical properties of rocks, which will store petrophysical data for surface and drill core samples from mineralised districts. The database was developed using ArcGIS to enable easy integration of this petrophysical data with existing geological and geophysical information.

The system employs a relational database structure that is designed to allow flexibility in encoding information, while still retaining the ability to undertake complex queries, including the capacity to account for the hierarchical nature of geological classification systems. The spatial database of petrophysical data will be used as an essential input to help constrain regional potential geophysical inversions.

Data from the mineralised rock sequences of western Tasmania are currently being entered into the system, including information for approximately 2000 samples provided by Mineral Resources Tasmania.

Other Tasmanian data will be acquired from exploration company reports and UTAS theses. When compilation of all existing data is complete, and significant gaps in the spatial or stratigraphic coverage have been identified, these gaps will be filled by targeted sampling of archival drill core. On completion of the Tasmanian pilot project, the database will be extended to incorporate data from other major Australian mineralised districts, which will provide a resource for future regional and local geophysical interpretation projects.

Sunset over the Central African Copperbelt.



Program 3: Discovery

Project P3.L1 The rapid approximate inversion of TEM data

Leader: P Fullagar

Team Member: M Roach

Student: R Schaa

A fast, approximate 3D TEM modelling and inversion algorithm, VPem3D, is under development. VPem3D is based on the concept of TEM moments, in which the ground is divided into cubic cells, and electromagnetic interaction between volume elements is ignored. Linear combination of the moments from the individual cubic cells is an acceptable approximation at late times within the resistive limit.

The transformation from multi-channel, time-domain EM data into the moment-domain effectively converts the problem from one associated with 3D TEM inversion to one involving 3D magnetic inversion. Depth resolution as provided by multi-channel TEM data is lost during the process of time-integration. However, conductivity-depth imaging (CDI) sections, which convert time to depth implicitly, can be used to generate starting models for inversion.

The key result is that 3D TEM inversions, utilising the VPmg inversion framework, can be performed in minutes, rather than hours. The method is suitable for moving loop (including airborne) and fixed loop TEM.

Project P3.L2 Geochemical and geological halos in green rocks and lithocaps – The explorer's toolbox for porphyry and epithermal districts (AMIRA P765A)

Leaders: D Cooke, B Gemmell, Z Chang

Team Members: M Baker, H Chen, J Wilkinson, N White, S Inglis

Collaborators: R Freidman, J Hedenquist, P Hollings

Students: N Jansen, R Kyne, G Sweet

This AMIRA research project aims to provide tools that help to extend the detection limit of geochemical footprints associated with porphyry and epithermal deposits, and further focus exploration activity in altered domains that enclose and obscure mineralisation.

Porphyry-related mineral districts host many major ore deposits of diverse styles and metal associations. Exploration in these districts can be complicated by shallow-level alteration systems (e.g. lithocaps) and structural complexities. At deeper erosion levels, it can be difficult to identify the locations of productive ore zones that are interspersed between barren gaps of weakly developed hydrothermal alteration (green rocks). Furthermore, it can be difficult to evaluate and appreciate the significance of unmineralised veins that occur in these environments.

Porphyry-epithermal mineral districts are typically zoned, and the understanding of zoning has been an important tool for exploration. However, the various mineral assemblages and textures that characterise each zone can be produced by barren hydrothermal systems, or by non-mineralising processes, such as regional metamorphism. Discriminating mineralised and barren systems, being able to locate well-mineralised hydrothermal centres, and recognising the distal footprints of mineralisation continue to be great challenges to explorers.

Field campaigns were undertaken at Yanacocha, Perol and Tantauatay (Peru), El Teniente (Chile), Ixhuatan (Mexico), Baguio (Philippines), Shuteen (Mongolia), Chelopech (Bulgaria) and Timok (Serbia). Existing sample suites from Baguio, Mankayan, Batu Hijau, Collahuasi and El Teniente were subjected to further geochemical analyses. One blind site test was completed in December. U-Pb dating of samples from Baguio was completed by Richard Friedman at UBC.

One research assistant (Inglis) and two postdoctoral research fellows (Baker and Chen) have been appointed, and Visiting Professor, Jamie Wilkinson, has arrived at CODES. MSc student Sweet, and Honours student Kyne, were appointed at Lakehead University.

Sponsors' meetings were held at CODES in early June and early December 2008.

Project P3.L3 Origin and setting of Congolese-type copper deposits (AMIRA P872)

Leaders: D Selley, S Bull, M Hitzman

Team Members: M Duffett, J Halpin, L Koziy, P McGoldrick, S Meffre, R Scott

Collaborators: P Emsbo, N Harris, S Sebagenzi

During its final year, this successful project achieved its primary goals of: 1) developing holistic models for the structural, sedimentological, and hydrological evolution of the Katangan Basin; and 2) developing pragmatic exploration tools for sediment-hosted Cu ores, applicable in central Africa and similar geological environments worldwide. Results were presented at a final sponsors' meeting held in southern DR Congo and northern Zambia in October. The meeting included a week-long technical and field-based program and attracted more than 100 participants, making it one of the largest geological conventions held in central Africa.

Perhaps the most significant contribution to the understanding of the Central African Copperbelt was the resolution of macro-scale basin architecture. To achieve this outcome, the research team applied a multidisciplinary approach, integrating regional isopach mapping, balanced cross-section construction, gravity modelling, zircon provenance analysis, sequence stratigraphic methods, and thermo-barometric modelling of metamorphic assemblages.

The results demonstrate that gross extensional architecture of the basin was maintained throughout Lufilian inversion, and that modification via high magnitude thrusting during orogenic episodes was considerably less pronounced than previously thought (within principal ore-bearing parts of the basin, at least). Classical ores cluster above the periphery of a hitherto unrecognised or, at best, poorly constrained asymmetric syn-rift basin within dismembered, carbonate/sulfate-dominated post-rift strata. These two tectono-stratigraphic entities were originally separated by a thick sequence of rift-maximum salt; the latter now withdrawn or dissolved. During later stages of accommodation development, the basin became ubiquitously decoupled at the level of salt, leading to accumulation of upper stratigraphic levels within a compartmentalised array of sub-basins. Much of the complex deformation that characterises the classical ore horizons, and to a lesser extent the upper basin fill, resulted from this syn-extensional halokinesis.

The hydrological evolution of this basin framework was examined using a highly sophisticated numerical fluid flow modelling approach. These models employed, for the first time, fully-coupled sediment compaction, fluid density contrast, and thermal fluid driving forces. They demonstrated a two-fold basin hydrology: 1) macro-scale convection of residual evaporitic brines, involving lower syn-rift strata and underlying basement rocks, both of which were potential contributors to the metal content of the fluid; and 2) episodic release or expulsion of metal-bearing brines through lateral terminations of, and/or punctuations in, the evaporitic horizons that coincide vertically with the tapering edges of the underlying syn-rift basin. The models raise the potential for stratiform and/or fault-controlled mineralisation being formed at various times and stratigraphic levels about the periphery of the Katangan Basin.

Constraints on ore fluid composition were determined via Cl-Br analysis of fluid inclusions contained in sulfide phases from several Congolese and Zambian ores. Despite the diverse structural and lithostratigraphic nature of the ores examined, a common ore fluid type was indicated, involving a highly evolved (i.e. evaporated) seawater-derived brine. The very dense and highly saline character of this fluid type is likely to have contributed to its interaction with large volumes of potential metal source rocks, as well as its metal scavenging capacity.

The highly saline nature of the ore fluid type is probably also linked to rare earth element anomalism associated with some of the larger Congolese ore systems – varying systematically with metal tenor, and recorded faithfully in a variety of heavy mineral phases.

A final technical report will be submitted to sponsors in February 2009, with preparation of papers for publication planned during the following six-month period.

Some of the participants at the final P3.L3 sponsors' meeting in the Democratic Republic of Congo.



Program 3: Discovery

Project P3.L4 3D geophysical inversion evaluation

Leaders: M Duffett, M Roach

Team Member: P Fullagar

This project uses a mineralised, structurally complex portion of western Tasmania as a test bed to evaluate several different approaches to 3D potential field inversion.

The Razorback study area, between Zeehan and Rosebery (encompassing Renison) in western Tasmania, was chosen for its high physical property contrasts and relatively strong constraints from high-quality surface mapping and drilling.

Analysis of the extensive drill core petrophysical data set was completed. Over 12 potentially distinguishable geological unit groupings were identified, confirming the suitably challenging nature of the Razorback rock volume as a target for complex inversion.

Project P3.L7 Shales and carbonates – Improved vectors for Rosebery-Hercules-style VHMS in the central Mt Read Volcanics, Tasmania

Leader: A McNeill

Team Members: B Gemmell, S Gilbert, S Inglis

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 – the 'Holy Host' – and that this horizon has been adequately tested to a depth of 150–200 m.

Therefore, from the perspective of exploration, it is important to define the location and down-dip extent of the 'Holy Host' and to locate alteration envelopes that may be associated with VHMS mineralisation.

This project addresses these problems by using the geochemistry of shales to aid in defining the position of the 'Holy Host', and by using the mineralogy and geochemistry of shale and carbonates associated with the Rosebery and Hercules orebodies to develop vectors to mineralisation.

Work during the year comprised geological logging of drill holes and sampling of shale units at the Rosebery Mine on section 2400mN (above and up-dip of Y Lens), section 1200mN (above K lens) and from the Rosebery shale regionally (White Spur area). Data from these areas will be used to assess proximal to distal variations in whole-rock geochemistry. This will be further supported by LA-ICPMS trace element geochemistry of pyrite and pyrrhotite.

Preliminary trace element variations within pyrrhotite and pyrite are showing promise as potential vectors. Overall, the Co and Ni contents of pyrrhotite, and the Co, As and Zn contents of pyrite, are much lower in distal samples than in those immediately above the ore. In contrast, Au, Te and As are higher in distal pyrites. Additional data is being acquired to confirm these trends and to assess variations between the five different textural types of pyrite that have been identified.

Project P3.L8 Low- and high-sulfidation epithermal mineral deposits, Australia and Pacific region

Leaders: B Gemmell, D Cooke

Team Member: S Micklethwaite

Students: C Chamberlain, L Clark, V Galvan, B Sutopo

Research concentrated on determining the geological and geochemical constraints on the formation of low- and high-sulfidation epithermal deposits, which will lead to improved genetic and exploration models. As an outcome from previous PhD research, two significant papers (Davies et al. 2008a, 2008b) were published in *Economic Geology*, namely 'The development of a mineralised diatreme complex', and 'The genesis of mineralisation at the Kelian Deposit, Indonesia'.

The postdoctoral, PhD and Master of Economic Geology research projects funded by Newcrest Limited at the Gosowong goldfield, Halmahera Island, Indonesia were initiated in July. Steven Micklethwaite began his postdoctoral study, which involves a deposit- to district-scale study of the Gosowong goldfield and aims to characterise its epithermal systems through integration of structural, geochemical, geochronological and geological studies. Lindsey Clark began her PhD project, which will investigate the geology and genesis of the Kencana epithermal Au-Ag deposit in order to obtain a better understanding of its geological, structural, mineralogical and geochemical characteristics. A Masters of Economic Geology project on the epithermal and porphyry deposits at Toguraci is being undertaken by Daud Silitoga, a Newcrest employee at Gosowong. Initial field seasons were completed in the second half of 2008 and a major progress report was delivered in December.

Victor Galvan continued his PhD research on the geological and geochemical evolution of carbonate-base-metal Ag-Au epithermal veins at Palmarejo, Mexico, and the surrounding district. The study develops a detailed understanding of the geological evolution of the district. This is achieved through the investigation of the mineralisation history, geochemistry and relationships to grade distribution, documentation of vein stratigraphy and paragenesis, spatial and temporal distribution of alteration assemblages, and the geochemistry of the mineralising fluids. Results will be used to develop better exploration models for additional resource discovery. A major progress report was delivered in December.

Corrie Chamberlain, a Master of Economic Geology student, continued to investigate the Kilkenny vein deposit within the Cracow epithermal system in Queensland. Corrie's thesis project involves a geological description of the deposits (host rocks, structure, mineralisation and alteration) and detailed research into the vein paragenetic stages and textural and metal zonation throughout the horizontal and vertical extent of the vein. The aim of the thesis is to compare the Kilkenny deposit to other deposits in the Cracow goldfield. This will provide a better understanding of the features and controls on mineralisation, which can be applied to mineral exploration in the district.

Bronto Sutopo's PhD research project, sponsored by Newmont Mining, investigates the high- and low-sulfidation mineralisation in the Martabe district, Indonesia, with the aim of understanding the ore genesis and developing criteria for enhanced exploration in the district. Martabe is a complex deposit, with alteration and mineralisation related to both low- and high-sulfidation fluids emplaced into a diatreme and volcanic dome environment. Bronto completed his analytical work (LA-ICPMS, geochronology, stable isotopes) and, at the end of the year, was writing his thesis.

Project P3.L9 The Tweefontein Sector of the Platreef, South Africa

Leader: J Foster

Team Member: D Hutchinson

Collaborator: R Keays

This project builds on several years of combined research and experience, and is designed to explore and develop new models for the formation of the Ni-Cu-Platinum-Group Element (PGE) mineralisation in the northern limb of the Bushveld Complex, South Africa.

The mafic-ultramafic hosted orebody forms part of the world's largest layered igneous intrusion, which hosts a significant proportion of the world's total known reserves of platinum and palladium, as well as other elements such as rhodium, gold, chromium, nickel and copper.

The main eastern and western portions of the complex are noted for their laterally continuous and economically important layering – the so-called 'reefs', the most important of which are the Merensky and UG2 Chromitite.

In marked contrast, observations in the northern limb are scale-dependent. This paradoxical character of the Bushveld Complex has perplexed those who have worked on it and is the focus of intense scientific research and debate.

The lower portion of the northern limb in the southern sector is host to economic Ni-Cu-PGE mineralisation, which can be variably developed over ~150 m. This zone of mineralisation, known as the Platreef, is considerably thicker than the Merensky Reef to which it is often compared.

The original magmatic geochemical signature of the Platreef has been significantly modified by the presence of variably digested country rock xenoliths and the addition of footwall derived contamination. One of the primary challenges is to unravel the various geochemical and mineralogical signatures and to derive a model for the formation of the reef.

Looking east across the northern limb of the Bushveld Complex from the top of the roof granites across to the footwall contact (range of hills in the background).



Program 3: Discovery

New Initiatives:

Ambient seismic energy techniques (ASET)

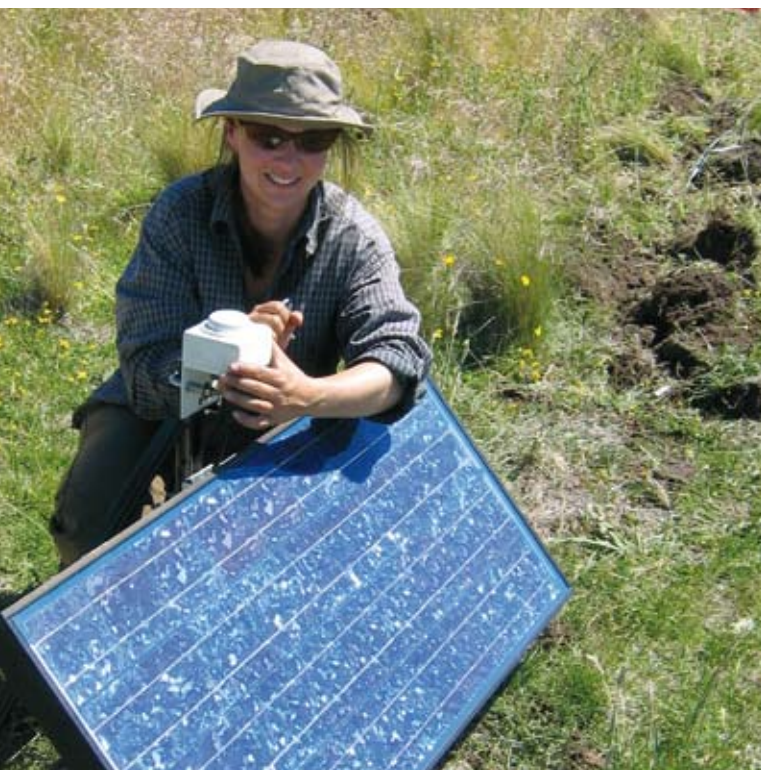
Leader: A Reading

Collaborators: N Rawlinson, E Saygin, M Sambridge

Student: N Heckscher

ASET are new seismic analysis techniques that rely on natural and man-made background seismic signals that have previously been thought of as 'noise'. The structure has successfully been determined on a continent-wide scale using these signals, and this project aims to push the concept to higher frequencies with the potential for high-resolution earth imaging. The project commenced in late 2008 with a visit to one of the main collaborators, Nick Rawlinson of the Research School of Earth Sciences (RSES) at ANU. Subsequently, work started on a new combination of sensors and recorders appropriate to ASET. As a result, ten passive seismic station sets were prepared at the RSES and freighted to Hobart, where work began immediately to configure the equipment for a pilot deployment. This deployment aims to determine the energy present in the ambient seismic wavefield at high frequencies, and the potential of the method for mine-scale 3D imaging.

Anya Reading installing a GPS antenna for a pilot study for the ambient seismic energy initiative.



GLODISC module A2 (AMIRA P1022) the applied rapid constrained inversion of TEM data

Leaders: P Fullagar, J Foster

Student: R Schaa

An approximate 3D TEM inversion algorithm has been under development at CODES during the past three years (P3.L1) to address the need for rapid, integrated interpretation. The algorithm relies on the concept of magnetic moments, which are time-weighted integrals of the TEM decay. In effect, the moment transformation converts the problem from one associated with 3D TEM inversion to one involving 3D magnetic inversion. The underlying assumption is that the net TEM response can be reproduced via superposition of the responses of individual sub-volumes – i.e. that EM interactions between volume elements can be ignored. This assumption is usually acceptable at late times, and it is the late time signature that is normally most important in exploration.

The new project expands on previous research outcomes, fully develops the 'independent spheres' model and builds new code into the VPMg framework. Key areas of research include an assessment of accuracy and precision, the development of a method to account for conductivity gradients, and an improved adaptation for the interpretation of downhole TEM.

The new advanced model will be tested in a number of data-rich environments, using a variety of constrained inversion styles (homogenous, heterogeneous, stochastic and contact geometry). The outcomes will be further assessed relative to conventional unconstrained inversion.

The geology, geochemistry and genesis of the Avebury Ni deposit, Tasmania: implications for exploration

Leaders: J Foster, T Crawford

This project uses well-constrained drill sections to outline the geological framework of the Avebury Ni deposit. Samples will be collected and analysed for a combination of major elements, trace elements, precious metals, stable isotopes and radiogenic isotopes. The data will be assessed to determine the roles of different fluid-related inputs into the alteration of the ultramafic body and their relevance to the redistribution of ore elements.

Opposite: View south from the Baguio lithocap to the Black Mountain porphyry Cu-Au deposit, Baguio district, Philippines – Project P3.L2.



Program 4

Objectives

- *Create an integrated, cross-disciplinary geometallurgical research platform that delivers fundamental knowledge, tools and methods to the global mining industry for optimising sustainable and profitable mineral extraction*
- *Develop more effective approaches to the definition of mineralogy, element deportment and texture that can be linked to mineral processing performance and efficiency at a range of scales*
- *Provide improved attributes or indices of processing performance that can be embedded in block models to define processing domains, which can be exploited in mine planning and optimisation*
- *Deliver new, cross-discipline geometallurgical education, training and awareness*

Leader

Steve Walters

Team Members

Ron Berry, Dee Bradshaw*, Alan Bye*, Alex Cuisson, Nenad Djordjevic*, Peter Fullagar*, Julie Hunt, Jon Huntington*, Maya Kamenetsky, Toni Kojovic*, Ryan McCasker*, Claire McMahon, Simon Michaux*, Rob Morrison*, M Newton*, Khoi Nguyen*, G Parkes*, Melissa Quigley*, A Richmond*, Esther Soden*, Pat Walters*, Yicai Wang*, Kia Yang

(*partner research organisation team member)

PhD Students

Natalee Bonnici, Cathy Evans (JKMRC), Richard Hartner (JKMRC), Luke Keeney (JKMRC), George Leigh (JKMRC), Anita Parbhakar, Adel Vatandoost

Collaborators

Datamine – M Newton

CSIRO – Jon Huntington, Melissa Quigley, Kia Yang

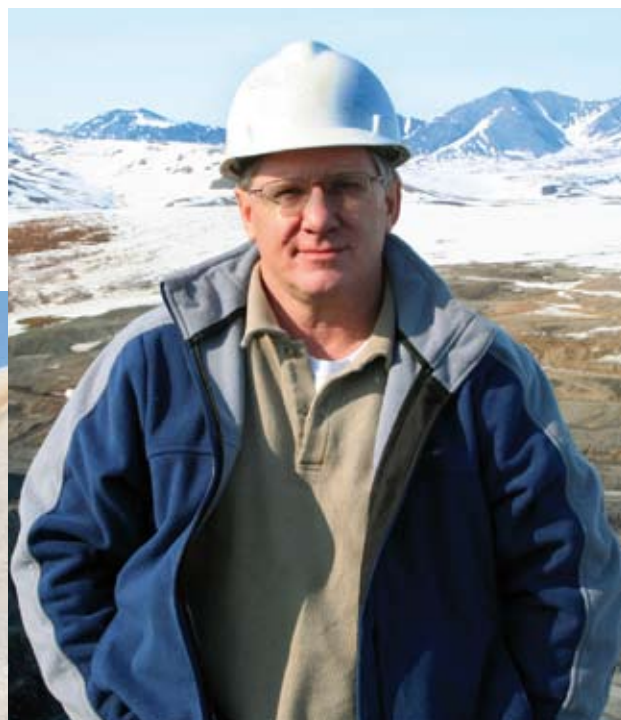
Fullagar Geophysics – Peter Fullager

Golders – A Richmond

JKMRC – Dee Bradshaw, Nenad Djordjevic, Toni Kojovic, Ryan McCasker, Simon Michaux, Rob Morrison, Khoi Nguyen, Geoff Parkes, Esther Soden, Pat Walters, Yicai Wang

WH Bryan Centre – Alan Bye

Steve Walters, Program Leader



Highlights

- The AMIRA P843 GeM^{III} (Geometallurgical Mapping and Mine Modelling) project is the centrepiece of the CODES Recovery Program and is one of the world's largest research projects addressing the emerging multi-disciplinary area of geometallurgy. The project, which runs from July 2005 to June 2009, has attracted over \$6 million in support from 19 industry sponsors in addition to \$2 million CODES Centre of Excellence funding. This represents the largest AMIRA project in the history of CODES.
- Preparations for a GeM^{III} project extension (AMIRA P843A) are well advanced. The proposed research programs include a broader scope of geometallurgical research topics and commodities, together with new collaborations, particularly in the areas of hydrometallurgy and environmental geometallurgy.
- The partnership with JKMRC at the University of Queensland remains a key feature of the program, together with significant collaborations with CSIRO Exploration and Mining (HyLogger group) and the WH Bryan Mining and Geology Research Centre at the University of Queensland (geostatistics and spatial modelling).
- Many of the new technology developments to support more automated core logging and more rapid geometallurgical testing are reaching maturity with documentation of detailed protocols and application examples. Several of these tools have potential for technology transfer to industry.
- Integrated predictive geometallurgical modelling using a range of multivariate statistical techniques is underway for three of the Level 1 case study sites. Initial outcomes indicate benchmarked improvements on current practice.
- Beta versions of a suite of new software tools for texture analysis and multivariate modelling have been released to sponsors.
- Two major sponsor meetings were held in 2008, with each meeting attended by over 70 delegates. Extensive technical reports were released, containing 36 papers.



Program 4: Recovery

Outlook

The major initiative for the Recovery Program in 2009 will be the renewal (P843A) of the AMIRA P843 GeM^{III} project. This will be a four-year extension due to start in mid-2009. Plans are well advanced for defining the research scope of AMIRA P843A in close consultation with industry. It is planned that the extension will involve new geometallurgical research directions in the area of blasting, environmental characterisation and hydrometallurgy, in addition to consolidating and validating outcomes from the current research. This will involve new collaborations with other centres of research expertise.

The five research modules being developed for AMIRA P843A are:

- **Geometallurgical modelling of environmental indices** – development of more cost-efficient, small-scale testing and modelling to provide predictive geometallurgical indices for environmental attributes, mainly in the areas of propensity for dust generation and speciation and the characterisation of texture-related, acid-base reactions. It will also provide new and more effective micro-analytical technologies to map the deportment of deleterious and harmful trace elements, with an emphasis on secondary mobility and bioavailability. This work will be carried out in collaboration with the Centre for Mined Land Rehabilitation at the Sustainable Minerals Institute.
- **Geometallurgical blasting indices** – provision of improved rock mass characterisation attributes into existing hybrid stress blast modelling, through adaptation of technologies largely already developed in AMIRA P843. Areas to be addressed include petrophysical proxies for bulk strength; modification of the Comminution Index test; investigation of more rapid physical testing technologies (e.g. high energy RBT applications); and provision of more automated meso-scale geotechnical parameters derived from core imaging.
- **Deterministic comminution modelling** – significant progress was made in the development of testing and geometallurgical modelling methodologies for crushing and grinding in AMIRA P843. An important outcome was the demonstration of a more deterministic approach to predictive comminution behaviours, based on integration of bulk mineralogy and texture attributes into class-based modelling. Work will focus on the potential to undertake large-scale validation and refinement of this approach using data-rich case study sites.
- **Texture-based liberation and recovery modelling** – a wide range of hardware and software tools were developed in AMIRA P843 for meso- and micro-scale texture mapping and extraction of sophisticated textural attributes. Partnerships will be sought with sites undertaking conventional recovery testing in order to validate and benchmark these predictive methodologies. Work will also be undertaken to develop rapid testing methods for comparative flotation recovery.
- **Development of geometallurgical leaching indices** – this will be a major new undertaking for AMIRA P843A, in collaboration with the Parker Centre. Many of the geometallurgical technologies and methodologies developed in AMIRA P843 will be extended and adapted to leaching applications, including a range of new and customised physical tests for comparative leaching performance. It is expected that research will focus on geometallurgical aspects of Ni laterite, Cu-Au sulfide and Cu-Au oxide-related acid, cyanide and pressure leaching performance.

A successful extension of the GeM^{III} project will consolidate the CODES Centre of Excellence in Ore Deposits as a premier global centre of expertise in geometallurgical research.

Introduction

Geometallurgy involves a quantified and spatially constrained approach to ore characterisation in terms of relationships to critical processing performance behaviours. This emerging discipline is increasingly recognised as a discrete and high-value activity that reflects an ongoing commercial and cultural trend towards more effective mine site integration and optimisation.

Industry recognition of the need for large-scale, integrated geometallurgical research to support this trend resulted in the commencement of the AMIRA P843 GeM^{III} project in mid-2005. This key new research direction for CODES represents a significant, cross-discipline collaboration, bringing together four major Australian research groups for the first time:

- CODES – the ARC Centre of Excellence in Ore Deposits at the University of Tasmania, a world leader in economic geology-related research.
- The Julius Kruttschnitt Mineral Research Centre (JKMRC) at the University of Queensland, a world leader in mining and mineral processing research.
- The WH Bryan Mining Geology Research Centre (BRC) at the University of Queensland, which aims to be a world leader in mining geostatistics, operations research and optimisation in mine design and planning.
- The CSIRO Exploration and Mining HyLogger group, a world leader in automated spectral reflectance logging.



Julie Hunt standing in front of a dyke-like ore zone of massive pyrrhotite, chalcopyrite and pentlandite at Vale Inco's South Mine, Sudbury.

A key approach is the development of a suite of new or modified measurement and testing methodologies, used for early-stage geometallurgical characterisation, typically at core scale during feasibility. This includes more automated 'machine vision' capabilities to supplement or replace visual core logging approaches; development of more flexible and cost-effective capabilities for automated mineral mapping and microscopy; and delivery of a suite of integrated small-scale and lower-cost physical tests for measuring processing performance parameters.

The diverse set of attributes provided by the core logging, mineral mapping, textural analysis and small-scale testing suites, provides a large and potentially complex multivariate data matrix. This matrix includes intrinsic, rock-based properties such as detailed mineralogy and texture, combined with machine-based testing outcomes that can be used as proxies for processing performance. Effective population and geometallurgical modelling of this data matrix requires a range of sophisticated, software-based analytical methods.

The primary aim of the project is to provide an integrated 'tool kit' of technologies and methods to support quantified definition of geological variability as it impacts on metallurgical performance. This requires improved approaches to ore characterisation in terms of machine-based process parameters such as hardness, comminution energy, size reduction, liberation potential and product recovery. These parameters are used to populate

Core projects

Project P4.L1 (AMIRA P843) GeM^{III} project (Geometallurgical Mapping and Mine Modelling)

This is currently the only active project within Recovery. The AMIRA P843 GeM^{III} project is based on six modules that address the needs of integrated geometallurgy, with individual modules equivalent in funding and scope to projects in other programs:

Project P4.L1.1 Automated core logging linked to processing domain definition

Project P4.L1.2 Integrated micro-analytical mineral mapping

Project P4.L1.3 Textural classification, simulation and modelling

Project P4.L1.4 Correlation and calibration of textural categories with processing performance

Project P4.L1.5 Geostatistical attribution of processing performance attributes

Project P4.L1.6 Provision of formalised geometallurgical awareness, education and training

(L prefix denotes industry-linked project.)

deposit-scale block models, typically through the application of geostatistics. Incorporation of geometallurgical parameters into resource modelling supplements traditional geology and grade-based attributes, enabling a more holistic approach to economic optimisation of mineral production. Sophisticated geometallurgical block models can be used to predict and optimise economic attributes such as throughput, grade, grind size and recovery.

Detailed geometallurgical models that reflect inherent variability aim to reduce the technical risk associated with the design and operation of mines. A systematic geometallurgical approach is particularly important in the feasibility stage as a precursor to design, where physical access to, and knowledge of, an ore deposit is typically limited and evolving. Geometallurgical information can be used to optimise flow sheet design and equipment sizing, with a view to predicting and optimising plant performance and production over the life of the project.

Many of the technologies and methodologies being developed have the potential to change current geometallurgical practice and to provide benchmarked improvements.

Program 4: Recovery

Industry sponsorship and ARC funding for AMIRA P843 GeM^{III} project

Nineteen companies currently support the project via three levels of sponsorship:

- **Level 1** involving a maximum of six significant site-based studies. Sponsors: Newcrest, Newmont, Rio Tinto, Teck, Vale Inco and Xstrata.
- **Level 2** with no designated site-based studies. Sponsors: AngloGold Ashanti, Anglo Platinum, Barrick, BHP Billiton, Codelco, Penoles, Vale and OZ Minerals.
- **Level 3** 'supplier' sponsors who provide specialist services, software or hardware relevant to the project. Sponsors: Datamine, Golder Associates, Metso Minerals, ioGlobal and GEOTEK.

This represents over \$6 million of direct industry cash support over the life of the project, plus substantial in-kind support for site-based activities. A further \$2 million of ARC funds will be provided through the Centre of Excellence.

The six operations provided by Level 1 sponsors for site-based research activities represent a mix of world-class copper-gold, lead-zinc-silver and nickel-copper sulfide deposits, with a predominance of hard-rock open pit mining methods and flotation-based mineral processing and recovery circuits. The six study sites provide opportunities for developmental research through comparison of new techniques and methodologies with existing data and current practices (typically involving mature operations); and validation research where the outcomes of development can be tested and trialled under operational conditions (typically involving deposits undergoing expansion or feasibility). The sites are:

- **Aqqaluk zinc-lead-silver** – a satellite deposit adjacent to the Red Dog mine in NW Alaska, USA; provided by Teck Cominco. Currently undergoing advanced feasibility.

- **Boddington copper-gold** – sulfide resource below the depleted Boddington oxide open pit mine south of Perth in Western Australia; provided by Newmont (JV with AngloGold Ashanti). The project is currently under development.
- **Bingham Canyon copper-gold-molybdenum** – mature open pit porphyry Cu/skarn system near Salt Lake City, USA; provided through Rio Tinto (Kennecott Utah Copper).
- **Cadia East copper-gold** – porphyry copper system adjacent to the Cadia Hill and Ridgeway deposits near Orange, New South Wales, Australia; provided by Newcrest. Currently undergoing advanced feasibility.
- **Ernest Henry copper-gold** – mature open pit iron-oxide-associated copper-gold system north of Cloncurry, NW Queensland, Australia; provided by Xstrata. Currently looking to extend production underground.
- **Sudbury nickel-copper-gold-PGE** – underground nickel-sulfide operations in the Sudbury district, Canada; provided by Vale Inco.

P4.L1.1 Automated core logging linked to processing domain definition

Leader: S Walters

Team Members: J Huntington, M Quigley, Kai Yang, P Fullagar, J Hunt

Students: A Vatandoost, L Keeney, N Bonnici

Traditional visual logging techniques produce outputs that are generally not designed to correlate with mineral processing attributes. In addition, visual logging has poor QA/QC compared to other data types and is often performed by junior staff, exacerbated by the current trend to de-skilling. This module employs a

Delegates view the poster presentation at the eighth AMIRA P843 sponsor meeting in Hobart.



novel approach based on automated bench-scale logging instrumentation for petrophysical and mineralogical measurement, which is designed to help overcome these problems.

This involves use of GEOTEK automated core loggers, CSIRO HyLogger systems and a hand-held EQUOTip hardness testing instrument. The GEOTEK MSCL system incorporates high-resolution digital imaging, gamma ray attenuation bulk density, magnetic susceptibility, P-wave velocity and resistivity measurements. A GEOTEK XYZ logger system was acquired in 2008 for dedicated high-resolution imaging, which allows meso-scale mineral identification linked to the application of advanced image analysis software systems.

The CSIRO HyLogger is based on short wavelength infra-red (SWIR) spectral reflectance, which provides information on mainly hydroxyl-bearing minerals such as clays, chlorites and micas. Potential breakthroughs in mineralogical identification using new thermal infra red (TIR) loggers, developed by CSIRO, are also being trialled in the project.

In combination with existing assay data and visual logging, this provides a diverse 'matrix' of multivariate attributes involving direct measures and proxies of mineralogy and texture. This matrix can be used as inputs to predicting and modelling processing performance parameters, such as throughput and recovery determined using other testing methods.

Around 6000 metres of core from the six Level 1 sponsor sites have been logged at high resolution, using this detailed core logging suite. The data has been used to select around 1000 representative samples for more detailed destructive testing, and analysis for mineralogy, texture, comminution performance and liberation.

P4.L1.2 Integrated micro-analytical mineral mapping

Leader: R Berry

Team Members: J Hunt, C McMahon, S Walters, M Kamenetsky

Students: N Bonnici, R Hartner, C Evans

Current practice for geometallurgical characterisation is typically based on an empirical testing approach. This involves a relatively small number of samples undergoing physical bench-scale testing to simulate actual processing outcomes – such as rock hardness and throughput – with results extrapolated into resource models on a large-scale domain basis. A key aspect of the GeM^{III} project is the development of deterministic models, used to identify and model more fundamental controls on processing behaviours. These controls typically involve detailed mineralogical and textural attributes at a range of scales. Resulting deterministic models are used to identify key controls and identify potential proxies, which define more specific measurements that enable the extrapolation of processing performance indices to much larger data sets, such as existing assays or logging.

Provision of high volumes of quantified textural attributes requires a suite of more automated meso- and micro-scale imaging and microscopy technologies. The prime example of this approach is the widespread adoption of automated SEM-based instruments, such as the JKTech MLA and Intellection QEMSCANTM.

The mineral identification and mapping capabilities provided by these systems result in quantified digital imaging of classified mineral maps, highly amenable to software-based image analysis of mineralogy and texture. The techniques have proven highly effective for the quantified analysis and interpretation of liberation in comminuted products, such as concentrates and tailings. The majority of major mineral companies now operate in-house facilities.

A key aspect of the GeM^{III} project is the development of systems that provide greater quantities of classified mineral mapping with a broader range of cost and resolution options. This mainly involves the development of more automated optical microscopy systems linked to advanced image analysis software, and the use of continuous core scale imaging, which can also be processed into classified mineral maps. The use of optical and core imaging systems provides more information on meso-scale textural associations prior to size reduction and liberation. This delivers a more predictive modelling approach compared to reactive analysis of processing product and waste. This particularly applies to mapping of gangue phases in low-grade systems, which have a major influence on comminution performance.

The project utilises two GEOTEK high-resolution core imaging systems, two Leica DM6000 automated microscopes, and has access to MLA research facilities at CODES and JKMRC. Over 6000 metres of high-resolution core imaging and around 3000 MLA and optical mineral maps have been completed to date. This information provides a range of textural and mineralogical inputs that can be linked to simulation and modelling of processing performance (P4.L1.3).

P4.L1.3 Textural classification, simulation and modelling

Leader: S Walters

Team Members: R Berry, K Nguyen, J Hunt, Y Wang, N Djordjevic

Students: N Bonnici, G Leigh, C Evans

The traditional textural classification and categorisation schemes used by geologists are poorly correlated with, and calibrated against, processing performance. At the hand specimen/core scale, traditional geological classification schemes are largely based on visual observation that can be subjective and experience-based.

The advent of automated digital mineral mapping, outlined in P4.L1.2, presents new opportunities for a more systematic and reproducible approach to textural classification and categorisation that is based on quantified, statistical methods. However, automated mineral mapping techniques generate large volumes of increasingly complex measurements that can challenge even computer-based classification methods.

Program 4: Recovery

A major aspect of the GeM^{III} project is the development of a suite of sophisticated, software-based tools for analysing and categorising textural relationships relevant to modelling mineral processing outcomes. These were released as beta versions to sponsors during 2008 and represent a significant advance in texture analysis and simulation capabilities for geometallurgical application.

P4.L1.4 Correlation and calibration of textural categories with processing performance

Leader: T Kojovic

Team Members: S Michaux, R Morrison, G Parkes, R McCasker, N Djordjevic, S Walters

Students: C Evans, L Keeney

A wide variety of physical tests are employed to assess processing performance. These include strength (UCS, Point Load), hardness (Bond Work Index), comminution (JK Drop Weight and Sag Mill Comminution Tests) and bench-scale flotation or leach testing. The majority of testing is conducted during the feasibility stage, with the results directly influencing processing plant design. Incomplete knowledge, or non-representative results, can have a major negative effect on achieving design capacity and economic performance, particularly during start-up.

A key objective of the GeM^{III} project is to create a new approach to geometallurgical characterisation that enables highly constrained (small volume) samples, with defined textural and mineralogical attributes, to be tested for processing performance. This required the development of a suite of new and modified physical testing methods capable of providing meaningful processing parameters based on large numbers of small sample volumes (typically 2 m of half NQ or HQ core).

This approach allows fundamental relationships to be determined, based on geologically constrained inputs provided from the other research modules. The aim is to develop predictive models of processing performance through the application of integrated and calibrated modelling, based on textural and mineralogical attributes. Once identified, many of these attributes can be supplied through other measurement technologies that do not necessarily require physical testing.

The project has developed an integrated suite of new and modified testing methods to support geometallurgical modelling; with an emphasis on comminution testing and throughput modelling. This includes the JK RBT, which is designed to provide rapid impact hardness results and a novel Comminution Index – designed to be inserted into routine assay sample preparation to give a first-pass indication of crushing and grinding performance. Comminution Index testing provides geometallurgical information at potentially the same scale as assays, and extensive trials are underway with a commercial laboratory to provide the test as a routine service to sponsors.



Pat Walters with an RBT device for rapid hardness testing at the Julius Kruttschnitt Mineral Research Centre at the University of Queensland.

P4.L1.5 Geometallurgical modelling and geostatistical attribution of processing performance attributes

Leader: A Bye

Team Members: A Richmond, M Newton

Student: L Keeney

Effective statistical incorporation of non-grade geometallurgical attributes, such as hardness or throughput into resource models, is a significant challenge. This reflects the non-additive, and potentially non-linear, nature of geometallurgical attributes in machine-based systems. Use of small numbers of composited samples in current geometallurgical testing programs does not facilitate detailed evaluation of statistical methodologies, and the risk involved in presuming additivity.

The approach to large numbers of small-scale geometallurgical testing (linked to deterministic modelling being developed in the GeM^{III} project) is providing new opportunities to evaluate these challenges. Various statistical and spatial modelling techniques are being investigated, including plurigaussian and conditional simulation. This is linked to new approaches for multivariate, class-based modelling, designed to more effectively identify processing domain boundaries. New software tools to support these capabilities have been released to sponsors.

P4.L1.6 Provision of formalised geometallurgical awareness, education and training

Many of the outcomes from the GeM^{III} project represent a new approach to the emerging field of geometallurgy. While the aim is to provide a 'tool kit' of more effective technologies and methods within an overall generic framework, application to individual deposits and processing outcomes requires customisation and expertise. A key aspect in this application is team-based, cross-discipline integration and communication, which requires support through education and training.

Because of the foundation nature of the research, and the requirement to build critical mass and cross-discipline integration within the research organisations, opportunities for wider education and training within the current project have been limited – restricted to geometallurgical awareness workshops provided to sponsor companies.

More formalised education and training courses are considered vital aspects of the GeM^{III} extension proposal. These are likely to include a formalised Masters course in geometallurgy based on the highly successful, modularised, part-time Master of Economic Geology program, which is currently offered by UTAS in conjunction with the University of Western Australia, James Cook University and Curtin University. Discussions with sponsors indicate a high degree of support for this approach. Individual course units will be offered across the expanded range of research organisations participating in the extension phase of the project.

PhD projects in the Recovery Program

Natalee Bonnici (CODES): Textural and mineralogical characterisation of copper-gold systems in relation to process mineralogy.

Adel Vatandoost (CODES): Automated petrophysical characterisation of drill core and potential relationships to mineral processing attributes.

Anita Parbhakar (CODES): Texture-based approaches to predictive geo-environmental modelling.

Cathy Evans (JKMRC): Texture-related flotation characteristics of ores.

Luke Keeney (JKMRC): Integrated geometallurgical modelling of the Cadia East deposit.

George Leigh (JKMRC): Wavelet analysis of texture parameters related to mineral processing.

Richard Hartner (JKMRC): Integration of MLA and optical microscopy.

Control room at the Clarabelle Mill at Vale Inco's Sudbury operations.



Program 5

Objectives

Develop new analytical techniques, ensuring that research is driven by innovative technology, at the cutting edge of analytical developments relevant to ore deposit research

Providing research staff and students with access to the state-of-the-art micro-analytical equipment within Australia and overseas, and maintain their awareness of the new analytical developments

Leader

Leonid Danyushevsky

Team Members

Stacey Borg (joint appointment with CSIRO), Zhaoshan Chang, David Cooke, Garry Davidson, Barbara Etschmann (joint appointment with CSIRO), Jeff Foster, Sarah Gilbert, Anthony Harris, Janet Hergt (University of Melbourne), Rob Hough (CSIRO), Brett Johnson (University of Melbourne), Vadim Kamenetsky, Jamie Laird (joint appointment with CSIRO), Ross Large, Jeff McCallum (University of Melbourne), Katie McGoldrick, Peter McGoldrick, Sebastien Meffre, Karin Orth, Chad Paton (joint appointment with University of Melbourne), Phil Robinson, Chris Ryan (CSIRO), Terrie Sawyer, Clara Wilkinson, Jamie Wilkinson, Jon Woodhead (University of Melbourne)

PhD Students

Heidi Pass, Olga Vasyukova

Collaborators

Australian National University – John Mavrogenes, Marc Norman

Australian Synchrotron – David Paterson, Martin de Jonge

CSIRO – Weihua Liu, Robin Kirkham

Geoscience Australia – Terry Mernagh

Hefei University of Technology (China) – Taofa Zhou

Imperial College (London) – Andrew Berry

National Synchrotron Light Source (USA) – Pete Siddons

United States Geological Survey – Steve Wilson

University of Adelaide – Joel Brugger

University of Chicago (USA) – Matthew Newville, Stephen Sutton

University of Munster (Germany) – Chris Ballhaus

University of Western Australia – Stefan Haggeman



Highlights

- Development of a technique for analysis of Cu isotopes by solution MC-ICPMS.
- Successful testing of an imaging capability with Maia-96 detection system at the X-ray Fluorescence Microprobe beamline of the Australian Synchrotron, which enables simultaneous capturing detail over a range of scales from 1 μm particles to subtle zonation over several millimetres.
- Initiation of an ion-beam electrochemistry project on the CSIRO Nuclear Microprobe aimed at better understanding the depositional mechanisms of gold in sulfide minerals.
- Development of a new laser ablation cell within the CODES LA-ICPMS facility.

The Technology Program explores and develops novel, state-of-the-art analytical and data interpretation techniques to enhance the understanding, exploration and exploitation of deep-earth resources. Current research projects are focused 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, and the development of new stable-isotope solution-based analytical techniques. Many of the projects include close collaborations with several of the Centre's nodes.

Leonid Danyushevsky, Program Leader

Outlook

The main research focus in 2009 will be on:

- Expanding both the equipment base and the range of techniques within the CODES LA-ICPMS analytical facility at UTAS – including, in-situ mercury and sulfur isotope analysis and quantitative imaging.
- Development of computational algorithms for quantitative LA-ICPMS imaging at the UTAS hub and the University of Melbourne node.
- Developing an ion-beam electrochemical technique at the CSIRO Nuclear Microprobe, which is aimed at better understanding the depositional mechanisms of gold in sulfide minerals.



Program 5: Technology

Core projects

Project P5.F1 Analytical developments in the CODES LA-ICPMS facility

Project P5.F2 Pb and Cu isotopes in sulfides, silicate melt inclusions and fluid inclusions using multi-collector ICP-MS

Project P5.F3a Developmental research into the use of synchrotron in ore deposit studies

Project P5.F3b CODES-CSIRO synchrotron technology development

Project P5.F4 Nuclear microprobe analytical developments

Project P5.F5 Application of PIXE technologies to hydrothermal processes: mineral trace element zoning and composition of single fluid inclusions

Project P5.F6. Trace element and isotope developments in the CODES LA-ICPMS facility

Project P5.F8 Cracking the sulfate isotopic composition problem in ancient hydrothermal systems: application of the carbonate-associated sulfate (CAS) method

(F prefix denotes fundamental research project.)

Project P5.F1 Analytical developments in the CODES LA-ICPMS facility

Leader: Leonid Danyushevsky

Team Members: Sarah Gilbert, Peter McGoldrick, Phil Robinson

Collaborators: Chris Ballhaus, Marc Norman

The composition of the NiS standard for analysis of PGE and Au in sulfides has been determined by 1) solution ICP-MS, in cooperation with Marc Norman (ANU), and 2) LA-ICPMS, using a number of available PGE standards. These standards are:

- synthesised (Fe,Ni)S sulfide standard 8b, developed by the group headed by Chris Ballhaus (University of Munster),
- a synthesised, pressed-powder precipitated sulfide standard MESS-3 developed by USGS, and
- Lombard iron meteorite.

The NiS standard is now used routinely for PGE analysis and mapping at CODES LA-ICPMS analytical facility. A paper describing the standard is in preparation and will be submitted for publication in 2009.

Our search for a homogeneous, natural carbonate mineral that can be used as a primary standard for LA-ICPMS of carbonates proved fruitless. As an alternative, we acquired a synthesised pressed-powder precipitated carbonate standard MACS-3 from USGS. This standard is currently being assessed in cooperation with USGS, and will be available for use in 2009.

Sebastien Meffre at the CODES LA-ICPMS facility.





Chad Paton in the multi-collector ICPMS laboratory at the University of Melbourne.

Project P5.F2 Pb and Cu isotopes in sulfides, silicate melt inclusions and fluid inclusions using multi-collector ICP-MS

Leaders: Janet Hergt, Sebastien Meffre

Team Members: Zhaoshan Chang, David Cooke, Leonid Danyushevsky, Jeff Foster, Sarah Gilbert, Ross Large, Chad Paton, Jon Woodhead

During 2008, development work on protocols for the separation and isotopic analysis of copper were largely completed, although further refinement of the method is ongoing. Having established protocols, a micro-drilling sampling regime was designed to identify the extent of Cu-isotope fractionation, both between ore deposits and within single systems, and of subsequently constraining the primary causes of Cu-isotope fractionation in natural systems. To date, 33 samples spanning 12 diverse ore deposits have been analysed. A review paper summarising progress in Cu-isotope analysis and showcasing the work of this project is currently in preparation.

Further sampling was conducted employing the previously developed protocols for Pb-isotope analysis of pyrite. In addition, preliminary testing of the potential to produce Pb-isotope 'image maps' by laser ablation produced promising results.

The recently developed 'lolite' software package from the University of Melbourne has proven to be of significant interest to several CODES-related projects, and preliminary work is underway to make suitable import modules, and other adaptations, that will allow CODES' data to be manipulated using the software.

Project P5.F3a Developmental research into the use of synchrotron in ore deposit studies

Leaders: Andrew Berry, Anthony Harris

Team Members: David Cooke, Vadim Kamenetsky, Chris Ryan, Clara Wilkinson, Jamie Wilkinson

Collaborators: John Mavrogenes, Terry Mernagh, Matthew Newville, Stephen Sutton

CODES, together with research partners at Imperial College, London, and the University of Chicago, has advanced the current understanding of metal complexation in hydrothermal fluids at magmatic conditions. In-situ, non-destructive spectroscopy experiments have been completed on natural fluid inclusions in miarolitic quartz in a granite, intimately associated with reduced tin-rich ore deposits. Cu X-ray absorption spectra (XAS) from natural fluid inclusions up to 700°C were recorded using synchrotron radiation at the GSE-CARS beamline at the Advanced Photon Source, Chicago. Two inclusion groups were studied with contrasting Cu concentrations (between 0.02 and 0.8 wt% Cu), where Cu can be shown to be homogeneously distributed in solution at temperatures above salt dissolution (between 350 and 550°C). X-ray absorption near edge structure (XANES) spectra of the resultant hydrothermal fluid recorded an intense edge feature near 8983 eV that is characteristic of the linear $[\text{CuCl}_2]$ - complex. This spectrum was obtained at all temperatures between 200 and 700°C, from 15 inclusions. Extended X-ray absorption fine structure (EXAFS) spectra recorded at 700°C were modelled to give a Cu-Cl bond length of 2.19 Å. The results provide unambiguous evidence that $[\text{CuCl}_2]$ - is the only stable Cu-Cl complex in natural brines under magmatic hydrothermal conditions. This is the first time that Cu speciation has been determined at these temperatures and demonstrates the utility of fluid inclusions as sample cells for the spectroscopic study of fluids. When compared with other spectroscopic studies of similar ore systems, it appears that $[\text{CuCl}_2]$ - is stable in both low density vapour-rich and saline ore solutions associated with sulfur-poor hydrothermal fluids across the magmatic-hydrothermal transition.

New spectroscopic experiments, performed from room to high temperatures, have extended the suite of elements studied to include Cu, Fe, Mn and Zn. The Cu K-edge XANES spectra, acquired at room temperature and at high temperature, shows that Cu^{2+} is present at ~25°C, whereas Cu^+ occurs in solution at higher temperatures (>200°C). High-temperature (>500°C) laser Raman spectroscopy (in collaboration with Geoscience Australia) failed to confirm the presence of detectable hydrogen, which would have helped to explain this reversible and repeatable change in Cu oxidation state. Although all available high-temperature X-ray absorption spectra confirms that $[\text{CuCl}_2]$ - is the only stable Cu-Cl complex, $[\text{ZnCl}_4]^{2-}$ (for example) is the stable Zn-Cl complex in natural brines up to 700°C. By studying the speciation of a number of metals in the same system, from

Program 5: Technology

magmatic to depositional temperatures, we are able to identify differences between elements, or changes with temperature, that may explain how and when metals decouple, and the geochemical evolution of ore-forming solutions.

X-ray spectroscopic experiments and mapping have been performed (at the GSE-CARS beamline) to investigate metal complexes in sulfides found in economically important hydrothermal ore systems. Preliminary data has been acquired for invisible Au found in enargite from high-sulfidation epithermal ore deposits. This mineral chemistry work is critically important for attaining a better understanding relating to a number of areas, from fundamental ore-forming processes through to mining and mineral processing.

Project P5.F3b CODES-CSIRO synchrotron technology development

Leader: Chris Ryan

Team Members: Stacey Borg, Leonid Danyushevsky Barbara Etschmann, Anthony Harris

Collaborators: Joel Brugger, Martin de Jonge, Robin Kirkham, Weihua Liu, David Paterson, Pete Siddons

CSIRO, together with a consortium of six organisations, was successful in an ARC LIEF bid to develop a suite of advanced spectroscopic tools to probe the extreme chemistry of ore fluids and the complexity of natural materials. These tools include a high-temperature and pressure chemistry cell, and a revolutionary spectroscopy detector system known as Maia, both to be located at beamlines at the Australian Synchrotron (AS).

The high-TP cell is being developed by the CSIRO Extreme Chemistry team and the Minerals, Metals and Solutions group at the University of Adelaide. The construction is well advanced and

it is anticipated that tests will be conducted early in 2009. This will provide a valuable tool for probing the chemistry of ore metals in the extreme physical and chemical conditions encountered in ore systems and their magmatic precursors.

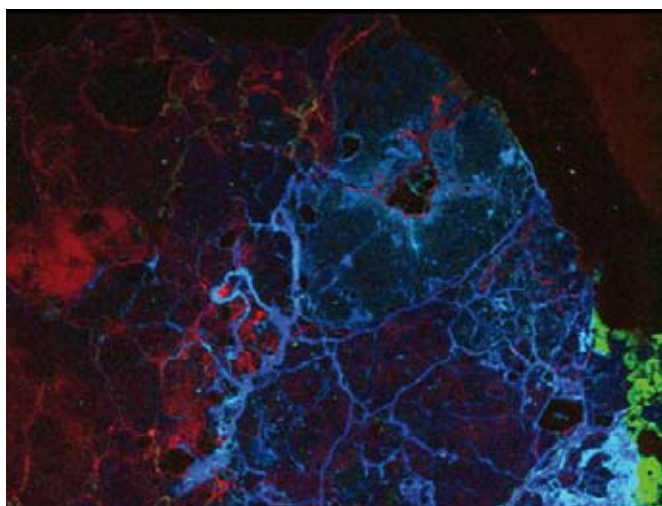
Barbara Etschmann, Weihua Liu and Stacey Borg were involved in successful extreme chemistry experiments at AS, including:

- (i) the characterisation of Cu^+ in super-critical aqueous fluids, which revealed a strong pressure effect that could provide a strong ore deposition mechanism;
- (ii) a search for effective P complexing of Cu in solution, which revealed no competitive P complex;
- (iii) the thermodynamics of Bi in co-existing fluids and melts, which demonstrated that a Bi-dominant melt could effectively scavenge Au from under-saturated hydrothermal fluids;
- (iv) the thermodynamics of Te in hydrothermal fluids, which is often associated with gold mineralisation;
- (v) combined SXRF mapping, XANES and XRD measurements of Au in natural carbonates;
- (vi) speciation of covalently-coordinated Ni in solutions and the development of the XAFS beamline at the AS;
- (vii) mechanisms of Au accumulation by the metallophillic bacterium *Ralstonia metallidurans*;
- (viii) the spectroscopic study of Cu-S-Cl systems in low-density brines.

The Maia advanced spectroscopy detector system is being developed by CSIRO in collaboration with the National Synchrotron Light Source (NSLS) and Brookhaven National Laboratory (BNL). The concept is to build an array of 384 silicon detectors with full spectral data acquisition for each detector, and real-time processing of each detector signal (to a maximum



Part of the Project P5.F3b team at the X27A beamline at the National Synchrotron Light Source, Brookhaven National Laboratory, New York, during a test of the Maia-96 detector system and its application in SXRF imaging.



Gold-bearing clay (10 x 10 mm area, 1.25 micron pixel size) showing distribution of Br, As and Fe in red-green-blue, respectively. The image was collected during testing on a prototype Maia-96 detector.

of 100M events per second). Design and construction are well advanced and it is anticipated to start tests using the full array early in 2009.

In parallel, further improvements in the prototype system, Maia-96, have enabled a series of demonstration experiments at the X-ray Fluorescence Microprobe (XFM) beamline at the AS. These have demonstrated unprecedented imaging capabilities, including 8000 x 8000 pixel images and increases time per pixel from 10 ms to 50 μ s, with full X-ray spectra (4096 channels) collected for each of the 96 detectors at count rates of up to 3.5 Mc/s. For the first time, detail can be captured over a range of scales from 1 μ m scale particles and overgrowth rims, up to subtle zonation in trace elements (e.g. away from alteration veins) over several millimetres.

Development of algorithms for the analysis of these large datasets, aimed at capabilities for chemical state imaging and 3D fluorescence tomography, is continuing. Exhaustive analysis of last year's XANES image stack data, collected at the NSLS, has been used to show that deconvolution of SXRF components can be used to generate XANES spectra for each pixel in an image as a basis to extract species components. However, the quality of the data was not good enough for viable species imaging. The lessons learnt will be utilised in follow-up trials of the technique on the XFM beamline in 2009.

Project P5.F4 Nuclear microprobe analytical developments

Leader: Jamie Laird

Team Members: Leonid Danyushevsky, Chris Ryan

Collaborators: Rob Hough, Brett Johnson, Jeff McCallum

This project is divided into two parts: (a) better understanding mineral electrochemistry; and (b) developments in analysis of fluid inclusions using PIXE and novel Rutherford Backscattering Spectrometry (RBS) techniques.

(a) Mineral Electrochemistry: Progress is subdivided into two categories – Theoretical and Experimental:

- **Theoretical:** a background review into mineral electrochemistry in the context of several CODES research projects has been completed. This includes a review of semiconductor-electrochemistry in the context of natural minerals of interest to both CODES and CSIRO.
- **Experimental:** the focus to date has primarily been on developing instrumentation for the ion beam electrochemistry project. We have several techniques for characterisation of various aspects nearing completion including: (1) Capacitance Voltage profiling of impurity structures and Helmholtz layers in electrochemical cells; (2) Current Voltage profiling; (3) probed thermoelectric voltage measurements; and (4) Hall effect vs. temperature measurements for estimating mineral resistivity/activated carrier density/carrier mobility. This last technique is extremely useful and will form the backbone of sample selection and comparison to theoretical modelling. It is a standard technique for measuring the electrical characteristics of natural minerals including, most notably, pyrite.

In parallel with the above developments, we are in the process of building a custom holder for the CSIRO microbeam line to enable spatial-temporal charge injection measurements. This will include a temperature stage (0–400°C) and will allow correlation with some of the bulk electrical measurements (1–4) mentioned above.

(b) Fluid Inclusions: Simulations of Non-RBS mode mapping have been performed, using SIMNRA. These simulations have shown the feasibility of segregating quartz and a fluid inclusion in an RBS spectrum, and the possibility of extracting accurate geometrical information regarding the inclusion. This information can then be fed into PIXE data for more accurate analytical extraction of elemental concentrations within an inclusion.

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Project P5.F5 Application of PIXE technologies to hydrothermal processes: mineral trace element zoning and composition of single fluid inclusions

Leader: Zhaoshan Chang

Team Members: David Cooke, Leonid Danyushevsky, Vadim Kamenetsky, Chris Ryan

Collaborator: Taofa Zhou

Ten alunite grains from seven samples from the Mankayan District, Philippines, have been mapped using PIXE. It has been found that alunite can contain significant amounts of Pb, Sr, Zn, As, Ga and Ba in the lattice. As alunite is one of the most common minerals in advanced argillic alteration in high-sulfidation epithermal deposits that are typically located above porphyry deposits, the findings indicate that alunite geochemistry may be an effective tool in the exploration for high-sulfidation epithermal deposits and porphyry deposits at depth.

Project P5.F6 Trace element and isotope developments in the CODES LA-ICPMS facility

Leader: Sebastien Meffre

Team Members: Leonid Danyushevsky, Sarah Gilbert

This project had three objectives in 2008: (1) Determine the optimum conditions for the analysis of galena by laser ICPMS; (2) improve on the reliability of sulfur isotope determination on the ICPMS; (3) build and test a new constant geometry laser ablation chamber.

- Galena from a variety of Pb deposits worldwide were analysed, both with solution ICPMS and laser ICPMS, using special tuning conditions to turn down the sensitivity of the ICPMS. Slow (1 micron/s) lines, 10 micron in width, proved to give the best results. We also experimented with increasing the counting time of ²⁰⁴Pb to try and improve precision. This proved to be detrimental to precision if the signal varied in intensity during the analysis. The technique was used on various projects throughout the year. The technique is working well, although it is less precise than solution quadrupole ICPMS; therefore it will be used mostly as a reconnaissance tool to help choose samples for solution multi-collector ICPMS analysis.
- Improvements to the reliability of sulfur isotope measurements were briefly investigated, but the work was placed on hold until a new chamber is available (see below). It was felt that this would greatly improve the precision of the analyses.
- Chamber developments proceeded throughout 2008 with the first iteration fitted on the UP193ss laser probe in September. A second iteration, with further improvements, was completed in November, and the final iteration is expected to be ready

early in 2009. The new chamber offers a constant geometry between the ablation site and the tubing that transports the ablated material out of the chamber; a fast response time between the laser pulse and the material arriving to the ICPMS; a smooth signal that does not vary between spots; and the ability to have four sample blocks in the chamber at one time. We expect to build the second chambers for the UP213 laser probe late in May 2009.

Project P5.F8 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, Janet Hergt, Katie McGoldrick, Karin Orth

Collaborator: Stefan Haggeman

This project evaluates the concept of substituted sulfate in hydrothermal carbonate minerals. This material is unexploited in hydrothermal research, and refinements to existing techniques are required to both extract the isotopic information and to image the low-level abundances of sulfate that appear to be typical of hydrothermal carbonate. These sulfur levels (mainly <100 ppm) lie below detection for beam-based stable isotope analytical methods. Therefore, wet chemical extraction is currently the only method for isolation of sufficient sulfur for isotopic analysis. In turn, the wet chemical extraction method requires large sample weights (10–60 g), which raises issues of smearing of isotopic signal if the hydrothermal carbonate paragenesis is complex and/or not uniform. This issue resulted in the team progressing a strategy of imaging and analysing the sulfur in hydrothermal carbonates to determine its distribution in typical hydrothermal veins, particularly its behaviour during prolonged hydrothermal histories.

This characterisation focused exclusively on the Canadian Mt Polley alkalic porphyry-hosted Cu-Au deposit, using samples provided by PhD student Heidi Pass. We investigated: (1) syn-ore carbonates from veins with calcite-anhydrite-bornite-chalcocopyrite-analcite-muscovite assemblages; and (2) near ore and regional sedimentary carbonates (the latter contained low S levels, <50 ppm). This completed our inventory of sulfate behaviour in Mt Polley carbonates. The syn-ore vein carbonates were characterised in great detail, using cathodoluminescence and microprobe techniques, but the sulfur-in-carbonate relations have not been evaluated at this stage.

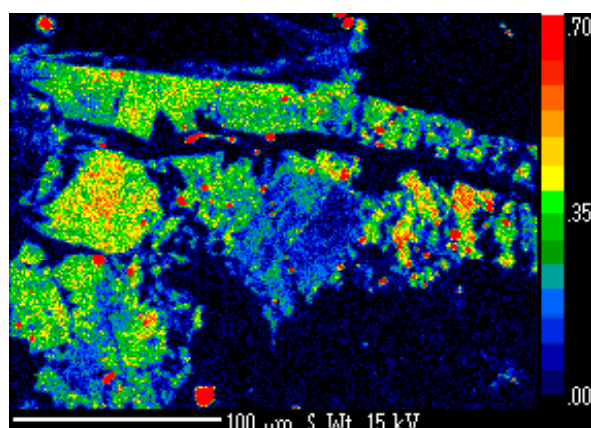
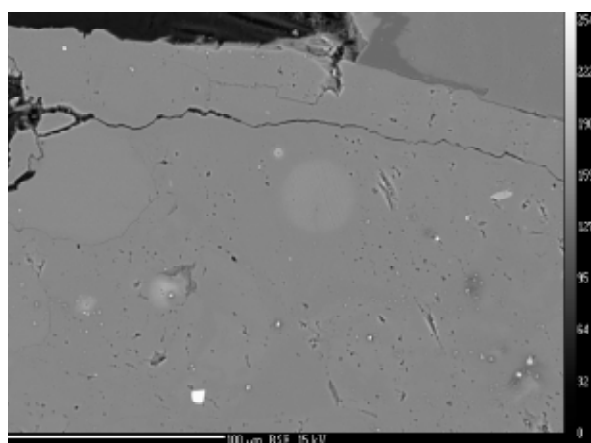
Previously, a picture emerged, from a range of systems, that higher temperature carbonates contain lower abundances of sulfate. However, the syn-ore carbonates at Mt Polley, in places, commonly contain primary carbonate bands with very high

sulfur abundances (up to 0.2 wt%), as well as lower S bands (down to ~50 ppm). In comparison, early sulfate-rich carbonate from post-ore veins contains 200–500 ppm S. This indicates that the controls on sulfate substitution must be more complex than simple thermal influence. The high temperature veins display good evidence of equilibrium growth between anhydrite, bornite/chalcopyrite and carbonate, but there is also strong evidence of replacement of anhydrite by carbonate, mainly in the form of needle-like zones of high S, imaged by microprobe mapping within carbonate. This was also seen in the post-ore carbonates. It is likely that at high (300–400°C) temperature, high sulfate abundances in carbonate may develop, both through equilibrium precipitation of carbonate and anhydrite (when sulfate is partitioned in significant amounts into both minerals), and as relics within areas of carbonate-replaced anhydrite. It is likely that the prevailing Ca mineral in this system is determined by XCO_2 values. As in the post-ore veins, there is good evidence that the cracks, formed during younger hydrothermal events, leached sulfate and other trace elements, although this was not a dominant effect in this case. The isotopic analyses of these veins likely record the integrated isotopic compositions relevant to syn-ore conditions, which provides confidence in the relevance of the CAS technique.

In other aspects of this project, collaborations are progressing that are enabling analysis of carbonates in a wide range of hydrothermal systems. An important example is analysis of vein, breccia matrix, and replacement carbonate in upgraded Hamersely-style iron formations of the Carajas district. This is a multidisciplinary project, which has involved CAS analysis, microprobe S and trace element mapping, stable isotopes and Sr isotopes. The project is sponsored by UWA, with the abovementioned analytical component being the responsibility of CODES' staff. A manuscript is in preparation.

Other activities within Program 5

- Ruben Chan, CODES Database Manager, continued work on developing a database of chemical analyses produced at the CODES LA-ICPMS facility.
- Petrolog 3.0, a new version of the unique, user-friendly software package for modelling processes of magma crystallisation and melt inclusion evolution, has been released.



The benefits of detailed element mapping are shown here for syn-ore carbonate at Mt Polley. The back-scattered electron image at the top shows little element-related tone variation, but S mapping underneath reveals large areas of sulfur-soaked carbonate.

Graduate Research and Training

Research Higher Degree Program

Research Higher Degree (RHD) students make a major contribution to the research activities at CODES. Approximately 90% of RHD projects are integrated into our five research programs and about 66% of the projects involve collaborations with industry.

There were 48 PhD and three MSc students enrolled in the CODES RHD program in 2008. This group includes four new PhD students – Nicholas Jansen from Canada, Kirill Bychkov from Russia, plus Fiona Best and Lindsey Clark from the UK. Four students submitted their theses for examination – Felipe Urzua, Lee Evans and Weerapan Srichan (all PhD) and Takayuki Manaka (MSc). Felipe and Lee have taken full-time positions in industry and Weerapan has accepted a lecturing position at the School of Earth Sciences, Chiang Mai University, Thailand. Takayuki will begin a PhD degree at CODES in 2009.

Eight PhD students suspended their candidature for part or all of the year, and a further eight chose part-time candidature, primarily to take positions in the minerals industry. One PhD student withdrew from candidature. The withdrawal, suspensions and part-time enrolments have reduced the effective PhD workforce to around 31, which is adequate but below the target of 40. However, a mitigating factor was the lure of high-paying jobs in the minerals industry during the majority of this period.

The 2008 RHD cohort included 28 international students representing 17 nationalities, nine of whom were at least partly funded by CODES scholarships. All the new students in 2008 were international and all serious enquiries to date regarding 2009 enrolments have been from international students. CODES' success in attracting students from overseas is underpinned by our international reputation as a research training centre, our ability to invest ARC Centre funds in scholarships, and the generous support by UTAS in the form of international student fee waivers.

Many of CODES' RHD students are members of the UTAS Student Chapter of the Society of Economic Geologists. Chapter leader Nic Jansen and his team organised a highly successful series of professional events during the year, including short courses, lectures and field trips. These were complemented by an array of social activities that featured wine tastings, ice hockey matches, barbeques and quiz nights. Five students – Jacqueline Blackwell, Nic Jansen, Anita Parbhakar, Heidi Pass and Abhisit Salam – were successful in winning SEG research grants and awards that will help fund their PhD research.

CODES RHD students and staff with an interest in volcanology meet regularly for informal discussions of current research or to present reports on conferences or fieldwork. Although known as the 'Volcanology Group', a wide cross-section of the CODES community has been attending the meetings, which have been organised by Sarah Gordee and Andrea Agangi. In 2008, topics covered included the IAVCEI conference and field trips in Iceland, the 1982 eruption of El Chichon, surtseyan tuff rings and maars in Utah, ignimbrites on Gran Canaria, origin of pseudopillows, Australia's only active volcanoes on Heard and Macdonald islands, and pillow lavas at Cape Grim.



Jocelyn McPhie, Coordinator Graduate Research.

Master of Economic Geology Program

The CODES Master of Economic Geology (MEconGeol) program is part of the National Mineral Geoscience Masters Program that is supported by the Minerals Council of Australia. CODES offers five short courses into the cooperative program that is jointly presented with Curtin University, the University of Western Australia (UWA) and James Cook University. The program has continued to attract new recruits in 2008 and there are now over 37 students in the program, with a number of admissions still pending.

During a busy training year, CODES presented three Masters short courses, including: Volcanology and Mineralisation in Volcanic Terrains (April); Brownfields Exploration (June) and Ore Deposit Models and Exploration Strategies (October).

Jocelyn McPhie and Bruce Gemmell led the 21 participants in the Volcanology short course through a two-week examination of modern volcanic successions of the North Island, New Zealand, and the more ancient Mount Read Volcanics of western Tasmania. The participants comprised 12 MEconGeol students and nine industry participants.

Twenty-two participants took part in the Brownfields Exploration short course led by Tony Webster, Mike Roach and Steve Walters from CODES, plus external presenters Simon Gatehouse and Vic Wall. The participants comprised 13 MEconGeol students, five industry participants and two senior representatives from one of CODES' research collaborators in the Democratic Republic of Congo (Gecamines).

Despite the full houses for Volcanology and Brownfields, by far the largest attendance was for the Ore Deposit Models and Exploration Strategies short course. Participants included 19 MEconGeol students and 24 industry geologists. The intensive program was conducted by CODES' presenters Stuart Bull, David Cooke, Jeff Foster, Bruce Gemmell, Anthony Harris, David Hutchinson, Ross Large, Peter McGoldrick, Andrew McNeill, Rob Scott, David Selley, Steve Walters and Tony Webster. Students completed a heavy workload that comprised a mix of practical and lecture sessions on a range of topics relating to the genesis of ore deposits, with exploration models presented for each style. The standards achieved by the participants were very high, with three High Distinctions, 16 Distinctions and four Credits awarded.

The Ore Deposit Models short course was preceded by a highly successful three-day 'Exploration on the Edge Symposium'. Over 60 industry, government and academic geoscientists from all over the world attended this event and several stayed on for parts of the Ore Deposit Models course.

CODES continued its close relationship with the Minerals Council of Australia through the council's Minerals Tertiary Education Consortium (MTEC). The support from MTEC is used to enable the exchange of Honours and Masters students between universities. This provides CODES' students with the benefit of having access to specialised courses that would not normally be available at UTAS. It also presents students from the mainland with the opportunity to travel to Tasmania to experience courses offered by CODES.

Honours Program

Honours student numbers remained stable at nine (based on mid-year students being counted in the year they finish). This continues a three-year trend that has resulted in half to two-thirds of our undergraduate students deciding to take up well-paid jobs in industry, rather than continue to Honours level.

Projects were spread across the disciplines in the following categories: geothermal geophysics (1), resource geophysics (1), regional geophysics (1), volcanology (1), sedimentology (1), structure and geochronology (1), and economic geology (1). Three projects were based in Tasmania, with the others in Western Australia and Thailand.

The Honours year was administered by Garry Davidson, with Peter McGoldrick supervising the coursework aspects. CODES staff Michael Roach (3 students), Anya Reading (3 students), Ron Berry, Sebastien Meffre, Mark Duffet, Stuart Bull, Garry Davidson and Jocelyn McPhie undertook student supervision.

CODES postgraduate students on Ngauruhoe volcano, New Zealand.



Outreach

Outreach

CODES, in conjunction with the UTAS School of Earth Sciences, took part in numerous activities in 2008 aimed at promoting the earth sciences to the broader community and specific target groups.

For the younger age group, 10 primary schools were visited where presentations were provided demonstrating geological work techniques, including a glimpse of the travel and adventure that is an integral part of this career path.

Michael Roach conducted an extended program for Grade 8 students at Taroona High School, Hobart, working with the teachers to develop an investigation of the geology along the foreshore near the school.

Grade 11–12 students from four schools took part in separate half-day visits, during which they learnt about earthquake energy and what earthquakes can reveal about global tectonics.

As part of our participation in the Siemens Science for Schools program, visiting students took part in activities related to the topics: 'earthquake waves' and 'the rocks that make up Tasmania.' Further geological activities were made available through the Australian Student Mineral Venture, drawing on the expertise of museum curator Izzy von Lichten and CODES' geologists.

Michael Roach undertook a program of visits to six large pre-tertiary colleges, where he spoke to students who are making subject choices that will determine the options available to them at university. As geology is not generally taught at pre-tertiary level in Tasmania, these visits are a particularly important part of our program to promote the earth sciences as a career option.

As well as speaking to school students, we also provided activities to science teachers who visited UTAS during in-service training programs. As part of these activities, materials for earth science exercises or projects were made available for the teachers to take back to their classrooms. CODES staff members also made energetic contributions at stalls at the UTAS Open Day and careers expositions hosted by Elizabeth College and Rosny College. All these events were open to students from throughout southern Tasmania.

This year's public lecture in the Tasmanian program for National Science Week, entitled 'Imaging the Interior of the Earth', was delivered by CODES' Senior Geophysics Lecturer, Anya Reading, in association with the Australian Institute of Physics. Anya was also Guest Editor of the July issue of *Physics Education*, which is aimed at teachers and lecturers of pre-tertiary and first-year university students. This themed issue focused on aspects of earth sciences applied to understanding the atmosphere, ice and deep tectonic structure of the polar regions of the Earth.



Mike Roach with a student during one of a number of visits to CODES by local school groups during the year.



Deputy Director, Bruce Gemmell, at Forest Pre-school in Sydney, where he introduced his youthful audience to the wonders of 'volcanoes and rocks'.

Opposite: Well-known science communicator and entertainer Adam Spencer speaks to the Graeme Clark Forum panel members, including Deputy Director Bruce Gemmell. The Forum was an ARC initiative to showcase research outcomes to the wider community.

G R A E M E

Outcomes

Wednesday, 18 June 2008
Parliament House, Canberra

www.arc.gov.au



Industry Links and Research Collaborations

Objectives

To be a research focus for the national and international minerals industry

To 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 our research. We will continue to collaborate with industry, and both national and international researchers and organisations, to further cement our place as a premier centre for ore deposit research.

Industry Links

CODES has strong, enduring and mutually beneficial links with AMIRA International and 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.

Role of AMIRA International

AMIRA facilitates 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 2008, AMIRA funded these major projects for CODES:

- P843 (GeM^{III} project – P4.L1) Geometallurgical Mapping and Mine Modelling
- P872 (P3.L3) Origin and setting of Congolese-type copper deposits
- P962 (P1.F4) Ni-PGE potential of mafic and ultramafic – a combined melt inclusion and numerical modelling approach
- P765A Geochemical and geological halos in green rocks and lithocaps – The explorer's toolbox for porphyry and epithermal districts.

Role of Industry Partners

Ten Australian and international mining companies make up the group of CODES industry partners: Anglo American, AngloGold Ashanti, Barrick Gold, BHP Billiton, Newcrest Mining, Newmont Mining, Rio Tinto, St Barbara Mines, Teck and OZ Minerals. Each of our sponsor companies provides support of \$20,000 to \$80,000 in cash per year to the research budget of the Centre of Excellence. A total of \$1,590,000 has been guaranteed over five years. 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 on 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.

Research Collaborations and International Visitors Program

During the year CODES built on its reputation for cultivating research collaborations with other Australian and international research organisations. In 2008, collaborative research was conducted with 47 international and 10 national organisations (see Appendices, pp. 102–105).

Collaborative research between our international and Australian-based partners is also being facilitated by joint research appointments. The table opposite details each of the collaborating institutions with the joint researchers and their funding source. These researchers are based at our collaborating partner institutions and incorporate research visits to CODES throughout the term of their research project.

Funding will continue to be used to support our International Visitors Program which attracts high-profile researchers to CODES. In 2008, the following major international research collaborators were supported to visit CODES for more than two months each:

- Professor Yoshi Goto (Muroran Institute of Technology, Muroran, Hokkaido, Japan) – visited Jocelyn McPhie from December 2007 to March 2008 to collaborate on Project P1.F3.
- Dr Mengist Teklay (University of Muenster, Germany) – visited Leonid Danyushevsky and Tony Crawford from April 2007 to March 2008 to collaborate on origin of Ethiopian flood basalts.
- Associate Professor Pavel Yu Plechov (Moscow State University, Russia) – visited Leonid Danyushevsky from 15 May 2008 to 31 August 2008 to collaborate on modelling of crystallisation processes.
- Professor Eduard Konnikov (Institute of Experimental Mineralogy, Chernogolovka, Russia) visited Leonid Danyushevsky, Andrew McNeill and Sandrin Feig from 1 December 2007 to 31 January 2008 to collaborate on the origin of the Dovyren magmatic complex within AMIRA Project P962.
- Professor Alexei Ariskin (Vernadsky Institute of Geochemistry, Moscow, Russia) visited Leonid Danyushevsky, Andrew McNeill and Sandrin Feig from 15 January 2008 to 15 April 2008 to collaborate on the origin of Dovyren magmatic complex and modelling of crystallisation processes within AMIRA Project P962.
- Dr Peter Hollings (Lakehead University, Canada) visited David Cooke from February to May 2008 to work on AMIRA Project P765A.
- Zahra Bonyadi (PhD student, Tarbiat Moellem University, Tehran, Iran) visited Garry Davidson and Sebastien Meffre from February to July 2008 to work on aspects of IOCG-related mineralisation in the Bafa district, Iran (P2.F4).

Researchers who work jointly in CODES and our collaborating organisations

<i>Institution</i>	<i>CoE ARC Grant</i>	<i>Node matching funds</i>	<i>Industry/AMIRA funds</i>	<i>University/CSIRO funds</i>
Julius Kruttschnitt Mineral Research Centre, University of Queensland	Steve Walters Robert Morrison Simon Michaux Alan Bye	Ben Adair	Nenad Djordjevic Khoi Ke Nguyen Yicai Wang	
University of Melbourne	Chad Paton Jon Woodhead			Janet Hergt
Australian National University	Angela Halfpenny (100%)			Stephen Cox
CSIRO Exploration and Mining	Barbara Etschmann (50%) Jamie Laird (50%)	Barbara Etschmann (50%) Jamie Laird (50%)		Chris Ryan Weihua Liu Stacey Borg
Mineral Deposit Research Unit, University of British Columbia, Canada			Kirstie Simpson Thomas Bissig	
Colorado School of Mines, USA			Nick Harris	Murray Hitzman
Vernadsky Institute, Russia				Alexei Ariskin



Technology Transfer

Objectives

To involve end-users (exploration and mining companies) in research planning, research evaluation and research adoption

To promote technology transfer so that innovative research outcomes are accessible to end-users

To 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 2008, 149 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 Hermann and R Large (sold 257 copies in 2008)
- *Volcanic textures: a guide to the interpretation of textures in volcanic rocks* (1993). Authors: J McPhie, M Doyle and R Allen (sold 193 copies in 2008)
- *New developments in Broken Hill-type deposits*. CODES Special Publication 1 (1996). Editors: J Pongratz and GJ Davidson (sold 5 copies in 2008)
- *Basins, fluids and Zn-Pb ores*. CODES Special Publication 2 (1999). Editors: O Holm, J Pongratz and P McGoldrick (sold 11 copies in 2008)
- *Volcanic environments and massive sulfide deposits* (2000). Authors: M Solomon and DI Groves (sold 11 copies in 2008)
- *The geology and origin of Australia's mineral deposits* (2000). Authors: M Solomon and DI Groves (sold 17 copies in 2008)
- *Giant ore deposits: characteristics, genesis and exploration*. CODES Special Publication 4 (2002). Editors: D Cooke and J Pongratz (sold 27 copies in 2008)
- *24ct Au workshop*. CODES Special Publication 5 (2004). Editors: DR Cooke, C Deyell and J Pongratz (sold 24 copies in 2008)
- *The geology of the Broken Hill Pb-Zn-Ag deposit, NSW, Australia* (2006). Author: AE Webster (sold 22 copies in 2008)

Commercial Products and Processes

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

Short Courses, Workshops and Conferences for End-users

The past year is unsurpassed in terms of the number of short courses and workshops delivered by CODES staff. Twenty-one courses were held at various locations around the world including Canada, South Africa, Thailand, Indonesia, Iceland and Australia.

Total attendance by industry geologists, academic researchers and postgraduate students was over 900, with 25 CODES staff involved in delivering the lectures.



Delegates at the Ore Deposit Models and Exploration Strategies short course.

2008 Short Courses/Workshops/Conferences led by CODES

<i>Title</i>	<i>Presenters (CODES presenters in bold)</i>	<i>No. of Attendees</i>	<i>Location</i>	<i>Date</i>
Volcanology and breccias for the explorationist – from description to interpretation	Jocelyn McPhie, David Cooke, Bruce Gemmell , Kirstie Simpson, Andrew Davies	50	Vancouver, Canada	25–27 Jan
The Platreef: a review	Jeff Foster , Tony Naldrett, Alan Wilson, Judith Kinnaird, Iain MacDonald	12	Anglo Platinum, Johannesburg	Feb
An Introduction to U-Pb geochronology	Sebastien Meffre	21	Dept of Mineral Resources, Thailand	Feb
Introduction to mining structural geology	Tony Webster	19	Oxiana Ltd, Golden Grove Operation	Feb
The nickel market and active magmatic sulfide systems	Jeff Foster	10	Zinifex, Melbourne	Mar
VIEPS Honours exploration skills mapping camp	Andrew McNeill, David Selley, Tony Webster, Martin Jutzeler	26	Near Rosebery, Tasmania	Mar
Volcanology and mineralisation in volcanic terrains	Jocelyn McPhie, Bruce Gemmell, Ross Large, Andrew McNeill	22	New Zealand and western Tasmania	30 Mar –13 Apr
Ore deposit models for exploration	Peter McGoldrick, Rob Scott, Jeff Foster, Bruce Gemmell, David Cooke, Garry Davidson	20	University of Melbourne	7–11 Apr
Geometallurgy with reference to the Platreef	Jeff Foster	16	Anglo American, Johannesburg	Apr
Brownfields exploration	Steve Walters, Michael Roach, Andrew McNeill, Peter McGoldrick , Simon Gatehouse, Vic Wall, Angela Lorrigan, Grant Macdonald, Travis Murphy, Dave Green, Kate Godber	21	CODES	9–20 Jun
Volcanic-hosted massive sulfide deposits	Bruce Gemmell	15	Breakwater Resources, Myra Galls mine, Canada	23–24 Jun
SEG-GSSA 2008 Workshop on Central African Copperbelt	David Selley, Stuart Bull, Ross Large, Murray Hitzman	18	Misty Hills, Johannesburg	Jul
Low sulfidation epithermal Au-Ag deposits	Bruce Gemmell, Steven Micklethwaite, Lindsey Clark	20	Newcrest, Gosowong mine, Indonesia	30 Jul–6 Aug
Imaging the interior of the Earth (National Science Week Public Lecture)	Anya Reading	50	UTAS	19 Aug
Recent development in explosive volcanism	Jocelyn McPhie, Sharon Allen , C Bonnadonna, M Barnney, A Clarke, B Houghton, J Phillips, I Skilling, S Takarada, A Woods	90	IAVCEI General Assembly, Reykjavik, Iceland	23–24 Aug
Geological mapping skills	Sebastien Meffre	35	Dept of Mineral Resources, Thailand	11–15 Sept
Conclusions from AMIRA P765 Project	Bruce Gemmell	15	Goldfields, Perth, WA	23 Oct
'Exploration on the Edge' Symposium	Anthony Harris, Tony Webster, Huayong Chen, Garry Davidson, Mark Duffett, Bruce Gemmell, Ross Large, Peter McGoldrick, David Selley , Tim Baker, Frank Bierlein, Ralph Bottrill, Mathew Briggs, Geoff Derrick, Greg Hall, Scott Halley, Richard Morris, Lorraine Torckler	60	CODES	27–29 Oct
Ore deposit models and exploration strategies	Anthony Harris, Tony Webster, David Cooke, Steve Walters, Bruce Gemmell, Ross Large, Peter McGoldrick, Stuart Bull, Rob Scott, Dave Hutchinson, Andrew McNeill, Jeff Foster	35	CODES	30 Oct–7 Nov
Ore deposit models and exploration	Zhaoshan Chang, David Cooke	300	Yunnan, China	1–5 Nov
SSEG Workshop on SEDEX deposits: a global perspective	David Leach, Peter McGoldrick	23	PACRIM 2008	22–23 Nov
Magmatic sulfide systems: theory and examples	Jeff Foster	20	BHP Billiton	Dec

Performance Indicators

Key result area	Performance measure	Target	2008
Research findings			
	Publications in international journals	40 pa	55
	Reports to industry collaborators	50 pa	149
	Special issues and/or research monographs	1 per 2 yrs	0
	Invitations to give keynote conference presentations	10 pa	13
	Papers at national/international meetings	60 pa	91
Investigators			
	Average % of CIs research in Centre (UTAS node)	70%	80%
	Average % of PIs research in Centre (Other nodes)	20%	27%
	Percentage of team-based projects	80%	72%
	Percentage of Australian cross-institutional projects	30%	37%
Research training and professional education			
	Percentage of RHD students attracted from other states of Australia (excluding Tasmania)	40%	75%
	Percentage of RHD students attracted from overseas	30%	60%
	Honours students in Centre programs	10	9
	RHD students in Centre programs	35	48 PhD, 3 MSc
	Percentage of student projects linked with industry	50%	72%
	Professional short courses/workshops for industry	5 pa	21
International, national and regional links and networks			
	Centre national or international major conferences/workshops	1 per 2 yrs	1 (On the Edge Symposium)
	Registrants at Centre conferences/workshops	50 pa	900
	International and national visitors per year	30 pa	177
	Major collaborative projects with other global centres/groups	10	11
	External collaborators using Centre equipment	10 pa	8
End-user links			
	Frequency of meetings with industry representatives	10 pa	22
	End-user representatives to Science Planning Panel and Advisory Board	20%/50%	20%/40%
	Frequency of meetings with AMIRA Research Coordinator	10 pa	14
	Number of industry visitors to Centre	50 pa	130
Organisational support			
	Annual cash contributions from UTAS (see Table 1)	\$1,300,000	\$1,597,026
	Annual cash support from CoE nodes (see Table 1)	\$250,000	\$250,000
	Annual cash support from industry (see Table 1)	\$1,450,000	\$3,646,611
	Number of new organisations recruited to or involved in the Centre	1 pa	0
	New annual cash support from industry	\$200,000	\$2,197,000

Key result area	Performance measure	Target	2008
Governance			
	Joint post-doctoral appointments between collaborative institutions/ organisations	5	9 (3 CSIRO, 1 ANU, 3 JKMRC, 1 UMelb, 1 UBC)
	Balance and experience of Advisory Board members		50% Academic, 40% Industry, 10% Government
	Annual review of strategic and business plans		Yes
	Effectiveness of Centre Research Committee		Yes
	Effectiveness of Science Planning Panel		80%
	Public profile of Centre	High	Internationally – very high; Nationally – high; Locally – low
National benefit			
	Centre research has input into a major mineral discovery	1 per 5 yrs	Newcrest discovery
	Employment of Centre's postgraduates by minerals industry	>65%	80%

Attendees of the Ore deposits of SE Asia project Annual Review Meeting in November.



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 Commonwealth Government covers five years' funding from 2005 to 2010, with a mid-term review in November 2008. 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 agreement.

2008 Cash Income

Total CODES income for 2008 was \$9.8 million (see Table 1). This was derived principally from industry (37%), the ARC (38%) and the University of Tasmania (16%) (see Figure 1).

The main income streams over time are compared in Figure 2, demonstrating that ARC funding is now being exceeded by other funding at a ratio of 1.6:1 (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.

Figure 1: Total cash income 2008

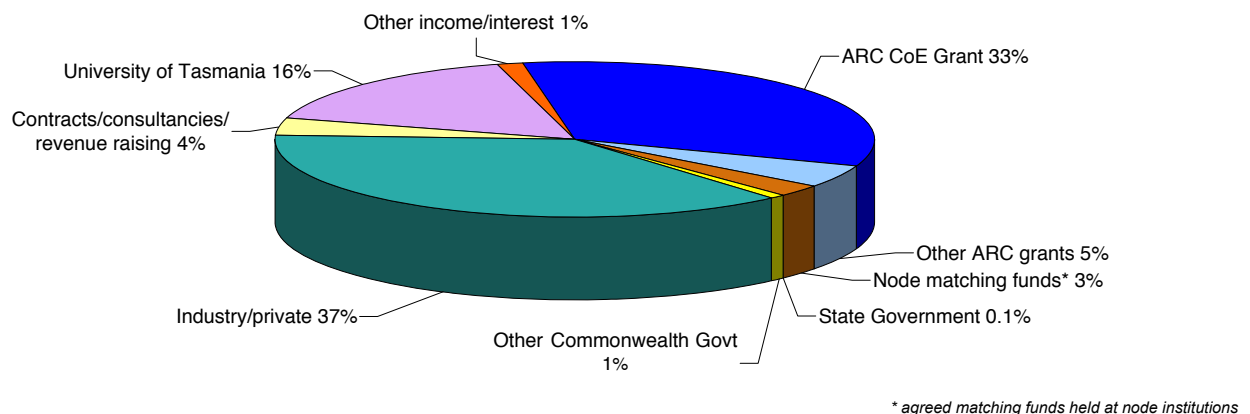


Figure 2: Comparison of CODES main income streams 2000–2008

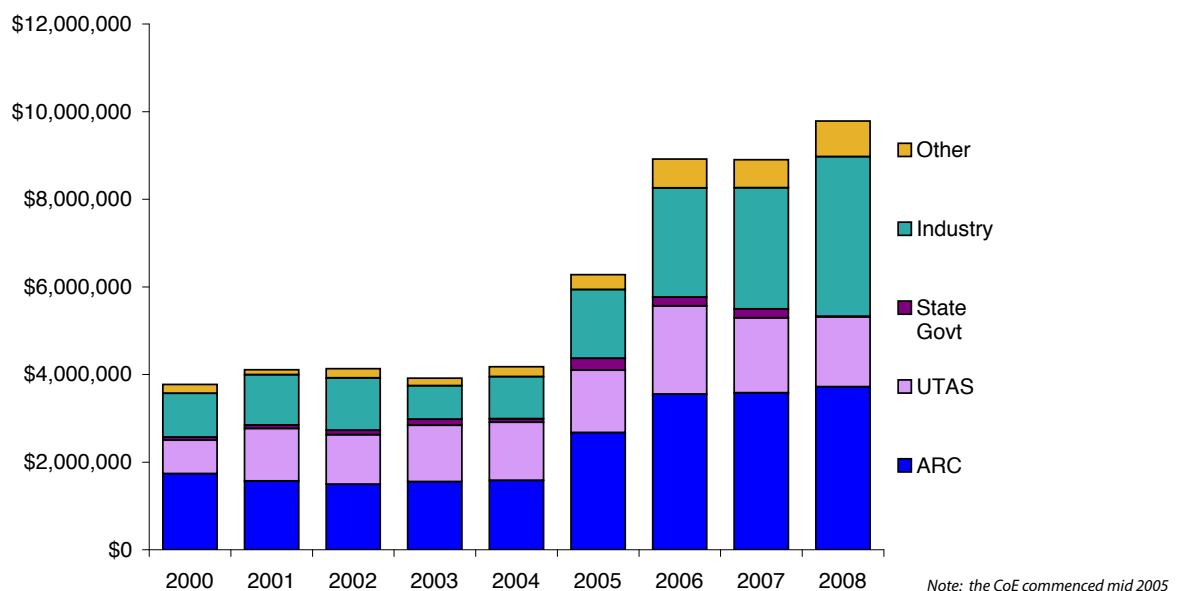


Table 1: Cash income financial statement 2005–2008

	(half yr) 2005	2006	2007	2008
ARC – Centre of Excellence Grant				
<i>CoE agreed core funding*</i> – 2005 indexation (not received until 2006)	0	31,500	0	0
<i>CoE agreed core funding*</i> – ARC Grant	1,500,000	3,121,198	3,184,402	3,248,088
	1,500,000	3,152,698	3,184,402	3,248,088
CoE nodes' matching funds (agreed matching funds held at node institutions)				
<i>CoE agreed core funding**</i>	0	295,000	255,000	250,000
Additional funding (pre-existing or new)	0	0	0	0
	0	295,000	255,000	250,000
Other ARC grants				
<i>CoE agreed core funding*</i>	0	0	0	0
Additional funding (pre-existing or new)	328,791	397,325	394,338	471,524
	328,791	397,325	394,338	471,524
Other Commonwealth Government funds				
<i>CoE agreed core funding*</i>	0	0	0	0
Additional funding (pre-existing or new)	7,184	19,649	24,666	62,680
	7,184	19,649	24,666	62,680
State Government funds				
<i>CoE agreed core funding*</i>	200,000	200,000	200,000	0
Additional funding (pre-existing or new)	68,000	852	4,000	8,000
	268,000	200,852	204,000	8,000
Local Government funds				
<i>CoE agreed core funding*</i>	0	0	0	0
Additional funding (pre-existing or new)	0	0	0	0
	0	0	0	0
Industry/private funds				
<i>CoE agreed core funding*</i>	868,646	1,582,507	1,825,010	2,158,677
Additional funding (pre-existing or new)	444,803	909,552	938,913	1,487,935
	1,313,448	2,492,059	2,763,923	3,646,611
Contracts/consultancies/revenue raising				
<i>CoE agreed core funding*</i>	0	0	0	0
Additional funding (pre-existing or new)	143,787	286,675	306,743	368,160
	143,787	286,675	306,743	368,160
University of Tasmania – host institution support				
<i>CoE agreed core funding*</i>	343,744	1,334,728	1,147,471	1,128,759
Additional funding (pre-existing or new)	383,623	678,064	566,682	468,267
	727,367	2,012,792	1,714,152	1,597,026
Other income sources/interest				
<i>CoE agreed core funding*</i>	0	0	0	0
Additional funding (pre-existing or new)	4,348	60,006	53,000	131,585
	4,348	60,006	53,000	131,585
Total annual income	4,292,926	8,917,056	8,900,226	9,783,674
Grand total of all income to date				31,893,882

*see Table 2(a) for summary of the *CoE agreed core funding* agreement

**see Table 3 for summary of the node cash funding agreement

Finances

The CoE Collaborator/Contributor Cash Income Agreement

The CoE funding agreement with the ARC requires that \$3 million per annum ARC funding will be matched, dollar for dollar, with agreed core funding from collaborators/contributors. This combined cash income is used to fund core research projects. Table 2(a) tracks the original CoE agreement against cash received to date. Table 2(b) lists additional income received towards core and non-core projects. The shaded right-hand column in Table 2 demonstrates that all agreed cash funding from the collaborators/contributors (except that of UTAS the hub) was up to date at the end of 2008. The grand total shows that CODES has currently received \$10.7 million more towards all 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 annually, in cash, with the exception of the CoE nodes, which are treated differently, as detailed in the next column.

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 2008:

ARC income: In addition to the CoE Grant (\$3.25 million), CODES received three ARC Linkage grants and two Discovery/Fellowship grants amounting to \$0.5 million. All other ARC grants previously held by CODES Chief Investigators were rolled into the CoE Grant in 2005.

CoE node income: The CoE's Australian nodes comprise the University of Queensland, University of Melbourne, Australian National University and CSIRO Exploration and Mining. The CoE agreement requires that CODES transfers 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 (see Table 3). Although these matching funds are counted as income to the CoE (Table 1 and Table 2), they are actually held and expended at the node institutions. Expenditure of both portions of node funding is reported annually to CODES. To date, all nodes have received their agreed ARC income from CODES and all have contributed their agreed matching funds (see shaded columns in Table 3).

State Government income: The agreed three-year funding from the State Government of Tasmania ceased at the end of 2007.

Industry income: All sources of industry funding increased in 2008, mainly due to the start-up of new key industry research projects. This increase is contributing to the overall income surplus shown in Table 2. Total industry funding (as shown in Table 1) was \$3.65 million, of which the largest contribution (57%) was from AMIRA International for CoE core and non-core research projects.

Host institution support: UTAS provided \$1.6 million cash funding to the CoE in 2008, of which \$1.1 million was its agreed core cash funding commitment to the ARC CoE. This funding relates to research salaries, PhD scholarships, equipment and income earned by the Centre from research output. In addition UTAS provided over \$1 million in-kind support to the CoE.



Table 2: Current status of the CoE's cash income agreement with its contributors – cash promised versus cash received

(a) Agreed core cash funding received to date (as promised in the original CoE Agreement)			
<i>Name of collaborator/contributor</i>			
University of Tasmania			
CSIRO Exploration and Mining (CoE node)			
University of Queensland (CoE node)			
University of Melbourne (CoE node)			
Australian National University (CoE node)			
State Government of Tasmania			
Minerals Council of Australia (MCA/MTEC)			
AMIRA International			
Industry partner – Anglo American			
Industry partner – AngloGold Ashanti			
Industry partner – Barrick Gold			
Industry partner – BHP Billiton (includes WMC contribution)			
Industry partner – Newcrest Mining			
Industry partner – Newmont Mining			
Industry partner – Rio Tinto			
Industry partner – Teck Cominco (now Teck)			
Industry partner – Zinifex (now OZ Minerals)			
Other Industry – Anglo American – Contrib. to Cooke student support			
Other Industry – Newcrest Mining – Contrib. to Cadia project			
ARC			
Total agreed cash income			
from the contributors to the CoE			
total promised and received to date (July 2005–Dec 2008)			
<i>promised</i>	<i>received</i>	<i>difference</i>	
4,302,500	3,954,702	(347,798)	
300,000	300,000	0	
175,000	175,000	0	
175,000	175,000	0	
150,000	150,000	0	
600,000	600,000	0	
280,000	475,572	195,572	
3,051,000	4,309,318	1,258,318	
135,000	135,000	0	
85,000	85,000	0	
85,000	85,000	0	
220,000	220,000	0	
60,000	60,000	0	
135,000	135,000	0	
85,000	85,000	0	
85,000	85,000	0	
135,000	135,000	0	
60,000	63,247	3,247	
552,066	561,703	9,637	
10,500,000	11,085,188	585,188	
21,170,566	22,874,729	1,704,164	
(b) Additional cash income earned to date (in addition to the above agreement)			
from the contributors to the CoE			
total received to date (July 2005–Dec 2008)			
<i>promised</i>	<i>received</i>	<i>difference</i>	
n/a	110,000	110,000	
n/a	40,000	40,000	
n/a	247,860	247,860	
n/a	1,946,601	1,946,601	
n/a	0	0	
n/a	114,179	114,179	
n/a	80,852	80,852	
n/a	0	0	
n/a	1,105,366	1,105,366	
n/a	248,939	248,939	
n/a	2,096,636	2,096,636	
n/a	10,000	10,000	
n/a	1,426,741	1,426,741	
n/a	1,591,978	1,591,978	
0	9,019,152	9,019,152	
Grand total of all income to date	21,170,566	31,893,882	10,723,316

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Table 3: Current status of the CoE cash funding agreement with its nodes – cash promised versus cash paid

Agreed funds contributed				from the CoE to its nodes			from the nodes to the CoE		
				total CoE ARC Grant income promised and transferred to the nodes to date (July 2005–Dec 2008)			total node matching funds promised and contributed at the node institution to date (July 2005–Dec 2008)		
Nodes				<i>promised</i>	<i>paid</i>	<i>difference</i>	<i>promised*</i>	<i>paid</i>	<i>difference</i>
CSIRO Exploration and Mining				300,000	300,000	0	300,000	300,000	0
University of Queensland				1,225,000	1,225,000	0	175,000	175,000	0
University of Melbourne				350,000	350,000	0	175,000	175,000	0
Australian National University*				350,000	350,000	0	150,000	150,000	0
University of British Columbia (Canada)				0	0	0	0	0	0
Colorado School of Mines (USA)				0	0	0	0	0	0
Johns Hopkins University (USA)				0	40,020	40,020	0	0	0
Totals				2,225,000	2,265,020	40,020	800,000	800,000	0

* the total matching funds promised by the nodes in the original CoE agreement equals \$825,000 to date not \$800,000 as shown above. The reason for this discrepancy is that ANU's matching funds schedule was revised in 2007 due to the late start of their project. Their five-year total of \$250,000 remains the same.

2009 Income Estimates

The current world financial crisis and steep decline in commodity prices are making it extremely difficult for CODES to get firm commitments on future funding from its usual external sources of income, such as mining companies. Uncertainty about commodity prices and their effect on income are impacting on the expenditure decisions of these companies. Therefore, it is anticipated that there will be a downturn in industry funding during the 2009–2010 period, despite our high profile and outstanding reputation internationally.

Although industry funding is likely to decrease in 2009, all other income streams are expected to remain stable.

2008 Expenditure of ARC CoE Grant

Summaries are provided in Table 4 and Figure 3 to demonstrate how CODES and its nodes have expended the ARC CoE Grant funds to date. The major areas of expenditure in 2008 were salaries, research travel, student scholarships and laboratory analyses.

The 2008 combined ARC CoE income and carry-forward of \$4 million was offset by expenditure of \$3.9 million, leaving an unspent carry-forward of \$55,741.

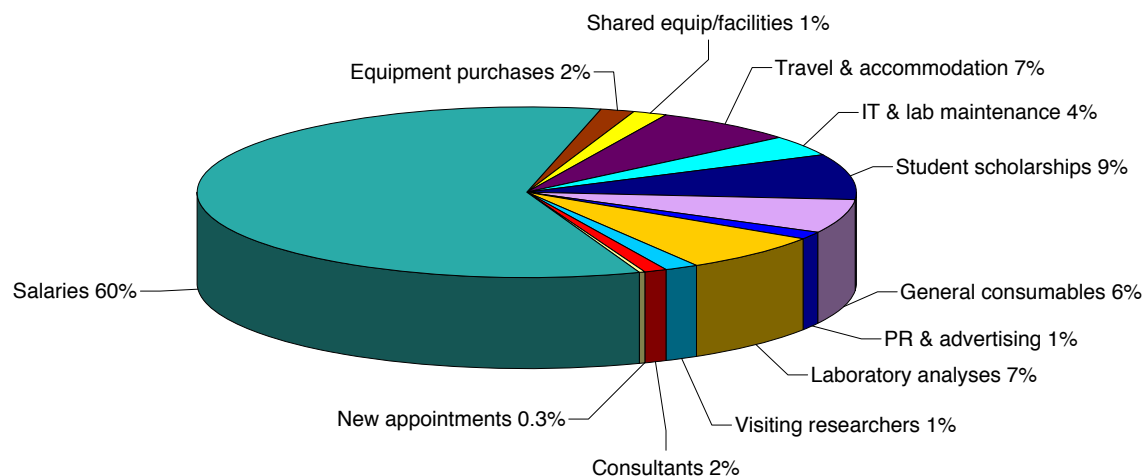
2009 Expenditure Estimates

Salary expenditure is expected to be high in 2009 due to several new research positions being filled during 2008. Other expenditure areas are predicted to be similar to previous years.

Table 4: Expenditure of ARC Centre of Excellence Grant 2005–2008 (CODES plus its nodes)

<i>Income</i>	<i>(half yr)</i>			
	2005	2006	2007	2008
Balance brought forward from previous year	0	954,886	1,345,188	711,979
Miscellaneous income (refund of expenses)	0	8,497	29,589	43,155
ARC income	1,500,000	3,152,698	3,184,402	3,248,088
	1,500,000	4,116,081	4,559,179	4,003,222
<i>Expenditure</i>				
Salaries	(348,511)	(1,237,351)	(1,833,309)	(2,335,312)
Equipment purchases	(890)	(83,645)	(305,991)	(70,624)
Equipment leased/hired	(362)	(22,635)	(6,894)	0
Shared equipment/facilities	(1,119)	(21,900)	(46,750)	(58,188)
Travel and accommodation (research)	(52,363)	(354,349)	(314,206)	(282,161)
IT and lab maintenance	(1,866)	(91,292)	(208,688)	(145,441)
Student scholarships	(31,856)	(297,768)	(349,671)	(346,311)
General consumables/maintenance	(67,517)	(244,347)	(217,941)	(246,561)
Public relations and advertising	(9,289)	(105,160)	(119,364)	(53,466)
Laboratory analyses	(29,900)	(212,256)	(307,733)	(288,411)
Consultants	0	(90,290)	(108,075)	(68,962)
Visiting academics	(9,002)	(9,900)	(19,311)	(41,665)
New appointment expenses	0	0	(9,267)	(10,381)
Miscellaneous	7,561	0	0	0
	(545,114)	(2,770,893)	(3,847,200)	(3,947,481)
Balance remaining at end of year	954,886	1,345,188	711,979	55,741

Figure 3: Expenditure of ARC Centre of Excellence Grant 2008



Finances

Notes to, and forming part of, the financial statements for 2008

The financial pages for 2008 were prepared by Christine Higgins, CODES' Finance Manager. Data for the financial statements was extracted from the UTAS Financial Management Information System and CODES' financial databases. All reports shown here have been 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 2008, with the following exceptions:

- The CoE node matching funds (approximately \$250,000 per annum) 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.
- In 2007, UTAS total core funding income in Tables 1 and 2 included \$69,000 of funding that was committed in 2007, but not actually received until March 2008. An adjustment was made to the 2007 financial statements to count this income in the year that it was due (2007). Similarly, it has been deducted from the 2008 UTAS income figure.

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

In 2008 there was a minor retrospective amendment made to the 2005 industry/private income figure which has increased the 2005 income total by \$20,000. This relates to \$20,000 of CoE agreed 2005 income, which was paid in advance by Teck Cominco 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 have met their CoE funding obligations within the five-year CoE agreement period. This amendment ensures that Table 1 data matches Table 2. Without it an anomaly between the two tables would exist.

Expenditure statement explanations

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

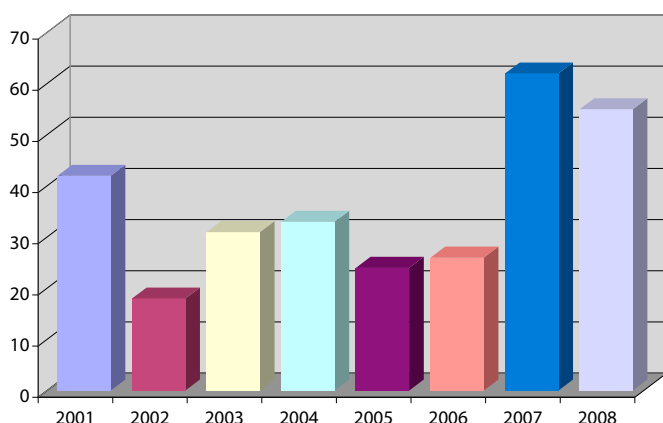
The expenditure financial statement and pie chart (Table 4 and Figure 3) include the following:

- 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)

Opposite: El Teniente mine, Chile.



CODES Publications 2008



CODES publications in refereed journals

Refereed journal articles (55)

Names in bold within this section are CODES/nodes authors.

- Allen, SR**, Fiske, F and Cashman, KV. 2008. Quenching of steam-charged pumice: implications for submarine pyroclastic volcanism. *Earth and Planetary Science Letters* 274: 40–49. (Project P1.F3)
- Allen, SR**, **McPhie, J**, Ferris, G and Simpson, C. 2008. Evolution and architecture of a large felsic igneous province in western Laurentia: the 1.6 Ga Gawler Range Volcanics, South Australia. *Journal of Volcanology and Geothermal Research* 172: 132–147. (Project P1.F3)
- Baker, T, Mustard, R, Fu, B, Williams, PJ, Dong, G, Fisher, L, Mark, G and **Ryan, CG**. 2008. Mixed messages in iron oxide-copper-gold systems of the Cloncurry district, Australia: insights from PIXE analysis of halogens and copper in fluid inclusions. *Mineralium Deposita* 43: 599–608. (Project P5.F3b (P5.B3))
- Batanova, VG, Brüggmann, GE, Bazylev, BA, Sobolev, AV, **Kamenetsky, VS** and Hofmann, AW. 2008. Platinum-group element abundances and Os isotope composition of mantle peridotites from the Mamonia complex, Cyprus. *Chemical Geology* 248: 195–212. (Project P1.F6)
- Berry, AJ, **Danyushevsky, LV**, O'Neill, H St. C, Newville, M and Sutton, SR. 2008. Oxidation state of iron in komatiitic melt inclusions indicates hot Archaean mantle. *Nature* 455: 960–963. (Project P5.A2 (P5.F1))
- Berry, RF**, Steele, DA and **Meffre, S**. 2008. Proterozoic metamorphism in Tasmania: implications for tectonic reconstructions. *Precambrian Research* 166(1–4): 387–396. (Project P5.A1 (P5.F6))
- Brugger, J, **Etschmann, B**, Pownceby, M, Liu, W, Grundler, P and Brewster, D. 2008. Tracking the chemistry of ancient fluids: oxidation state of Europium in hydrothermal scheelite. *Chemical Geology* 257: 26–33. (Project P5.F3b (P5.B3))
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- Chang, Z** and Meinert, LD. 2008. The Empire Cu–Zn Mine, Idaho, USA: exploration implications of unusual skarn features related to high Fluorine activity. *Economic Geology* 103: 909–938. (Project P2.N2; P5.F5 (P5.B2b))
- Chang, Z**, **Large, RR** and Maslennikov, V. 2008. S-isotopes in sediment-hosted orogenic gold deposits: evidence for an early timing and a seawater sulfate source. *Geology* 36: 971–974. (Project P2.N2; P5.F5 (P5.B2b))
- Danyushevsky, LV**, **Falloon, TJ**, **Crawford, AJ**, Verbeeten, A, **Tetroeva, SA** and **Leslie, RL**. 2008. High-Mg adakites from Kadavu Island Group, Fiji, SW Pacific: evidence for an adakite magma series. *Geology* 36(6): 499–502. (Project P5.A2 (P5.F1))
- Davies, AGS, **Cooke, DR**, **Gemmell, JB** and **Simpson, KA**. 2008. Diatreme breccias at the Kelian gold mine, Kalimantan, Indonesia: precursors to epithermal gold mineralisation. *Economic Geology* 103(4): 689–716. (Project P2.N4; P3.L8)
- Davies, AGS, **Cooke, DR**, **Gemmell, JB**, van Leeuwen, T, Cesare, P and Hartshorn, G. 2008. Hydrothermal breccias and veins at the Kelian gold mine, Kalimantan, Indonesia: genesis of a large epithermal gold deposit. *Economic Geology* 103(4): 717–757. (Project P2.N4; P3.L8)
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- Elburg, M and **Kamenetsky, VS**. 2008. Limited influence of subducted continental material on mineralogy and elemental geochemistry of primitive magmas from Indonesia-Australia collision zone. *Lithos* 105: 73–84. (Project P1.F6)
- Falloon, TJ**, **Danyushevsky, LV**, **Crawford, AJ**, **Meffre, S**, **Woodhead, JD** and Bloomer, SH. 2008. Boninites and adakites from the northern termination of the Tonga Trench: implications for adakite petrogenesis. *Journal of Petrology* 49(4): 697–715. (Project P5.A1 (P5.F6))
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- Grundler, P, Brugger, J, Meisser, N, Ansermet, S, **Borg, S, Etschmann, B**, Testemale, D and Bolin, T. 2008. Xocolatlite, $\text{Ca}_2\text{Mn}_4+2\text{Te}_2\text{O}_{12} \cdot \text{H}_2\text{O}$, a new tellurate related to kuranakhite: description and measurement of Te oxidation state by XANES spectroscopy. *American Mineralogist* 93: 1911–1920. (Project P5.F3b (P5.B3))
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- Hou, ZQ, **Khin Zaw**, Rona, P, Li, YQ, Qu, XM, Song, SH, Peng, LG and Huang, JJ. 2008. Geology, fluid inclusions, and oxygen isotope geochemistry of the Baiyinchang pipe-style volcanic-hosted massive sulfide Cu deposit in Gansu Province, northwestern China. *Economic Geology* 103: 269–292. (Project P1.L2; P2.F3)
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- Meffre, S, Large, RR, Scott, R, Woodhead, J, Chang, Z, Gilbert, SE, Danyushevsky, LV**, Maslennikov, V and **Hergt, JM**. 2008. Age and pyrite Pb isotopic composition of the Giant Sukhoi Log sediment-hosted gold deposit. *Geochimica et Cosmochimica Acta* 72(9): 2377–2391. (Project P5.F5 (P5.B2b), Project P2.N2)
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- Reading, AM** and Heintz, M. 2008. Seismic anisotropy of East Antarctica from shear-wave splitting: spatially varying contributions from lithospheric structural fabric and mantle flow? *Earth and Planetary Science Letters* 268: 433–443.
- Reading, AM**. 2008. Bouncing continents: insights into the physics of the polar regions of the Earth from the IPY POLENET initiative. *Physics Education* 43: 383–391.
- Rosa, CJP, **McPhie, J**, Relvas, JMRS, Pereira, Z, Oliveira, T and Pacheco, N. 2008. Facies analyses and volcanic setting of the giant Neves Corvo massive sulfide deposit, Iberian Pyrite Belt, Portugal. *Mineralium Deposita* 43: 449–466. (Project P1.F1; P1.F3)
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- Solomon, M**. 2008. Brine pool deposition for the Zn–Pb–Cu massive sulfide deposits of the Bathurst mining camp. I. Comparisons with the Iberian pyrite belt. *Ore Geology Reviews* 33: 329–351. (Project P2.F3)
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- Cooke, D. 2008. Circum-Pacific porphyry copper, gold and molybdenum deposits: AusIMM PACRIM Congress 2008, The Pacific Rim: Mineral Endowment, Discoveries & Exploration Frontiers, Gold Coast, Australia, November 2008. Plenary lecture.
- Cooke, DR, Hollings, P and Holliday, J. 2008. Circum-Pacific porphyry copper, gold and molybdenum deposits: AusIMM PACRIM Congress 2008, The Pacific Rim: Mineral Endowment, Discoveries & Exploration Frontiers, Gold Coast, Australia, November 2008, pp. 7–14.
- Cox, S. 2008. Invited presentation at the Hubble Quorum at the US Geological Survey prior to American Geophysical Union. December 2008.
- Cox, S. 2008. The dynamics of stress and fluid pressure states in fracture-controlled hydrothermal systems – implication for ore genesis: AusIMM PACRIM Congress 2008, The Pacific Rim: Mineral Endowment, Discoveries & Exploration Frontiers, Gold Coast, Australia, November 2008. Plenary lecture.
- Giger, S, Cox, SF and Tenthorey, E. 2008. Slip localization, fault weakening and slow earthquakes as a consequence of fault gouge strengthening in hydrothermal regimes – insights from laboratory experiments: Fall meeting American Geophysical Union, San Francisco, USA, December 2008. Invited keynote lecture.
- Hitzman, M, Broughton, D, Selley, D, Bull, S, Large, R, McGoldrick, P, Scott, R, Koziy, L, Woodhead, J, Barra, F, Croaker, M, Pollington, N and Mackay, W. 2008. A new view of the Zambian Copperbelt: SEG-GSSA 2008 Conference, Johannesburg, South Africa, July 2008.
- Kamenetsky, VS. 2008. Melt/fluid immiscibility in common magmas: melt inclusion approach and implications. EGU General Assembly, Vienna, Austria, April 2008.
- Khin Zaw. 2008. Effectively using geospatial information for exploration in SE Asia and South China: Conference on GIS in Mining and Exploration, Brisbane, Australia, September 2008. Invited paper.
- Khin Zaw. 2008. Tectonic and metallogenic relations of South China and SE Asian Terranes: International Conference on Tectonics of northwestern Indochina, Chiang Mai, Thailand, February 2008. Keynote address, Abstract volume, p. 17.
- Large, R, Bull, S, Cooke, D, McGoldrick, P, Scott, R and Selley, D. 2008. Advances in genetic understanding of sediment-hosted base metal and gold deposits: The 33rd International Geological Congress, Oslo, Norway, August 2008.
- McGoldrick, P. 2008. SEG workshop on sedimentary zinc deposits (with David Leach from USGS) at AusIMM PACRIM Congress 2008, The Pacific Rim: Mineral Endowment, Discoveries & Exploration Frontiers, Gold Coast, Australia, November 2008.
- Ryan, CG, Siddons, DP, Moorhead, G, Kirkham, R, De Geronimo, G, Etschmann, BE, Dragone, A, Dunn, PA, Kuczewski, A, Davey, P, Jensen, M, Ablett, JM, Kuczewski, J, Hough, R, de Jonge, M and Paterson, D. 2008. High performance X-ray fluorescence imaging using a massively parallel detector array and real-time spectral deconvolution: a catalyst for new applications in geology, Invited presentation to the Next Generation Science Workshop of the the third Asia Oceania Forum on Synchrotron Radiation Research, Melbourne, Australia, December 2008.
- Selley, D, Broughton, D, Scott, R, Hitzman, M, Bull, S and Koziy, L. 2008. The ores of Central African Copperbelt: where to now?: Mineral Exploration Roundup, Vancouver, Canada, January 2008.

Research reports to industry (149)

- Baker, M and Cooke, DR. 2008. Collahuasi and El Teniente Districts, Chile: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors Meeting 1, Hobart, June 2008, pp. 81–96. (Project P3.L2)
- Baker, M and Wilkinson, JJ. 2008. El Teniente, Chile – fieldwork overview, October–November 2008: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 2, Hobart, December 2008, pp. 103–108. (Project P3.L2)
- Baker, M, Cooke, DR, Sweet, G and Hollings, P. 2008. Baguio district: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 2, Hobart, December 2008, pp. 79–85. (Project P3.L2)
- Bath, A and Cooke, DR. 2008. The importance of biotite for the deposition of sulfides at the Lorraine Cu-Au Porphyry deposit, north-central British Columbia: Shallow- and Deep-Level Alkalic Mineral Deposits: Developing an Integrated Exploration Model, Year 3 – Porphyry Module, Final update to sponsors, Williams Lake, Canada, September 2008, pp. 7.1–7.31.
- Blackwell, J, McPhie, J, Cooke, DR and Simpson, K. 2008. Lithofacies associations and evolution of the Minifie ore zone, Ladolam gold deposit, Lihir Island, PNG: Shallow- and Deep-Level Alkalic Mineral Deposits: Developing an Integrated Exploration Model, Year 3 – Epithermal Module, Final update to sponsors, Orange, NSW, November 2008, pp. 4.1–4.21. (Project P1.F3)
- Bull, S and Selley, D. 2008. A sequence- and chemo-stratigraphic interpretation of the Central African Copperbelt, P872 – Sediment-hosted copper deposits of Congolese, Zambian and central Australian basin systems, Final report to sponsors. (Project P3.L3)
- Bull, S, Selley, D and Large, R. 2008. Implications of the C and O isotopic arrays at the level of ores, P872 – Sediment-hosted copper deposits of Congolese, Zambian and central Australian basin systems, Final Report to sponsors. (Project P3.L3)
- Bull, S. 2008. A sequence stratigraphic interpretation of the Central African Copperbelt, P872 – Sediment-hosted copper deposits of Congolese, Zambian and central Australian basin systems, Penultimate report to sponsors. (Project P3.L3)
- Byrne, J, Tosdal, R and Chamberlain, C. 2008. Magmatic-hydrothermal evolution and zonation of a breccia-centered Cu-Au alkalic porphyry: Southwest Zone, Galore Creek: Shallow- and Deep-Level Alkalic Mineral Deposits: Developing an Integrated Exploration Model, Year 3 – Porphyry Module, Final update to sponsors, Williams Lake, Canada, September 2008, pp. 3.1–3.21.
- Chambefort, I, McPhie, J and Kamenetsky, V. 2008. Olympic Dam mafic facies. Progress Report for BHP Billiton, November 2008. 22 pp and CD. (Project P1.F3)
- Chambefort, I. 2008. The Cu-Au Chelopech deposit, Panagyurishte district, Bulgaria: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 2, Hobart, December 2008, pp. 51–57. (Project P3.L2)
- Chang, Z and Baker, M. 2008. Report on the P765A field visit to Tantauatay, 28 April to 2 May 2008: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal

- districts, Sponsors' Meeting 1, Hobart, June 2008, pp. 119–138. (Project P2.N2; P3.L2)
- Chang, Z and Baker, M. 2008. Tantahuatay, Peru: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 1, Hobart, June 2008, pp. 97–110. (Project P3.L2)
- Chang, Z and Gemmell, JB. 2008. Batu Hijau, Indonesia: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 1, Hobart, June 2008, pp. 53–69. (Project P2.N2; P3.L2)
- Chang, Z and Hedenquist, J. 2008. Perol porphyry – Cocanes lithocap: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 1, Hobart, June 2008, pp. 71–79. (Project P2.N2; P3.L2)
- Chang, Z, Chen, H and Inglis, S. 2008. Blind site testing – a lithocap site of OZ Minerals: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 2, Hobart, December 2008, pp. 115–119. (Project P2.N2; P3.L2)
- Chang, Z, Chen, H, Judger, L, Xu, Q and Hedenquist, J. 2008. Report on AMIRA P765A field sampling program at Shuteen, Mongolia: preliminary results and initial comments: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: Report to Rio Tinto, Mongolia, September 2008, 11 pp. (Project P3.L2)
- Chang, Z, Hedenquist, J and Baker, M. 2008. Cerro Yanacocha deposit and Kupfertil porphyry: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 1, Hobart, June 2008, pp. 7.1–7.9. (Project P5.F5(P5.B2b))
- Chang, Z, Hedenquist, J and Baker, M. 2008. Cerro Yanacocha deposit and Kupfertil porphyry: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 2, Hobart, December 2008, pp. 19–23. (Project P2.N2; P3.L2)
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- Chang, Z, White, N, Hedenquist, J, Deyell, C, Cooke, DR and Ireland, T. 2008. Exploring lithocaps – practical tools to focus on targets in the lithocap environment: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Workshop, Hobart, December 2008, pp. 5–16. (Project P3.L2)
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- Chang, Z, White, NC and Cooke, DR. 2008. Quarterly Report to the Hebei Hua Ao Mining Industry Company No. 6, 6 pp. (Project P2.N2; P5.F5(P5B2b))
- Chang, Z, White, NC, Hedenquist, J, Deyell, C, Cooke, D and Ireland, T. 2008. Exploring lithocaps: Practical tools to focus on targets in the lithocap environment: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 2, Pre-meeting Sponsors' Workshop, Hobart, December 2008, pp. 2.1–2.12. (Project P2.N2)
- Chang, Z. 2008. Mankayan district, Philippines: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 1, Hobart, June 2008, pp. 37–52. (Project P2.N2; P3.L2)
- Chang, Z. 2008. Skarn and skarn deposits: Ore Deposit Models and Exploration Shortcourse, Yunnan Geological Survey, Kunming, China, November 2008, pp. 345–432 (in English and Chinese). (Project P2.F1)
- Chen, H, Chang, Z, Cooke, DR and Chambefort, I. 2008. Chelopech mine, Bulgaria: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 2, Hobart, December 2008, pp. 59–69. (Project P3.L2)
- Chen, H, Chang, Z, Cooke, DR and Chambefort, I. 2008. Timok belt, Serbia: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 2, Hobart, December 2008, pp. 35–44. (Project P3.L2)
- Cooke, D, Gemmell, B, Chang, Z, Zhou, T and Ireland, T. 2008. Exploring in green rocks: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 2, Pre-meeting Sponsors' Workshop, Hobart, December 2008, pp. 3.1–3.18. (Project P2.N2)
- Cooke, DR and Gemmell, JB. 2008. Blind site testing: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 1, Hobart, June 2008, p. 139. (Project P3.L2)
- Cooke, DR and Wilkinson, JJ. 2008. ARC linkage grant application – relationship to P765A: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 2, Hobart, December 2008, pp. 11–12. (Project P3.L2)
- Cooke, DR, Baker, M, Hollings, PN and Sweet, G. 2008. Baguio District, Philippines: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 1, Hobart, June 2008, pp. 9–23. (Project P3.L2)
- Cooke, DR, Chang, Z, Chen, H and Chamberfort, I. 2008. Introduction to AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts: Report to Dundee Precious Metals, Bor, Serbia, July 2008, 14 pp. (Project P3.L2)
- Cooke, DR, Chang, Z, Danyushevsky, L and Gilbert, S. 2008. Analytical protocols and data reduction: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Workshop, Hobart, December 2008, pp. 39–44. (Project P3.L2)
- Cooke, DR, Gemmell, B, White, NC and Chang, Z. 2008. AMIRA P765A, Discussion and forward program: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 2, Hobart, December 2008, pp. 17.1–17.4. (Project P2.N2)

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- Cooke, DR, Gemmell, JB, Chang, Z, Zhou, T and Ireland, T. 2008. Exploring in green rocks: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Workshop, Hobart, December 2008, pp. 19–36. (Project P3.L2)
- Cooke, DR, Gemmell, JB, White, NC and Chang, Z. 2008. Discussion and forward program: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 2, Hobart, December 2008, pp. 121–124. (Project P3.L2)
- Cooke, DR, Inglis, S and Chang, Z. 2008. Developing the Explorer's Toolbox – Mapping Mineral Compositions: AMIRA P765A – Geochemical and Geological Halos in Green Rocks and Lithocaps: The explorer's toolbox for porphyry and epithermal districts, Sponsors' Meeting 1, Hobart, June 2008, pp. 111–118. (Project P3.L2)
- Cooke, DR, Large, RR, Bull, SW and McGoldrick, PJ. 2008. The giant sediment-hosted Zn-Pb-Ag deposits of Northern Australia: Ore Deposit Models and Exploration Shortcourse, Yunnan Geological Survey, Kunming, China, November 2008, pp. 272–292 (in English and Chinese).
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- Cooke, DR, Wilson, AJ, Harris, AC, Lickfold, V, Harper, B, House, M, Wolfe, R, Holliday, J and Tedder, I. 2008. Alkalic porphyry Au-Cu deposits of the Macquarie Arc, NSW. AusIMM PACRIM Congress 2008 – The Pacific Rim: Mineral Endowment, Discoveries and Exploration Frontiers, Field Guide, Field Trip No.1, 18–21 November, pp. 25–47. (Project P2.L1; P2.L3)
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- Cuisson, AL. 2008. Vein orientation in Ridgeway and its implication to mineralisation and structural controls. Structure Meeting, April 2008, Cadia Valley Alkalic Porphyry Ore Deposits: Deconstructing the System Architecture, ARC Centre of Excellence in Ore Deposits & Newcrest Mining Limited, Orange, NSW, pp. 4.1–4.26. (Project P2.L1; P2.L3)
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- Galvan, VH, Cooke, DR, Gemmell, JB, Maslowsky, M, Zesati, C and Castorena, J. 2008. Epithermal gold-silver veins at Palmarejo, Guadalupe and La Patria, Chihuahua, Mexico, AusIMM Publication Series No 11/2008, pp. 49–56. (Project P3.L8)
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Opposite: Field trip, Tasman Peninsula, Tasmania.



Appendices

CODES Postgraduate Students 2008

<i>Student</i>	<i>Supervisors</i>	<i>Project</i>	<i>Support</i>
Bachelor of Science (Honours) (9)			
Traci Cooper	Khin Zaw, Meffre	Origin and features of MVT mineralisation in southern Thailand	Ore deposits of SE Asia
Mark Davidson	Bull, Berry	Sedimentology and provenance of the Burnie Formation	School of Earth Sciences
Michelle Farran [^]	McPhie, Berry	Volcanic, metamorphic and structural architecture of the Prospero-Tapinos nickel sulfide host succession	Sir Samuel Mines NL
Amanda Geard [^]	Berry, Meffre	Geology of the Klaeng Region (SE Thailand): lithology, structure and geochronology	OZ Minerals (formerly Oxiana)
Hilary Goh*	Roach, Reading, Davidson	Properties of rocks in north eastern Tasmania for geothermal exploration	KUTh Energy
Stephen Kuhn*	Roach, Duffett	Potential field geophysical interpretation of the Cave Rocks Region, WA	St Ives Gold Mine
Sam Maloney*	Khin Zaw, Meffre	Mineralisation characteristics of Ang Noi Prospect, Century tenement, Lao PDR	Argonaut Resources (Laos) Co Ltd, Ore deposits of SE Asia project
Thomas Methorst [^]	Roach, Reading, Davidson	Gravity survey of Flinders Island	MRT
Alice Wilkinson	Khin Zaw, Meffre	Geological setting and mineralisation characteristics of sedimentary rock-hosted Langu Au deposit, Satun district, southern Thailand	Ore deposits of SE Asia
Master of Economic Geology (37)			
César Eduardo Aguirre Mascarelli		coursework only	
Abdul Gafar Arbi		coursework only	
Paluku Batsotsi	Selley	An aspect of the geology of the Kinsevere Project, in the Katangan copperbelt, D R Congo	
John Christopher Bedi		coursework only	
John Edmund Brewster		coursework only	
Mark Nigel Burdett		coursework only	
Colin Morgan Carter		coursework only	
Jenny Catoc		coursework only	
Corrie Chamberlain		Geology, geochemistry and genesis of the Kilkenny Low Sulfidation Epithermal Deposit, Cracow, Queensland	
Martin Manuel de la Cueva Torres		coursework only	
David Francis Freeman		coursework only	
Darren Hicks		coursework only	
Yansan Jamyambaatar	Harris, Cooke	Northparkes porphyry copper deposit	Rio Tinto Gobi Exploration JV
Benjamin John Jones		coursework only	
Brian Kay	Foster	Combined economic and geologic evaluation of eastern Australian gold projects – selection of acquisition targets	
Martin Kent	Webster	An aspect of Broken Hill geology (to be decided)	
Youjin Lee	Khin Zaw	A study of the mineralogy, alteration and ore genesis of the Bong Mieu Gold Mine, central Vietnam	Korea Resources Corp
Neil Macalalad		coursework only	
Ador Maut Makuei		coursework only	
Mannie Mehu		coursework only	
Matthew O'Neill		coursework only	
Olufolajimi Richard Ogunleye		coursework only	
Katie Marie Perrin		coursework only	
Anna Terese Price		coursework only	
Peter Ian Pring		coursework only	
Scott Randall		coursework only	

<i>Student</i>	<i>Supervisors</i>	<i>Project</i>	<i>Support</i>
Alan Riles		coursework only	
Jonathan Robbeson	Webster	An aspect of Broken Hill resource estimation	
Budi Santoso		coursework only	
Daud Silitonga		coursework only	
Philip Smerchanski		coursework only	
Linda Sprigg		coursework only	
Leo Subang		coursework only	
Pearse Sweeny		coursework only	
Jason Triffit		coursework only	
Bruce Whittaker		coursework only	
Kalem Peter Wright		coursework only	
Master of Exploration Geoscience (2)			
Terence Hoschke	Large, Roach	Geophysical signatures of gold-copper porphyry systems	
Takayuki Manaka [^]	Khin Zaw, Meffre	Geological setting and mineralisation characteristics of the Long Chieng Track and Ban Houayxai deposits, Lao PDR	ARC Linkage, CoE, Pan Australian
Master of Science (1)			
Paul Ferguson	Davidson	Origin of large negative magnetic anomalies in oceanic crust, Macquarie Island	SEG
Doctor of Philosophy (48)			
Andrea Agangi	Kamenetsky, McPhie, Allen	Magmatic and volcanic evolution of giant intraplate felsic igneous provinces: Gawler Range Volcanics and Hiltaba Suite, South Australia	TPRS co-fund Scholarship, CoE, PIRSA, UTAS
Darren Andrews	Roach	Geophysical monitoring of acid mine drainage at Savage River Mine, Northwestern Tasmania	Australian Bulk Minerals, APA-I
Adam Bath	Kamenetsky, Crawford, Cooke	The geochemistry of melt inclusions and mineral phases from the Mount Polley and Lorraine alkalic Cu-Au porphyry deposits: implications for the formation of ore deposits	BCGS, SEG, CoE Top-up, APA Scholarship, Alkalic project, UBC, MDRU
Susan Belford	Davidson, McPhie, Large	Genetic and chemical characterisation of the Archaean Jaguar VHMS deposit	APA-I, SEG, Jabiru Metals Ltd, CoE
Fiona Best	Danyushevsky, Falloon	Chalcophile and volatile contents and petrogenesis of primitive arc and backarc basin magmas: assessing magmatic contributions to volcanic-hosted seafloor mineralisation	CoE, UTAS
Jacqueline Blackwell	Cooke, McPhie	Characteristics and origins of breccias in an alkalic epithermal gold deposit: Ladolam, Lihir Island, Papua New Guinea	CoE, Alkalic project, SEG/ Newmont, SEG Canada, TPRS co-fund Scholarship, LGL Gold, UTAS
Natalee Bonnici	Walters, Berry, Hunt	Textural and mineralogical characterisation of Cu-Au systems in relation to process mineralogy	GeM ^{III} project, TGRS Scholarship
Bryan Bowden	Davidson	Geology, geochemistry and genesis of the Prominent Hill IOCG Deposit, South Australia	CODES, AGSO, Minotaur Resources, Goldstream Mining NL, PIRSA
Kirill Bychkov	Danyushevsky	Numerical modelling of sulfide precipitation from mafic magmas with implications for the formation of layered intrusions	CoE, UTAS
Reia Chmielowski	Berry	The metamorphic history of Tasmania	TGMS, TPRS co-fund Scholarship
Lindsey Clark	Gemmell, Cooke	The geology and genesis of the Kencana epithermal Au-Ag Deposit, Gosowong Goldfield, Halmahera Island, Indonesia	Newcrest
Mawson Croaker	Selley, McGoldrick, Bull	Geology and genesis of the Nkana copper deposit, Zambia	AMIRA, TPRS Scholarship
Paul Cromie	Khin Zaw, Cooke, White	Geological setting, geochemistry and genesis of the Sepon Mineral District, Laos PDR	OZ Minerals (formerly Oxiana), SEG, CSIRO, APA Scholarship
Ana Liza Cuison	Cooke, Harris, Berry	Geology and genesis of the Ridgeway porphyry Au-Cu deposit, NSW	Newcrest, SEG (McKinstry Fund)

Appendices

<i>Student</i>	<i>Supervisors</i>	<i>Project</i>	<i>Support</i>
Sang Quang Dinh	Crawford, Berry	Geochronology and geological evolution of the northern margin of the Kontum massif, central Vietnam	Vietnamese Government, CODES
Lee Evans*	Davidson, Cooke	Ground waters in wet, temperate sulfide mining districts: delineation of modern fluid flow and predictive modelling to improve management after mine closure (Rosebery, Tasmania)	OZ Minerals (formerly Pasminco), APA-I
Cathy Evans (JKMRC)	Walters, Johnson (UQ), Manlapig (UQ), Kojovic (UQ)	The relationship between mineral characteristics of ores and the variation in their processing attributes	GeM ^{III} project
Nathan Fox	Cooke, Harris	Controls on alteration and mineralisation in the Cadia East Au-Cu porphyry copper deposit, NSW, Australia	Newcrest
Russell Fulton	Gemmell, Berry	Geology and geochemistry of the hanging wall argillite, Greens Creek VHMS deposit, Alaska: implications for ore genesis and exploration	Kennecott Greens Creek Mining
Victor Hugo Galvan-Gutierrez	Cooke, Gemmell, McPhie	Palmarejo carbonate base-metals silver-gold epithermal deposit, Trogon Project, Chihuahua, Mexico	IPRS, Bolnisi Gold NL
Sarah Gordee	McPhie, Allen	Characteristics of submarine volcanic facies in oceanic arc depocentres	TPRS co-fund Scholarship, CoE, UTAS
Timothy Ireland	Cooke, Berry	Geological framework of porphyry and epithermal mineralisation in the Collahuasi District, Tarapac á, Chile	APA Scholarship, AMIRA P765, SEG (McKinstry Fund), Newmont Mining Corporation
Nicholas Jansen	Gemmell, Chang	Geology and geochemistry of the Ixhuatan Lithocap, and its relationships to porphyry and epithermal mineralisation	AMIRA P765A, Kinross, IPRS
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, 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
Luke Keeney (JKMRC)	Walters, Morrison (UQ)	Integrated geometallurgical modelling of the Cadia East deposit	GeM ^{III} project
George Leigh (JKMRC)	Gay (UQ), Morrison (UQ)	Multi-resolution image analysis for process mineralogy	GeM ^{III} project
Wallace Mackay	Selley, Bull	Sedimentology and structure of the Curdimurka Subgroup, Willouran Range, South Australia	APA-I, AMIRA
Rodney Maier	McGoldrick, Large	Pyrite and base metal trace-element halos in the northern Australia Zn-Pb-Ag deposits	Anglo American, Teck Cominco
Claire McMahon	Davidson	Controls on the major and trace elements content of pyrite in hydrothermal alteration envelopes	ARC
Janina Micko (MDRU)	Tosdal (MDRU), Dipple (MDRU)	The hydrothermal genesis of the alkalic Cu-Au porphyry deposit, Galore Creek, northwestern British Columbia	Alkalic project
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
Anita Parbhakar	Walters, Edraki (UQ)	Predictive environmental mineralogy and geochemical techniques: a new approach to integrated acid rock drainage characterisation	GeM ^{III} project in collaboration with UQ
Heidi Pass	Cooke, Davidson, Chang	Chemical and mineralogical zonation patterns in alkalic mineral systems – Implications for ore genesis and mineral exploration	Alkalic project, Imperial Metals, Geoscience BC, SEG Canada, TPRS co-funded Scholarship
Nicole Pollington	McGoldrick, Bull	Sedimentology, mineral paragenesis and geochemistry of the Konkola North copper deposit, Zambia	AMIRA, APA-I
Lee Robson	Roach	Application of remote sensing for geological mapping in western Tasmania	TGMS, TPRS co-funded Scholarship

<i>Student</i>	<i>Supervisors</i>	<i>Project</i>	<i>Support</i>
Patrick Sack	Gemmell, Berry	Characterisation of the footwall lithologies, Greens Creek VHMS deposit, Admiralty Island, southeast Alaska	KGCMC, SEG, IPRS
Abhisit Salam	Khin Zaw, Meffre, McPhie	Geology and genesis of the Chatree Deposits, Phetchabun Province, central Thailand	Kingsgate Consolidated Ltd, IPRS, SEG, ARC Linkage, CoE
Ralf Schaa	Fullagar, Roach, Reading	Rapid approximate imaging of electromagnetic data acquired using distributed multichannel data acquisition systems	APA-I, CODES
Blackwell Singoyi	Davidson, Khin Zaw, Large	Controls on the geochemistry of magnetite in hydrothermal fluids	IPRS, CODES, TGMS, SEG
Weerapan Srichan [^]	Crawford, Berry	Petrochemistry, geochronology and tectonic implications of Chiang Khong-Lampang-Tak Volcanic Belt, Northern Thailand	Royal Thai Government, CODES, IGCP, OZ Minerals (formerly Oxiana Ltd)
Bronto Sutopo	Gemmell, Cooke	The Martabe Au-Ag high-sulphidation epithermal mineralisation in the Tapanuli Selatan District, North Sumatra Province, Indonesia: implications for ore genesis and exploration	Newmont Mining Corporation
Sofia Tetroeva	Danyushevsky, Crawford	Petrology and geochemistry of adakites and related rocks from the Hunter Ridge, Southwest Pacific	IPRS, CODES/CoE
Felipe Urzua*	Cooke	Geology, geochronology and structural evolution of La Escondida Copper District, Northern Chile	BHP Chile
Olga Vasyukova	Kamenetsky, 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 ^{III} project
Wojciech Zukowski	Cooke, Crawford	Geology and mineralisation at Lake Cowal district, NSW, Australia	Barrick Gold, SEG, CoE, TPRS co-funded Scholarship, Alkaline project, UTAS

* Degree completed but not yet graduated

[^] Graduated

AMIRA P765A field trip, Chelopech, Vozdol river valley, Bulgaria.



Appendices

Research Collaborations with CODES 2008

<i>Institution</i>	<i>Researcher</i>	<i>CODES collaborators</i>	<i>Project</i>
International collaborations (in addition to Centre partners)			
Department of Mineral Resources, Thailand	S Khositantont	Khin Zaw, S Meffre	P1.L2 Ore deposits of SE Asia
GeoForschungs Zentrum Potsdam, Germany	R Thomas	P Davidson	General research collaboration
Geological Survey of Canada	J Peter	JB Gemmell	P2.F3 Volcanic-hosted massive sulfide deposits
University of British Columbia, Canada	K Simpson, T Bissig	D Cooke	P2.L3 Shallow and deep-level alkalic mineral deposits
	R Friedman	D Cooke, Z Chang, M Baker	P3.L2 Transitions and zoning in porphyry-epithermal districts
Hefei University, China	Taofa Zhou	D Cooke, Z Chang, S Meffre	P2.N3 Polymetallic mineralisation and associated magmatic and volcanic activity in the Luzong basin, middle and lower Yangtze River, eastern China
		D Cooke	P3.L2 Transitions and zoning in porphyry-epithermal districts
Imperial College, UK	A Berry	A Harris, D Cooke, V Kamenetsky	P5.F3 Developmental research into the use of synchrotron in ore deposit studies
		L Danyushevsky	P1.F2 Modern magmatism in the southwest Pacific
Indian School of Mines, Dhanbad, India	D Asthana	A Crawford, A McNeill, P Davidson, S Meffre, R Berry	P1.F1 Geodynamic controls on the fertility of fold belts and cratons
Institute of Earth Sciences-Academia Sinica, Taipei, Taiwan	G Zellmer	V Kamenetsky, M Kamenetsky	P1.F6 Unmixing in magmas: melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
Colorado State University, USA	H Stein	Khin Zaw	P1.L2. Ore deposits of SE Asia
Institute of Experimental Mineralogy, Moscow, Russia	E Konnikov	L Danyushevsky, A Crawford, V Kamenetsky, A McNeill	P1.F4 Ni-PGE potential of mafic and ultramafic magmas – a combined melt inclusion and numerical modelling approach
Institute of Geochemistry and State Key Laboratory of Ore Deposit Geochemistry, Chinese Academy of Sciences, Guiyang, China	XY Song	L Danyushevsky, A Crawford	P1.F1 Geodynamic controls on the fertility of fold belts and cratons
Institute of Geological and Nuclear Sciences, NZ	C de Ronde	V Kamenetsky, J McPhie	P1.F3 Felsic magmas: volatile and metal budgets during magma evolution – a combined melt inclusion and volcanological approach
Institute of Geological and Nuclear Sciences, NZ	K Faure	A Harris, D Cooke, R Berry, J McPhie	P2.L1 District- to deposit-scale structural and geochemical study of the Cadia porphyry Au-Cu deposits
Institute of Geology and Mineralogy, Novosibirsk, Russia	S Smirnov	V Kamenetsky, R Large	P2.N1 Phase and chemical composition of high-temperature hydrothermal systems undergoing interaction between silicate rocks/magmas and aqueous fluid
Lakehead University, Canada	P Hollings	D Cooke, JB Gemmell, Z Chang	P3.L2 Transitions and zoning in porphyry-epithermal mineral districts
University of Witwatersrand, South Africa	A Wilson	J Foster	New initiatives
Otago University, NZ	D Crow, D Mackenzie	R Large	P3.F2: Sediment-hosted gold-arsenic deposits: genesis and exploration models
University of British Columbia, Canada	J Mortenson	JB Gemmell	P2.F3 Volcanic-hosted massive sulfide deposits
University of Ottawa, Canada	J Hedenquist	D Cooke, JB Gemmell, Z Chang	P3.L2 Transitions and zoning in porphyry-epithermal mineral districts
University of Malaya, Malaysia	Azman Ghandi	Khin Zaw	P1.L2 Ore deposits of SE Asia
IGM, Lisbon, Portugal	CMC Inverno	M Solomon	P2.F3 Neves Carvo massive sulfide deposits in Portugal
Chaing Mai University, Thailand	Phisit LitraKum	Khin Zaw	P1.L2 Ore deposits of SE Asia
Hefei University, China	Feng Yuan, Yu Fan, Luojun Zhang	D Cooke	P2.N3 Polymetallic mineralisation and associated magmatic and volcanic activity in the Luzong basin, middle and lower Yangtze River, eastern China
Nanjing University, China	Lianxing Gu	Khin Zaw	P2.F3 Volcanic-hosted massive sulfide deposits in China

<i>Institution</i>	<i>Researcher</i>	<i>CODES collaborators</i>	<i>Project</i>
MDRU, Canada	R Tosdal	D Cooke	P2.L3 Shallow and deep-level alkalic mineral deposits
		A Harris	P2.L1 District- to deposit-scale structural and geochemical study of the Cadia porphyry Au-Cu deposits
University of Alberta, Canada	R Creaser	A Harris	P2.L1 District- to deposit-scale structural and geochemical study of the Cadia porphyry Au-Cu deposits
Laurentian University, Canada	S Piercey	JB Gemmell	P2.F3 Volcanic-hosted massive sulfide deposits
University of Malaya, Malaysia	Teh Guan Hoe	Khin Zaw	P2.F3 Volcanic-hosted massive sulfide deposits in Malaysia
University of Ottawa, Canada	T Monecke	JB Gemmell	P2.F3 Volcanic-hosted massive sulfide deposits
Chinese Academy of Geological Science, China	Zengqian Hou	Khin Zaw	P2.F3 Volcanic-hosted massive sulfide deposits in China
Queens' University, Canada	D Layton-Matthews	JB Gemmell, R Large	P2.F3 Volcanic-hosted massive sulfide deposits in China
Universiti Kebangsaan Malaysia, Malaysia	Wan Faud, Wan Hassan	Khin Zaw	P1.L2 Ore deposits of SE Asia
Hanoi University of Geology and Mining, Vietnam	Hai Thanh Tran	Khin Zaw, J Halpin	P1.L2 Ore deposits of SE Asia
Russian Academy of Science	V Maslennikov	R Large, R Scott, S Bull, L Danyushevsky, S Gilbert, S Meffre, Z Chang	P2.L2 Controls on the formation and sulfide trace-element signatures of sediment-hosted gold deposits
		R Large, R Scott, S Meffre, Z Chang	P2.L4 Genesis of the giant Sukhoi Log gold deposit, Siberia
United States Geological Survey, USA	P Emsbo	S Bull, P McGoldrick	P1.F5 Global ocean chemistry, marine basins and mineralisation
		R Large, R Scott, S Bull, L Danyushevsky, S Gilbert, S Meffre, Z Chang, H Thomas	P2.L2 Controls on the formation and sulfide trace-element signatures of sediment-hosted gold deposits
		D Selley, S Bull, R Scott, M Duffett, P McGoldrick, M Hitzman*, J Halpin, S Meffre	P3.L3 Origin and setting of Congolese-type copper deposits
University of California, USA	T Lyons	S Bull, P McGoldrick	P1.F5 Global ocean chemistry, marine basins and mineralisation
University of Oregon, USA	K Cashman, P Wallace	S Allen	P1.F3 Felsic magmas: volatile and metal budgets during magma evolution – a combined melt inclusion and volcanological approach
University of Hong Kong, China	MF Zhou	A Crawford, A McNeill, J McPhie, P Davidson, S Meffre, R Berry	P1.F1 Geodynamic controls on the fertility of fold belts and cratons
University of Huelva, Spain	R Saez, M Toscano	JB Gemmell, M Solomon, R Large, Khin Zaw, A Harris	P2.F3 Volcanic-hosted massive sulfide deposits
University of Lisbon, Portugal	J Relvas, F Barriga	A Crawford, R Berry, P Davidson, A McNeill, J McPhie, S Meffre	P1.F1 Geodynamic controls on the fertility of fold belts and cratons
Institute of Frontier Research on Earth Evolution, Japan	Y Tamura	S Allen	P1.F3 Felsic magmas: volatile and metal budgets during magma evolution – a combined melt inclusion and volcanological approach
University of Lubumbashi/ Gécamines, Zambia	S Sebagenzi	D Selley, S Bull, R Scott, M Duffett, P McGoldrick, M Hitzman*	P3.L3 Origin and setting of Congolese-type copper deposits
University of Ottawa, Canada	M Hannington	JB Gemmell	P2.F3 Volcanic-hosted massive sulfide deposits
Smithsonian Institution, USA	R Fiske	S Allen	P1.F3 Felsic magmas: volatile and metal budgets during magma evolution – a combined melt inclusion and volcanological approach

Appendices

<i>Institution</i>	<i>Researcher</i>	<i>CODES collaborators</i>	<i>Project</i>
Vernadsky Institute, Moscow, Russia	A Ariskin	L Danyushevsky, A McNeill, A Crawford	P1.F1 Geodynamic controls on the fertility of fold belts and cratons
		L Danyushevsky, A McNeill	P1.F4 Ni-PGE potential of mafic and ultramafic magmas – a combined melt inclusion and numerical modelling approach
Geomarine Research, NZ	B Hayward	S Allen	P1.F2 Modern magmatism in the Southwest Pacific
University of Science and Technology, Beijing, China	Yuling Xie, Zengqian Hou	D Cooke, Z Chang, L Danyushevsky, V Kamenetsky	P2.N5 T-P-X evolution of carbonatite melt-fluids and REE ore-forming processes in the Mianning-Dechang REE metallogenic belt
National Taiwan University, Taiwan	S-L Chung	V Kamenetsky	P1.F6 Unmixing in magmas: melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
Institute of Geology and Mineralogy, Novosibirsk, Russia	A Golovin, V Sharygin, L Zhitova	V Kamenetsky, M Kamenetsky	P1.F6 Unmixing in magmas: melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
Vernadsky Institute of Geochemistry, Moscow, Russia	V Batanova, V Naumov, A Sobolev	V Kamenetsky	P1.F6 Unmixing in magmas: melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
Institute of Geological and Nuclear Sciences, NZ	K Faure	V Kamenetsky, M Kamenetsky	P1.F6 Unmixing in magmas: melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
Guangzhou Institute of Geochemistry, PR China	WD Sun	V Kamenetsky	P1.F6 Unmixing in magmas: melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
Hebrew University, Jerusalem, Israel	O Navon, Y Weiss	V Kamenetsky, M Kamenetsky	P1.F6 Unmixing in magmas: melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
Lakehead University, Canada	R Mitchell	V Kamenetsky, M Kamenetsky	P1.F6 Unmixing in magmas: melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
Ghent University, Belgium	M Elburg	V Kamenetsky	P1.F6 Unmixing in magmas: melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
University of Manitoba, Canada	A Chakhmouradian	V Kamenetsky	P1.F6 Unmixing in magmas: melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
Geological Survey of Denmark and Greenland, Copenhagen, Denmark	TFD Nielsen	V Kamenetsky, M Kamenetsky	P1.F6 Unmixing in magmas: melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts
National collaborations (in addition to Centre partners)			
Australian National University	M Shelley	L Danyushevsky, V Kamenetsky, P McGoldrick, P Robinson, S Gilbert	P5.F1 Developments in LA-ICPMS of sulfides, fluid inclusions and carbonates
Australian National University	I Campbell, C Allen	A Harris, D Cooke, R Berry, J McPhie, R Tosdal*	P2.L1 District-to-deposit-scale structural and geochemical study of the Cadia porphyry Au-Cu deposits
Monash University	R Keys	J Foster	New initiatives
University of Adelaide	D Giles	A Crawford	P1.F1 Geodynamic controls on the fertility of fold belts and cratons
Primary Industry & Resources SA	M Fairclough, S Curtis	J McPhie	P1.F3 Felsic magmas: volatile and metal budgets during magma evolution – a combined melt inclusion and volcanological approach
Geological Survey of NSW	B Stevens, D Glen	A Crawford	P1.F1 Geodynamic controls on the fertility of fold belts and cratons
Geological Survey of Qld	I Withnall	A Crawford, R Berry	P1.F1 Geodynamic controls on the fertility of fold belts and cratons

<i>Institution</i>	<i>Researcher</i>	<i>CODES collaborators</i>	<i>Project</i>
Geoscience Australia	T Mernagh	V Kamenetsky, P Davidson	P1.F3 Felsic magmas: volatile and metal budgets during magma evolution – a combined melt inclusion and volcanological approach
		M Solomon, Khin Zaw, A Harris	P2.F3 Volcanic-hosted massive sulfide deposits
Monash University	R Keays	A Crawford	P1.F1 Geodynamic controls on the fertility of fold belts and cratons
Primary Industries NSW	Ian Percival	A Harris, D Cooke, R Berry, J McPhie, R Tosdal*	P2.L1 District- to deposit-scale structural and geochemical study of the Cadia porphyry Au-Cu deposits
University of Queensland, Dept of Earth Sciences	S Golding	Khin Zaw, S Meffre	P1.L2 Ore deposits of SE Asia
Australian National University	J Mavrogenes	A Harris	P5.F3a Developmental research into the use of synchrotron in ore deposit studies
Geological Survey of NSW	Ian Percival	A Harris, D Cooke	P2.L1 District- to deposit-scale structural and geochemical study of the Cadia porphyry Au-Cu deposits



Appendices

Visitors to CODES 2008

Industry visitors			
Visitor	Institution	Purpose of visit	Date
Aaron Wehrle	Gold Fields Ltd	P765A Meeting	Dec
Adrian Dance	Metso Minerals Process Technology (Asia-Pacific)	P843 Meeting	Feb/Nov
Adrian McArthur	St Barbara	CODES Science Planning Meeting and Advisory Board Meeting	Jun
Aidan Giblett	Newmont Asia Pacific Pty Ltd	P843 Meeting	Feb/Nov
Alan Bye	WH Bryan Centre	P843 Meeting	Feb
Alan Goode	AMIRA International Limited	P843 Meeting	Feb
		P765A Meeting	Jun/Nov
		CODES Science Planning Meeting and Advisory Board Meeting	Jun
		ARC Review Meeting	Nov
Alan Wilson	Anglo American Exploration Australia Pty Ltd	P765A Meeting	Jun
		P872 Research Update Meeting	Jun
Andrew Jenkins	AngloGold Ashanti	P843 Meeting	Feb
Andrew Stewart	VALE – Tethys Mining LLC	P765A Meeting	Dec
Andrew Wurst	Gold Fields International Exploration	P765A Meeting	Jun
Andy Lapworth	Datamine Software Limited	P843 Meeting	Feb/Nov
Andy W Stradling	Teck Cominco Metals Ltd	P843 Meeting	Feb
Angus McFarlane	BHP Billiton	P843 Meeting	Feb
Anthony Wesson	BHP Billiton	P843 Meeting	Nov
Aubrey Paverd	Compania de Minas Buenaventura	P765A Meeting	Jun
Baris Gazanfer Yildirim	Teck Cominco	P843 Meeting	Nov
Barun K Gorain	Barrick	P843 Meeting	Feb
Belinda Moss	BHP Billiton	P843 Meeting	Feb/Nov
Bevin Wong	Xstrata Copper	P843 Meeting	Feb
Brett Davis	Dundee Precious Metals Inc	P765A Meeting	Jun
Cam Allen	Teck Cominco	P McGoldrick & CODES	May
Cameron Cairns	Pan Australian Resources	Ore Deposits of SE Asia Meeting	Mar/Nov
Carlos Delgado	BHP Billiton, Minera Escondida Ltda	P843 Meeting	Nov
Carlos Krebs	Codelco	P843 Meeting	Nov
Chris Betts	Zinifex Limited	P843 Meeting	Feb
Chris Gauld	Vale Inco	P843 Meeting	Feb
Chris Oates	Anglo American	CODES Update Meeting	Apr
Claire Chamberlain	Teck	P765A Meeting	Dec
Dale Sims	Newcrest Mining Limited	P843 Meeting	Nov
Dan Alexander	JK Tech	P843 Meeting	Feb
Dan Olberg	Oxiana Limited	P765A Meeting	Jun
Dan Power	Newmont Asia Pacific	Ore Deposits of SE Asia Meeting	Mar/Nov
Darren Andrews	St Barbara	P765A Meeting	Dec
David Braxton	Anglo American Exploration Australia Pty Ltd	P765A Meeting	Jun/Dec
		P872 Research Update Meeting	Jun
David First	Freeport-McMoRan Exploration Corporation	P765A Meeting	Jun/Dec
		CODES Science Planning Meeting and Advisory Board Meeting	Jun
David Hartman	BHP Billiton	P843 Meeting	Nov
David Lawie	ioGlobal	P843 Meeting	Feb/Nov
David Meade	OZ Minerals	P765A Meeting	Dec
David Sun	Sinosteel Australia	Andrew McNeill	Nov
David Wallace	Zinifex	Ore Deposits of SE Asia Meeting	Mar
Dean Collett	Newcrest Mining Limited	P843 Meeting	Feb
		ARC Review Meeting	Nov
Deming Whitman	AMIRA International Limited	P843 Meeting	Feb
Dewetia Latti	Rio Tinto Limited	P843 Meeting	Feb
Donna Sewell	AngloGold Ashanti Limited	P765A Meeting	Jun/Dec
		CODES Science Planning Meeting and Advisory Board Meeting	Jun

<i>Visitor</i>	<i>Institution</i>	<i>Purpose of visit</i>	<i>Date</i>
Elizabeth da Fonseca	Vale	P843 Meeting	Nov
Gavin A Yeates	BHP Billiton	P843 Meeting	Feb
Geoff Gault	JK Tech	P843 Meeting	Feb
Geoff Lane	Rio Tinto	P843 Meeting	Feb/Nov
Geoff Richmond	OZ Minerals	P843 Meeting	Nov
Glen Masterman	Kinross Gold Corporation	P765A Meeting	Dec
Gray Bailey	AMIRA International Limited	P843 Meeting	Feb
Greg Wilkie	Rio Tinto Limited	P843 Meeting	Feb
Henni Coetzee	Datamine	P843 Meeting	Feb
Ian Willis	Anglo American	CODES Science Planning Meeting and Advisory Board Meeting	Jun
		ARC Review Meeting	Nov
Ileana Inocencio	AMIRA International Limited	P843 Meeting	Feb
James Cannell	Oxiana Limited	P765A Meeting	Jun
James Pinakis	ioGlobal	P843 Meeting	Nov
Jamie Diaz	Codelco	P843 Meeting	Nov
Jared Broome	OZ Minerals	P843 Meeting	Nov
Jayson Meyers	Sinosteel Australia	Andrew McNeill	Nov
Jillian Terry	BHP Billiton	P843 Meeting	Feb/Nov
Jim Phelan	BHP Billiton	P843 Meeting	Feb
Joe Cucuzza	AMIRA International Limited	P843 Meeting	Feb
John Cooke	Equinox Minerals Limited	P765A Meeting	Jun
John Dow	DowGold	CODES Science Planning Meeting and Advisory Board Meeting	Jun
		ARC Review Meeting	Nov
John Hammond	Newmont Exploration Pty Ltd	P843 Meeting	Feb
John Holliday	Newcrest Mining Limited	CODES Science Planning Meeting and Advisory Board Meeting	Jun
John Jackson	Vale Exploration	P843 Meeting	Feb
John Larson	Zinifex	CODES Science Planning Meeting and Advisory Board Meeting	Jun
John Twomey	Ernest Henry Mining Pty Ltd	P843 Meeting	Feb
Jonathon Graham	Datamine Australia	P843 Meeting	Nov
Julio Beniscelli Troncoso	Codelco	P843 Meeting	Feb
Kai Yang	CSIRO Exploration and Mining	P843 Meeting	Feb
Katherine Stewart	BHP Billiton	P843 Meeting	Feb
Kathy Ehrig	BHP Billiton	P843 Meeting	Feb/Nov
Keith Kenny	AngloGold Ashanti	P843 Meeting	Feb/Nov
Kirsty Hollis	Newmont Asia Pacific Pty Ltd	P843 Meeting	Nov
Larry Stewart	Zinifex	Ore Deposits of SE Asia Meeting	Mar
		Jeff Foster	May
Lindy Yeates	BHP Billiton	P843 Meeting	Feb
Lynda Daley	Newmont Asia Pacific Pty Ltd	P765A Meeting	Jun/Dec
		CODES Science Planning Meeting and Advisory Board Meeting	Jun
Malcolm Newton	Datamine Australia	P843 Meeting	Nov
Marnie Pascoe	BHP Billiton Nickel West	P843 Meeting	Nov
Matt Clifford	Ernest Henry Mining Pty Ltd	P843 Meeting	Feb
Matthew Dalziel	AMIRA International Limited	P843 Meeting	Feb
Melanie Holland	Geotek Ltd	P843 Meeting	Feb
Michael Glinsky	BHP Billiton	P843 Meeting	Nov
Michael N Richards	Equinox Minerals Limited	P765A Meeting	Jun/Dec
Mick Sharry	OZ Minerals	Ore Deposits of SE Asia Meeting	Nov
Mike Cawood	Teck Cominco Australia Pty Limited	P765A Meeting	Jun
		CODES Science Planning Meeting	
Neil Macalalad	Anglo American Exploration (Philippines) Inc	P765A Meeting	Dec
Nichola A McKay	Teck Cominco Metals Ltd	P843 Meeting	Feb/Nov
Nick Beaton	Datamine Australia	P843 Meeting	Feb/Nov

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<i>Visitor</i>	<i>Institution</i>	<i>Purpose of visit</i>	<i>Date</i>
Nick Green	BHP Billiton	P843 Meeting	Feb/Nov
Patrick Waters	Anglo American Exploration (Philippines) Inc	P765A Meeting	Dec
Paul Agnew	Rio Tinto Exploration Pty Limited	P765A Meeting	Jun/Dec
		CODES Science Planning Meeting	Jun
		ARC Review Meeting	Nov
Paul Kittler	BHP Billiton	P843 Meeting	Feb/Nov
Paul Lauricells	Sandfire Resources	CODES	May
Pedro Carrasco Castelli	Codelco	P843 Meeting	Feb/Nov
Peter Fullagar	Fullagar Geophysics Pty Ltd	P843 Meeting	Feb
Peter Hill	Southern Gold	Ore Deposits of SE Asia Meeting	Dec
Peter J Schultheiss	Geotek Ltd	P843 Meeting	Feb
Puru L Shrestha	BHP Billiton	P843 Meeting	Feb/Nov
Rex Brommecker	Barrick	CODES Science Planning Meeting	Jun
Richard K Preece	BHP Billiton	P843 Meeting	Feb
Rob Coghill	Indochine	Ore Deposits of SE Asia Meeting	Mar
Rob Wall	ioGlobal	P843 Meeting	Feb/Nov
Robert Barr	Newmont Exploration Pty Ltd	P843 Meeting	Nov
Robert S Schouwstra	Anglo Platinum RPM	P843 Meeting	Feb/Nov
Roberto Fréaut	Codelco	P843 Meeting	Nov
Rod Holcombe	OZ Minerals	Ore Deposits of SE Asia Meeting	Dec
Ron James	Kingsgate Consolidated	Ore Deposits of SE Asia Meeting	Mar/Nov
Russell Hooper	Oxiana Limited/OZ Minerals	P843 Meeting	Feb/Nov
Russell Sweeney	Rio Tinto Exploration Pty Limited	P843 Meeting	Jun
Shauna Nichol	Anglo Platinum RPM	P843 Meeting	Nov
Shu Zhan	Zeehan Zinc	CODES Science Planning Meeting and Advisory Board Meeting	Jun
Stephen Perkins	Xstrata Copper Exploration	P843 Meeting	Feb
Steve Liddell	BHP Billiton	P843 Meeting	Feb/Nov
Steve Wilson	Teck Cominco	P843 Meeting	Nov
Stuart Graham	Rio Tinto Exploration Pty Limited	P765A Meeting	Dec
Stuart Masters	Oxiana Limited/OZ Minerals	P843 Meeting	Feb/Nov
Stuart Smith	OZ Minerals	Ore Deposits of SE Asia Meeting	Mar/Nov
		P765A Meeting	Jun/Dec
		P843 Meeting	Feb
		CODES Science Planning Meeting and Advisory Board Meeting	Jun
Suziany Rocha	Rio Tinto Exploration Pty Limited	P765A Meeting	Jun
Terry Hoschke	Newmont Exploration Pty Ltd	P765A Meeting	Dec
Tom Evans	Xstrata Copper Exploration	P765A Meeting	Dec
Tom Gibbons	Barrick	P843 Meeting	Feb
Tony Hope	Indochine	Ore Deposits of SE Asia Meeting	Mar/Nov
Trevor Beardsmore	Barrick Gold of Australia Limited	Ore Deposits of SE Asia Meeting	Mar/Nov
		P765A Meeting	Jun/Dec
		CODES Science Planning Meeting	Jun
Trevor Ellice	Zinifex Rosebery Mine/OZ Minerals	P843 Meeting	Feb/Nov
Vanessa Liebezeit	BHP Billiton	P843 Meeting	Feb/Nov
National academic and government visitors			
Angela Halfpenny	Australian National University	CODES Science Planning Meeting and Advisory Board Meeting	Jun
Benjamin J Adair	JKMRC	P843 Meeting	Feb
		Advisory Board Meeting	Jun
		ARC Review Meeting	Nov
Cam McCuaig	CET-UWA	CODES	May
Cam Quinn	Geological Survey of NSW	Tony Crawford	May
Cathy Evans	JKMRC	P843 Meeting	Feb
David Boakye	WH Bryan Centre	P843 Meeting	Feb
David Green	Mineral Resources Tasmania	CODES Science Planning Meeting	Jun

<i>Visitor</i>	<i>Institution</i>	<i>Purpose of visit</i>	<i>Date</i>
Dee Bradshaw	University of Cape Town/SMI	P843 Meeting	Feb
Derek Marshall	UWA/Ironbark	Peter McGoldrick	Aug
Gabe Sweet	Lakehead	P765A Meeting	Dec
George Leigh	JKMRC	P843 Meeting	Feb
Geoff Green	Mineral Resources Tasmania	CODES Science Planning Meeting	Jun
Graham Carr	CSIRO	CODES Science Planning Meeting and Advisory Board Meeting	Jun
		ARC Review Meeting	Nov
Jamie Laird	CSIRO	CODES Science Planning Meeting	Jun
Jon Huntington	CSIRO Exploration and Mining	P843 Meeting	Feb
Kai Yang	CSIRO Exploration and Mining	P843 Meeting	Feb
Khoi Nguyen	JKMRC	P843 Meeting	Feb
Luke Keeney	JKMRC	P843 Meeting	Feb
Ned Stolz	Geoscience Australia	CODES Science Planning Meeting	Jun
Nenad Djordjevic	JKMRC	P843 Meeting	Feb
Nick Oliver	JCU-EGRU	David Cooke/Ross Large	May
		CODES ARC Review Meeting	Nov
Reyhaneh Tabatabaei	JKMRC	P843 Meeting	Feb
Richard Hartner	JKMRC	P843 Meeting	Feb
Rob Morrison	JKMRC	P843 Meeting	Feb
Sergio Vianna	JKMRC	P843 Meeting	Feb
Simon Michaux	JKMRC	P843 Meeting	Feb
Stephen Cox	Australian National University	CODES Science Planning Meeting and Advisory Board Meeting	Jun
		ARC Review Meeting	Nov
Steve Algie	MTEC	Tony Webster	Aug
Tim Napier-Munn	University of Queensland – SMI	P843 Meeting	Feb
Toni Kojovic	JKMRC	P843 Meeting	Feb
Tony Brown	Mineral Resources Tasmania	CODES Science Planning Meeting and Advisory Board Meeting	Jun
Yicai Wang	JKMRC	P843 Meeting	Feb
Ying Gu	JK Tech	P843 Meeting	Feb
International academic and government visitors			
Alexei Ariskin	Vernadsky Institute of Geochemistry, Moscow, Russia	Visited Leonid Danyushevsky, Andrew McNeill and Sandrin Feig to collaborate on the origin of Dovyren magmatic complex and modelling of crystallisation processes within AMIRA P962.	Jan–Apr
Bombile Bosongo	Gecamines, Congo	Attending shortcourse and collaborative research on the ARC – AMIRA P872	27 Oct–8 Nov
Cornel De Ronde	IGNS – New Zealand	Jocelyn McPhie, Vadim Kamenetsky	Oct
Eduard Konnikov	Institute of Experimental Mineralogy, Chernogolovka, Russia	Visited Leonid Danyushevsky, Andrew McNeill and Sandrin Feig to collaborate on the origin of Dovyren magmatic complex within AMIRA Project P962	Dec 07–Jan 08
Farahnaz Daliran	Geological Survey of Iran in Germany	Paul Davidson	Jan
Janina Micko	MDRU-UBC	David Cooke	Apr
Kabamba Wa Kabamba	Gecamines, Congo	Attending shortcourse and collaborative research on the ARC – AMIRA P872	27 Oct–8 Nov
Kirstie Simpson	MDRU	Alkaline Project Breccia Book	May
Mengist Teklay	University of Muenster	Visited Leonid Danyushevsky and Tony Crawford to collaborate on origin of Ethiopian flood basalts	Apr 2007–Mar 2008
Nick Arndt	University of Grenoble	Leonid Danyushevsky	Jun
Pavel Yu Plechov	Moscow State University, Russia	Visited Leonid Danyushevsky to collaborate on modelling of crystallisation processes	May–Aug
Peter Hollings	Lakehead University, Canada	Visited David Cooke to work on AMIRA P765A	Feb–May
Somboon Khositantont	Department of Mineral Resources, Thailand	Ore Deposits of SE Asia Meeting	Nov
Yoshi Goto	Muroran Institute of Technology, Muroran, Hoakkaido, Japan	Visited Jocelyn McPhie to collaborate on P1.F3	Dec 2007–Mar 2008
Zahra Bonyadi (PhD student)	Tarbiat Moallam University, Tehran, Iran	Visited Garry Davidson and Sebastien Meffre to work on aspects of IOCG-related mineralisation in the Bafra district, Iran (P2.F4)	Feb–Jul

Appendices

Major externally funded research projects*

AMIRA-ARC Centre of Excellence projects 2008 [†]						
Investigators	Project	Industry Partners	Period	CoE-ARC Funding for 2008	AMIRA Funding for 2008	Misc Funding for 2008
Danyushevsky, Crawford, Kamenetsky, Sobolev (Max Planck Inst)	AMIRA P962. Ni-PGE potential of mafic and ultramafic magmas – a combined melt inclusion and numerical modelling approach	Anglo American, BHP Billiton, Votorantim Metals	2007–2010	\$113,000	\$142,920	\$0
Scott, Large, Emsbo (USGS), Maslennikov (RASci)	AMIRA P923. Controls on the formation and sulfide trace element signatures of sediment-hosted gold deposits	Barrick, Golden Gryphon, Newcrest, Newmont, Perseverance, St Barbara Mines	2005–2008	\$0	\$42,750	\$10,701
Walters, Berry, Djordjevic, Fullagar, Hunt, Huntington, Kojovic, Bye	AMIRA P843. GeM ^{III} (Geometallurgical Mapping and Mine Modelling)	AngloGold Ashanti, Anglo Platinum, Barrick, BHP Billiton, Codelco, Datamine, Geotek, Golder Associates, ioGlobal, Metso Minerals, Newcrest, Newmont, Penoles, OZ Minerals, Rio Tinto, Teck, Vale, Vale Inco, Xstrata	2005–2009	\$546,364	\$1,574,380	\$349
AMIRA-ARC Linkage projects 2008 [†]						
Investigators	Project	Industry Partners	Period	ARC Funding for 2008	AMIRA Funding for 2008	Misc Funding for 2008
Cooke, Gemmell, Chang, Baker, Chen, White	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, Newcrest Mining, Newmont Mining, OZ Minerals, Rio Tinto, St Barbara, Teck	2008–2011	\$0	\$301,350	\$2,792
Selley, Bull, McGoldrick, Hitzman (CSM)	AMIRA P872. Sediment-hosted Cu-deposits of Congolese, Zambian & central Australian basin systems	Anglo American, Anvil Mining, BHP Billiton, Entreprise Generale Malta Forrest, Equinox Minerals, First Quantum Minerals, Gecamines, Phelps Dodge, Rio Tinto, Teal Mining, Vale Inco	2005–2009	\$132,000	\$0	\$15,715
Other ARC Linkage projects 2008 [†]						
Investigators	Project	Funding Body	Period	ARC Funding for 2008	Other Major Funding for 2008	Misc Funding for 2008
Davidson	Genesis of platinum group element-rich, unconformity-style, hydrothermal mineral deposits, as inferred from a Northern Territory example	Department of Primary Industry, Fisheries & Mines	2006–2009	\$26,140	\$8,000	\$1,028
ARC Discovery Grants 2008 [†]						
Investigator	Project		Period	ARC Funding for 2008	Misc Funding for 2008	
Allen	Discovery Grant: Submarine explosive eruptions of silicic magma: constraints on products and processes from modern sea-floor examples, ancient successions and experiments		2004–2008	\$127,228	\$0	
Kamenetsky	APF and Discovery Grant: Unmixing in magmas: melt and fluid inclusion constraints on identity, timing and evolution of immiscible fluids, salt and sulfide melts		2005–2009	\$174,510	\$0	

* projects with greater than \$10,000 external (non-CoE-ARC) funding per year

† ARC funding for these projects comes from the CoE-ARC Grant

^ ARC funding for these projects comes directly from the ARC Discovery or Linkage programs

Industry and other externally funded research grants 2008*					
<i>Investigators</i>	<i>Project</i>	<i>Funding Body</i>	<i>Period</i>	<i>Funding for 2008</i>	<i>Misc Funding for 2008</i>
Chang, Cooke, White	Caijiayang Zn-Au deposit: geological characteristics and their implications to exploration	Hebei Hua Ao Mining	2007–2009	\$50,000	\$0
Cooke	Palmarejo carbonate base-metals silver-gold epithermal deposit, Chihuahua, Mexico	Bolnisi Gold NL	2006–2008	\$68,163	\$0
Cooke, Deyell, Tosdal (UBC)	Shallow and deep-level alkalic mineral deposits	University of British Columbia	2005–2008	\$44,421	\$0
Foster, Hutchinson	Tenor variation in the Tweefontein sector of the Platreef, South Africa	Anglo American Exploration Luxembourg SARL	2008–2010	\$144,009	\$0
Foster	Avebury nickel pilot study, Tasmania	OZ Minerals	2008–2009	\$10,125	\$0
Gemmell, Micklethwaite	Deposit- to district-scale study of the Gosowong Goldfield	Newcrest Mining Limited	2007–2010	\$138,309	\$100
Gemmell	Geology of Niblack VHMS Deposit, Alaska: implications for ore genesis and exploration	Niblack Mining Corporation	2007–2010	**	\$0
Gemmell, Berry	Geology and geochemistry of the footwall phyllite, Greens Creek VHMS deposit, Alaska: implications for ore genesis and exploration	Kennecott Greens Creek Mining Company	2004–2008	\$16,039	\$0
Harris, Cooke, Berry	District- to deposit-scale structural and geochemical study of the Cadia porphyry Au-Cu deposits	Newcrest Mining Limited	2005–2008	\$118,147	\$1,066
Khin Zaw, Meffre	Ore Deposits of SE Asia	Barrick Gold, Indochine Resources Ltd, Kingsgate Consolidated Ltd, Newmont Asia Pacific, OZ Minerals, Pan Australian Resources, Southern Gold Ltd	2008–2010	\$300,000	\$0
Large, Bull, Thomas	Geochemistry of shales and LQ veins at Bendigo: a new approach to assist selection of drill targets	Bendigo Mining Ltd	2008–2009	\$19,000	\$0
McPhie, Kamenetsky, Chambefort	Mafic igneous facies at Olympic Dam	BHP Billiton	2008–2010	**	\$0
Webster	Investigation into the potential for lead-zinc and other styles of mineralisation at Broken Hill	Perilya Broken Hill Ltd	2007–2009	\$20,000	\$0
Webster	Structure and deformational history of the Savage River magnetite orebodies	Australian Bulk Minerals	2008–2009	\$24,000	\$0

* projects with greater than \$10,000 external (non-CoE-ARC) funding per year

** project started, funding not yet received

Activity Plan 2009

Project	Team leader(s)	Activity plan
Program 1		
P1.A5	AJ Crawford, J Foster, A Reading	Liaise with key ground holders and GSWA to clear way forward for fieldwork. Spend 10–14 days in GSWA offices, locating and sampling company drill core/chips, and commencing fieldwork, based likely in Esperance. Commence LA ICPMS zircon dating and petrographic and geochemical/geochronological studies of Fraser Complex.
P1.A6	AJ Crawford, J Foster, D Cooke	AJ Crawford to travel to India for ~20 days and J Foster for 10 days in October 2009 to carry out transects across the Hutti, Kolar and Jonnagiri greenstone belts in the Darwar craton, and one key transect through the Bastar craton further north to establish the lithostratigraphy of the host sequences to the Au in these mineralised belts. In 2010, similar transects will be carried out across greenstone keels in the western Dharwar craton, which is unmineralised. Detailed sampling will be followed up by petrographic and geochemical studies of representative samples. Geochronology will focus on the upper, more evolved sections of thick sills that are present in all the greenstones sequences, and which are likely to be comagmatic with the host greenstones volcanic successions.
P1.F1	AJ Crawford	P1.F1.1 1: Sample from core and outcrop both near-mine and remote Potosi Gneiss and potobolite, and commence relevant analytical work with UMelb node (Maas, Woodhead). 2: Publication of paper in <i>Geology</i> and/or <i>Economic Geology</i> on the new model for the origin of Broken Hill Pb-Zn mineralisation. Project P1.F1.3 1: Complete study of the Sterling Valley Volcanics and submit to <i>Australian Journal of Earth Sciences</i>. 2: Complete one further sampling trip to Rosebery, then MC-ICPMS analytical work on the isotopic and trace element geochemistry of felsic rocks in the Mt Read Volcanics, and their zircons. 3: Submission of Susan Belford's PhD thesis on the Jaguar deposit. 4: Submission of paper to <i>Journal of Volcanology and Geothermal Research</i> on the facies architecture of the Neves Corvo host sequence in the Iberian Pyrite Belt (Rosa, McPhie, Relvas). Project F1.1.4 1: Work with BSc(Hons) student Carla Vincent and Anglo American to complete a study of the petrogenesis and mineralisation of the Dido Tonalite west of Greenvale. 2: Visit Prof Bob Henderson at James Cooke University following the SGA conference in Townsville in August 2009 to complete a paper for <i>Australian Journal of Earth Sciences</i> on the tectono-magmatic development of the northern end of the Tasman Line. Project F1.1.6 1: Complete a paper for <i>Geology</i> on the ultimate source of gold in the Victorian turbidite-hosted gold deposits.
P1.F2	L Danyushevsky, AJ Crawford	1: Continue sample analysis of rocks collected during SS10/2004 and SS08/2006. 2: Detailed study of melt inclusions in olivine phenocrysts from samples covering a range of magma types. This work commenced in 2008. 3: Fiona Best will visit the synchrotron in Chicago to measure oxidation state of melt inclusions in olivine. 4: An initial study of the compositions of minerals and melt inclusions in more evolved samples from the study area. 5: Undertake a third research voyage to the Hunter Ridge (L Danyushevsky, Chief Scientist) if seetime is granted during 2009. 6: If the 2009 voyage goes ahead, submit for analysis new samples (thin sections; wholerock XRF; solution ICPMS; isotope MC-ICPMS analyses; electron microprobe analysis of mineral and volcanic glass compositions (major elements, Cl, S); FTIR analysis for H₂O contents of volcanic glasses; LA-ICPMS of glasses).
P1.F3	V Kamenetsky, J McPhie	1: Determine volatile and metal abundances in Taupo Volcanic Zone rhyolitic magmas. 2: Establish the controls on explosive degassing of felsic magmas in subaqueous settings. 3: Reassess the importance of a magmatic contribution to the Olympic Dam hydrothermal system. 4: Determine the trace element and volatile abundances in Gawler Range Volcanics rhyolitic magmas. 5: Develop a new model for the pumice-rich facies at Dogashima. 6: Completion of A Agangi's PhD thesis and near completion of S Gordeev's PhD thesis.

Project	Team leader(s)	Activity plan
P1.F4	L Danyushevsky	Work on the project will continue according to the research plan. The next sponsors' meeting will take place in Hobart in March 2009, where the details of the research program for the second year of the project will be discussed.
P1.F5	P McGoldrick, S Bull	Complete CAS work on McArthur Basin and Mt Isa Basin stratigraphic sections. Progress textural, geochemical and isotopic investigations of the HYC ore to low-grade and barren hangingwall transition. Undertake organic biomarker pilot study of Century samples (including Grypania sample). Complete reviews of manuscripts submitted to <i>Mineralium Deposita</i> Special Issue.
P1.F6	V Kamenetsky	Revise two papers provisionally accepted in <i>Lithos</i> on melt immiscibility in kimberlite magmas from SW Greenland and Slave Craton (Canada). Prepare a publication on the role of skarn-related fluids in the Mt Vesuvius magmatic system in transporting Mo, Sn and W. Prepare a publication on petrology and geochemistry of carbonate-chloride enriched Udachnaya-East pipe kimberlite. Continue working on interstitial melting/crystallisation assemblages in eclogite and peridotite xenoliths from different kimberlites, including a visit of Dr Zdislav Spetsius, the expert from the Institute of Diamond Industry, ALROSA Company, Ltd., Yakutia, and PhD student from RSES, ANU. Start analytical work on fresh kimberlites from the Ekati property (BHP Billiton). Investigate compositional zoning in magmatic perovskites from kimberlites, carbonatites and ultra-alkaline magmas. Sr isotope analyses of perovskite should follow. Prepare a publication on the 'magmatic' link between Gondwana break-up and compositions of 190 Ma Karoo and modern S. Atlantic melts. Continue assembly of analytical and literature data for a publication on primary magmas in the Emeishan LIP. Continue supervision of O Vasyukova's work on the true nature of fluids parental to quartz in mineralised porphyries. Design experiments on orthopyroxene dissolution in carbonatitic melt (with Dr O Safonov, Institute of Experimental Mineralogy, Russia). Study volatile contents of the Gorgona komatiitic magmas using SIMS at WHOI.
P1.L2	Khin Zaw, S Meffre	Provide a new tectonic model of SE Asia based on a synthesis of existing data coupled with our new well-constrained geochemical and geochronological database. Provide more accurate geological maps and regional cross-sections for key areas across the whole of mainland SE Asia. Establish ore deposit summaries including ages of host, mineralisation and geochemical and isotopic signatures. Compile data sheets for each rock examined in detail. Update maps and data on website during life of project.
Program 2		
P2.L1	D Cooke, A Harris	This project will conclude at the end of 2009. Final reports for both the district- and deposit-scale work are being finalised. All analytical work will cease. Knowledge transfer will ramp-up to comprise numerous informal discussions, emails (already on-going), combined with more formal reports and presentations. We will attempt to assemble the world-wide exploration groups of Newcrest to review all research findings. We will aim to develop a continuing or new research effort with Newcrest Mining Limited.
P2.L3	R Tosdal, D Cooke, T Bissig, K Simpson	Completion of PhD theses by Zukowski, Pass, Bath and Blackwell at CODES. Completion of MSc thesis by Byrne and PhD thesis by Micko at MDRU. Preparation of alkalic special issue for <i>Economic Geology</i> (edited by Bissig and Cooke).
P2.N2	Z Chang	1: Finish the project by the end of March. Submit final report. 2: Write a manuscript. Submission after the confidentiality period.

Activity Plan 2009

Project	Team leader(s)	Activity plan
P2.N5	Y Xie	1: Determine the composition of melt inclusions, melt-fluid inclusions and fluid inclusions in minerals such as quartz and fluorite, and then establish the path of compositional evolution. 2: Investigate the processes that led to the transition from melt to ore-forming fluid in the carbonatite-related REE deposits. 3: Investigate the partitioning of REE and metals between melts and fluids in the Mianning-Dechang REE belt. 4: Submit a paper to an international journal and give a presentation at international conference.
P2.F1	SF Cox, D Cooke	1: Plan to complete the structural analysis of the Porgera gold deposit and provide an understanding of how fracture-controlled flow pathways have evolved during the evolution of the hydrothermal system, the processes controlling this evolution, and how it influenced Au ore distribution and grades. 2: Commence a structural analysis of the Northparkes Cu-Au system as the second of our case studies to explore the development of fracture-controlled fluid pathways in intrusion-related regimes.
P2.F2	S Bull	The main emphasis will be to publish the modelling work completed so far, which has profound implications for our understanding of the genesis of sediment-hosted Cu deposits. A manuscript on the original Zambian sections intended for <i>Geology</i> is currently in preparation. This will be followed by one or two publications resulting from the work on the extended section that investigates compaction- versus density-driven flow, and various geological scenarios including fluid flow patterns during salt tectonism. The next phase of model development would be to utilise a code that incorporates poroelastic effects into a numerical code. This will enable us to investigate the relationship between fluid flow associated with pore fluid overpressuring during deformation and ore genesis in systems such as mesothermal gold. Preliminary investigations have been held with our collaborator Grant Garven on the best way to proceed in this direction, which could involve incorporating poroelastic effects into our current code or utilising a commercially available package.
P2.F3	B Gemmell, M Solomon	Sub-project 1: The role of mantle volatiles at Neves Corvo: sulphur data largely available but Nd isotopes under consideration. Determining the manner of deposition of the Lombador orebody using textures at drill-core to micro-scale: largely textural and mineralogical, including MLA, MP, plus known or estimated parameters such as nucleation energy, rates of diffusion, degree of supersaturation, mineral metastability, etc. Sub-project 2: Continue dating of Mount Read Volcanic belt lithologies in collaboration with Jim Mortensen (UBC) Continue investigating the Jaguar (Western Australia), Greens Creek (Alaska), Yaman-Kasy (Russia), Baiyinchang (China) Tasik Chini (Malaysia) and Chahgaz (Iran) VHMS deposits. Find PhD student and/or post-doc and initiate Niblack study, pending on Committee Bay Resources decision. Sub-project 3: Collaborate on CAMIRO project. Submit Que River Shale pyrite chemistry paper. Sub-project 4: Continue LA-ICPMS and LA-sulfur studies on PACMANUS, Palinuro and Panarea samples.
P2.F4	GJ Davidson	The unconformity-U style research will be reported under a new project heading in 2009 (P2.B6). IOCG research will be reported as P2.B4. The IOCG research will bring several areas to a new understanding: C McMahon and G Davidson will collaborate with J Laird from CSIRO to evaluate electrochemical effects on element enrichment in Nico cobalt-goldrich ores, and this will contribute to C McMahon's research thesis on trace element incorporation into pyrite. On the Prominent Hill project, we are prioritising write-up of the dating component, bringing together recent U-Pb apatite and monazite work, and Ar-Ar work undertaken in collaboration with Geoscience Australia and ANU. Submission of a manuscript on REE mobility in an Iranian high-temperature magnetite-apatite deposit (a related ore type), building on the laboratory work undertaken at CODES by Z Bonyadi in 2008. Aim to commence a new student-focused project on the genesis of a Cloncurry IOCG deposit in collaboration with Exco Resources, using seed funding from the CoE.

<i>Project</i>	<i>Team leader(s)</i>	<i>Activity plan</i>
Program 3		
P3.F2	R Large, S Bull	1: Redraft AMIRA proposal for three-year funding of new sediment- and volcanic-hosted gold project. Secure sponsors by May 2009 (RRL). 2a: Bendigo field visit and strat logging (SB, HT). 2b: Complete phase 2 of Bendigo Project in March; report to company (HT, RRL). 3: Phase 3 of Bendigo Project – background gold in turbidites of Victorian Goldfield (HT). 4: Prepare manuscripts for publication on Bendigo research (HT, RRL, SB). 5: Field visit to Otago Goldfield (RRL, HT). 6: Pyrite petrography and LA-ICPMS on Otago samples (HT). 7: Report on Otago research (HT, RRL).
P3.F3	J Foster	Compilation of the current research leading to a publishable manuscript, and comparison of these results to mineralising systems from other mafic-ultramafic Ni-Cu-PGE desposits.
P3.F4	J Foster, M Roach	Complete translation of old format data to new database format. Add data from Geoscience Australia.
P3.F6	A Reading	1: Ambient seismic energy The seismic stations of the pilot study will be deployed from Dec 2008–June 2009 over a test-region of contrasting lithology in the Midland Valley, Tasmania. The project aims to a) establish some protocols for recording ambient seismic energy; b) determine the nature of the ambient seismic wavefield in this moderately populated region; and c) make preliminary determinations of structure along the 2D pilot survey line. 2: Computational Geophysics This is a new area of research for 2009 and aims to bring the extensive geological and geophysical databases and industrial community contacts at CODES together with the developments in computer simulation and imaging. The priority is to establish a platform for computational geophysics within CODES. Initial projects include innovative approaches to seismic structure, heat flow and collaboration on laser ablation imaging.
P3.L1	P Fullagar, M Roach	Completion of R Schaa's PhD thesis. Continuation of research under AMIRA P1022 (GLODISC): (i) geometry inversion (ii) inversion of downhole TEM (iii) upgrade user interface
P3.L2	D Cooke, B Gemmell, Z Chang	1: Field campaigns are planned for Cerro Casale, Collahuasi, El Teniente, Ixhuatan, Tantauatay, Yanacocha and Perol in the first half of 2009. 2: A sponsors' field meeting in Chile and Peru is scheduled for May 2009. 3: Sampling at Batu Hijau in early 2009. 4: Fieldwork at Timok in the latter half of 2008. 5: Evaluation of magnetite and carbonate chemistry. 6: Complete four blind site tests.
P3.L3	D Selley, S Bull, M Hitzman	1: Completion of the final technical report in February 2009. 2: Examine the potential for Re-Os age dating of ore host strata and ore sulfides from Zambian and Congolese deposits. 3: Prepare papers for publication at the end of the project's confidentiality period (mid-2010), or earlier if agreement from sponsors is reached.
P3.L4	M Roach	Complete software (VPmg, 3DGeoModeller, UBC-GIF) inversion runs. Incorporate supervised classification approach (Project P3.F1) in the latter. Develop methodology for quantitative evaluation.
P3.L7	A McNeill	Complete shale project and present results to sponsor company by mid-February.

Activity Plan 2009

Project	Team leader(s)	Activity plan
P3.L8	B Gemmell, D Cooke	Completion of B Sutopo's PhD thesis. Completion of C Chamberlain's Master of Economic Geology thesis. Continuation of the Gosowong district and Palmarejo projects. Publication of the Olberg and Gemmell paper on the application of geological and geochemical-based prospectivity analysis to the discovery of the Kencana epithermal Au-Ag deposit, Indonesia. Submit the Gemmell et al. paper on hydrothermal alteration associated with epithermal Au-Ag deposits for publication. Initiate discussions to begin new low- and high-sulfidation epithermal deposit studies.
P3.L9	J Foster	Characterisation of the mineralisation character on the farm Tweefontein in the northern limb of the Bushveld Complex, RSA. This will include detailed examinations of geochemistry and mineralogy with special emphasis on the economically important minerals for Ni-Cu-PGEs (i.e. sulfide minerals plus platinum-group minerals).
P3.L10	J Foster, P Fullager	Industry to fund GLODISC A2
Program 4		
P4.L1	S Walters	The major initiative for the Recovery program in 2009 will be a renewal of the AMIRA P843 GeM ^{III} project (P843A). This will be a four-year extension due to start in mid-2009. Plans are well advanced for defining the research scope of AMIRA P843A in close consultation with the industry. It is expected that the P843A will involve new geometallurgical research directions in the area of blasting, environmental characterisation and hydrometallurgy, in addition to consolidating and validating outcomes from the current research.
Program 5		
P5.A3	J Hergt, C Paton	Extend the previously developed method for laser ablation Pb-isotope analysis in pyrite to allow the production of Pb-isotope 'image maps'. Investigate the potential of laser ablation Sr-isotope analysis of carbonates as a method of determining the source of ore-forming fluids.
P5.B2	J Laird, C Ryan	Aims for 2009 include testing the technique for extracting better quantitative information on fluid inclusions (correcting PIXE data for geometrical effects). This requires calibration with simulations for a well-defined artificial sample. Once this aim is met we shall begin analyses on real CODES samples to be supplied by J Wilkinson or A Harris.
P5.B2a	J Wilkinson, C Ryan, J Laird	1: Test use of internal standardisation (e.g. using Cl and multiple internal standards) for improving geometric correction of PIXE data. 2: Assess use of PIGE spectrum for quantification and internal standardisation using Na. 3: Test use of accurate volumetric determination using the spindle stage and laser confocal microscopy on PIXE quantification. 4: Direct comparison of PIXE and LA-ICP-MS data on the same inclusions.
P5.B2b	C Ryan	1: Develop capabilities for studying the role of CO₂ in the transport and deposition of ore metals, especially Cu, Au, Co and Ni. 2: Experimental investigations of Co and speciation in hydrothermal fluids and zinc-acetate complexation. 3: Europium speciation and oxidation state in tracking chemistry of gold forming fluids.
P5.B1	L Danyushevsky	Improve capabilities in electron microscopy and X-ray microanalysis facility in certain areas.
P5.C1	C Paton, L Danyushevsky, S Meffre	Build on the existing structure of the 'lolite' software package to produce improved data reduction algorithms for laser ablation.
P5.C2	C Ryan, C Paton, A Reading	Develop advanced algorithms for the processing of 'image maps' acquired by laser ablation.
P5.C3	L Danyushevsky	Continuing development of Petrolog 3.0.
P5.C4	C Paton, L Danyushevsky, S Gilbert	Integrate the lolite data reduction package into the existing CODES database.
P5.A2 (P5.F1)	L Danyushevsky, S Meffre	In 2009, the main application development will involve: 1: Characterisation of carbonate primary standard MARC-3. 2: Developing sulphur isotopic measurement using Agilent 7500cs in the collision cell mode. 3: Developing a technique for quantitative analysis of Hg in sulfides.

<i>Project</i>	<i>Team leader(s)</i>	<i>Activity plan</i>
P5.A4 (P5.F2)	J Hergt, J Woodhead, C Paton, S Meffre	Continue to develop novel analytical methods for the analysis of stable isotopes relevant to ore deposits. Continue and expand on the existing Cu-isotope sampling regime. Investigate the potential of other stable isotope systems relevant to ore deposits (e.g. Li and Zn).
P5.B4a (P5.F3a)	A Harris, A Berry	Using leading-edge synchrotron technology, this research aims to undertake two related spectroscopic studies investigating metal complexes found in metal ores and the solutions from which they precipitated. We aim to study MeCl and MeS species in ore fluids from contrasting sulfur-poor and sulfur-rich environments. New research will investigate the location of important ore-forming elements in sulfides. Research outcomes have significance for the formation, discovery and recovery programs within CODES.
P5.B3 (P5.F3b)	C Ryan	1: Establish a world-leading capability on the XFM beamline of the AS for high-resolution, large area and high-throughput SXRF trace element imaging and chemical state imaging. 2: Establish a user facility at the XAS beamline of the AS for high-PT in-situ experiments to probe the behaviour of ore metals under extreme chemical conditions.
P5.B1 (P5.F4)	J Laird, C Ryan	The main aims for 2009 are to further develop ion microbeam systems for mapping mineral electrochemistry of relevance to CODES. Samples are currently being prepared at CODES and the system here will be ready for use sometime early to mid-next year. The initial system will not include an in-situ cell which will be added mid- to late next year. We expect to analyse pyrite assemblages using charge injection mapping and correlate results with electrical data to be collected. Time permitting we will attempt to do simple tests using an in-situ electrochemical cell and possibly perform simulations to verify models to be established.
P5.B2b (P5.F5)	Z Chang	1: Increase the understanding of trace element substitution mechanism in alunite. 2: Investigate the difference in fluid compositions from barren and fertile intrusions.
P5.A1 (P5.F6)	S Meffre, L Danyushevsky	1: Finish new ablation cell. 2: Test the new Agilent 7500a mass-spectrometer delivered in late February to decide which ICPMS is better suited for silicate analyses. 3: Testing of new excimer laser for U-Pb geochronology. 4: Development of the stainless steel interface between lasers and ICPMS.
P5.F8	GJ Davidson, D Cooke	1: Chemical separations: Process Mt Polley samples that are now characterised for S distribution; use these data to finalise method paper for publication. 2: Complete and submit chemical separation methods paper. 3: Write up and submit paper on sulfur transfer during carbonate evolution at Mt Polley by end of semester 2, 2009, after analysis of the microprobe chemical data. 4: Provide a further test of the CAS technique by sampling at Yellowstone National Parks Mammoth hot springs to evaluate sulfate in carbonate that was formed under known conditions in a natural system. 5: Process Sunrise Dam lode gold samples, and the Yellowstone samples, for stable isotopes. Undertake microprobe mapping of selected samples.

