



Centre for Ore Deposit Research

An ARC Special Research Centre

at the University of Tasmania

• Australia •

Annual Report 2004



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CODES Mission

The Centre for Ore Deposit Research is committed to leadership in fundamental and applied research into ore-forming processes in volcanic arc and rift settings, involving close collaboration with Australian and international researchers and the mineral exploration industry.

CODES Goals

- To build upon the success of the Key Centre for Ore Deposit and Exploration Studies (CODES) by integrating the applied aspects of CODES ore deposit research with fundamental research expertise in igneous petrology, volcanology, sedimentology, tectonics and fluid processes.
- To develop a centre in the top rank of international research centres specialising in ore deposit geology.
- To develop a national intellectual focus for research in metallogenesis in volcanic arcs and rift basins.
- To improve collaboration and technology transfer with end-users to give the Australian mineral exploration industry a competitive advantage in Australia and the west Pacific region.
- To undertake collaborative research with industry and MRT aimed at increasing the discovery rate of major mineral deposits in Tasmania.
- To increase our research focus on mineral deposit studies in the western Pacific and South East Asia.
- To expand our international linkages with other specialist centres in the field.
- To develop an international quality postgraduate and postdoctoral program to produce graduates and researchers able to identify and pursue new fundamental research initiatives and/or lead industry in the exploration for new mineral resources.

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Quartz-sphalerite-galena veins in chlorite-illite altered andesite fragments surrounded by cockade bands of sphalerite-galena-quartz chalcedony. A late-stage barren, crustiform banded quartz-chalcedony vein (1 cm wide) cuts through the sample. Permata vein, Mt Muro low sulfidation epithermal Au-Ag deposit, Kalimantan, Indonesia.

Director's Report

2004 was an exciting year for CODES and considerable success was achieved in both our core fundamental research and industry linkage programs. CODES core research involves five major programs with principal focus on understanding ore-forming processes in magmatic arcs and extensional sedimentary basins. This Annual Report presents highlights of the progress and achievements in these five programs.

The quality of a research centre is recognised by the achievements of the people that make up the centre and how they work together as a team. CODES is internationally regarded for its benchmark team-based research. However a very pleasant outcome in 2004 has been the individual recognition of several of our research staff and postgraduate students:

- David Cooke, Leader of Program 5, was selected by the Society of Economic Geologists as the Thayer Lindsley travelling lecturer for 2005. This award is in recognition of David's excellent team-based research on the genesis of epithermal gold and porphyry copper deposits and his ability to deliver exciting presentations on these topics.
- Jocelyn McPhie, Leader of Program 2, was awarded a Personal Chair at the University of Tasmania, for her internationally recognised research in the field of volcanic facies analysis.

- Vadim Kamenetsky has been awarded a prestigious ARC Professorial Fellowship to continue his research at CODES. Dima has been leading our research on the melt-fluid transition in magmatic systems (Program 1), concentrating on the release of volatiles and metals to form magmatic ore fluids.
- Anthony Harris received the 2004 Waldemar Lindgren Award from the Society of Economic Geologists. The award is given for excellence in economic geology research by a person under 35 years of age, and resulted from, amongst other things, a collaboration between Anthony and Dima Kamenetsky on the melt-fluid transition in magmas that generate porphyry copper-gold deposits.
- Nicky Pollington, PhD candidate, received an award from the Society of Economic Geologists for one of the best research poster presentations at the SEG 2004 Conference in Perth.
- Based on work carried out at CODES, former PhD student Nick Direen and Tony Crawford won the Stillwell Award for the best paper in the Australian Journal of Earth Sciences (2003) as voted by the Editorial Board of that journal.

CODES core research funding from the Commonwealth Government, through the Australian Research Council,

ceases in 2005, and for the past 18 months we have been actively talking with our stakeholders and other collaborators about future directions for the Centre. At our Science Planning Meeting in March, involving researchers, collaborators and industry supporters, there was strong agreement on three points: (1) we should continue to develop our role as one of the world-leading research centres in ore deposits, (2) we should maintain our very successful structure of a focussed one-node centre at the University of Tasmania to avoid the problems of multi-node centres, and (3) we should develop research strengths in two key areas of critical future importance to the minerals industry: exploration geophysics and geochemistry.

In collaboration with the JK Minerals Research Centre at University of Queensland, we have developed a major new research thrust in the area of geochemistry that is being enthusiastically received by the minerals industry. This initiative has been led by Associate Professor Steven Walters and includes a team of researchers and postgraduate students from CODES and JKMRRC. In the area of exploration geophysics, we plan to build our team to a similar level of expertise and international standing as that in ore deposit geology and geochemistry at CODES. The UTAS School of Earth Sciences currently teaches a full BSc (Hons) degree in geophysics. Academic staff Mike Roach and James Reid specialise in the areas of electrical geophysics, magnetics and petrophysical properties of ore deposits. Expansion of our capability in geophysics will be done by key collaborations with other national and international groups and by establishing a Chair in exploration geophysics. Our focus will be on the geophysical attributes of different ore deposit types that can be modelled to improve exploration success, mineral processing and mine planning.

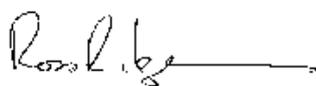
The new directions in geometallurgy and exploration geophysics form key elements in our application for an ARC Centre of Excellence in Ore Deposits that was submitted in October 2004. The application builds upon our international standing in ore deposit geology and ore deposit environments, and has received exceptional support from our stakeholders, including UTAS, AMIRA International, CODES Industry Partners, the Minerals Council of Australia and the State Government of Tasmania. Partners in the Centre of Excellence bid include the University of Queensland, Melbourne University, ANU, University of British Columbia, Colorado School of Mines and Johns Hopkins University. The outcome of this application will be known by May 2005.

On-going efforts throughout 2004 to increase industry collaborative research funding has been rewarded with the negotiation of three new AMIRA projects. Gone are the days, when companies agreed to fund research on the basis of a simple research proposal. Now-days research concepts and projects need to be "sold" to companies by way of a combination of the research proposal with a road-show to company offices involving power point presentations with hard milestones, deliverables and outcomes with a demonstrated relationship to the company bottom line. It is thus with some satisfaction that we can announce the three new AMIRA projects that will underpin some of the key research in the proposed Centre of Excellence, having attracted total industry funding of \$3.4 million over four years. AMIRA P872, led by David Selley (CODES) and Murray Hitzman (CSM), will extend our research on sedimentary copper mineralisation to include the world-class deposits in the southern Congo. AMIRA P843, led by Steve Walters is a collaboration with JKMRC on

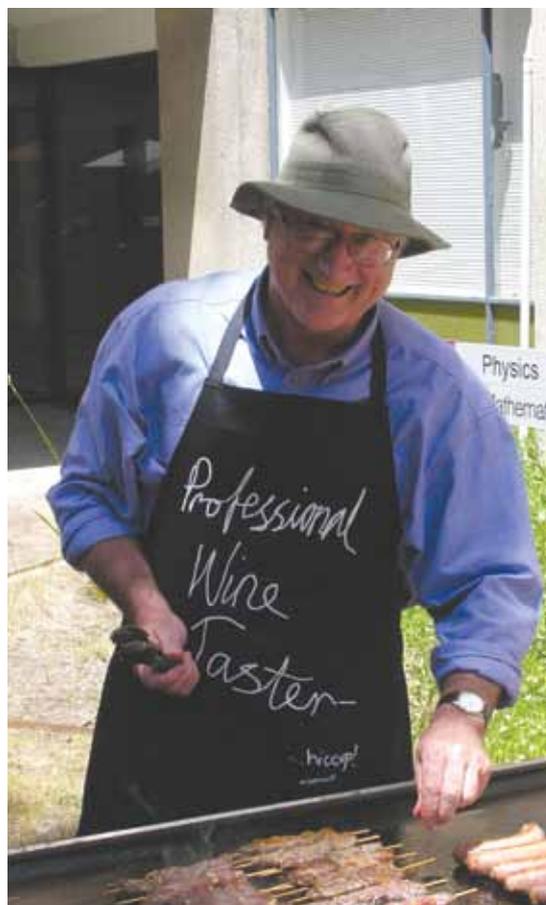
geometallurgical mapping and mine modelling. AMIRA P923 led by Rob Scott and Ross Large will investigate a new geochemical approach to terrane selection and deposit vectoring for sediment-hosted gold deposits.

The depth of the education and skills crisis in the mineral resources sector has hit the industry hard in 2004, and is also having a strong effect on CODES capacity to attract postgraduate students. The supply of Australian PhD candidates has diminished significantly leading us to cast the net much wider to increase our intake of top international students. The current shortage of PhD candidates is further compounded by the continual decline in undergraduate student numbers, with commencing first year geology numbers dropping by 36% over the past four years across all Australian Universities. Through a targeted recruitment program UTAS has managed to go against the trend, with a 70% increase in first-year geology students in 2004 reaching our highest ever enrolment of 136. This turnaround in numbers is critical for the future of our School and will impact favourably on our graduate output to industry, and flow-on to boost research higher degree numbers in the future. Although the CODES honours graduating class dropped to 15 in 2004, and will be around 12 in 2005, it still represents one of the largest geoscience Honours classes at an Australian University.

In concluding, I thank our industry sponsors for their support of our research programs and student projects throughout 2004, and the CODES research team, technical and administrative staff, and postgraduate students for their dedication and achievements.



Ross R Large
Director





Staff & Management

Director

The Director, Ross Large, has hands-on scientific involvement in several of the centre's research programs. He is responsible for the scientific leadership and operation management of the centre and is supported by the Executive Committee and the Advisory Board.

CODES technical and administrative staff: L to R, Philip Robinson, Di Steffens, June Pongratz, Katrina Keep, Simon Stephens, Christine Higgins, Katie McGoldrick, Alistair Chilcott and Peter Cornish.

Science Planning Panel

The Science Planning Panel meets annually for a one-day forum of presentations concerning 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.

Staff

Staff changes for 2004 included Steve Walters' appointment to lead the Centre's GEM^{III} research program in 2005, Zhaoshan Chang joined the CODES team as a post doctoral research fellow, and Katrina Keep replaced Kylie Kapeller as Personal Assistant to the Director.

CODES employs 25 research staff and twelve administrative and technical staff that are funded by the SRC grant, industry and the university. Nine of the academic staff and ten of the general staff are joint appointments between CODES and the School of Earth Sciences.

Advisory Board

The Advisory Board meets annually to review progress of the Centre and to advise on future directions. Members of the Board represent major industry sponsors, University of Tasmania senior management, and other key national geoscience organisations. Ross Andrews (Rio Tinto), Nick Franey (Anglo American) and John Holliday (Newcrest Mining) joined the board in 2004.

Executive Committee

The Executive Committee membership consists of the five program leaders plus administrative managers and meets, on average, six times a year. The Executive Committee works closely with the Director to develop the Centre's aims, strategies, plans and performance indicators.

CODES STAFF 2004	Research interest	% in CODES
Director, Professor Ross Large, BScHons (UTas), PhD (UNE)	Volcanic-hosted and sediment-hosted massive sulfides	100
Deputy Director, Professor Tony Crawford, BScHons, PhD (Melb U)	Petrology, geochemistry and tectonics of volcanic arcs	50
Academic Staff		
Dr Sharon Allen, BSc (Massey), MSc (AuckU), PhD (MonU)	Volcanic facies analysis	50
Dr Ron Berry, BSc (Flinders) PhD Flinders	Structure of mineralised provinces, CHIME dating	50
Dr Stuart Bull, BSc Hons, PhD (MonU)	Clastic and carbonate sedimentology and volcanology	100
Dr Zhaoshan Chang, BSc, PhD (PekingU), PhD (Wash. State U)	Skarn, porphyry, and epithermal deposits; LA-ICPMS zircon dating	100
Assoc. Prof. David Cooke, BScHons (LaT U), PhD (Mon U)	Fluid-rock interaction and hydrothermal geochemistry	50
Dr Leonid Danyushevsky, PhD (Vernadsky Inst.)	Petrology, geochemistry, application of melt inclusions	50
Dr Garry Davidson, BScHons (ANU), PhD (UTas)	Sulfur isotope geochemistry and Cu-Au ores	50
Dr Cari Deyell, BSc (Queens) PhD (UBC)	Geochemistry and mineralogy of hydrothermal systems	100
Assoc. Prof. Bruce Gemmell, BSc (UBC), MA, PhD (Dart.)	VHMS deposits and epithermal Au-Ag	50
Dr Cathryn Gifkins, BScHons (Mon U), PhD (UTas)	Volcanic textures and alteration	100
Dr Anthony Harris, BScHons, PhD (UQ)	Ore Deposit Geology/geochemistry	100
Mr Wally Herrmann, BScHons (Mon U), M.Econ.Geol. (UTas)	Alteration and exploration in volcanic settings	100
Professor Dima Kamenetsky, PhD (Vernadsky Inst.)	Petrology and geochemistry of melt inclusions	50
Dr Peter McGoldrick, BScHons, PhD (Melb U)	Geochemistry of ore deposits and their halos	75
Professor Jocelyn McPhie, BAHons (Macq U), PhD (UNE)	Volcanic facies architecture and volcanic textures	50
Dr Sebastien Meffre, BScHons, PhD (Syd U)	Petrology and tectonics of the SW Pacific	50
Dr Andrew Rae, MSc (Otago), PhD (UTas)	Ore deposit geology/hydrothermal processes	100
Dr James Reid, BScHons, MSc (Syd U), PhD (Macquarie U)	Geophysical electromagnetic and electrical methods	50
Dr Michael Roach, BScHons (Newcastle U), PhD (UTas)	Electrical geophysical responses of sulfide ores	50
Dr Robert Scott, BScHons, PhD (Mon U)	Structural geology	100
Dr David Selley, BScHons (Adelaide), PhD (UTas)	Structural geology/basin analysis	100
Dr Michael Solomon, MSc, PhD (UTas), DSc (U Ldn)	Geochemistry and genesis of mineral deposits	25
Dr Andrew Tunks, BScHons (Monash), PhD (UTas)	Gold deposits	75
Dr Khin Zaw, BSc (Yangon U), PhD (UTas)	Fluid inclusions, SE Asian metallogensis	100
Dr Steve Walters, BScHons, PhD (Sheffield)	Sediment hosted base metals, applied mineralogy, exploration technologies, geo metallurgy	100
Dr Fernando Della Pasqua, PhD (UTas)	Petrology, volcanology	70
Technical/Administrative Staff		
	Position	
Mr Michael Blake, BSc (UTas)	Research Assistant	100
Mr Alistair Chilcott, BComp (UTas)	Computer Systems Officer	70
Ms Sarah Gilbert BScHons (UTas)	Research Assistant	100
Ms Christine Higgins, Grad. Cert. Management (UTas)	Finance Manager	50
Ms Nilar Hlaing, BSc (Yangon U)	Research Assistant; Publications Assistant	20
Ms Kylie Kapeller	PA to Director (to June 2004)	100
Mrs Katrina Keep	PA to Director (from June 2004)	100
Mr Simon Stephens	Manager Lapidary Services	50
Mrs Katie McGoldrick	Laboratory Assistant	80
Ms June Pongratz	Publications Manager	50
Mrs Dianne Steffens	Finance Assistant	100
Mr Peter Cornish	Laboratory Manager	50
Mr Philip Robinson	Analytical Services Manager	70
Ms Isabel Von Lichtan	Curator	20

Advisory Board
2004



ADVISORY BOARD

Chair: Andrew Glenn	Pro Vice-Chancellor (Research), University of Tasmania
Jim Reid	Dean, Faculty of Science Engineering and Technology, University of Tasmania
Ross Large	Director, CODES
Tony Crawford	Deputy Director, CODES
Ross Andrew	Consulting Geologist, Rio Tinto
Tony Brown	Executive Director, Mineral Resources Tasmania
Nick Franey	Vice President Exploration Asia Pacific, Anglo American
Bruce Gemmell	Head, School of Earth Sciences, University of Tasmania
Alan Goode	Research Coordinator, AMIRA International
David Groves	Director, Centre for Global Metallogeny, University of Western Australia
John Holliday	Principal Geologist- SE Australia, Newcrest Mining Limited
James Macdonald	Global Geoscience Leader, BHP Billiton - Mineral Exploration
Jocelyn McPhie	Program 2 Leader, CODES
Chris Pigrim	Chief, Minerals and Geohazards Division, Geoscience Australia
Noel White	Consultant

EXECUTIVE COMMITTEE

Chair: Ross Large	Director, CODES
Tony Crawford	Deputy Director, Program 1 Leader
Jocelyn McPhie	Program 2 Leader
Bruce Gemmell	Program 3 Leader and Head of the School of Earth Sciences
Peter McGoldrick	Program 4 Leader
David Cooke	Program 5 Leader
Christine Higgins	Finance Manager
Kylie Kapeller/ Katrina Keep	Personal Assistant to the Director
June Pongratz	Publications Manager

SCIENCE PLANNING PANEL (includes Executive Committee)

Ross Andrew	Consulting Geologist, Rio Tinto
Nick Franey	Vice President Exploration Asia Pacific, Anglo American
Alan Goode	Research Coordinator, AMIRA International
Geoff Green	Managing Geologist, Metallic Minerals and Geochemistry, Mineral Resources Tasmania
David Groves	Director, Centre for Global Metallogeny, University of Western Australia
John Hammond	Chief Geologist, Newmont Exploration
Paul Heithersay	Branch Manager, Geological Survey, Primary Industries & Resources South Australia
John Holliday	Regional Exploration Manager, Newcrest Mining Limited
Jon Hronsky	Team Leader - Project Generation, WMC Resources
Rob Krcmarov	Manager - Project Development Barrick Gold
James Macdonald	Global Geoscience Leader, BHP Billiton - Minerals Exploration
Andrew McNeil	Senior Geologist, Zinifex
Noel White	Consultant

CODES High Flyers

Four CODES staff have received recognition for their recent achievements.

David Cooke was selected by the Society of Economic Geologists as the Thayer Lindsley travelling lecturer for 2005. This is in recognition of his excellent research on the genesis of epithermal gold and porphyry copper deposits and the quality of his lecture presentation and teaching skills. David is the first Australian to receive the award since it was established by SEG in 1970. David will be travelling to Canada, USA, China, Philippines, Chile, Peru, New Zealand and within Australia to deliver his lectures.

Dima Kamenetsky has been awarded a prestigious ARC Professorial Fellowship for 2005–2009 to continue his research at CODES. Dima has been leading our research on the melt-fluid transition in magmatic systems (Program 1), concentrating on the release of volatiles and metals to form magmatic ore fluids. The topic of his ARC Fellowship is ground-breaking research in both the fields of igneous petrology and ore deposit geology. Exsolution (unmixing) 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 atmosphere, hydrosphere, crustal hydrothermal systems, and formation of magmatic ore

deposits. The project applies Dima's own "know how" in the field of melt inclusion studies and state-of-the-art microanalytical techniques to directly address the impact of melt/fluid unmixing on the chemical evolution of some typical magmatic systems and magmatic nickel-sulfides.

Anthony Harris was selected to receive the 2004 Waldemar Lindgren Award for 2004 from the Society of Economic Geologists. The award is given for excellence in economic geology research by a person under 35 years of age. The awarding committee noted that Anthony, although only 28 years of age, already has an impressive record of publications, not just in leading journals (*Science* and *Geology*), but containing significant and groundbreaking findings.

Anthony's first publication (Harris and Golding, 2002, *Geology*, v.30) demonstrated that magmatic, not meteoric, fluids were responsible for copper-rich phyllic alteration at the Endeavour 26 North porphyry ore deposit (central NSW). Such findings were contrary to the conventional genetic models for porphyry copper deposits. While this work was not the first to recognise this, it was the first paper in a major journal to clearly state what was emerging from a number of different studies. Together with Vadim Kamenetsky, Noel White and collaborators from the CSIRO, Anthony has

documented multi-phase melt-liquid-vapour inclusions in the early stage quartz veins at Bajo de la Alumbrera porphyry ore deposit (NW Argentina). Such was the significance of this discovery that the results were published in *Science* (2003, v.302). This exciting observation gives new insights into the magmatic-hydrothermal transition in porphyry ore deposits, including the ability to characterise the ore-forming fluids at the very point they separated from the source magma.

Ross Large has been selected to receive the 2005 Haddon King Medal by the Australian Academy of Science. The Haddon King Medal recognises the contributions of the late Haddon King to the application of the geological and related sciences to the search for mineral deposits in Australia. The award is made every two years to a scientist, resident in Australia or elsewhere, for original and sustained contributions to earth and related sciences. The award is for work of particular relevance to the discovery, evaluation and exploitation of mineral deposits, including the hydrocarbons. Ross received the award for his outstanding research contributions to the study of, and exploration for, massive sulfide deposits in volcanic and sedimentary environments.



L to R: David Cooke,
Dima Kamenetsky and
Anthony Harris



24 carat Au Workshop Review

CODES hosted an international workshop, *24 Carat Gold*, in June 2004, supported by the Minerals Council of Australia (MCA). There was excellent feedback from the 111 attendees, some of whom came from such far-flung places as Canada, USA, Philippines, Indonesia and Ghana.

Thirteen of the participants undertook the workshop as part of the Masters in Economic Geology degree, including four students from UWA doing the course under the National Masters umbrella.

Nine lucky participants took part in the pre-workshop field trip which visited Mount Lyell and Rosebery mines and went underground at Henty. They also enjoyed a night at the Cradle Mountain Lodge. Trip leaders Ross Large and Kim Denwer provided in-depth information about the geology of western Tasmania, with deposit descriptions from industry geologists Andrew McNeil and Don Macansh.

The workshop presenters gave a range of up-to-date, informative talks about a variety of styles of gold mineralisation including lode Au, porphyry Cu-Au, low sulfidation epithermal Au, VHMS Au, high sulfidation epithermal Au and carbonate replacement Au. In addition to a bevy of world-class international speakers, past CODES graduates Andrew Davies, Alan Wilson and Adrian Byass gave presentations. Workshop participant John Walsh asked lots of challenging questions and prompted considerable discussion to supplement the talks.

Dinner at the Wrest Point Casino was sensational, made more enjoyable by MC Andrew Tunks making a very public but no doubt false confession. Ross Large, President of the Society of Economic Geologists (SEG), gave a stirring after-dinner speech ('I had a dream') about his vision of an industry unaffected by the metal-price cycle and how good it would be to see everyone in full employment and geologists in demand. A transcript of this talk was published in the July SEG newsletter.

If you missed this workshop, 13 of the one-hour keynote presentations from selected industry and academic specialists have been published in *24 Carat Gold – CODES Special Publication 5*. The presentations addressed the following issues:

- Characteristics of a hydrothermal gold deposit type
- Anatomy of a giant gold deposit discovery.

Seven of the papers contained within this volume summarise the characteristics and origins of gold deposits: lode gold (Robert), porphyry copper-gold (Cooke), low and intermediate sulfidation epithermal gold (Gemmell), volcanic-hosted massive sulfide gold (Hannington), high sulfidation epithermal gold (Hedenquist), gold skarns (Meinert) and Carlin-type gold (Cline). There is also one overview paper on the structural architecture of porphyry and epithermal deposits (Tosdal). Five papers deal with the anatomy of giant ore deposit discoveries, and characteristics of those deposits (Tarkwa/Damang–Tunks; Oyu Tolgoi–Ivanhoe Mines; Kelian–Davies; La Ronde–Gosselin; Pueblo Viejo–Kesler). This volume also contains papers summarising the characteristics of four deposits discussed in the exploration forums: Cadia Quarry (Wilson), Teresa and Victoria (Garcia), Golden Grove (Pring) and Martabe (Levet).

The volume, edited by David R. Cooke, Cari Deyell and June Pongratz, is available for \$AUD75.00 each (plus postage, packing and GST).

To obtain copies of this book, please email <publications@codes.utas.edu.au> or go to the CODES website publications page <www.codes.utas.edu.au> to download the order form.



Speakers at the 24 ct Au workshop. Back row (L to R): Andrew Tunks, Doug Kirwin, Dick Tosdal; fifth row: Alan Wilson, Peter Pring; fourth row: Mark Hannington, Brian Levett, Guy Gosselin, David Cooke; third row: Noel White, Francois Robert, second row: Bruce Gemmell, Steve Kesler, Larry Meinert, Joey Garcia; front row: Jeff Hedenquist, Andrew Davies, Jean Cline.

GeM^{III} - a major new collaborative research direction for CODES

As part of strategic development linked to the Centre of Excellence bid, during 2004 CODES has been involved in the development of a major new research initiative in the area of 'geometallurgy'. This involves the cross-discipline interface between ore deposit characterization, mining and mineral extraction. This interface has been identified by industry as critical to optimizing and improving the sustainability of modern mining operations, with very little existing coordinated research.

Project development has been led by Associate Professor Steve Walters who joined CODES in 2004 after a long industry career in mineral exploration and applied research. Given the cross-discipline challenge of creating a new metallurgical research initiative, one of the most important initial developments was the establishment of a formal collaboration between CODES and the Julius Kruttschnitt Mineral Research Centre (JKMRC) at the University of Queensland. The JKMRC is widely regarded as a world leader in mining and mineral processing research and this is the first time the two high profile groups have worked together.

JKMRC led by former Director Professor Tim Napier-Munn and CODES, have been working closely with AMIRA to develop a major new metallurgical research initiative. Project development included extensive consultation with industry, involving meetings with over 20 companies in Australia, South Africa and North America. The feedback was used to define key research activities and required outcomes. The process also resulted in formal collaboration with the WH Bryan Mining Geology Research Centre (BRC) at the University of Queensland, recognized as a world leader in mine planning and optimization. This culminated in a project development workshop held in Brisbane during early September.

Integrated collaboration between three of the world's largest and highest profile centers for applied mineral research, forms the basis of the AMIRA P843 GeM^{III} project – Geometallurgical Mapping and Mine Modelling. The P843 proposal was submitted to potential industry sponsors in late September 2004 with eight companies signing up by October, providing a total of over \$600k per annum of direct funding. This represents the largest and most ambitious AMIRA project that CODES has

been involved with. According to Dr Alan Goode from AMIRA International such rapid project development and support are unprecedented for major AMIRA projects and reflect the extremely positive reception of the project concept by global companies.

The current sponsor list includes Barrick, CVRD, Newmont, Rio Tinto, Teck Cominco, WMC, Xstrata and Zinifex, with other sponsor companies expected to join in the short-term. A feature of the project will be site-based research carried out at a number of world-class mining operations provided by sponsors.

This support and timing enabled the P843 project to be included for matching ARC funding in the CODES Centre of Excellence bid and also submission as a separate ARC Linkage application that will run in parallel providing an alternative funding option. Pending ARC funding outcomes, the project is due to commence in July 2005 for a period of four years. Industry is supporting a ramp-up phase between January-July 2005, to facilitate ongoing project planning and team building. Associate Professor Steve Walters will be project manager as a joint appointment between the University of Tasmania and University of Queensland.

Although presented as discrete modules, a key aspect of the GeM^{III} project is integration of outcomes. The emphasis will be on research that can potentially generate new methodologies, tools and protocols that have the potential to significantly change current practices. Initial focus will be on metalliferous applications, although many of the outcomes are expected to be generic. The GeM^{III} project forms the core of Program 4 'Recovery' in the CODES Centre of Excellence bid.

It is anticipated that a successful outcome will lead to a long-term collaborative platform for metallurgical research that delivers a number of projects to industry. An important aspect of this vision includes the provision of education and training that breaks down current cross-discipline divides and inspires the next generation of more multi-skilled mining professionals.

For more details contact: Associate Professor Steve Walters <steve.walters@utas.edu.au>, phone +61 (0)412 319 233

The AMIRA P843 GeM^{III} project will be based on a modular research structure involving:

1 A more effective approach to on-site core and chip logging based on automated multi-sensor instruments with routine software-based interpretation of data to define domains either through direct correlation with small-scale testing or use of indirect proxies for both mining (geotechnical) and processing attributes.

2 An integrated micro-analytical 'mineral mapping' approach to quantified ore characterization that will expand current SEM-based techniques. This will involve integration with other analytical platforms including optical microscopy, IR microscopy, electron microprobe and the Laser Ablation microprobe. The aim is to provide cost-effective methods that allow more extensive use of automated mineral mapping at an early stage of ore characterization.

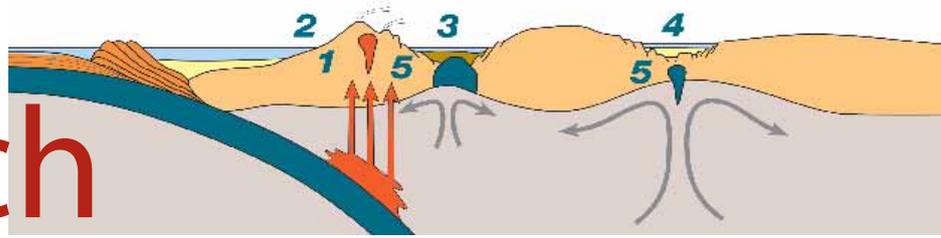
3 Development of new techniques for 2D/3D textural classification relevant to mineral processing based on mathematical simulation of quantified data derived from Modules 1 and 2.

4 Development of a methodology to correlate mineralogical and textural simulation with the results of empirical small-scale geotechnical and mineral processing testing, leading to a fundamental modelling approach that creates new mining and processing attributes.

5 Provision of methods to spatially model the distribution of new ore processing attributes into orebody models and integrate this modelling to mine planning optimization and ore evaluation.

6 Provision of formalised metallurgical awareness, education and training.

Research



CODES research activities are grouped into five major programs. Our philosophy is for each CODES researcher to participate in at least two of the major programs as this encourages a team approach in a multi-disciplinary environment.

Nearly all of our projects, especially the larger ones, are collaborations with other national or international researchers or research groups. Research higher degree students are integrated into our research teams and benefit from the interaction and advice of researchers, both in the Centre and from our collaborators.

CODES RESEARCH ACTIVITIES

CODES research projects include core activities funded by the SRC Grant (indicated by CORE after the project number) and non-core activities, funded by AMIRA, industry and other ARC grants.

Core research activities encompass basic research of a longer-term nature that is directed at understanding ore-forming environments and Cu, Au, Zn, Pb and Ag mineralisation processes in arc and rift settings. The non-core activities are concentrated on shorter-term strategic and applied research, and are commonly funded by AMIRA, industry or ARC SPIRT grants.

PROGRAM 1 Tectonics, magmas and fluids

- Igneous petrogenesis
- Melt inclusions
- Volatile/melt partitioning
- Porphyry Cu-Au deposits
- Tectonics and ores of SE Asia and SW Pacific

PROGRAM 2 Volcanic facies architecture and ore-forming environments

- Submarine volcanic facies
- Subaerial volcanic facies
- Volcanic influences on ore formation
- Eruption and emplacement processes
- Textural evolution of volcanic rocks

PROGRAM 3 Ores in volcanic arcs

- Genesis of seafloor massive sulfides
- Recent seafloor sulfide deposits
- Genesis of epithermal Ag-Au ore deposits
- Magmatic connections to hydrothermal fluids
- Alteration haloes and lithogeochemistry
- Sulfur cycling in the crust

PROGRAM 4 Ores in continental rift basins

- Basin architecture
- Stratiform Zn-Pb-Ag ores
- Fluid recharge and discharge
- Ore deposit haloes
- Sedimentary Cu deposits
- Broken Hill type deposits
- Fe-oxide Cu-Au deposits

PROGRAM 5 Hydrology and chemistry of hydrothermal systems

- Hydrological modelling of ore systems
- Hydrogeology of sedimentary rift basins
- Hydrogeology of submarine volcanic successions
- Modelling porphyry Cu systems
- Thermodynamics of hydrothermal systems
- Coupled hydrology and fluid chemistry

Major global industry–CODES projects

1 Trace element analysis of sulfides by LA-ICPMS: new applications for exploration vector geochemistry

Investigators: Garry Davidson, Andrew Rae, Marc Norman, Leonid Danyushevsky
Partners: Placer, Newmont, AngloGold, Anglo American, BHP Billiton, Newcrest

2 Geochronology, metallogenesis and deposit styles of the Loei Fold Belt in Thailand and Laos PDR

Investigators: Khin Zaw, Sebastien Meffre, Wally Herrmann, Sue Golding, Mark Barley, Anthony Harris

Partners: Kingsgate Consolidated, Pan Australian Resources, Oxiana Resources

3 Sunrise-Cleo sulfide trace elements, SWIR and volcanic facies vectors

Investigator: Wally Herrmann
Partner: AngloGold

4 Geology of the Escondida district

Investigators: Andrew Tunks, Masters student: Felipe Urzua
Partner: BHP Billiton



6 AMIRA P765: Transitions and zoning in porphyry-epithermal districts: indicators, discriminators and vectors

Investigators: David Cooke, Bruce Gemmell, Cari Deyell, Noel White
Partners: AMIRA International, AngloGold, Placer Dome, TeckCominco, Goldfields, Newcrest Mining, Anglo American, Newmont

7 Project P845

“Geometallurgical mapping and mine modelling – GEM^{III}”

Investigators: Steve Walters, Ron Berry, Ross Large (CODES); Rob Morrison, Roussos Dimitrakopoulos, Tim Napier-Nunn (JKMRC); and a team of more than 20 researchers

Sponsors: Newmont, Rio Tinto, XStrata; Barrick, CVRD, Teck Cominco, WMC, Zinifex

8 AMIRA P872: Cu-Co

mineralisation in the Congolese, Zambian and central Australia basin systems

Investigators: Peter McGoldrick, Stuart Bull, David Selley, Rob Scott, David Cooke, Ross Large; Murray Hitzman (CSM)

Partners: AMIRA International, Anglo American (Zamanglo), AngloVaal Minerals, BHP Billiton, PIRSA, First Quantum – Mopani, INCO, MIM Exploration, Outokumpu, Phelps Dodge Exploration, Rio Tinto, Straits Resources, TeckCominco, WMC

Australian Student Pro

BACHELOR OF SCIENCE (HONOURS)

- 1 Nathan Allen
Origin and features of Cambrian gold mineralisation in the Elliott Bay area, Tasmania
- 2 Adam Bath
Petrogenesis of the Gawler Range Volcanics from a melt inclusion perspective
- 3 Michael Bavea
Groundwater delineation and chemistry of the Smithton Dolomite karst aquifer
- 4 Kate Bromfield
Palaeoenvironmental reconstruction of the Jurassic, using plant macrofossils from a site at Lune River, Southeast Tasmania
- 5 Richard Chopping
High resolution geophysical pit mapping at the St Ives gold mine, WA
- 6 Andy Crawford
Origin of the Bond Range porphyry
- 7 Nicholas Fitzpatrick
Controls on intrusive gold-related mineralisation in the Lisle/Golconda area, northeastern Tasmania
- 8 Kerrin Gale
Vein paragenesis of the Backdoor Prospect, Telfer district
- 9 Kate Godber
Ground magnetic mapping of the oceanic crust, Macquarie Island
- 10 Jhana Hale
Geophysical investigation and interpretation of the Temma area, northwestern Tasmania
- 11 Ben Hey
Geophysics of granite-hosted old mineralisation beneath the Enterprise workings, northeastern Tasmania

- 12 Ned Howard
Alteration facies at the Darwin Southorebody, Henty, Tasmania
- 13 David Kratzman
Volcanology of the Sterling Valley volcanics, Mount Read Volcanics, Tasmania
- 14 Todd McGilvray
Geology and mineralisation of Oceana Zn-Pb deposit, Zeehan area
- 15 Chris Parker
Vulnerability and aquifer potential of the Cowrie Siltstone aquifer around the Circular Head waste transfer site using geophysical, hydrogeochemical and hydrological methods
- 16 Lee Robson
A remote sensing and geophysical investigation of the central midlands, Tasmania
- 17 Aaron Scollard
Seismic investigation of the southern D'entrecasteux Channel, southern Tasmania
- 18 John Stephenson
A geophysical investigation of Frances Creek, Northern Territory
- 19 Trent Strickland
Origin and significance of copper-bearing breccia at the E42 gold deposit, New South Wales
- 20 Brett Thomas
Geology of the Minjar Project, Western Australia
- 21 Ian Wilson
HEM data levelling – The Clump, northwestern Tasmania

MASTER OF ECONOMIC GEOLOGY

- 22 Leon Bagas
Geology of the Paterson Orogen
- 23 Steven Lewis
Structure and lithostratigraphy of the Harp Prospect, Broken Hill

- 24 David Nixon
Gold mineralisation in the Tanami region
- 25 Dan Power
Gold mineralisation at Groundrush, Tanami

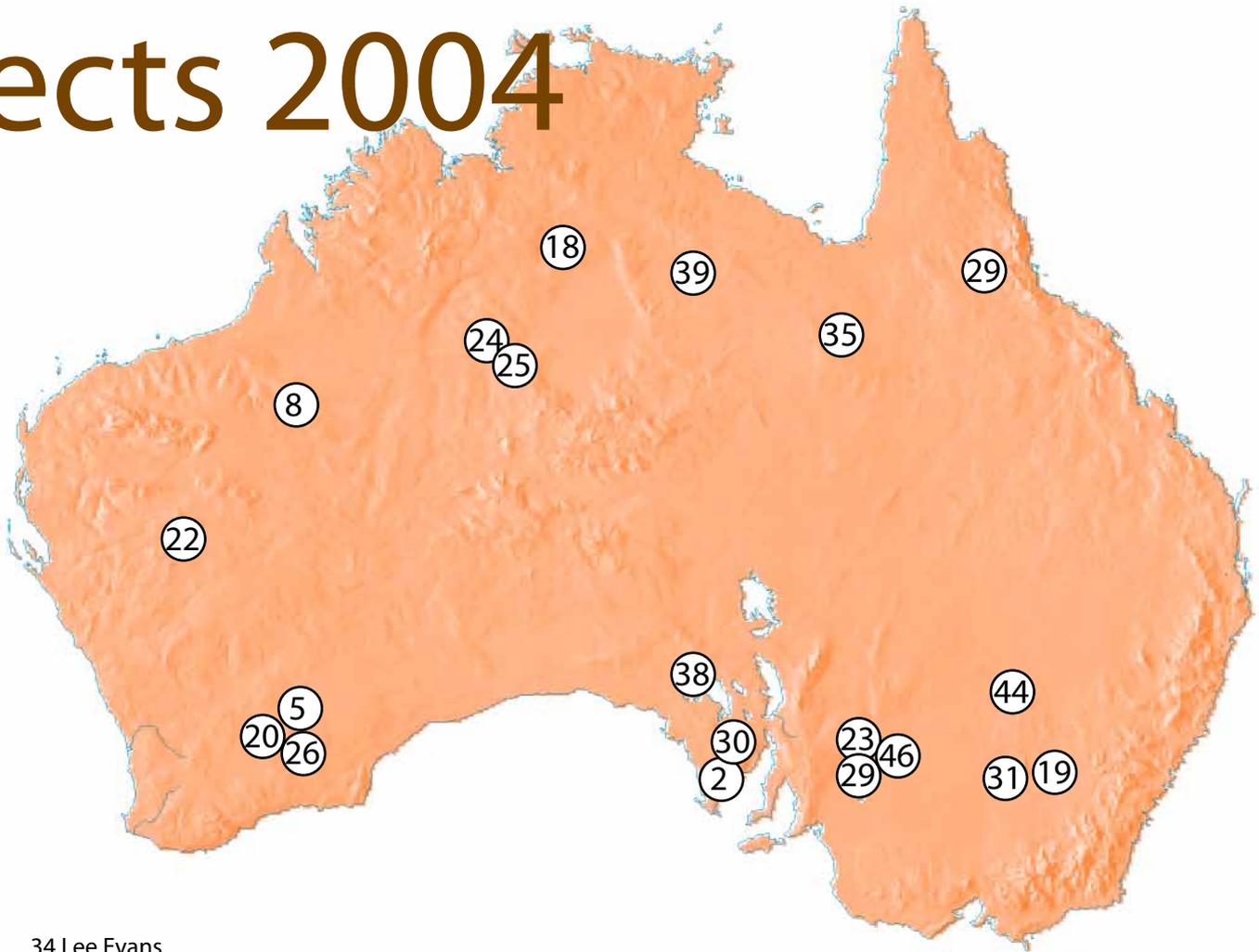
MASTER OF EXPLORATION GEOSCIENCE

- 26 Matthew Hope
The Geological Evolution of the Norseman Area, Western Australia
- 27 Terence Hoschke
Geophysical signatures of gold-copper porphyry systems

DOCTOR OF PHILOSOPHY

- 28 Darren Andrews
Time-lapse geophysical monitoring of acid drainage at Savage River Mine, northwestern Tasmania
- 29 Michael Baker
Palaeoproterozoic magmatism in the Georgetown Block, north Queensland, and comparisons with Broken Hill block
- 30 Bryan Bowden
Iron oxide copper-gold related alteration history of the Mt Woods Inlier, SA, with special emphasis on the Prominent Hill prospect
- 31 Katharine Bull
Facies architecture of the Ural volcanics, NSW
- 32 Kim Denver
Mineralogical, geochemical and isotopic investigation of the Mount Lyell Cu-Au orebody and alteration system
- 33 Gregory Ebsworth
Regional volcanic facies analysis of the Tyndall Group, Mount Read volcanics, Tasmania

Projects 2004



34 Lee Evans
Groundwaters in wet, temperate sulfide mining districts: Delineation of modern fluid flow and predictive modelling to improve management after mine closure (Rosebery, Tasmania)

35 Owen Hatton
Basin configuration, sedimentology and volcanology of the Toole Creek Volcanics, Mount Isa region, Queensland

36 Lyudmyla Koziy
Numerical simulation of fluid flow and fluid chemistry in sedimentary basins

37 Steven Lewis
Sulfidic hydrothermal alteration in late brittle faults, Macquarie Island

38 Wallace Mackay
Sedimentology and structure of the Curdimurka Subgroup, Willouran Range, South Australia

39 Rodney Maier
Pyrite and base metal trace element haloes in the northern Australian Zn-Pb-Ag deposits

40 Neil Martin
Genesis of the Rosebery VHMS deposit, western Tasmania

41 Claire McMahon
Controls on the geochemistry of hydrothermal pyrite in ore systems

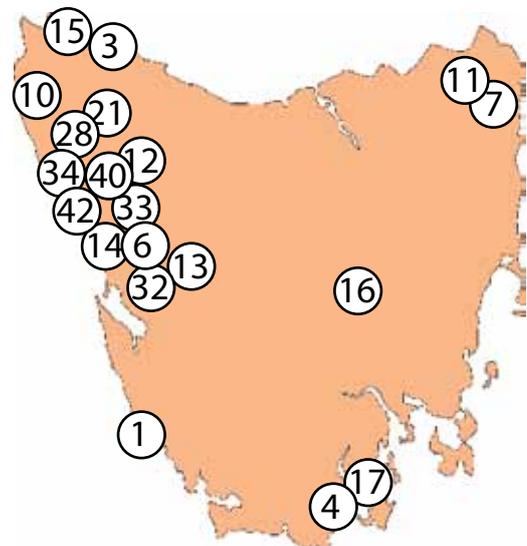
42 Lee Robson
Application of remote sensing for geological mapping in western Tasmania

43 Blackwell, Singoyi
Controls on the geochemistry of magnetite in hydrothermal fluids

44 Craig Stegman
Geochemistry and structure of gold-basement mineralisation in the Cobar gold field, NSW

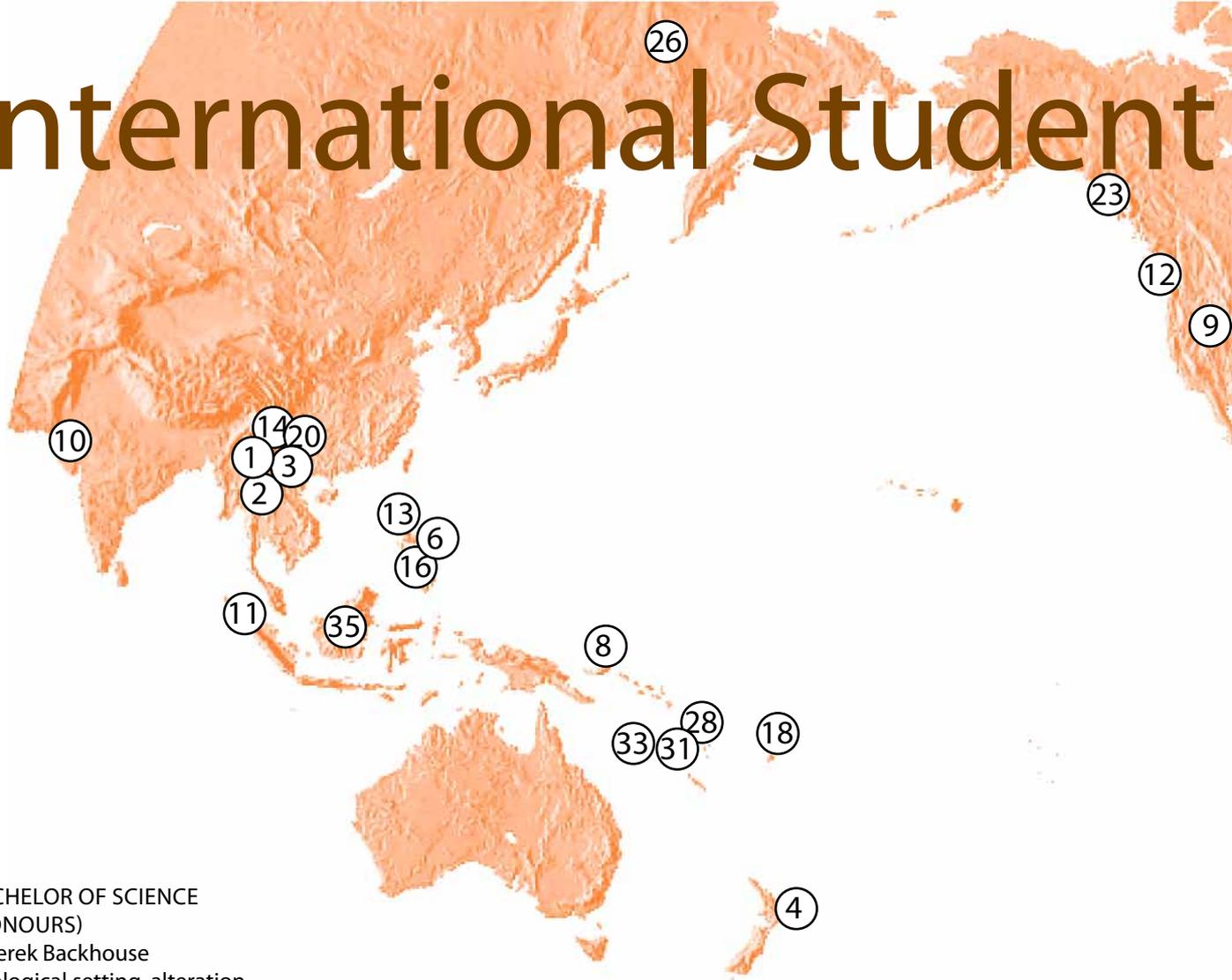
45 Andrew Tyson
Geophysical characteristics of porphyry and epithermal deposits

46 Tony Webster
The structural evolution of the Broken Hill Pb-Zn-Ag deposit, New South Wales



9 37

International Student



BACHELOR OF SCIENCE (HONOURS)

1 Derek Backhouse
Geological setting, alteration and nature of mineralization at the Phu Kham copper-gold deposit, Laos PDR

2 Grace Cumming
Volcanic facies of the Chatree gold mine, central Thailand

3 Teera Kamvong
Geochemistry and genesis of Phu Lon copper-gold skarn deposit, northeast Thailand

4 Emma Mathews
Stratigraphy and volcanology of a submarine apron from an offshore stratovolcano, Waitakere group, Muriwai, New Zealand

5 Hugh Tassell
Seismic investigation into the ice thickness and seabed topography beneath the Amery Ice Shelf, Eastern Antarctica

MASTER OF ECONOMIC GEOLOGY

6 Alan Ignacio
Boyongang porphyry system

7 Lennard Kolff
Seemandoo iron deposit, Guinea, West Africa

8 Mannie Mehu
Regional exploration around Lihir

9 Gem Midgley
Isotopic variations in Carlin-type gold deposits, Nevada

10 Nalin Shah
Geology and dating of the Mangalwar Complex, with reference to Rampura Agucha, Rajasthan, India

11 Bronto Sutopo
Matarbe high-sulfidation epithermal deposit, Indonesia

MASTER OF EXPLORATION GEOSCIENCE

12 Albert Chong
Geology, mineralization, metal distribution and genesis of the Polymetallic Ridge and Marshall Zones, Battle Lake Camp, Vancouver Island, Canada

13 Rene Gonzales
Regional structure, Boyongang

14 Kamonporn Kromkhun
Geological setting, alteration, mineral paragenesis, & nature of ore fluids at 'H' zone, Chatree gold deposit, central Thailand

15 Felipe Urzua
Regional geology of Escondida district, Northern Chile

DOCTOR OF PHILOSOPHY

16 David Braxton
Origin of the Boyongan porphyry Cu-Au system, Philippines

17 James Cannell
El Teniente porphyry Cu-Mo deposit, Chile: geology, geochemistry and genesis

18 Dene Carroll
Tectono-magmatic evolution of eastern Viti Levu, Fiji.

Projects 2004



19 Mawson Croaker
Geology and genesis of the Nkana copper deposit, Zambia.

20 Paul Cromie
Geological setting, geochemistry and genesis of the Sepon mineral district, Laos

21 Paul Davidson
Melt inclusions in porphyry Cu-Au-hosting magmatic systems (Chile)

22 Peter Frikken
Breccia-hosted Cu-Mo mineralisation at Rio Blanco, Chile

23 Russell Fulton
Geology and geochemistry of the hanging wall argillite, Greens Creek VHMS deposit, Alaska: implications for ore genesis and exploration.

24 Tim Ireland
Geology and structural evolution of the Collahuasi District, Northern Chile.

25 Ben Jones
Genesis of the Antapaccay Cu-Au porphyry deposit, Peru.

26 Maya Kamenetsky
Nature of primary melts in intracratonic settings: application of melt inclusions studies to kimberlites (Siberia)

27 Lyudmyla Koziy
Numerical simulation of fluid flow and fluid chemistry in sedimentary basins.

28 Roman Leslie
Petrology and geochemistry of shoshonites in the southwest Pacific

29 Nicole Pollington
Sedimentology, mineral paragenesis and geochemistry of the Konkola North Copper deposit, Zambia.

30 Carlos Rosa
Submarine volcanic successions in the Iberian Pyrite Belt, Portugal

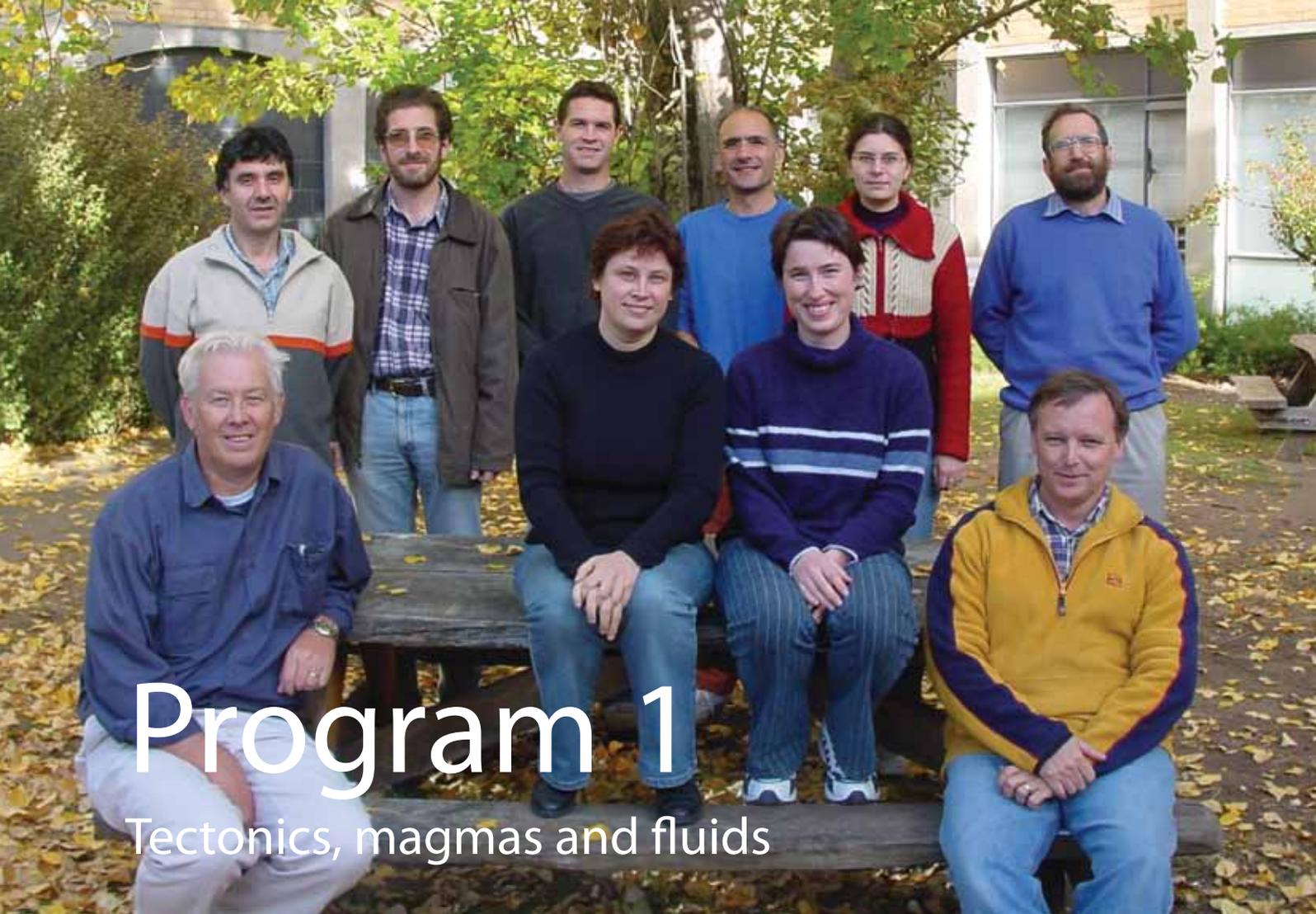
31 Christian Schardt
Controls on hydrothermal fluid migration by volcanic facies architecture: implications for massive sulfide deposit formation. (Lau Basin)

32 Andrew Stewart
Volcanic facies architecture and evolution of Milos, Greece

33 Sofia Tetroeva
Petrology & geochemistry of adakites & related rocks from the Hunter Ridge, Southwest Pacific

34 Andrew Tyson
Geophysical characteristics of porphyry and epithermal deposits.

35 Andrew Wurst
Geology and genesis of the Permata-Batu Badinding-Hulubai and Kerikil Au-Ag low sulfidation epithermal deposits, Mt Muro, Kalimantan, Indonesia.



Program 1

Tectonics, magmas and fluids

Research within Program 1 is divided between three broad themes.

The geochemical signatures of magmatic rocks are used to decipher the tectonic setting of eruption/emplacement of magmatic rocks in ancient fold belts, and better understand the tectonic setting of magmatic-related mineralisation.

Both melt and fluid inclusions in minerals are used to elucidate and compare the magmatic-hydrothermal transition in mineralised and unmineralised systems.

Modern geochemical and petrological techniques are used to address fundamental problems in the genesis of magmatic rocks.

Program 1 team: L to R, Tony Crawford (seated), Dima Kamenetsky, Leonid Danyushevsky, Michael Baker, Maya Kamenetsky, Fernando Della Pasqua, Sarah Gilbert, Sofia Tetroeva, Phil Robinson, David Steele (seated).

Objectives

To apply state-of-the-art ideas and techniques drawn from our combined expertise in modern igneous petrology and geochemistry to document the nature of volatile components in mantle-derived magmas from different tectonic settings.

To elucidate the processes involved in the evolution of late magmatic fluids responsible for porphyry copper-gold, and high-sulfidation epithermal gold/silver mineralising systems.

To build on our existing program of fundamental research in igneous petrology and geochemistry of magmatism in arc, backarc and ocean floor settings, in order to better understand the genesis of ore deposits in the entire context of the evolution of arc systems and rift basins.

To document the geochemical and petrological signatures of ancient (Tertiary to Archean) volcanic successions which host major ore deposits, in order to better understand their tectonic settings of eruption, to enable predictive exploration and definition of potentially fertile volcanic belts in Australian and South East Asian terrains.

Highlights

Awarding of ARC five-year Australian Professorial Fellowship to Dima Kamenetsky.

Program 1 researchers and their collaborators authored 12 publications in the following peer-reviewed international journals in 2004: *Nature*, *Journal of Petrology*, *Earth and Planetary Science Letters*, *Geology*, *Precambrian Research*, *Contributions to Mineralogy and Petrology*, *Mineralium Deposita*, *Resource Geology*, *Chemical Geology*, *Australian Journal of Earth Sciences* and *Journal of Volcanology and Geothermal Research* (2).

Successful ARC LIEF bid (Berry, Danyushevsky et al.) for scanning electron microscope with system for automated mineral mapping and textural analysis to support new geometallurgy research initiative (Central Science Laboratory): \$512,092.

Leonid Danyushevsky was Chief Scientist on R/V Southern Surveyor research cruise to the intersection of the Hunter Ridge proto-arc and the main spreading centre in the North Fiji Basin, to investigate tectono-magmatic nature of this W Pacific setting characterised by abnormally hot upper mantle.

The CHIME monazite dating technique was developed for routine operation using the electron microprobe (CSL)

PhD awarded to Paul Davidson (Fluid and melt inclusions in Taupo Volcanic Zone and Rio Blanco rhyolitic magmas).



Team Leader
Tony Crawford

Team Members
Ron Berry, Leonid Danyushevsky, Fernando Della Pasqua, Anthony Harris, Vadim Kamenetsky, Sebastien Meffre, Phil Robinson, David Steele (CSL), Khin Zaw

PhD Students
Michael Baker, Dene Carroll, Paul Davidson, Ding Quang Sang, Patricia Durance (part-MonashU), Ben Jones, Maya Kamenetsky, Roman Leslie, Weerapan Srichan, Sofia Tetroeva,

Collaborators
CSL (UTas), Geoscience Australia, CSIRO E&M, Geological Survey of NSW, Geological Survey of Victoria, Australian Crustal Research Centre and School of Earth Sciences MonashU, UAdelaide, Research School of Earth Sciences ANU, Max Planck Institute for Geochemistry (Germany), Vernadsky Institute of Geochemistry and Cosmochemistry (Russia).

Core Projects in Program 1
1.1 Volatiles and chalcophile elements in porphyry Cu-Au-hosting magmas
1.2 Volatile elements and chalcophile metals in magmas from different supra-subduction zone tectonic settings
1.3 Development of analytical techniques

Project 1.1 CORE
Volatiles and chalcophile
elements in porphyry-Cu/Au-
hosting magmas

V Kamenetsky, A Harris,
A Crawford, D Cooke, L
Danyushevsky, TMernagh (AGSO),
D Steele (CSL), C Ryan and E von
Achterbergh (CSIRO N Ryde), S
Garwin, N White (consultant);
PhD students P Davidson, B Jones,
R Leslie.

This program aims to investigate
the murky window between the
temperatures at which typical
felsic magmas crystallise (>700°C)
and the temperatures recorded
in fluid inclusions in high-
temperature veins in intrusive
rocks hosting porphyry-Cu/Au
deposits. This involves monitoring
magmatic fluid evolution from
felsic magmas approaching
their solidus, and attempting to
follow the subsequent evolution
and pathways of these fluids.
The principal tool used is melt
inclusion studies, using heating
stage methodologies supported
by element distribution mapping
based on PIXE imagery done in
collaboration with Dr Chris
Ryan (CSIRO E&M).

With colleagues from
Russia, CSIRO and PhD
student Paul Davidson, Dima
Kamenetsky published a
paper in Chemical Geology
describing a detailed study
of the evidence for late stage
immiscibility between silicate
melts and aqueous fluids,
producing volatile exsolution
from the Omsukchan Granite
in NE Russia. These findings
have wide applicability,
and in a related paper in
Resource Geology, Harris et al.
described volatile exsolution
and its relationship with
mineralisation at the Bajo de
la Alumbrera porphyry copper-
gold deposit, NW Argentina

Paul Davidson was awarded
his PhD based on a study in which
he compared melt and fluid
inclusions in quartz phenocrysts
from the mineralised Rio Blanco-
Los Bronces porphyry Cu deposit

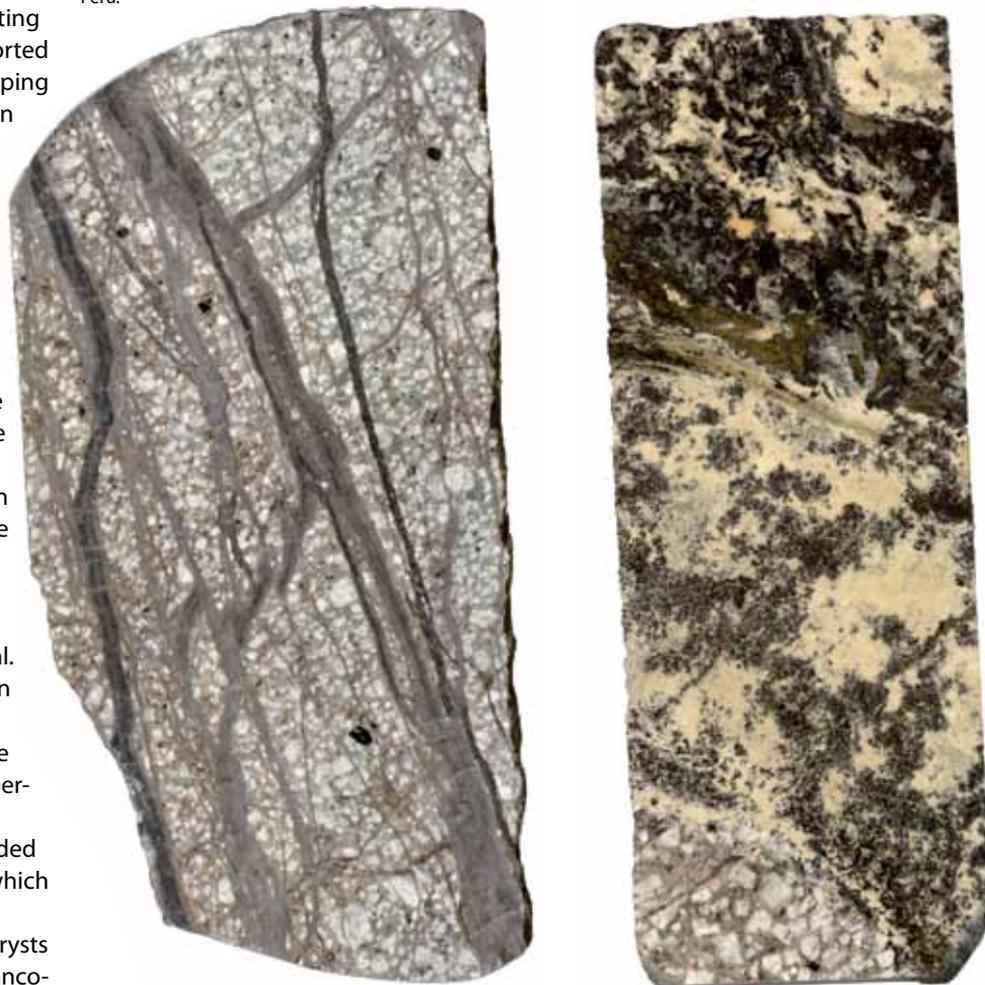
Left: Banded
type A quartz-
chalcopyrite veins
cutting plagioclase-
hornblende-biotite
phyric monzodiorite
porphyry (ATP1), at
the Atalaya intrusive
centre. BHP Billiton's
Antapaccay Cu-
Au-(Mo) porphyry
and skarn deposit,
Altiplano, southern
Peru.

Right: Retrograde
siderite-calcite-
bornite-chalcopyrite
exoskarn cut by
open-bimodal,
quartz-plagioclase-
hornblende-biotite
phyric, quartz
monzodiorite porphyry
(ASP2), at the
Antapaccay South
intrusive centre. BHP
Billiton's Antapaccay
Cu-Au-(Mo) porphyry
and skarn deposit,
Altiplano, southern
Peru.

in Chile with those in the
unmineralised Okataina rhyolite
from the Taupo graben in New
Zealand. Paul demonstrated for
the first time the occurrence
of remarkable two-phase
magmatic emulsions composed
of co-trapped silicate melt and
hydrosaline brine trapped in
quartz phenocrysts, and that
the brines are strongly enriched
in copper. With support from
Newmont, Paul continues his
porphyry-related studies, applying
his skills to a project examining
the nature of late magmatic
fluid evolution in quartz
phenocrysts from the Batu Hijau
deposit in Indonesia (Davidson,
Crawford, Kamenetsky, Garwin).
This porphyry Cu-Au deposit is
unusual in that it is hosted within
a low-K (tonalitic) felsic suite,
and it offers the potential to
compare fluids exsolving from this
K-poor suite with those exsolving
from medium-K (Rio Blanco)

and high-K (Emperor, Didipio, N
Parkes, Cadia) suites.

PhD student Ben Jones
continued his study of the
Antapaccay porphyry copper-
skarn deposit in Peru. During
the year, Ben also assembled an
extensive database on whole-
rock geochemistry of igneous
units associated with porphyry-
copper mineralisation in both
the Andes, and the SW Pacific.
He prepared numerous mineral
separate samples across the full
fractionation range represented
by the Antapaccay batholith in
preparation for melt inclusion
studies, and gathered microprobe
analyses of the main minerals in
the host rock magmatic system,
including amphiboles, titanites,
apatites, pyroxenes, micas and
feldspars.



Project 1.2 CORE
Volatile elements and chalcophile metals in magmas from different supra-subduction zone tectonic settings

A Crawford, L Danyushevsky, V Kamenetsky, D Steele (CSL); PhD students M Kamenetsky, R Leslie, S Tetroeva

Detailed studies of melt inclusions trapped in primitive olivine phenocrysts in lavas from diverse SW Pacific tectonic settings have shown that many are not, in fact, representative of the main magma that transported the host olivines to the surface (Danyushevsky et al., *Journal of Petrology*) Rather, many melt inclusions are trapped in olivines that grow in ephemeral reaction zones between magma chambers and wallrocks, where crystallisation is non-steady state, providing the opportunity for stunted olivine crystallisation to trap melt inclusions preferentially. The paper by Danyushevsky et al. demonstrates clearly that significant magmatic interactions occur between mantle and lower crustal wallrock, and with cumulates in the base of arc crust. This discovery forced a significant realignment of our approach in this particular project, with a key task being distinguishing melt inclusions that do represent major magma batches relevant to magma genesis, and those representing transient small volume reaction zone melts. Continuing work on mid-ocean ridge basalts and arc basalts has shown that careful melt inclusion studies can indeed provide very useful data about magmatic volatile and chalcophile element budgets.

In December, Roman Leslie submitted his PhD on the petrogenesis of the shoshonitic magmatic suite that hosts the Emperor gold deposit in Tavua caldera, Viti Levu (Fiji). This detailed petrological study focussed mainly on the mafic lavas in Tavua, and noted

that many melts trapped as melt inclusions in primitive to evolved olivine compositions have anomalous compositions that do not represent the main magma package involved (see above). Criteria for identification of 'useful' melt inclusions were developed and applied to the Tavua shoshonites. Roman's thesis provides new data for magmatic budgets of S, Cl and chalcophile elements during the fractionation of this typical SW Pacific shoshonite suite.

Patty Durance continued her PhD petrological research on the genesis of primitive arc tholeiites from the Hunter Ridge, and took part in the R/V Southern Surveyor cruise that swath-mapped the ridge-arc intersection and successfully dredged rocks from 35 locations of the seafloor in this region. Also a shipboard participant on the Hunter Ridge cruise was PhD student Sophia Tetroeva, who is studying the petrogenesis of adakitic magmas and their high-Mg andesite precursors in this region of abnormally hot mantle. Subduction of South Fiji Basin northward beneath the active spreading centre of the North Fiji backarc basin produces a very hot shallow upper mantle regime. Here, partial melting, rather than dehydration of the subducting slab, occurs, and the resultant plagiogranite or tonalitic melts rise through and react with the shallow mantle peridotite, generating diverse and unusual high-Mg andesite and adakite magmas. Given the recently recognised importance of adakitic magmas in the Andes, where primary magma compositions are masked or obliterated by crustal contamination, this study can provide valuable information on the Cl, S and chalcophile element variations in magmas generated by slab melting, rather than those produced by 'normal' mantle wedge melting triggered by dehydration of the subducting slab.

Project 1.3 CORE
Development of analytical techniques

L Danyushevsky, P Robinson, M. Norman, S. Meffre, R Berry, A Rae, G Davidson, D Steele (CSL); PhD students M Kamenetsky, N Martin (Program 3), D Clark (Program 4)

The CODES-funded ICPMS continued to provide excellent data to diverse projects through the year, in both solution mode, and via laser ablation analysis. The multi-sponsored industry project on trace element contents of sulfides has progressed well following development of key standards for laser ablation microanalysis. Continued improvement of the LA-ICPMS analytical procedure to date zircons and titanite via U-Pb micro-isotopic analysis has taken place, with resultant applications to numerous projects, including Palaeozoic rocks in north Queensland, Palaeoproterozoic zircons from the Georgetown Block, Mesoproterozoic zircons from the Stuart Shelf, Late Neoproterozoic rocks from King Island, and mainly Cretaceous and Tertiary zircons from SW Pacific arc basement suites in the Norfolk Ridge-Norfolk Basin region.

Ron Berry and David Steele have improved the microanalytical system for dating of monazite using the new microprobe (CHIME method), and this useful technique is now receiving considerable attention from CODES staff and students. .

Project 1.4
Origin and metallogensis of Ordovician volcanic belts in central western New South Wales

A Crawford, D Cooke, S Meffre, R Scott, J McPhie; D Glen, I Percival, J Watkins and L Barron (GSNSW); C Simpson (Consultant), M Fanning (PRISE-ANU)

This collaborative project between CODES researchers, industry

partners, and the Geological Survey of NSW was completed in 2002. A Thematic Issue of the Australian Journal of Earth Sciences containing 17 papers deriving from this project is scheduled for publication in mid-2005.

Project 1.5
Modern and ancient fold belt volcanics

A Crawford, S Meffre, L Danyushevsky, D Kamenetsky, P Quilty; D Giles (Austr. Crustal Research Centre, MonashU), G Yaxley (PRISE-RSES), A Sobolev (Vernadsky Institute of Geochemistry and Cosmochemistry, Moscow), I Withnall (GSQueensland), B. Stevens (GSNSW), R Herzer and N Mortimer (Institute of Geological and Nuclear Sciences, NZ), P O'Brien & N Exon (Geoscience Australia), C Laporte & M Allenbach (U New Caledonia), P Vasconcelos (UQld), I Duddy

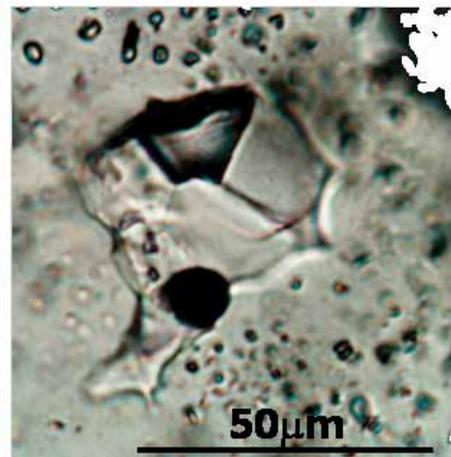
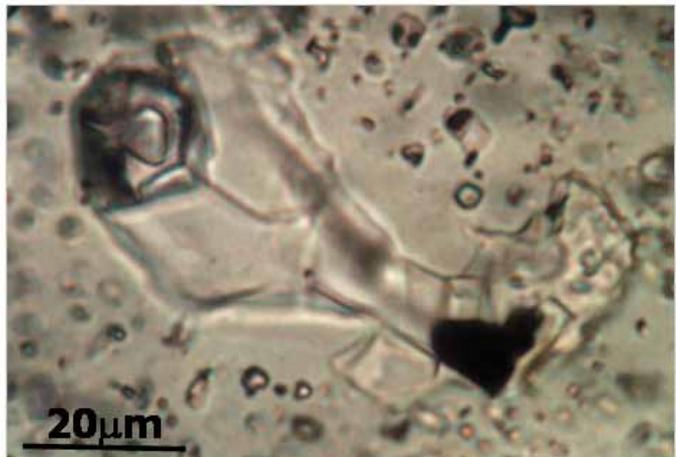
Multiphase carbonate-chloride-sulphate melt inclusions in the groundmass olivine of the Udachnaya-East kimberlite pipe. These inclusions are ample evidence that the deepest of all terrestrial magmas evolve towards essentially non-silicate anhydrous compositions.

(Geotrack International), P Hollings (Lakehead U, Canada), R Glen (GSNSW); PhD students M Baker, D Carroll, P Durance, S Tetroeva

Modern Settings
A major research effort continued on the project 'Tectonic Paradox of the E Margin of the Australian Plate, 120 Ma–0 Ma', that commenced in 2003 supported by an ARC Discovery Grant to Tony Crawford. This project centres on the rocks dredged from a cruise of the R/V Southern Surveyor to the Norfolk Ridge-Norfolk Basin region between New Zealand and New Caledonia, aimed at elucidating the geological and tectonic evolution of the subduction factory in the SW Pacific. Since a large part of the continental crust of eastern Australia (Tasman Fold Belt System) was produced in subduction-related arc-backarc basin systems such as in the current SW Pacific, 'unravelling' these fold belts will be facilitated

by a broad-ranging understanding of the spatial, temporal and compositional evolution of the SW Pacific region.

Geochemical data have been gathered for best-preserved rocks from 35 dredges carried out during the research cruise. Important among these are (1) First basaltic oceanic crust sampled from the Norfolk Basin (the last backarc basin globally to be sampled), about which considerable debate exists as to whether this basin formed in the Cretaceous, or Miocene. Ar-Ar dating on these and other dredged rocks is in progress in collaboration with Prof P Vasconcelos (U Queensland). (2) Seamounts from the southern end of the Loyalty seamount chain, believed before the cruise to be a primitive intra-oceanic arc, but shown by dredging to be composed of Miocene shoshonites. (3) Peridotites exposed at the seafloor and forming an extensive ophiolitic domain over 500 km long,



probably representing a southern continuation of the New Caledonian ophiolite; sandstones containing abundant detrital blue amphiboles in the same dredges probably represent material eroded from the high-pressure sole of the ophiolitic allochthon, and will provide excellent constraints on the timing of ophiolite emplacement. (4) Basaltic lavas dredged from scarps at the northern end of the Norfolk Ridge are presently being dated, and bear some compositional similarities to Cretaceous lavas of the Whitsunday Province of coastal Queensland. (5) Terrigenous sandstones dredged further south on the same ridge, close to Norfolk Island, contain zircons and apatites dated by LA-ICPMS and apatite fission track analysis at 95-120 Ma, indicating that the Mid-Cretaceous extensional basins filled with volcanoclastic detritus, such as those between Tasmania and Victoria, extended considerably further east, beyond the Lord Howe Rise. Micropalaeontological studies by Patrick Quilty (School of Earth Sciences) have proved invaluable in dating the dredged sedimentary rocks. Each of these suites throws new light on evolution of the region, and based on the results of this cruise, we aim to complete an update to the 2003 synthesis paper (Crawford et al.) on the tectonic development of the SW Pacific.

Based on a successful application (Danyushevsky & Crawford) for ship-time using the new National Facility vessel R/V Southern Surveyor, Leonid Danyushevsky was Chief Scientist for a 25-day cruise to the region where the southern end of the main spreading system in the North Fiji Basin intersects the embryonic submarine Hunter Ridge arc. During the cruise, more than 1000 km of magnificent swath imagery of the seafloor of this intriguing and complex region was collected, along with 35 dredge hauls of basement rocks. Detailed laboratory-based

studies of the dredged rocks, and tectonic interpretation of the swath mapping results, began in late 2004, and form part of the PhD studies of Sofia Tetroeva and Patty Durance.

Dene Carroll (PhD: Tectono-magmatic evolution of SW Viti Levu, Fiji) returned home to New Zealand to contribute to undergraduate teaching at his alma mater, Victoria University of Wellington, but is in the final stages of write-up of his thesis, which should be submitted mid-2005.

Other Program 1 studies with published output on modern magmatic systems include,

- A paper by Sun, Arculus, Kamenetsky and Binns on release of gold-bearing fluids in convergent margin magmas prompted by magnetite crystallisation (Nature).
- A paper by Sun, Bennett and Kamenetsky on the mechanism of Re enrichment in arc magmas (Earth & Planetary Science Letters).
- A paper by Raos and Crawford on the petrogenesis of modern basalts forming the northern end of the island of Efate in the Vanuatu island arc (Journal of Volcanology Geothermal Research).
- A paper in Geology by Maya Kamenetsky, Dima Kamenetsky, Leonid Danyushevsky and colleagues documenting for the first time, the mineralogy and composition of the primary kimberlite magma, as recorded in the groundmass and melt inclusions in olivine microphenocrysts from the ultra-fresh Udachnaya East kimberlite.
- A paper by Rae, Cooke, Phillips and Zaide-Delfin on the nature of magmatism at Palinpinon geothermal field, Negros Island, Philippines, with implications for geothermal activity and regional tectonics (Journal of Volcanology Geothermal Research)
- A paper by Exon, Quilty, Lafoy, Crawford and Auzende describing rocks dredged from

Miocene volcanic seamounts on northern Lord Howe Rise (Australian Journal of Earth Sciences).

- A paper by Yaxley, Dima Kamenetsky, Maya Kamenetsky and colleagues on the implications for flood basalt genesis of new data for melt inclusions in olivines from the Baffin Bay picrites.

Ancient Fold Belt Studies

In collaboration with David Giles (Australian Crustal Research Centre, MonashU) and Ian Withnall (GS Queensland), new mapping and sampling of key lithostratigraphic units along the eastern margin of the Georgetown Block in the Greenvale region has been backed up by extensive new whole-rock geochemical data, and LA-ICPMS dating (of both detrital zircons in sandstones, and magmatic zircons in lavas and intrusive rocks). This work aims to define the tectono-magmatic development of the northern end of the Tasman Line, to compare it with better defined areas along the western margin of the Tasman Fold Belt System in the southeast of Australia.

The east coast of King Island contains a key series of exposures of the Tasman Line, and a paper in Precambrian Geology by Meffre, Direen, Crawford and Kamenetsky contributed to the development of our understanding of this continental-scale feature, showing that it represents in part a reworked ~580 Ma rift system, supporting the conclusions of two earlier papers by our group (Direen and Crawford, 2003a, b).

Michael Baker completed a second instalment of his PhD fieldwork on the Palaeoproterozoic magmatism and metamorphism of the western section of the Georgetown Block. New analytical data has been collected for the Dead Horse Metabasalt and Cobbold Dolerite suites that dominate the magmatic record of the region, and U-Pb zircon ages determined for several late-stage granophyres sampled from the upper sections

of a number of thick doleritic sills. Monazite dating is in progress to better constrain the relationships between igneous events and metamorphism.

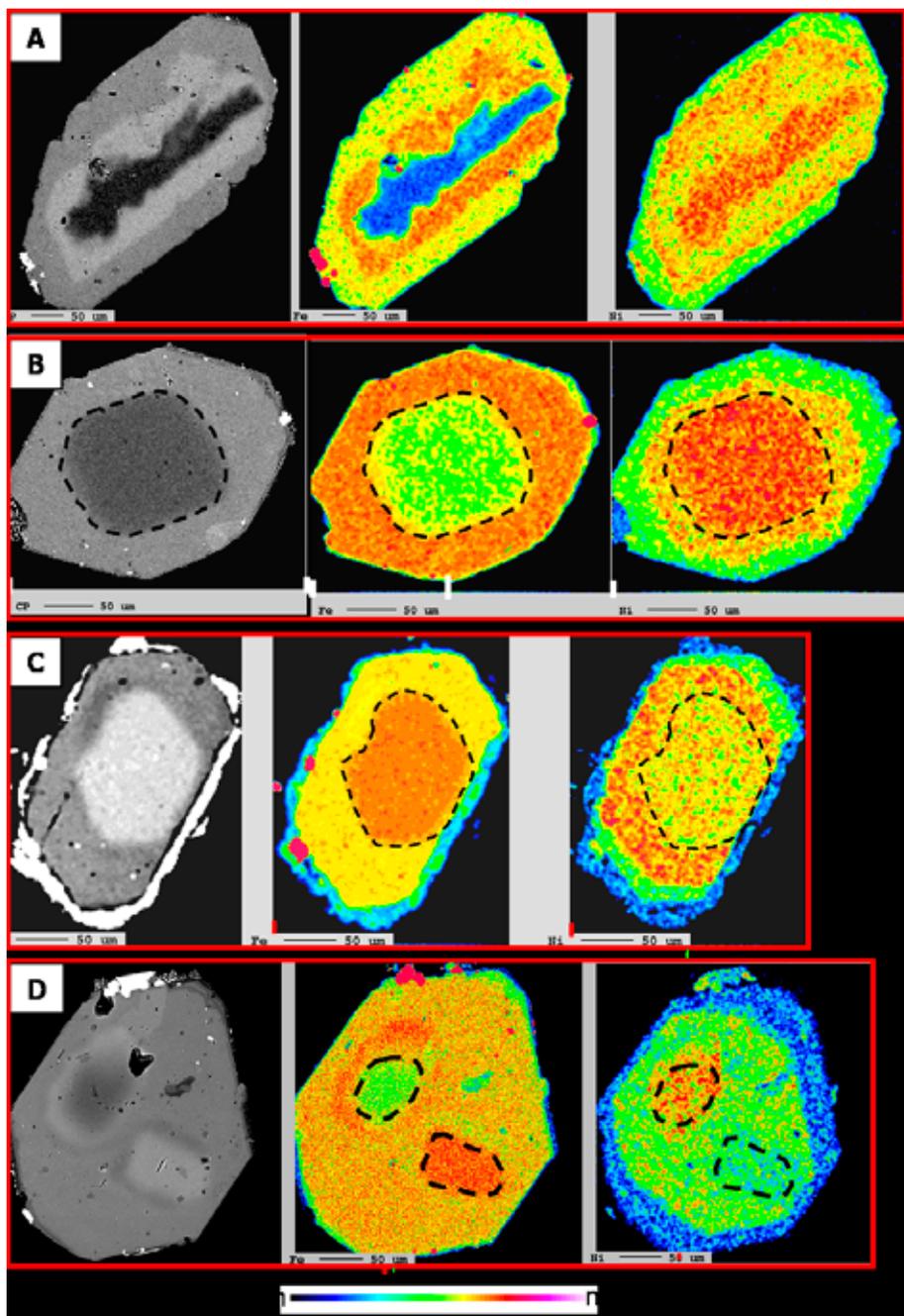
With Barney Stevens (GSNSW), Tony Crawford continued a detailed documentation of the geochemical variations and significance of the amphibolites in the Broken Hill Block in NSW. In particular, detailed step-sampling across sills was undertaken to test whether these may be used as a way-up indicators to clarify regional structural relations, and to evaluate the links between these abnormally Fe-rich tholeiites and mineralisation in this block. Broken Hill Block amphibolites are being compared with those of apparently identical age from the Georgetown Block and Mt Isa to elucidate the distribution and role of Fe-rich tholeiites in Palaeoproterozoic magmatism in eastern Australia.

Project 1.6
Tectonics and metallogeny of South China (AMIRA P603)

Khin Zaw, Clive Burrett, Ron Berry (School of Earth Sciences, UTas); Eleanor Bruce (Spatial Information Science, Geography and Environmental Studies, UTas); PhD students Weerapan Srichan, Dinh Quang Sang.

Although this project was completed in 2002, considerable effort has continued to be spent on publication of results

A Special Issue of Ore Geology Reviews edited by Khin Zaw and Stephen Peters (USGS) will contain 15 papers on the tectonics and mineral deposits of South China. The Special Issue is due for publication in mid-2005.



Strong zoning of the kimberlite groundmass olivine crystals (Udachnaya pipe, Siberia) points to their complex evolutionary history that possibly started at ~150 km depth, in the source region of diamonds.

Project 1.8
Geochronology, metallogeny and deposit styles of the Loei fold belt in Thailand Laos PDR (ARC Linkage)

Khin Zaw, S Meffre, W Herrmann, A Harris; S Golding (UQ), M Barley (UWA)

At the beginning of 2004, the ARC linkage project "Geochronology, metallogeny and deposit styles of Loei Fold Belt in Thailand and Laos PDR" commenced with the support of three companies: Kingsgate

Consolidated Ltd, Oxiana Limited and Pan Australian Resources NL. This project is supported by a yearly contribution of \$20,000 (plus \$30,000 in-kind support) from each sponsor. In addition, ARC is providing \$90,000 per annum for three years. The Loei Fold Belt, occurring between the Shan-Thai and Indochina terranes in SE Asia, is host to a diverse array of deposit styles containing significant gold and copper. As such, this belt is being actively explored with considerable backing by a number of Australian mining companies.

Despite numerous deposits (including skarn-type copper-gold, porphyry-related copper and mesothermal to epithermal vein gold deposits) being distributed along the belt, these deposits are not well documented and their metallogenic relationships are poorly understood.

This project aims to study the age, origin and styles of these deposits in the context of regional tectonic and magmatic events. To fulfil these aims, the project has been divided into three subprograms: (1) to establish a district-scale GIS geoscience data base (including all open-file geological, geochronological data); (2) to study the regional tectonic and metallogenic events of the belt, with emphasis on timing and magmatic-volcanic events and relationship to mineralisation; and (3) to undertake detailed deposit characterisation studies of key ore deposits throughout the belt. Ultimately, this project seeks to establish the timing of key events that lead to ore deposit formation, and to establish criteria that are useful in prioritising prospects throughout the Loei Fold Belt.

A major field program was undertaken in 2004 to sample the principal plutonic and volcanic rock suites for geochemistry and dating. Several students undertook field and laboratory studies as part of the overall project in 2004.

- Derek Backhouse studied alteration and mineralisation at the Phu Kham porphyry skarn copper-gold deposit.
- Kamonporn Kromkhun researched the vein styles and alteration at the Chatree epithermal gold mine.
- Teera Kamvong studied the intrusive rocks and mineralisation at the Phu Lon skarn copper-gold deposit.
- Grace Cummings undertook a volcanic facies analysis of the Permo-Triassic rocks in the Khao-Chatree district.

PhD Projects in Program 1

Michael Baker: Palaeoproterozoic magmatism in the Georgetown Block, N Queensland, and comparisons with Broken Hill block.

Dene Carroll: Tectono-magmatic evolution of eastern Viti Levu, Fiji.

Paul Davidson: Melt inclusions in porphyry Cu-Au-hosting magmatic systems. (graduated August 2004)

Dinh Quang Sang: Geological evolution of the northern margin of the Kontum Massif, central Vietnam.

Ben Jones: Genesis of the Antapaccay Cu-Au deposit, Peru.

Maya Kamenetsky: Melt inclusion studies of kimberlites and flood basalts.

Roman Leslie: Petrogenesis and volatile evolution of shoshonitic magmas.

Weerapan Srichan: Tectonic significance of the Lampang Volcanic Belt, northern Thailand.

Sofia Tetroeva: Petrogenesis of adakitic magmas.



Program 2

Volcanic facies architecture and ore-forming environments

Program 2 explores the connection between volcanic processes and the architecture of volcanic environments most suitable for ore deposit formation. Current projects in the Volcanology Program focus on the facies architecture of volcanic successions that host ore deposits in arc settings, primary and alteration textures in volcanic rocks, and the physical volcanology of extensive rhyolites.

The active composite stratovolcano, El Misti (5820 m), rising above the city of Arequipa in Southern Peru.

Objectives

To develop a better understanding of the facies architecture and evolution of volcanoes in modern and ancient arc settings.

To provide a sound volcanological framework for examining the interplay between volcanic processes and ore-forming hydrothermal systems, focussing in particular on volcanic successions associated with massive sulfide, porphyry copper-gold and epithermal gold-silver ore deposits.

To clarify the primary textural characteristics and textural evolution of fresh, glassy volcanic facies through syn-depositional, diagenetic and hydrothermal alteration stages.

Highlights

Results of CODES Volcanology research were featured at the 17th Australian Geological Congress in Hobart (17 abstracts, two symposia and a field trip) and the IAVCEI General Assembly in Pucon, Chile (five abstracts).

A new view of the volcanic host succession to massive sulfide deposits in the Iberian Pyrite Belt was presented at a field workshop in Portugal.

Volcanological research commenced in the highly prospective Loie Fold Belt in Thailand.

A new book by Cathryn Gifkins, Wally Herrmann and Ross Large on alteration in mineralised volcanic successions was completed.

Sharon Allen was appointed as Leader of the IAVCEI Commission on Explosive Volcanism.

New AMS data revealed outflow paths and source locations of extensive lavas in the Gawler Range Volcanics.

Core Projects in Program 2

2.1 Facies architecture models for submarine volcanic successions that host base- and precious-metal ore deposits in arc environments

2.2 Facies characteristics and textural evolution of submarine-emplaced rhyolitic pumice breccias

2.6 Phenocrysts and melt inclusions in arc lavas: textural and petrogenetic implications

2.7 Experimental simulations and textural analysis of submarine volcaniclastic mass-flow deposits that result from large-scale eruption and failure events.



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Jocelyn McPhie

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Fernando Della Pasqua, Cathryn
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PhD Students
Katharine Bull, Gregory Ebsworth,
Carlos Rosa, Andrew Stewart

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of Oregon (USA), Smithsonian
Institution (USA), Institute for
Frontier Research on Earth
Evolution (IFREE, Japan),
Institute of Geology and Mineral
Exploration (Athens, Greece),
National Institute for Engineering,
Technology and Innovation (INETI,
Lisbon, Portugal), Department
of Mineral Resources (Thailand),
Geological Survey of New
South Wales, Mineral Resources
Tasmania, Primary Industries
and Resources South Australia,
Akara Mining Limited (Thailand),
Silver and Baryte SA (Greece),
SOMINCOR (Portugal)



Project 2.1 CORE
Facies architecture models for submarine volcanic successions that host base- and precious-metal ore deposits in arc environments

J McPhie, S Allen, S Bull, C Gifkins, W Herrmann; R Allen (Volcanic Resources), S Khositantont (DMR, Thailand), S Meakin (GS-NSW), J Relvas (ULisbon); PhD students K Bull, G Ebsworth, C Rosa, A Stewart

Research for this project involves a combination of volcanic facies analysis and textural studies both in ancient, deformed and young, well preserved arc successions. In 2004, this project included contributions from four PhD students and three Honours students (summarised below), and collaboration with Program 1 (magma geochemistry and tectonics) and Program 3 (textural and compositional effects of hydrothermal alteration). Study areas included:
Anson Formation at Lewis Ponds, New South Wales
Ural Volcanics, New South Wales

Program 2 team: L to R, Jocelyn McPhie, Wally Herrmann, Sharon Allen, Kate Bull, Anthony Harris.

Mount Read Volcanics in western Tasmania
Iberian Pyrite Belt, Portugal
Milos, Greece
Loie Fold Belt, Thailand

Michael Agnew studied the geology and genesis of the Lewis Ponds polymetallic massive sulfide deposits, central western New South Wales, for his PhD and graduated at the end of 2003. At Lewis Ponds, the base-metal

sulfides occur in thick units of poorly sorted, limestone-bearing volcanic breccia in a succession intruded by a dacitic cryptodome. Michael and co-authors Stuart Bull and Ross Large published a paper in the Australian Journal of Earth Sciences entitled "Facies architecture of the Lewis Ponds carbonate and volcanic-hosted massive sulfide deposits, central western New South Wales".

Kate Bull at Lascar Volcano in northern Chile. In the middle ground are pyroclastic flow deposits from the 1993 eruption (Project 2.1).



Kate Bull continued working on the Early Devonian submarine volcanic successions in central western New South Wales, particularly the Ural Volcanics around Lake Cargelligo and the Mount Hope Volcanics farther north. Kate's project is conducted in collaboration with the Geological Survey of New South Wales. In 2004, she concentrated on writing chapters but also completed LA-ICPMS dating of zircons and obtained whole-rock compositional data on a suite of samples from the two main volcanic successions. Major results of her work in the Ural Volcanics, including a new 1:10,000 scale geological map, are in press in the Quarterly Notes of the Geological Survey of New South Wales. Kate presented aspects of her research at the 17th Australian Geological Congress in Hobart, the Society of Economic Geologists' conference in Perth, and the IAVCEI General Assembly in Pucon, Chile.

Greg Ebsworth has been studying regional variations in the internal stratigraphy of the Tyndall Group in western Tasmania, for his PhD research. Greg presented a paper at the 17th Australian Geological Convention in Hobart on the origin and significance of the crystal-rich sandstone facies that dominates much of the lower Tyndall Group throughout

its extent. Greg suspended his research for the remainder of 2004 in order to take a temporary industry position.

Two Honours projects were also conducted on the Mount Read Volcanics. David Kratzmann completed a study of the structure and facies architecture of the Murchison Gorge-Sterling Valley area. David's research was supported by Pasminco Exploration (now Zinifex). He mapped the major faults that separate the Sterling Valley Volcanics, Farrell Slates and Murchison Volcanics. Using volcanic facies analysis, he recognised a lava dome-dominated volcanic centre in the Murchison Volcanics. David's results have clarified the stratigraphy of this part of the Mount Read Volcanics and contributed to on-going efforts to refine regional correlations.

Californian geologist, mule packer and tree doctor Nate Allen commenced an Honours project examining the volcanic-hosted Sassy Creek gold prospect in the remote southern Mount Read Volcanics near Elliott Bay. Limited drilling on the prospect (Voyager 24) by Geopeko in the early 1980s and by TasGold Ltd in 2003, showed that it contains narrow high-grade auriferous quartz-sulfide veins in a 100-m-wide zone of <0.2g/t "anomalous" gold. Nate's project aims to

document the lithofacies of the felsic volcanic host rocks, mineralization styles, alteration assemblages, and geochemical and short-wavelength infrared characteristics, and to interpret the metallogenesis and economic potential of this enigmatic and under explored gold occurrence. TasGold has provided funding for geochemical analyses and helicopter access. Nate's research is contributing to more effective exploration and also to current understanding of the poorly known southern Mount Read Volcanics.

Another project in the Mount Read Volcanics was conducted in collaboration with Mineral Resources Tasmania, the Predictive Mineral Discovery Cooperative Research Centre at the University of Melbourne, and Fractal Technologies. The project involved Cathryn Gifkins, Wally Herrmann, Bronwyn Kimber and Jocelyn McPhie and aimed at producing a comprehensive database on Tasmanian geology that would stimulate mineral exploration. The project generated interactive GIS maps of the Mount Read Volcanics that show the distribution of the principal volcanic facies associations and hydrothermal alteration zones, the location of volcanic centres, and whole-rock and mineral compositions. Cathryn and Wally each presented papers on aspects

Jocelyn McPhie, Clive Boulter (U Southampton) and Raul Jorge (U Lisbon) puzzling over possible peperite at Rio Tinto, Spain.

Jose Polanco (Placer Dome) and Jocelyn McPhie examining host rocks to the Pueblo Viejo gold deposit in the Dominican Republic (Project 2.1).



of the interactive map at the 17th Australian Geological Convention in Hobart.

Carlos Rosa completed all the field work required for his PhD research on the volcanic successions in the Iberian Pyrite Belt, Portugal. This research is jointly supervised by Dr Jorge Relvas at the University of Lisbon and receives support from the Portuguese Science and Technology Fund, INETI and SOMINCOR mining company. Carlos has mapped sections in three main areas in Portugal, including the host succession to the giant Neves Corvo massive sulfide deposit. He has recognised two major associations: one association is dominated by submarine felsic lavas and the other is mainly composed of felsic pumice breccia generated by explosive eruptions. Carlos has also logged and sampled five sections through the volcanic succession in the Spanish part of the Iberian Pyrite Belt in order to assess regional facies variations. Carlos presented results of his research at the 17th Australian Geological Convention in Hobart and at the IAVCEI General Assembly in Chile. He is co-author of a paper on the geochemistry of volcanic rocks from one of his detailed sections, published in *International Geology Review*.

Also in the Portuguese Iberian Pyrite Belt, Carlos and Jocelyn McPhie led a field workshop examining two of the three areas that have been studied in detail. Participants included geologists from INETI, the University of Lisbon, the University of Huelva (Spain) and University of Southampton (UK). The field sections provide evidence for a new interpretation of the style and setting of the volcanic rocks that host massive sulfide ore bodies. The field work was followed by a meeting at the University of Lisbon at which Carlos, Jocelyn and Clive Boulter presented seminars exploring alternative interpretations of Iberian Pyrite Belt volcanology.

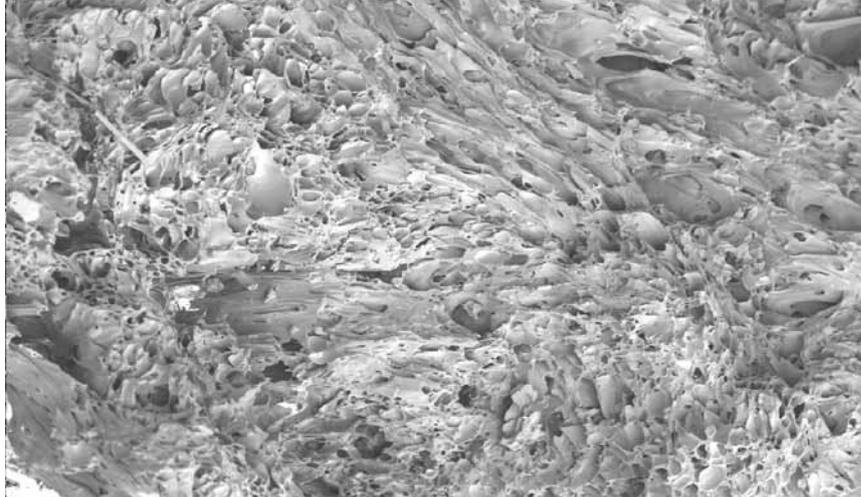
Andrew Stewart's PhD

thesis on the volcanic facies architecture of Milos, Greece, was passed and he graduated in August 2004. This research was conducted in collaboration with Dr Georges Vougioukalakis of the Institute of Geology and Mineral Exploration, Athens, and with Silver and Baryte SA, an exploration company active on the island. Andrew's thesis presents detailed information on the nature of volcanic and sedimentary facies making up the island, one of the largest volcanic islands in the Southern Aegean Volcanic Arc. The thesis also provides new constraints on the timing of the transition from a shallow submarine to a subaerial setting and the age of Au- and Ag-rich epithermal quartz veins. Andrew published a paper on the internal structure and growth of a dacitic cryptodome in 2003 (Stewart and McPhie, *Journal of Volcanology and Geothermal Research*). A second paper that deals with the origin of extremely coarse, submarine pumice breccia was published in 2004 (Stewart and McPhie, *Bulletin of Volcanology*). A third manuscript on the volcanic facies architecture and evolution of Milos is in review. Andrew also presented a summary of his research at the 17th Australian Geological Convention in Hobart.

The Volcanology program team contributed to two major new projects in other programs: an ARC Linkage project on the Loie Fold Belt in Thailand, led by Dr Khin Zaw (Project 1.8), and an ARC Linkage- and AMIRA-funded project on transitions and zonation in porphyry-epithermal districts, led by Associate Professor David Cooke (Project 5.18). Sharon Allen supervised an Honours project undertaken by Grace Cumming on the volcanic setting of the Chatree gold deposit at Khao Sai in the central part of the Loie Fold Belt. This project was conducted with the permission and support of Akara Mining Limited. Grace logged a series of drill core intersections that enabled reconstruction

of the style and setting of the volcanism represented by the host succession. She presented a summary of her results at the IAVCEI General Assembly in Pucon, Chile. Jocelyn McPhie also visited Thailand for a reconnaissance survey of the volcanic geology of the Loie Fold Belt, guided by Khin Zaw and Somboon Khositantont (DMR, Thailand). Pueblo Viejo (Placer Dome) in the Dominican Republic is one of the sites selected for detailed study in Project 5.18. The overall aim is to achieve a better understanding of the large magmatic-hydrothermal systems that produce porphyry-epithermal ore deposits. These deposits typically occur in complicated volcanic successions and/or subvolcanic intrusions. The nature of the host volcanic succession to the gold deposit at Pueblo Viejo has been contentious, and the uncertainty has contributed to disagreement and debate over ore genesis. Jocelyn McPhie, Cari Deyell and Jose Polanco (Placer Dome) carried out a detailed volcanic facies analysis of selected sections through the Pueblo Viejo deposit, and have radically revised previous interpretations. The results were presented to sponsors meeting in Hobart in December 2004.

Cathryn Gifkins, Wally Herrmann and Ross Large are the authors of a new book on the textural, mineralogical and compositional changes that accompany alteration of volcanic successions. The book focusses on hydrothermal alteration associated with volcanic-hosted massive sulfide deposits, and incorporates many of the outcomes of AMIRA project P439 ('Studies of VHMS-related alteration: geochemical and mineralogical vectors to ore'). The effects of diagenetic alteration and regional metamorphism are also reviewed. Summaries of alteration processes and products are complemented by a series of case studies based on deposits in Australia and overseas. The book was completed at the end



An SEM image of a rhyolitic pumice clast sampled by Sharon Allen and JAMSTEC colleagues from Kaiyo Knoll (800 m bsl), south of Japan. Field of view 0.5 cm.

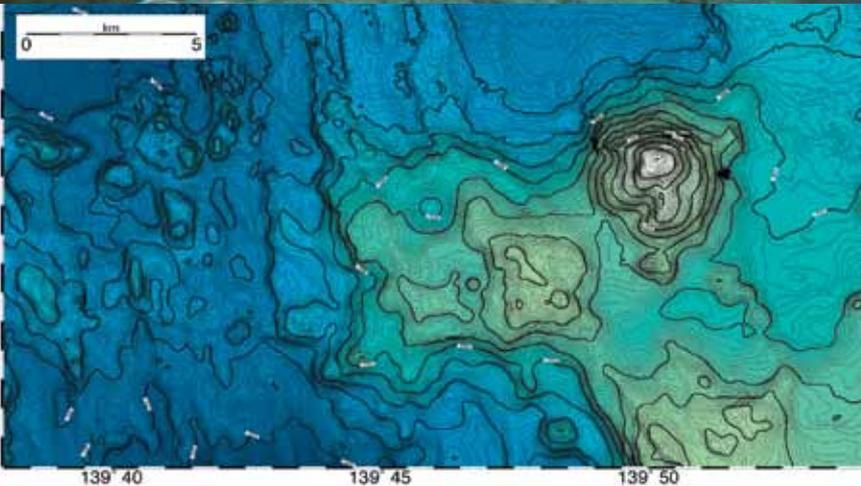


The Remotely Operated Vehicle "Hyper-dolphin" being deployed from the R/V Natsushima. The ROV retrieved samples and photographs of felsic seafloor volcanoes in the Izu-Bonin Arc south of Japan.



Giant (3-4 m across) rhyolitic pumice clasts occur on the surface of the rhyolitic Kaiyo lava dome at 800 m below sea level. The Kaiyo dome is one of three submarine domes surveyed and sampled by Sharon Allen and JAMSTEC colleagues for research on submarine felsic pumice.

Bathymetry map generated from Sea-BEAM data of the rhyolite domes on the sea floor west of Sumisu caldera, Izu-Bonin Arc. The map was produced on the R/V Natsushima and used to guide sampling of seafloor pumice by Sharon Allen and colleagues (Project 2.2).



of 2004, and will be printed and published early in 2005.

Project 2.2 CORE Facies characteristics and textural evolution of submarine-emplaced rhyolitic pumice breccias

S Allen, J McPhie, C Gifkins; R Allen (Volcanic Resources), Kathy Cashman (UOregon), Richard Fiske (Smithsonian Institution), Yoshihiko Tamura (IFREE); PhD students K Bull, A Stewart

Pumice breccia is a characteristic facies in submarine volcanic successions and common in the host successions to massive sulfide deposits. Major textural and compositional changes occur in glassy, porous pumice breccias during compaction, diagenesis, hydrothermal alteration and metamorphism. This project involves studies of modern (Izu-Bonin Arc, Japan), Pliocene (Milos, Greece) and Palaeozoic (Cambrian, western Tasmania; Early Devonian, New South Wales) pumice breccias.

In 2004, Sharon Allen served as Research Scientist on board the Natsushima at the invitation of Dr Yoshihiko Tamura (Group Leader, Institute for Frontier Research on Earth Evolution, IFREE). Sharon has established a collaborative research project with Tamura-San and Dr Richard Fiske (Senior Volcanologist, Smithsonian Institution, USA) on pumice generated by submarine felsic volcanoes. The cruise offered an unparalleled opportunity to study in situ rhyolitic pumice generated by submarine volcanoes of the Izu-Bonin Arc south of Japan. A Remotely Operated Vehicle (ROV) was used to observe, photograph and sample pumice at three seafloor volcanoes, each with different summit depths (1200 m, 600 m and 100 m bsl).

Sharon and Richard Fiske have used samples collected on the cruise in a series of experiments exploring rates of saturation and settling behaviour of submarine-



the texture can also result from early diagenetic compaction and alteration of glassy pumice in a wide variety of non-welded pumice-rich facies. This style of compaction foliation is the subject of a paper published in the *Journal of Volcanology and Geothermal Research* by Cathryn Giffkins, Jocelyn McPhie and Rodney Allen. The paper presents examples from the Cambrian Mount Read Volcanics in western Tasmania and the Miocene Green Tuff Belt in Japan and offers criteria that can be used to discriminate between diagenetic and welding compaction. The Early Devonian Ural Volcanics, New South Wales, also include volcanic facies that display bedding parallel foliations defined by *fiamme*. As part of her PhD research, Kate Bull has completed a review of *fiamme* in volcanic successions. Kate presented a summary at the Society of Economic Geologists Conference in Perth and the IAVCEI General Assembly in Pucon, Chile.

Project 2.3 CORE
Facies architecture of volcanic successions that host porphyry Cu-Au ore deposits in arc settings

C Simpson, W Herrmann, J McPhie; PhD student R Squire (graduated 2001)

Members of the Volcanology Program participated in a major research project led by Program 1 (Project 1.4) on the Ordovician volcanic successions of central western New South Wales. The final report was presented in 2001. A Thematic Issue of the *Australian Journal of Earth Sciences* devoted to the results of the project was published in 2004 and includes papers by Rick Squire, Jocelyn McPhie, Carol Simpson and Wally Herrmann. Rick and Carol also presented aspects of their research at the 17th Australian Geological Convention in Hobart.

erupted pumice. The experiments were performed in laboratories at the Smithsonian Institute Museum of Natural History in Washington DC. Sharon obtained additional data on the physical properties of the seafloor pumice samples at the University of Oregon, in collaboration with Professor Kathy Cashman. Pumice permeability and porosity were measured using a Helium pycnometer and capillary flow porometer, and the scanning electron microscope was used to characterise the different types

Valle de la Luna (Valley of the Moon), northern Chile. Salt diapir (foreground), made up predominantly of gypsum, intruded sedimentary rocks (background: Oligocene).

Valle de la Luna, northern Chile. Tertiary sedimentary rocks, folded to near vertical.

of pumice clasts in the sample set. The new field and laboratory data will provide constraints on eruption styles, fragmentation mechanisms, transport processes and vesiculation of felsic magmas at submerged vents.

Ancient pumice breccias commonly display a bedding-parallel foliation defined by altered and compacted pumice clasts (*fiamme*). The texture strongly resembles eutaxitic texture produced by compaction of hot pumice in welded pyroclastic deposits. However,

Project 2.6 CORE

Phenocrysts and melt inclusions in arc lavas: textural and petrogenetic implications

S Allen, V Kamenetsky; PhD student Paul Davidson

This project involves collaboration between Program 1 and Program 2 in research on phenocryst and melt inclusion populations in mainly felsic lavas from arc settings. There are two principal aims: to undertake textural analysis of phenocryst populations in felsic lavas, and to track melt-phenocryst relationships in fractionating magmas.

The first aim was dealt with in a paper by Sharon Allen and Jocelyn McPhie, published in 2003 in the *Journal of Volcanology and Geothermal Research*. The second aim was addressed in Paul Davidson's PhD research. Paul graduated in 2004. His PhD thesis is entitled "A new methodology for the study of the magmatic-hydrothermal transition in felsic magmas: applications to barren and mineralised systems" and used data from melt and fluid inclusions. Part of Paul's data came from inclusions in quartz phenocrysts in rhyolites from the Taupo Volcanic Zone in New Zealand. Paul's thesis addressed the constraints on the exsolution of magmatic vapour and aqueous liquids, as well as the nature and composition of the exsolved phases. He explored the influence of the pressure and temperature conditions of trapping, and the exact cooling path on the exsolution processes and products. His results shed light on the mechanisms involved in the transfer of metals from fractionating arc magmas to hydrothermal systems. Paul presented a paper on this topic at the 17th Australian Geological Convention in Hobart.

Project 2.7 CORE

Experimental simulations and textural analysis of submarine volcanoclastic mass-flow deposits that result from large-scale eruption and failure events

S Allen; A Freundt (GEOMAR), B Hayward (Geomarine Research), K Kurokawa (UNiigata)

Explosive eruptions and mass-failure events on volcanic islands deliver large quantities of volcanic particles to the sea. Deposits from such events are found throughout ancient submarine volcanic successions, including those that host massive sulfide deposits, and yet presently there are no physical constraints linking deposit characteristics with origin. These physical constraints are being studied by Dr Sharon Allen, using both experimental and field-based approaches.

Sharon has completed the experimental phase of the research in collaboration with Dr Armin Freundt at the Experimental Volcanology Laboratory, GEOMAR, Germany. In 2004, she compiled data from video records of experiments involving hot-dry, cold-dry and cold-wet starting materials, and completed grain size and componentry analyses of experimentally produced samples. Field research on submarine volcanoclastic mass-flow deposits in the Miocene Waitemata Group in New Zealand provided the data for a paper published in the *New Zealand Journal of Geology and Geophysics*. Sharon identified the principal down-current facies variations using a series of detailed sections at proximal (<30 km from the source), medial (~40 km) and distal (>60 km) locations. Emma Mathews completed an Honours thesis that contributed to this project in 2003 and presented a summary of the results at the 17th Australian Geological Convention in Hobart. Sharon conducted a facies analysis of

submarine pumiceous mass-flow units in the Miocene Green Tuff Belt, Japan, in collaboration with Dr Katsuki Kurokawa at Niigata University. They have completed detailed logging and sampling of sections through a series of contrasting units that will provide a framework for interpreting the source of the pumice and the transport and depositional mechanisms.

Project 2.8

Plagioclase ultraphyric lavas and caldera-related pyroclastic deposits on Tanna, Vanuatu

S Allen, F Della Pasqua, A Crawford; D Charlie (Vanuatu Geological Survey)

This project was funded by an Internal Research Grant awarded to Tony Crawford, Sharon Allen and Fernando Della Pasqua. The principal aim was to elucidate the links between plagioclase ultraphyric basalts and more evolved pyroclastic deposits in arc volcanoes, using a blend of volcanology (Program 2) and geochemistry (Program 1). The project focussed on the Upper Pleistocene to Recent Siwi Group at the active Yasur volcano, Tanna Island, Vanuatu, and involved mapping and sampling of several coastal sections.

The plagioclase ultraphyric basalts in the Siwi Group are lavas that contain very coarse plagioclase phenocrysts. Fernando Della Pasqua has completed a detailed geochemical and textural study of the lavas and recognised four populations of feldspar: anorthitic plagioclase xenocrysts; coarse, oscillatory zoned, less-calcic, euhedral plagioclase phenocrysts; calcic microphenocrysts; and K-feldspar rims. The presence of abundant coarse, euhedral plagioclase phenocrysts suggests a high volatile content in the magma prior to eruption. These lavas immediately underlie and are intercalated with trachyandesitic pyroclastic deposits (Siwi Group)

associated with formation of a 4-km-wide caldera. Fernando presented a paper on the plagioclase ultraphyric basalts at the 17th Australian Geological Convention in Hobart.

Few examples of trachyandesitic pyroclastic deposits have been described even though they are probably common in arc volcanic successions. Sharon Allen completed a detailed volcanological study of the trachyandesitic pyroclastic deposits of the Siwi Group that was published in the *Bulletin of Volcanology*. The examples in the Siwi Group are unusual in being composed of both non-vesicular spatter and highly vesicular pumice, implying marked variations in the efficiency of volatile exsolution prior to and during eruption. The pyroclastic deposits could result from catastrophic degassing of the high-volatile-content, plagioclase ultraphyric magma represented by underlying lavas. Sharon also summarized her results in a paper presented at the 17th Australian Geological Convention in Hobart.

Project 2.9

Volatile budget, volcanology and source-vent locations of voluminous felsic lavas: Mesoproterozoic Gawler Range Volcanics in South Australia

S Allen, F Della Pasqua, J McPhie, V Kamenetsky, A Harris; M Lackie (Macquarie U); M Schwartz (PIRSA); Honours student Adam Bath

This project builds on the results of a field-based study of the volcanology and facies architecture of the Mesoproterozoic Gawler Range Volcanics in South Australia (Project 2.4). The Gawler Range Volcanics is a continental intraplate volcanic province that includes voluminous (>10² km³) felsic lavas. Information on the location and nature of the source vents for the lavas is critical for calculations of outflow distances and eruption rates, and

for inferences regarding magma rheology. It is also of interest for mineral exploration. This project aims to constrain source locations and palaeoflow paths for one of the widespread lavas. It is funded by a Discovery Grant from the Australian Research Council and is also generously supported by Primary Industries and Resources South Australia.

The Eucarro Rhyolite (>500 km³) was selected for palaeoflow study as its extent and characteristics have been carefully documented in our previous work. Two palaeoflow techniques have been attempted. One technique (petrofabric analysis) involves statistical analysis of the lineations defined by the long axes of elongate phenocrysts (principally plagioclase) on oriented slabs. In general, long axes of elongate phenocrysts are aligned parallel to the local flow direction. Fernando Della Pasqua has carried out petrofabric analyses on samples from throughout the Eucarro Rhyolite. The other technique is anisotropy of magnetic susceptibility (AMS), and involves measurement of the magnetic properties of cores drilled from oriented samples. The AMS measurements were performed by Dr Mark Lackie at Macquarie University.

Results from the AMS analyses confirm that the Eucarro Rhyolite has a well preserved magnetic fabric and AMS foliations for samples along base-to-top transects through the unit match the patterns shown by other felsic lavas. The AMS data suggest that much of the lava followed northerly and easterly directed outflow paths from a source(s) located to the southwest of present outcrops. In addition, in all samples tested to date, directions defined by the long axes of elongate phenocrysts are parallel to the AMS foliations. Preliminary results have been presented at the 17th Australian Geological Convention in Hobart. Further research is underway to define the magnetic mineralogy

producing the AMS fabric and to identify structures and/or facies in the broadly defined source area that might be linked to eruptive centres.

Flood lavas such as the Eucarro Rhyolite involved eruption of exceptionally large volumes (>500 km³) of high-silica magma. Earlier mapping has shown that exotic granitic fragments are locally abundant in the Eucarro Rhyolite. New work by Sharon Allen and Anthony Harris has sought to characterise these granitic fragments, and in doing so ascertain new insights into the magmas that fed the flood lavas. An Internal Research Grant is funding this project.

Geochronological (undertaken via collaboration with ANU) and geochemical results imply that the coarse-grained granitic fragments in the Eucarro Rhyolite are in part co-magmatic, and not xenoliths derived from the crystalline basement. Microanalysis (using Laser Raman at Geoscience Australia) confirms that these granitic fragments once crystallized in a volatile-rich magma possessing high CO₂/CH₄ ratios. Recognition of this characteristic has important implications for the broader degassing history of these silicic magmas and resultant ore deposits. It could be that significant amounts of CH₄ (in addition to CO₂, SO₂, and HF) were degassed during emplacement of the volcanic succession, perhaps influencing the composition of the Mesoproterozoic atmosphere.

A second project involves a detailed examination of melt inclusions in quartz phenocrysts in the Eucarro Rhyolite. The melt inclusions were originally discovered by Vadim Kamenetsky and Nicole Morrow (Honours student 1997) in the course of the previous project on the Gawler Range Volcanics (Project 2.4) (Morrow et al. 2000). Adam Bath has extended this research for his Honours project, guided by Vadim. Adam has documented populations of high-density CO₂

fluid inclusions, glass inclusions and non-silicate melt inclusions. The glass inclusions have high concentrations of F, Cu, Mo, W, U and Pb that may reflect the concentration of these elements within the melt prior to eruption and subsequent degassing. Adam's new data have implications both for the mineral potential of the Gawler Range Volcanics, and the rheology of the magmas that produced the extensive rhyolitic lavas. In particular, high F could have lowered magma viscosity and promoted widespread outflow as lavas.

Other achievements and activities

Sharon Allen is on the Editorial Boards of both the Australian Journal of Earth Sciences and the Journal of Volcanology and Geothermal Research. In 2004, she was appointed Leader of the IAVCEI Commission of Explosive Volcanism.

Jocelyn McPhie is an Associate Editor for the Bulletin of Volcanology and Vice President of the International Association for Volcanology and Chemistry of the Earth's Interior.

Jocelyn McPhie spoke on ABC Radio in October 2004 in relation to growing unrest and eruptions at Mount Saint Helens, Washington, and in December 2004 in relation to the Boxing Day earthquake and tsunami.

Members of the Volcanology Program presented four short courses in 2004.

- The Masters of Economic Geology field-based short course on "Volcanology and mineralization in volcanic terranes" led by Jocelyn McPhie and Bruce Gemmell and run in New Zealand and western Tasmania (14–28 March 2004)
- A short course entitled "Volcanology and VHMS deposits" presented by Jocelyn McPhie and Bruce Gemmell at the University of Asmara in Eritrea. The course was sponsored by Sanu Resources,

Sub-Saharan Resources and Nevsun, three mining companies operating in Eritrea. About 70 participants from mining companies, the University of Asmara and the national geological survey attended the 6-day course (1–6 August 2004).

- Jocelyn McPhie and Wally Herrmann presented a four-day short course "Introduction to volcanology and hydrothermal alteration" to AngloGold Ashanti geologists at the Sunrise Dam Gold Mine in Western Australia (19–22 October 2004).
- The annual "Volcanic successions" short course run by Monash University was presented by Ray Cas, Jocelyn McPhie and Steve Beresford. The five-day course attracted 20 industry and survey participants (6–11 December 2004).

The Volcanology Program team made a major contribution to the 17th Australian Geological Convention held in Hobart in February 2004. Overall, the team presented 17 papers. Sharon Allen convened two technical sessions, one on volcanic hazards and the other on volcanic processes. Jocelyn McPhie led a pre-conference field trip with Keith Corbett, examining the Mount Read Volcanics in western Tasmania. Jocelyn and Peter McGoldrick served as editors of the Abstracts volume

PhD projects in Program 2

Katharine Bull: Character, setting and significance of Early Devonian volcanic successions in the western Lachlan Fold Belt.

Gregory Ebsworth: Internal facies variations and stratigraphy in the Tyndall Group: A key to correlations and tectonic setting of the Cambrian Mount Read Volcanics, western Tasmania.

Carlos Rosa: Character and setting of volcanic successions

that host massive sulfide ore deposits in the Iberian Pyrite Belt, Portugal.

Andrew Stewart: Facies architecture of an arc volcanic island – Milos, Greece. (graduated August 2004)



Program 3

Ores in volcanic arcs

Program 3 concentrates on the volcanic-hosted base-metal and epithermal precious metal ores in volcanic arc settings, emphasising the links between magmatic processes, magmatic hydrothermal fluids and ore formation.

Bronwyn Kimber
battling the elements
on Macquarie Island.

Objective

To determine the relationships between magmatism, volcanism and ore formation in volcanic arc settings, especially on the nature, diversity and genesis of massive sulfide copper-lead-zinc and epithermal gold-silver in modern and ancient, subaerial and subaqueous environments in Australia and the Pacific Rim.

Highlights

1 Delivery of a VHMS-volcanology short course in Eritrea

2 Graduation of two PhD students (Neil Martin, Andrew Wurst) and submission of Master of Exploration Geoscience thesis (Albert Chong)

3 Invited talks by Program 3 researchers at the international meetings; GSA, SEG 2004 and CODES 24 ct Gold workshop

4 Initiation of new research projects at Greens Creek, Alaska (VHMS) and Martabe, Indonesia (high-sulfidation epithermal)

Core Projects

3.1 Magmatic-volcanic evolution and generation of hydrothermal fluids in the backarc environment.

3.3 Active base and precious metal-rich massive sulfide deposition associated with submarine volcanism.

3.5 The nature, diversity and genesis of ancient massive sulfide copper-lead-zinc-silver-gold deposits in volcanic arc settings.

3.8 Subaqueous epithermal mineralisation, Conical Seamount, Tabar-Feni island chain (Papua New Guinea).



Team Leader
Bruce Gemmell

Team Members

Zhaoshan Chang, David Cooke, Garry Davidson, Cari Deyell, Wally Herrmann, Dima Kamenetsky, Khin Zaw, Ross Large, Jocelyn McPhie, James Reid, Michael Roach, Michael Solomon, Noel White

PhD Students

Singoyi Blackwell, Kim Denwer, Russell Fulton, Tim Ireland, Steve Lewis, Claire McMahon, Neil Martin, Andrew Tyson, Andrew Wurst

Collaborators

National: CSIRO E&M, Geoscience Australia, Mineral Resources Tasmania, Australian National University, University of Queensland, University of Western Australia, McArthur Ore Deposit Assessments Pty
International: AMIRA International, GEODE, University of Michigan, Duke University, Colorado School of Mines, Freiberg University, Geological Survey of Canada, University of Auckland, Volcanic Resources, Lulea University, University of Southampton, Institute of Mineralogy, Russia, Instituto Geológico y Minero de España, Geological Survey of Japan, Chinese Academy of Geological Sciences, Instituto Geológico e Mineiro (Portugal), Istanbul Technical University



Project 3.1 CORE
Magmatic-volcanic evolution and generation of hydrothermal fluids in the volcanic arc environment: a geochemical, isotopic and melt inclusion/ fluid inclusion study of volcanic arc lavas, related sub-volcanic intrusions and mineralisation

JB Gemmell, D Kamenetsky, Khin Zaw, M Solomon, R Large; W Sun, V Bennett, R Arculus and S Eggins (ANU); V Maslennikov (Institute of Mineralogy, Russia).

A critical and unresolved factor in VHMS genesis is the source of the ore-forming fluids: are these fluids dominantly magmatic and therefore directly related to magmatic processes in the volcanic arcs, or are they recycled seawater where the metals were derived by leaching of the volcanic rocks? Melt- and fluid-inclusion research has been designed to answer this question.

Dima Kamenetsky participated in several collaborative projects with researchers from Max-Planck-Institut for Geochemistry

Program 3 team: L to R, Mike Solomon, Steve Lewis, Susan Belford, Bruce Gemmell, Tim Ireland, Wally Herrmann, Ross Large, Gary Davidson.

(Weidong Sun), ANU (Vickie Bennett, Richard Arculus) and CSIRO (Ray Binns). His research on the mechanism of Re enrichment in arc magmas: evidence from Lau Basin basaltic glasses and primitive melt inclusions was published in a paper by Sun et al. (2004) in *Earth and Planetary Science Letters*. This paper outlined how rhenium and other trace element data were obtained in situ by LA-ICPMS analysis of submarine-erupted volcanic glasses and olivine-hosted melt inclusions from the Valu Fa Ridge, the south tip of the Lau Basin, in the southwestern Pacific Ocean. The chemistry of the Lau Basin basaltic glasses changes systematically from compositions similar to MORB in the Lau Spreading Centres, to more arc-like compositions in the Valu Fa Ridge, providing geochemical profiles both along the Lau Spreading Centres (ridges) and across the Valu Fa Ridge. The east seamount samples of the Valu Fa Ridge have diagnostic trace element ratios (Ba/Nb, Nb/U, Ce/Pb) close to global arc averages,

with high Ba/La, indicating addition of considerable amounts of subduction-released fluids. In contrast, samples from the west seamount and the Lau Spreading Centres show a smaller influence from subduction fluids. The variable degrees of subduction influences apparent in the chemistry of these suites provide an ideal means to explore the mechanisms of Re enrichment in undegassed arc magmas. All of the analysed arc melts have significantly higher Re concentrations than previously published, largely subaerially erupted samples, confirming that high Re is a characteristic of undegassed arc magmas. The east seamount samples are characterised by higher Re and lower Yb/Re than the more MORB-like Lau Spreading Centre lavas. The lack of correlation between Yb/Re and Fo of host olivine suggests that low Yb/Re is not due to magmatic differentiation. When the Lau Basin sample suite is plotted together with MORB data, Yb/Re is positively correlated with Ce/Pb and Nb/U, and negatively

correlated with Ba/Nb, indicating that Re is much more mobile than Yb during dehydration of subducted slabs. Thus, Re enrichment in arc magmas is likely due to addition of Re via fluids released from subducted slabs; the recognition of high Re in arcs favors arguments for a slab origin of radiogenic $^{187}\text{Os}/^{188}\text{Os}$ components in arc rocks.

Dima Kamenetsky's research on the release of gold-bearing fluids in convergent margin magmas prompted by magnetite crystallisation was published in a paper by Sun et al. (2004) in *Nature*. This paper describes copper-gold systematics in a suite of basalt-andesite-dacite rhyolite glasses and olivine-hosted melt inclusions from the eastern Manus backarc basin. The main objective of this work was to understand why most of the world's copper-gold ore deposits (epithermal/porphyry types) are associated with convergent margin magmas. Although copper and gold might ultimately have been recycled from the subducted slab, the subarc mantle is not particularly enriched in gold and copper, and so far the relationship between copper-gold mineralisation and subduction-derived magmas remains controversial. Many different genetic models have been developed to explain this relationship, building mainly on the fact that subduction zone magmas have a relatively high $f\text{O}_2$. In this work we demonstrate that the concentrations of gold and copper in the magmas decrease abruptly at ~57–58 wt% SiO_2 , and this coincides with the onset of magnetite crystallisation (Fe and Ti depletion in magmas). The proposed explanation of this phenomenon is that the metal depletion results from concurrent sulfur reduction as a result of $f\text{O}_2$ buffering, causing enhanced formation of copper-gold hydrosulfide complexes that become scavenged from crystallising melts into cogenetic magmatic aqueous fluids. This process can be particularly

efficient in oxidised arc magmas with substantial sulfate. This work also infers that subsequent migration and cooling of exsolved aqueous fluids can possibly link copper-gold mineralisation and arc magmatism in the Manus basin, and at convergent margins in general.

Khin Zaw continued research on the ore fluid chemistry of ancient and modern VHMS systems, using PIXE, LRS and microthermometry. Microthermometry and chemistry of ore fluids associated with ancient seafloor system at the Palaeozoic Molodezhnoye, Alexandrinskoye and Yaman-Kasy deposits in Russia is being undertaken in collaboration with Prof. Valeriy Maslennikov of Institute of Mineralogy, Russia. Preliminary fluid inclusion heating/freezing studies of two-phase fluid inclusions in barite from the Molodezhnoye tenantite-barite-hematite deposit indicate homogenisation temperatures of 217–292°C (average 260°C) and salinity of 2.2–6.6 (av. 3.3) NaCl wt% equiv. which is suggestive of dominant seawater (3.5 wt% NaCl) in the mineralized system. This collaborative research will apply PIXE, LRS and IR techniques to understand the nature and source of ore fluids, and mixing and boiling processes during the ore formation.

Project 3.3 CORE

Active base and precious metal-rich massive sulfide deposition associated with submarine volcanism

JB Gemmell, Khin Zaw, D Kamenetsky; T McConaghy and R Binns (CSIRO E&M); S Scott (UToronto), J Peter (GSC)

Manus Basin, Papua New Guinea: The actively forming hydrothermal deposits at the felsic-hosted PACMANUS site in the eastern Manus Basin, Papua New Guinea are considered to be regional-scale modern analogues

of the ancient volcanic-hosted mineral districts such as the Mount Read Volcanics and Mount Windsor Subprovince (Australia) and the Kuroko district (Japan). Bruce Gemmell and Ray Binns (CSIRO Exploration and Mining) completed a laser ablation sulfur isotope investigation of pyrite in the stockwork veins and associated wallrock alteration from drill core samples collected during ODP Leg 193 in order to ascertain the source(s) of sulfur (magmatic vs seawater sulfate) in the PACMANUS hydrothermal system. Eighty five laser ablation sulfur isotope analyses of pyrite from drill holes at the Roman Ruins (Site 1189) and Snowcap (site 1188) have been completed. The $\delta^{34}\text{S}$ values range from -1.0 to +16.3‰, with an average of +4.8‰. These values are consistent with sulfur isotope values obtained from sulfide-sulfate chimney and hydrothermally altered dacite collected at the seafloor at these sites. Preliminary interpretations indicate that there is a complex interaction between hydrothermal fluid, magmatic fluid and seawater at these sites. A manuscript reporting the results of this investigation is in preparation

Okinawa Trough, Japan: Collaborative research on modern seafloor systems focussing on the JADE hydrothermal field, Okinawa Trough, has been undertaken by Khin Zaw, in collaboration with researchers from the Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing and the Geological Survey of Japan, to understand the importance of magmatic input of ore fluids and metals. The Okinawa trough is an active, back-arc-spreading basin in which hydrothermal fluids are venting from black and white smoker chimneys along a felsic volcanic ridge. The Okinawa seafloor hydrothermal precipitates are comparable to Kuroko-type massive sulfide deposits in many respects. Both systems occur in back-arc settings and are hosted by a

suite of bimodal volcanic rocks. The following features in the JADE field support a magmatic component within this system: (1) the presence of a shallow-level felsic magma chamber 1–2 km beneath the seafloor; (2) anomalously high heat flow within the hydrothermal field; (3) a high content of CO₂ and CH₄ in the hydrothermal plume; (4) effervescence of volatile species (e.g., CO₂, CH₄, H₂, N₂) in the hydrothermal fluid that form independent discharges as CO₂-rich fluid through CO₂ hydrate pipes near black smoker chimneys; (5) helium isotope data demonstrate that these gases were derived from a mantle source; (6) high temperatures and moderate to high fluid-inclusion salinities; (7) oxygen isotopic compositions of altered rocks and quartz that indicate mineralising fluids have a δ¹⁸O composition consistent with a mixture of magmatic fluid and seawater. The outcomes of this research will appear in a paper by Zengqian et al. which has been accepted and will appear in April 2005 issue of *International Geology Reviews*.

Middle Valley, Juan de Fuca Ridge, Canada: Collaborative research on nature and chemical composition of Middle Valley ore fluids between researchers from Geological Survey of Canada (Jan Peter) and CODES (Khin Zaw, Ross Large and Bruce Gemmell) has continued to produce results. Preliminary LRS and PIXE analyses of the Middle Valley fluid inclusions indicate mixing of two fluids in the mineralised zone. The fluid inclusions yielded two types: (1) tabular-shaped inclusions with significant H₂S and CH₄ and enriched in calcium, lead and zinc, and (2) circular to rounded inclusions with CO₂, potassium and copper with lesser lead and zinc. These two types are found together in host mineral quartz suggesting a mixing of copper-rich (end-member magmatic origin?) fluids with zinc-rich (end-member seawater leached origin) fluids. A paper detailing the results of this research is

being prepared for submission to an international journal.

Project 3.5 CORE

The nature, diversity and genesis of ancient massive sulfide copper-lead-zinc-silver-gold deposits in volcanic arc settings

JB Gemmell, R Large, M Solomon, Khin Zaw, J McPhie, S Bull; PhD students M Agnew, K Denwer, R Fulton, N Martin, MSc student A. Chong; T Monecke (FreibergU & GSC), H Zhengqian (Chinese Academy of Geological Sciences, Beijing), G Lianxing, N Pie (NanjingU), V Maslennikov (Institute of Mineralogy, Miass, Russia), C Inverno (Instituto Geológico e Mineiro, Lisbon), F Tornos, C Quesada (Instituto Geológico y Minero de España, Salamanca), O Gaspar (Consultant, Porto)

There are many styles of ancient VHMS deposits. These include mounds, pipes, sheets, layered, stacked, stockwork, disseminated, distal re-worked and cyclic layered deposits. Our research suggests that a spectrum of massive sulfide deposit types develop in submarine volcanic environments. These types range from typical seafloor VHMS (zinc-lead-copper-silver-gold) deposits, through sub-seafloor shallow-water, replacement gold-rich epithermal styles, to deep sub-volcanic intrusion-related copper-gold-rich styles. To improve our understanding of the formation of VHMS deposits, a variety of ancient and modern deposits has been selected for detailed studies. These studies concentrate on the geological and geochemical attributes of the deposits, and aim to characterise the spectrum of VHMS deposits and their origins in submarine volcanic environments.

One of the highlights of the year was the invitation extended to Bruce Gemmell and Ross Large to give an invited talk on "Alteration and

lithogeochemical footprints of Australian VHMS and SEDEX deposits" at the Society of Economic Geologists meeting SEG 2004 "Predictive Mineral Discovery Under Cover" in Perth. Alteration and lithogeochemical research on volcanic-hosted massive sulfide (VHMS) and sediment-hosted (SEDEX) base-metal deposits in Australia has revealed the presence of complex and extensive halos (footprints) that depend on volcanic/sedimentary characteristics, fluid chemistry, metal content of the ores and longevity of the mineralising system. These models are also useful for discriminating between false or barren and fertile footprints. Stratiform sediment-hosted zinc-lead-silver deposits have very subtle, but far more extensive alteration/lithogeochemical footprints compared to VHMS deposits. In simple terms, the size of the alteration footprint is commonly related to the size of the ore deposit and its accumulated metal content. This research has resulted in the development of specific alteration/lithogeochemical halo models and associated vectors to guide explorer stoward ore-grade mineralisation in prospective VHMS and SEDEX environments. This talk summarised the important conclusions reached over the last decade from CODES research on VHMS and sediment-hosted base-metal deposits.

Mike Solomon, along with Ross Large and Khin Zaw, published a paper in *Ore Geology Reviews* (Solomon et al., 2004) describing the criteria for distinguishing brine pool-type from black smoker-type sulfide deposition in zinc-lead-copper volcanic-hosted massive sulfide deposits. Eight zinc-lead-copper massive sulfide deposits that appear to have formed on the sea floor (seven in Spain, one in Tasmania) are believed to have precipitated in brine pools, based on the salinities and temperatures of fluid inclusions in underlying stockworks. Comparing the

geological features of these deposits with those of the zinc-lead-copper massive sulfide ores of the Hokuroku Basin, Japan, which have formed as mounds from buoyant fluids of low salinity, shows that brine pool deposits have: (1) potentially very large size and tonnage, and high aspect ratio, (2) higher Zn/Cu and Fe/Cu values, (3) no evidence of chimneys, (4) relatively abundant framboidal pyrite and primary mineral banding, (5) reduced mineral assemblages (pyrite-arsenopyrite/pyrrhotite), and minor or rare barite in the massive sulfide, (6) associated stratiform and/or vein carbonates, (7) relatively unimportant zone refining, (8) lack of vertical variation in sphalerite and sulfur isotopic compositions, and (9) evidence of local bacterial sulfate reduction. Application of these criteria to the Rosebery deposit in Tasmania, for which there are no fluid inclusion data, leads to the conclusion that the southern section was deposited as separate lenses in a brine-filled basin or basins. Other potential candidates include Brunswick no. 12 and Heath Steele (Canada), Woodlawn and Captains Flat (New South Wales), Hercules and Que River (Tasmania), and Tharsis and the orebodies at Aljustrel (Spain and Portugal). Recently published fluid inclusion data for Gacun (China) and Mount Chalmers (Queensland) suggest that not all ores deposited from highly saline fluids have reduced mineral assemblages.

During 2004, research was undertaken on the following VHMS deposits: Rosebery, Mount Lyell (Tasmania), Waterloo, (Queensland), Lewis Ponds (NSW), Greens Creek (Alaska), and Feitais (Aljustrel, Portugal), Neves Corvo (Portugal), Tharsis (Iberian Pyrite Belt, Spain). Brief reports on the individual sub-projects within this overall study of VHMS and related deposits are given below.

Australia

Neil Martin completed his PhD study on the genesis of the

Rosebery deposit, Tasmania and graduated in December 2004. Neil demonstrated that the stratiform copper-lead-zinc K lens at Rosebery formed by sub-seafloor replacement.

Initial primary sphalerite-galena-rich mineralisation formed under relatively low-temperature (~200-250°C) and near neutral conditions, as a hot hydrothermal fluid mixed with cooler seawater and reacted with host sediments through which it passed. This mineralisation was characterized by primitive sulfide textures, including spongiform, atoll, colloform and skeletal morphologies. Utilising the laser ablation ICPMS analytical technique, this phase of mineralisation was found to be characterized by a low temperature trace element signature within the sulfide minerals that includes: elevated levels of manganese-nickel-arsenic-silver-antimony-gold-titanium-lead and low levels of cobalt-bismuth in pyrite; low Co/Ni and Bi/Pb ratio values in pyrite; low levels of copper-iron and elevated levels of zinc-silver-antimony-lead in sphalerite; and low levels of antimony-silver in galena. The low temperature sulfide and barite mineralisation locally preserved and albitised volcaniclastic plagioclase component. The low temperature sphalerite-galena mineralisation was locally overprinted by and interspersed with mineralisation formed at higher temperatures, as hot hydrothermal fluids passed through permeable horizons within the ore and adjacent sediments. This phase of mineralisation produced more coarsely crystalline pyrite textures, including anhedral to euhedral grains, aggregates and overgrowths on earlier sulfide phases. This phase of mineralisation was also characterized by a high temperature trace element signature within sulfide minerals that included: elevated levels of bismuth-tin, moderate levels of nickel-silver-antimony-

Quartz vein cutting intrusive clast in accretionary lapilli bearing phreatomagmatic breccia, Martabe high sulfidation gold deposit, Indonesia.



Purnama Prospect, Martabe high sulfidation gold deposit, Indonesia.



titanium-lead-cobalt, and low levels of manganese-arsenic-gold in pyrite; elevated Bi/Pb ratio values and moderate Co/Ni ratio values in pyrite; an increased iron content in sphalerite; and galena with elevated levels of antimony-silver. The lateral flow of high temperature (~300°C) hydrothermal fluid within the immediate footwall to sphalerite-galena ore produced discontinuous disseminated to massive pyrite-chalcopyrite mineralisation and chlorite alteration. The footwall mineralisation was characterised by euhedral pyrite morphologies, and a high-temperature sulfide-mineral trace-element signature comprising elevated cobalt-bismuth in pyrite; elevated Co/Ni and Bi/Pb ratio values in pyrite; and high levels of iron-manganese-copper-antimony-bismuth in sphalerite.

In a collaboration between CODES researchers Ross Large, Bruce Gemmell and Michael Blake, and Garry McArthur and Steve Richardson from McArthur Ore Deposit Assessments (MODA, Tasmania), a three-dimensional alteration model was developed for the entire Hellyer mineralised system. Shells of footwall and hanging wall alteration zones have been mapped out which enable an improved understanding of the morphology, composition and three-dimensional extent of the alteration system. The resultant model will be invaluable for exploration companies searching for further Hellyer-type VHMS deposits at greater depth in the Mount Read Volcanics. An abstract outlining the results of this study was presented at the Geological Society of Australia meeting in Hobart (February 2004).

A manuscript on the Hellyer VHMS deposit by Mike Solomon, with contributions from Bruce Gemmell and Khin Zaw, was published in *Ore Geology Reviews* in 2004. This paper reconstructs the geology at depth below the deposit, and the



Participants in the short course at the University of Asmara.

Eritrean short course

Bruce Gemmell and Jocelyn McPhie presented a short course in Eritrea from 31 July to 6 August. They were invited by Sanu Resources to give the six-day short course, which comprised four days of lectures and two days in the field, and covered physical volcanology and VHMS alteration and mineralisation. The short course was held at the University of Asmara, with up to 75 participants from the Eritrean Department of Mines, the University of Asmara, and three mining companies in the region: Sanu Resources Ltd, Sub-Sahara Resources and Nevsun Limited.

Eritrea is a northern African country bordered by Ethiopia, Sudan, Djibouti and the Red Sea. The capital, Asmara, a city of approximately 400,000 people, sits atop the Eritrean highlands at 2350 m. Jocelyn and Bruce visited in the middle of the wet season; the weather was cool and rainy - not quite what one would expect in sub-Saharan Africa.

The two days of field trips took the group to two base-metal prospects being explored by Sub-Saharan Resources: Debarwa south of Asmara and Adi Nefas to the north. Both of these prospects are hosted by deformed and metamorphosed Neoproterozoic formations of the Arabian-Nubian shield. The mineralisation at Debarwa occurs in steeply dipping, mafic and felsic volcanic successions and is marked by outcropping gossan and barite. At Adi Nefas, the volcanic succession is dominated by mafic volcaniclastic rocks intruded by rhyolitic dykes. The town of Adi Nefas is partly built on a gossan.

This short course drew unreserved positive feedback. The Eritrean geologists are very competent but they have very little experience or formal training in VHMS geology.

There are enormous opportunities for further research and mineral exploration in Eritrea. It is under-explored territory, especially the Neoproterozoic basement rocks, and offers significant potential for success in mineral exploration.

Bruce and Jocelyn extend their thanks to their principal hosts, Demetrius Pohl and Estephanos Ogbazghi, both from Sanu Resources, and Mengist Teklay, from the University of Asmara.

nature and source of the fluids and likely flowpaths involved in mineralisation. The paper postulates a dioritic pluton, at a depth of at least 3 km, which released fluid intermittently through an active fault system. The mineralisation and alteration at Hellyer resulted from the mixing of the magmatic fluid with convecting modified seawater.

Kim Denwer continued his PhD project research at Mount Lyell into how the giant Mount Lyell copper-gold ore body formed. Several months of fieldwork was followed by detailed SWIR (PIMA) analyses of alteration and a re-interpretation of the lead isotope systematics of the Mt Lyell ore signature.

Michael Agnew, who was awarded his PhD in 2003, published a paper in the Australian Journal of Earth Sciences (Agnew et al., 2004) on the facies architecture of the Lewis Ponds carbonate and volcanic-hosted massive sulfide deposits, central western New South Wales. Two stratabound massive sulfide zones, Main and Toms, occur in a tightly folded Upper Silurian succession of marine felsic volcanic and sedimentary rocks. Siltstone, mudstone and quartz crystal-rich sandstone overlie thick, tabular beds of poorly sorted mixed-provenance breccia, limestone-clast breccia and pebbly granular sandstone. The Lewis Ponds host sequence records a transition from coarse-grained polymictic volcanoclastic breccia and sandstone, upwards into mudstone, siltstone and minor volcanogenic sandstone, indicating deposition in a deepening, more restricted environment as volcanism waned and the basin progressively subsided. Another manuscript entitled "Lewis Ponds, a hybrid carbonate and volcanic-hosted polymetallic massive sulfide deposit, New South Wales, Australia" will be published in Mineralium Deposita in early 2005. In this paper, Agnew et al. utilise textural, composition and

isotopic studies to propose that low temperature dolomitisation of limestone-bearing facies in the main zone host sequence created secondary porosity and provided a reactive host rock for fluid-rock interactions. The main zone ore body was interpreted to form by lateral fluid flow and sub-seafloor replacement of the poorly sorted breccia and sandstone beds. Base-metal sulfide disposition probably resulted from dissolution of dolomite, fluid mixing and increased fluid pH. In contrast the Toms zone ore body was emplaced on the sea floor above a zone of focused up-flowing hydrothermal fluids.

Garry Davidson and Ross Large obtained ARC-Linkage funding in 2004, jointly supported by Jabiru Metals, for a new PhD study investigating the genetic and chemical characterisation of the pristine Archean Jaguar base-metal deposit (WA), with the aim of improving local and global prospectivity. Susan Belford will begin her PhD research in 2005.

International

Albert Chong completed his Master of Exploration Geoscience at Myra Falls (British Columbia, Canada). His study focused on the geology, mineralisation, hydrothermal alteration, metal zonation and genesis of the Jurassic Ridge Zone West orebody. The Ridge Zone West is a zinc-lead-copper-gold-silver-barium-rich VHMS deposit composed of stacked lenses of disseminated to massive mineralisation associated with fine and coarse-grained volcanosedimentary rocks. Four phases of mineralisation are identified in the Ridge Zone West deposit: (1) Lower lens mineralisation formed on the palaeo-seafloor with fine-grained facies sediments during a period of quiescence and consist of disseminated and banded mineralisation with pyrite framboids; (2) Main lens mineralisation is the most economically significant mineralisation observed, consists of sphalerite, pyrite, chalcopyrite,

galena, tetrahedrite-tennantite, and barite, and is formed by infiltration and replacement of dominantly permeable, coarse volcanoclastic deposits in a shallow sub-seafloor environment. Sulfide textures include anastomosing veins progressing up to massive sulfide with relic lithic clasts; (3) Upper lens mineralisation deposited on the paleo-seafloor during a secondary period of quiescence is composed of sulfide bands with graded grains and soft-sediment deformation textures, and (4) Upper lens mineralisation comprising late pyrite-chalcopyrite \pm sphalerite veins crosscutting siliceous mudstone breccias. Albert's geologic and genetic model will be an important aid to exploration in the Myra Falls district.

Based on research from her PhD thesis, Sarah Jones had a paper, (Jones, Herrmann and Gemmell) on the shortwave infrared spectral characteristics of the HW horizon and their implications for exploration in the Myra Falls volcanic-hosted massive sulfide camp, Vancouver Island, B.C. Canada, accepted for publication by Economic Geology. This study showed that SWIR analysis is an effective field-based exploration tool for quantifying the intensity of alteration associated with VHMS orebodies, and that trends in mineral compositions, even in very fine-grained rocks, can be used as mine-scale vectors to ore. A second paper from her thesis (Jones, Gemmell and Davidson) on the origin of the caprocks above VHMS deposits using evidence from petrology and fluid inclusions at the Myra falls VHMS camp, was submitted to Economic Geology for review.

Russell Fulton continued his PhD research on the geology and geochemistry of the hanging wall argillite, and its implications for ore genesis and exploration at the Greens Creek zinc-lead-silver-gold deposit on Admiralty Island in southeastern Alaska. Work undertaken in the previous

twelve months included whole rock chemistry, whole rock stable isotope chemistry, mineral chemistry, petrographic studies, data analysis and another field season in Alaska. Russell presented a poster on the mineral vectors in the hanging wall argillite, Greens Creek VHMS deposit, Alaska, at the SEG 2004 conference in Perth.

A new industry-funded (Kennecott Greens Creek Mining) PhD study of the footwall stratigraphy at the Greens Creek deposit was approved in 2004. This study will characterise the geologic and structural setting of the footwall phyllite and associated footwall lithologies with the aims of determine the depositional environment and architecture of the footwall phyllite and its relationship to massive sulfide formation.

Mike Solomon, in conjunction with Carlos Inverno (Instituto Geológico e Mineiro, Lisbon), Fernando Tornos (Instituto Geológico y Minero de España, Salamanca), Orlando Gaspar (Consultant, Porto), and the senior mine geologists of Somincor

Ltd at Neves Corvo, is studying the genesis of massive sulfide deposits in the IPB of Spain and Portugal. The genetic studies at Feitais in the Aljustrel field (Inverno, Solomon, and Barton) are complete and are being prepared for publication. The main remaining problems concern the origin of the sulfur, apparently of biogenic origin, and the reasons for the wide range of fluid inclusion salinities. At Tharsis, analytical data on the shales that host the ore lenses (Tornos, Conde, Solomon, and Spiro) have expanded and confirmed the brine pool interpretation of previous papers, and were presented at the SGA conference in Athens. The lack of fluid inclusion data for this deposit has hampered genetic interpretations

Mike Solomon has continued his collaborative at Neves Corvo. One project is investigating the formation of the Lombador and Neves Norte ore lenses, Neves Corvo, in collaboration with Carlos Inverno (Instituto Geológico e Mineiro) and Alfredo Ferreira, Paulo Caetano, and Nelson Pacheco (Somincor Ltd). Samples collected in October 2003 have been studied for

mineral compositions, textures, and sulfur isotope variation. Most of the Lombador samples have only undergone mild deformation, and show sedimentary or clastic textures, with sulfide and ore fragments of varying size occurring in a shale matrix. It is clear that massive sulfide ore has been eroded and resedimented. Neves Norte samples are invariably recrystallised and of very fine grain size, inhibiting textural studies. Sulfur isotope ratios range from 3 to -7 ‰ in both ore bodies, slightly extending the range previously determined by ourselves and others on the remaining ore bodies

A second project with Anthony Harris (CODES), Rinaldo Saez and Manuel Toscano (University of Huelva) and Chris Ryan (CSIRO) is studying PIXE analysis of inclusions from Hellyer and Aznalcóllar/Los Frailes VHMS deposits. A number of Hellyer and Los Frailes stockwork samples have been studied, identifying a few inclusions of possibly suitable size and depth for analysis. Determination of paragenesis in Los Frailes material is virtually impossible, due to the effects of deformation.



Fracture-controlled and selective epidote alteration, Batu Hijau porphyry copper gold deposit, Indonesia



Batu Hijau porphyry copper gold deposit, Indonesia

Project 3.6

Studies of VHMS-related alteration: development of geochemical and mineralogical vectors to mineralisation (ARC Linkage/AMIRA P439)

JB Gemmell, C Gifkins, W Herrmann, R Large, T Monecke (FreibergU-Geological Survey of Canada)

A paper outlining Thomas Monecke's (PhD 2003) investigation of how volcanic facies architecture of the host succession helped to unravel the temporal and spatial relationships between volcanism and massive sulfide formation at the Waterloo VHMS prospect in the Mount Windsor Subprovince, Queensland (Monecke, Gemmell and Herzig) has been accepted by Economic Geology. Thomas also wrote a paper proposing a dynamic model for the metasomatic enrichment of base and precious metals in VHMS deposits (Monecke et al.) that has been accepted by Earth and Planetary Science Letters.

In late 2004 the eagerly anticipated book "Altered Volcanic Rocks" authored by Cathryn Gifkins, Wally Herrmann and Ross Large was completed. This book was an outgrowth of years of several ARC and AMIRA funded research projects by CODES working with altered volcanic rocks, including incorporation results from AMIRA project P439 (see Project 2.1). The book is a practical guide for systematically describing and interpreting altered volcanic rocks, and determining their significance in terms of mineral deposit prospectivity. It discusses the processes and products of the common alteration styles in submarine volcanic settings, including diagenetic alteration, burial metamorphism, hydrothermal alteration and mineralisation, and intrusion-related alteration. It takes a multi-disciplinary approach combining alteration mineralogy, textures and intensity with litho geochemistry to constrain

the characteristics of different alteration styles. In addition, it provides a descriptive method for alteration facies nomenclature. It presents examples of the mineralogical, textural and compositional features of alteration facies and zones from ancient submarine volcanic successions in Australia, Canada, Japan and Iberia. To emphasize the ore deposit context, the book includes a major chapter that uses innovative illustrated data sheets to describe the main alteration facies or zones associated with a variety of volcanic-hosted massive sulfide (VHMS) deposits in the famous Cambrian Mount Read Volcanics in Tasmania and Cambro-Ordovician Mount Windsor Subprovince in Queensland. The final chapter describes and presents examples of how altered rocks and their characteristics may be applied to exploration for volcanic-hosted deposits. The book contains 275 pages with 127 figures and 66 full-page alteration data sheets, which include 274 colour photographs that illustrate the textural and mineralogical characteristics of different alteration intensities, facies and styles. The text is richly referenced throughout to provide basic source materials for students, academics and field geologists who may wish to delve further into the irresistible mysteries of altered volcanic rocks.

Project 3.7

Sulfur geochemistry of hydrothermally altered volcanic terrains

GJ Davidson, M Roach, R Berry, PhD student S Lewis; A Wakefield and B Kimber; J Alt (U Michigan); J Karson (Duke U); C Finn (USGS); A Brown (MRT, Tasmania), D. Teagle and PhD student R Coggan (USouthampton).

This research is predominantly focussed on Macquarie Island oceanic crust (~10 Ma old).

To recap, the program is using a variety of sulfur extraction tools to evaluate the sulfur isotope signal in low S altered rocks. There is a record of sulfur deposition and exchange in these rocks, which provides information on sulfur cycling at the edge of ore systems. We are attempting to integrate this information with the general hydrothermal history of terrains, and so some of our efforts are engaged in basic delineation of hydrothermal fluid flow patterns and hydrothermal conditions. This is the case for the Macquarie Island case study. The only fieldwork in 2004 was a major labour intensive magnetic mapping of the island, involving ~2500 line km of data acquisition by Bronwyn Kimber and Andy Wakefield, our sturdy volunteers, to whom we are greatly indebted. The work was optimised by the 2003 magnetic study of a smaller area by Kate Godber (UTas). Supported by ASAC grant 2409, our volunteers wintered on the island to obtain the data, because some critical areas are off-limits in the warmer months due to Sub-Antarctic wildlife breeding. This factor eliminated the possibility of detailed heli-mag surveys over the landmass. In 2005, the magnetic map will be compiled and released at the same time as submission of a paper for publication. The mapping delineated patterns of magnetic depletion due to hydrothermal activity, and enrichment due to serpentinisation, and so will be very valuable for mapping fossil fluid flow.

In other ongoing Macquarie Island work, PhD student Steven Lewis undertook alteration geochemistry, mineral chemistry, oxygen and sulfur isotope geochemistry, and geological compilation. Steve's study is determining the processes and history of a major hydrothermally altered NW fault zone (originally identified by J. Karson). The work is planned to complete in mid-2005. Steve presented his results at two international conferences

during 2004. Collaborative research on O and Sr profiles of the oceanic crust continued with the Michigan and UK groups, with further studies now including samples from Steven Lewis. Academic output on the Macquarie Island work was one paper in *Terra Nova* (Davidson et al., 2004) and seven conference abstracts.

Project 3.8 CORE
Subaqueous epithermal mineralisation, Conical Seamount, Tabar-Feni island chain, Papua New Guinea

JB Gemmell, R Sharpe; P Herzig (FreibergU); I Jonasson, M Hannington (GSC)

Bruce Gemmell and Robina Sharpe, in collaboration with Ian Jonasson and Peter Herzig published a paper in *Economic Geology* on sulfur isotope evidence for magmatic contribution to subaqueous and subaerial epithermal mineralisation: Conical Seamount and Ladolam gold deposit, Papua New Guinea. Conical seamount is a submarine alkali basalt volcano situated 10 km south of Lihir Island in the Tabar-Feni island chain, Papua New Guinea. Polymetallic (zinc-lead-silver-gold-arsenic-antimony) veins, pyritic stockwork, and hydrothermally altered rocks discovered on the summit of Conical seamount represent a unique example of submarine gold mineralisation with mineralogical, chemical, and textural characteristics common to some subaerial epithermal systems. The giant Ladolam epithermal gold deposit (42 Moz Au) is situated in the crater of an alkali stratovolcano on Lihir Island. Portions of the epithermal mineralisation and alteration assemblages at Ladolam are similar to those observed on Conical seamount. Conical seamount has the lightest, hydrothermal (i.e. non-diagenetic) sulfide $\delta^{34}\text{S}$ values, -17.5 to

6.1% , measured to date from modern sea-floor hydrothermal systems. Sulfides from the Ladolam gold deposit have a range of sulfur isotope values (-12.9 to 3.6%) similar to that of Conical seamount. Sulfur isotope data from Conical seamount and the Ladolam deposit suggest that magmatic volatiles have contributed a significant amount of sulfur to both these gold-rich hydrothermal systems.

Project 3.9
Epithermal gold-silver deposits: geological, geochemical and isotopic vectors to target major deposits (ARC Linkage/AMIRA P588)

JB Gemmell, R Sharpe, W Herrmann, R Scott, M Blake, J McPhie; S Simmons (UAuckland); PhD student A Wurst; MSc students D Olberg, B Young, G Cater; Honours student J Booth

Andrew Wurst completed his PhD research into the Permata-Batu Badingding-Hulubai (PBH) and Kerikil low-sulfidation gold-silver epithermal deposits at Mount Muro in central Kalimantan, Indonesia and graduated in December 2004. Andrew's thesis was one of the case studies of the ARC-AMIRA P588 project. PBH is a sericite/illite-adularia-quartz, silver-gold low-sulfidation epithermal vein deposit, examples of which are common to southwest USA and Mexico. The distribution and zonation of alteration, mineral textures, mineral composition and metals within the mineralised structures are a direct result of the mechanical and physicochemical processes of depressurisation through structure dilation and consequent boiling, cooling and mixing. Kerikil is an illite/sericite-gold-silver quartz-carbonate low-sulfidation epithermal breccia and stockwork deposit, examples of which are common in the SW Pacific and Indonesian archipelago. Study of the volcanological,

structural, mineralogical, metallogenic, alteration and isotopic characteristics of the PBH and Kerikil deposits have led to geological and geochemical vectors being established to aid mineral exploration at Mt Muro.

The results of the ARC Linkage/AMIRA P588 research project are to be included in a proposed special issue of *Economic Geology* tentatively titled "Setting, geochemistry and exploration significance of alteration associated with epithermal gold-silver deposits". It is anticipated that this issue will contain 12-14 papers (P588 research plus invited contributions) on epithermal deposits and districts from New Zealand, Indonesia, Philippines, Argentina and Australia, with Bruce Gemmell and Stuart Simmons as guest editors. Papers will be written and reviewed in 2005.

Project 3.10
Global comparison of volcanic-hosted massive sulfide districts (IGCP Project 502)

R Large, JB Gemmell, G Davidson; D Blundell (GEODE, Royal Holloway); R Allen (LuleaU, Volcanic Resources); F Tornos (ITGE); R Herrington (NHM, UK); V Maslennikov (RAS); P Weihed (LuleaU); P Herzig (FreibergU); S McCutcheon (DNRE Bathurst); H Gibson (LaurentianU); N Çagatay (Istanbul Technical University)

This project, led by R. Allen, F. Tornos, J. Peter and N. Çagatay, aims to compare a number of the world's important VHMS districts in order to define the key geological events that control the distribution and timing of high-value VHMS deposits; and thereby develop new criteria for locating these ore deposits. Present knowledge suggests that VHMS deposits form at specific times (in specific stratigraphic intervals) in marine, volcanically active, extensional basins. We propose that the key global issue

to be addressed is to document the connection between VHMS ore formation, magmatism and extensional tectonics. In this IGCP project we will focus on the following critical steps: (1) define the main different styles of VHMS ore deposit, (2) define the character and stratigraphic position of the ore horizons that host these VHMS deposits in about ten VHMS districts, (3) assess how far these horizons can be followed and in what way they change with distance from ore, (4) where possible, define the volcanic, tectonic or volcano-tectonic structure(s) that appear to localise VHMS deposits, (5) assess whether the VHMS horizons in each district are part of one or two specific basin-wide favourable stratigraphic intervals, (6) interpret the significance of these favourable stratigraphic intervals in terms of basin evolution, and (7) test the results and hypotheses on the other less well known VHMS districts.

This project is an integrated multi-disciplinary project with field and laboratory components. The work includes syntheses and new studies of volcanic architecture, regional tectonic evolution, regional magmatic evolution, radiometric dating of ore horizons, and studies of the various different styles of VHMS deposits. A network of

over 50 of the world's leading scientists (from 22 nations) in disciplines relevant to understanding VHMS deposits has been set up. The IGCP affiliation will enable expansion of this network and provide a platform for research funding applications. Via collaboration we will cross-fertilise the skills from one district/research group to the others and increase the knowledge and expertise in as many VHMS districts as possible to a level where detailed comparisons can be made across several disciplines using the same criteria in each district.

In 2004 there was a field workshop to the East Pontides mineral belt of Turkey, and in 2005 there will be a field workshop in the Bathurst mining camp, New Brunswick, Canada, held in conjunction with the GAC-MAC annual meeting in Halifax. Ross Large has been invited to make a keynote presentation on CODES research on VHMS deposits at the Halifax meeting.

Project 3.11
Epithermal deposits of the Pacific Rim

JB Gemmell, D Cooke, C Deyell; PhD student A Wurst; Master of Exploration Geoscience student B Sutopo

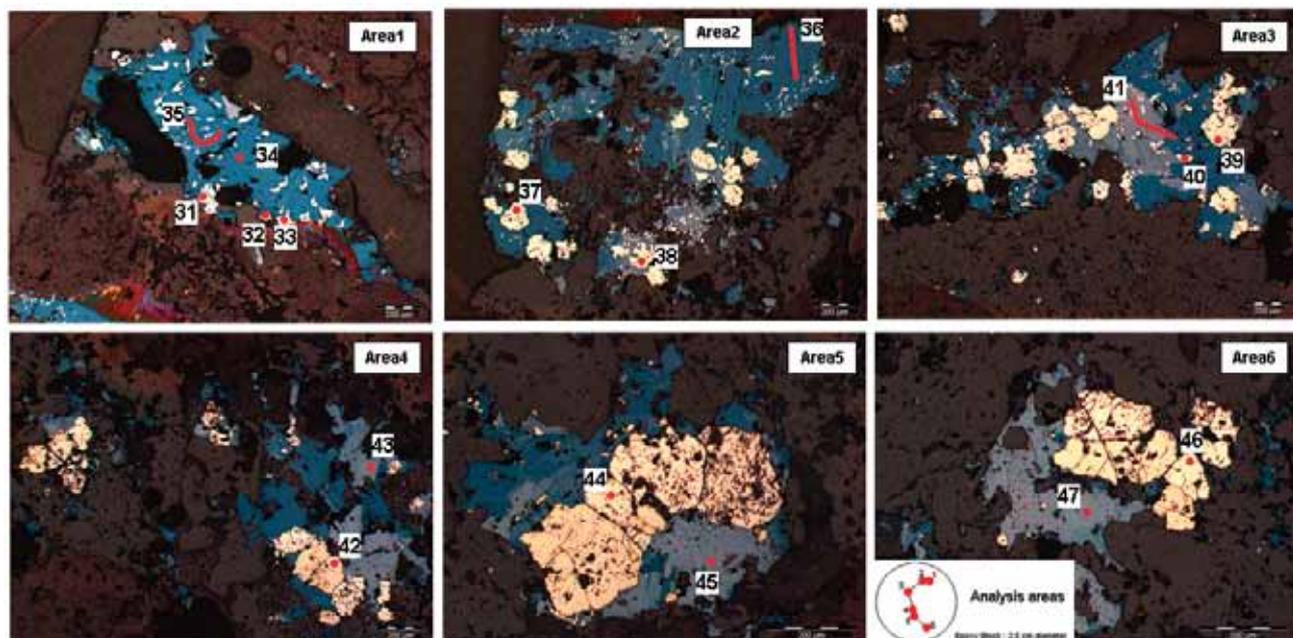
LA-ICPMS analysis spots on pyrite and copper sulfides, Yanacocha ore, northern Peru (Project 3.13).

The geology and genesis of epithermal deposits are being investigated at a number of locations in the southwest Pacific. Research has concentrated on determining the geological and geochemical constraints on the formation of epithermal deposits, which will lead to improved genetic and exploration models. This is a collaborative project between Programs 3 and 5. Refer to project 5.5 for additional information.

For details of Andrew Wurst's Phd research see project 3.9.

In 2004 a new Master of Exploration Geoscience student, Bronto Sutopo, initiated his thesis research at the Martabe high-sulfidation copper-gold deposit, Sumatra, Indonesia. Bronto's thesis will entail a comparative mineralogy, mineral chemistry and metal zonation study of the various ore bodies in the Martabe district.

Bruce Gemmell was invited to give a paper on low- and intermediate-sulfidation epithermal deposits at the CODES "24 Carat Gold" workshop. Low- and intermediate-sulfidation epithermal deposits have produced significant quantities of gold and silver, along with minor amounts of base metals, and continue to be a major target for precious metal explorers. As well



as research on ancient deposits, investigations of the modern analogs, active geothermal systems, have led to many new concepts in the understanding of epithermal deposits which aid in the development of genetic and exploration models.

Project 3.12

Stable and radiogenic isotope applications to ranking prospects in volcanic terrains (ARC Linkage)

G Davidson, W Herrmann, M Solomon, R. Large (UTas) Hons students K Bassano, N Williams, S Herrmann, A Woolford; M Barton (UArizona); D Green, G Green (MRT)

This ARC Linkage project, which finished in 2003, evaluated subtle isotope vectors around ore deposits in volcanic terrains. Results of the project have emerged from confidentiality and one paper was published on submarine advanced argillic alteration at the Basin Lake Prospect, western Tasmania, in *Economic Geology* (Williams and Davidson, 2004), and one abstract was presented.

Project 3.13

Trace element analysis of sulfides by LA-ICPMS: new applications for exploration vector geochemistry (ARC Linkage)

G Davidson, A Rae, R Large, S Guilbert, PhD students C McMahon, S Lewis and S Blackwell; M Norman (RSES, ANU)

This project commenced as an ARC-Linkage grant in 2003, now supported by Newmont Mining, BHP-Billiton, Anglo American, AngloGold Ashanti, Placer Mining and Newcrest Mining. The project includes the first year of a APAI-supported PhD project, (Claire McMahon) in late December. The Linkage component of the project aims to test hypotheses

of the source of metals in sulfides in the distal haloes of ore alteration systems. This is mainly being undertaken through radiogenic isotope analysis at RSES with Marc Norman. The industry component is aimed at characterising pyrite-based trace-element haloes around a wide variety of ore types. Singoyi Blackwell (PhD student) is also evaluating magnetite compositional variations at the Cannington BHT lead-zinc-silver deposit. Study sites

investigated in 2004 included (1) high sulfidation epithermal mineralisation from Yanacocha (A Rae); (2) a reconnaissance study of porphyry copper-gold alteration at Batu Hijau and infill samples from Cadia Far East (C McMahon, A Rae); (3) a major study of the Calinan-777 VHMS system alteration (A Rae), VHMS ore fringe alteration at Hercules and Hellyer, Tasmania (C McMahon, G Davidson), pyrite variation in oceanic crust sulfides from Macquarie Island (S Lewis;



Mount Polley deposit, BC, Canada, magnetite-garnet-chalcopyrite cemented breccia with late carbonate.

Pueblo Viejo, Dominican Republic, sphalerite-pyrite vein.

Pueblo Viejo, Dominican Republic, pyrite-sphalerite veins in folded sediments.

Pueblo Viejo, Dominican Republic, pyrite-sphalerite vein in laminated siltstone.



non confidential study), and along-strike analyses from the KB lode gold deposit (G Davidson). The work included low level trace element analysis of wholerock values of the samples used for LA-ICPMS work.

A sponsors meeting was held in June 2004, with a final meeting due in March 2005. Due to the confidential nature of the research, no refereed publications were produced during the year, but two abstracts on related studies were presented at international conferences.

Project 3.14

Transitions and zoning in porphyry-epithermal districts: indicators, discriminators and vectors (collaboration with Program 5, project 5.18) (ARC Linkage/AMIRA P 765)

D Cooke, JB Gemmill, C Deyell, Z Chang, N White, J Hedenquist (CSM); PhD students T Ireland, A Tyson

Porphyry-related mineral districts host many major ore deposits of diverse styles and metal associations. These include the porphyry (copper-molybdenum-gold) deposits themselves, but also epithermal gold-silver deposits, skarn copper-gold deposits, carbonate replacement zinc-lead-silver, and sediment-hosted gold. These districts continue to be major targets for both copper and gold explorers.

The purpose of this project (AMIRA P765), a collaboration between CODES Programs 3 and 5, is to determine the links between the diverse deposit styles within porphyry-related mineral districts, and identify where the highest grade copper and gold accumulations are expected to occur. We aim to improve exploration success in porphyry-epithermal districts by providing geological, geochemical, and geophysical vectors towards major metal accumulations, and indicate the likely distance. Study areas include Lepanto, and

Baguio (Mankayan, Philippines), Batu Hijau (Indonesia), Collahuasi (Chile), Pueblo Viejo (Dominican Republic), Colquijirca (Peru) and Cadia (Australia). This project has ARC-Linkage funding and industry funding through AMIRA (AngloGold Australia Limited, Placer Dome Inc, Teck-Cominco, Gold Fields Ltd, Newcrest Mining Ltd, Anglo American (Philippines) and Newmont.

Zhaoshan Chang joined the project as a postdoctoral fellow in June and began working on the Batu Hijau, Lepanto and Mankayan study sites. Tim Ireland continued his research on the structural and metallogenic evolution of the Collahuasi district. Andrew Tyson began his PhD research on the petrophysical characteristics of hydrothermal alteration in porphyry-epithermal districts in 2004 with his initial field site at Pueblo Viejo, Dominican Republic. Sponsors' meetings were held in June and December. For further detail see project 5.18.

Project 3.15

Petrophysical characterisation of ore and alteration types in the Skellefte District, Sweden

Michael Roach, Per Nilsson (Raycon, Sweden)

This Georange project (funded by the Swedish mining industry) on petrophysical characterisation of ore and alteration types in the Skellefte district, Sweden, and conducted by Michael Roach, was completed in 2004 with results presented at the Georange research meeting in Arvidsaur in September. This project involved acquisition of in-situ geophysical and laboratory petrophysical data from the Storliden and Maurliden deposits. These data were then used to construct two- and three-dimensional geophysical models of each deposit that were used to evaluate the likely geophysical responses of each system for a range of different techniques and acquisition parameters.

PhD Projects in Program 3

Singoyi Blackwell: Controls on the geochemistry of magnetite in hydrothermal fluids.

Kim Denwer: Mineralogical, geochemical and isotopic investigation of the Mount Lyell copper-gold orebody and alteration system.

Russell Fulton: Geology and geochemistry of the hanging wall argillite, Greens Creek VHMS deposit, Alaska: implications for ore genesis and exploration.

Tim Ireland: Structural and metamorphic evolution of the Collahuasi district, Chile.

Steven Lewis: Sulfidic hydrothermal alteration in late brittle faults, Macquarie Island.

Neil Martin: Genesis of the Rosebery VHMS deposit, western Tasmania. (graduated December 2004)

Claire McMahon: Controls on the geochemistry of hydrothermal pyrite in ore systems.

Andrew Tyson: Petrophysical characteristics of hydrothermal alteration in porphyry-epithermal districts. (commenced in 2004)

Andrew Wurst: Geology and genesis of the Permata-Batu Badinding-Hulubai and Kerikil gold-silver low-sulfidation epithermal deposits, Mt Muro, Kalimantan, Indonesia. (graduated December 2004)



Program 4

Ores in continental rift basins

Program 4 investigates the nature and origin of metalliferous mineral deposits of sedimentary basins, and the importance of sedimentary, diagenetic, volcanic and hydrodynamic processes involved in the formation of these deposits

Caption

Objective

To use a multi-disciplinary approach to improve our understanding of the origin of major metalliferous mineral deposits found in continental sedimentary basins. The program will emphasise the application of these results to refine and develop techniques used in the search for new resources.



Highlights

Commencement of a new industry sponsored project to continue work studying sedimentary copper deposits in the African Copperbelt and the Centralian Basin. This work is supported by AMIRA and the ARC (\$1.2 million over the next three years) and continues our previous successful collaboration with researchers from Colorado School of Mines

A session on 'Microbes and mineral deposits' was convened by Peter McGoldrick for the 17th Australian Geological Convention

Tony Webster's landmark PhD thesis, a comprehensive study of the geology and structure of the Broken Hill ore bodies, was examined and accepted.

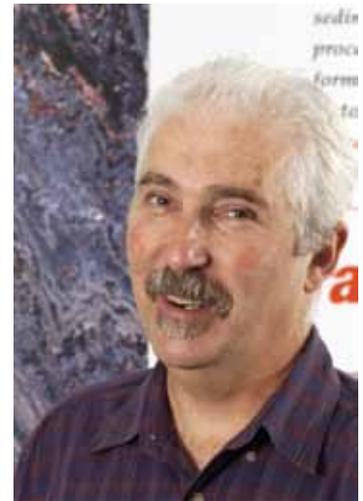
PhD student chapter Nicky Pollington received an SEG Award for best student poster at the Society of Economic Geologist international meeting in Perth.

A presentation called 'Proterozoic sedimentary exhalative (SEDEX) deposits and their links to evolving global ocean chemistry' co-authored by Peter McGoldrick was given by Tim Lyons (University of Missouri-Columbia) at the Geological Society of America Annual Meeting.

A workshop meeting between researchers from CODES and the Australian Centre for Astrobiology was held in December to discuss each group's work on the McArthur River zinc-lead-silver deposit.

Two invited papers, one led by Dave Selley (Sedimentary Cu deposits of Zambia) and the other by led by Ross Large (Stratiform Zn-Pb-Ag deposits of northern Australia) will appear in the 100th Anniversary Volume of Economic Geology due out late in 2005.

A new research project on sediment-hosted gold deposits led by Robert Scott and Ross Large has received strong funding support from industry.



Team Leader
Peter McGoldrick

Team Members
Stuart Bull, Garry Davidson, David Cooke, Ross Large, Robert Scott, David Selley

PhD Students
Bryan Bowden, Mawson Croaker, Wallace Mackay, Rod Maier, Nicky Pollington, Tony Webster*

Collaborators
Colorado School of Mines, Luleå University, Swedish Geological Survey, Johns Hopkins University, University of Adelaide, PIRSA, RSES-PRISE, Simon Fraser University, James Cook University, University of Missouri-Columbia

Core Projects in Program 4

4.1 Geological environment of stratiform Zn-Pb deposits in the Proterozoic basins of northern Australia.

4.2 Nature, timing and significance of fluid flow in Proterozoic sedimentary basins, and relationship to stratiform Zn-Pb-Ag ore formation.

4.5 Textural and isotopic studies of sediment-hosted Zn-Pb-Ag base metal deposits.

4.9 Development of novel laser and ICP-MS techniques for microanalysis of trace elements and isotopes in sulfidemineralised samples.

4.10 Microbes and the origin of Proterozoic Sedex Zn-Pb-Ag deposits.



Project 4.1 CORE
 Geological environment of stratiform zinc-lead deposits in the Proterozoic basins of northern Australia

S Bull, P McGoldrick, R Large

Although field work and laboratory studies for this project have now ceased, there is significant on-going output related to our research:

- Ross Large, Stuart Bull, Peter McGoldrick and Steve Walters are the CODES-based authors on a paper for the 100th Anniversary volume of Economic Geology entitled "Stratiform and stratabound Zn-Pb-Ag deposits of the Proterozoic sedimentary basins of northern Australia." The manuscript has been reviewed and accepted and is currently undergoing minor additional revisions suggested by the editors.
- Ross Large, Peter McGoldrick, Stuart Bull and David Cooke have contributed a chapter entitled "Proterozoic stratiform sediment-hosted zinc-lead-silver deposits of northern Australia" to a book published in early 2004 — "Sediment-

Program 4 team: L to R, David Selley, Mawson Croaker, Blackwell Singoyi, Brian Bowden, Rob Scott, Ross Large, Peter McGoldrick, Steve Walters, Gary Davidson

hosted lead-zinc sulfide deposits" — edited by M Deb and Wayne Goodfellow.

- Implications for the genesis of the HYC deposit, that arose from the results of sedimentological aspects of Tim Ireland's excellent honours thesis, have been published in Mineralium Deposita with Tim, Stuart Bull and Ross Large as co-authors.

Project 4.2 CORE
 Nature, timing and significance of fluid flow in Proterozoic sedimentary basins, and relationship to stratiform zinc-lead-silver ore formation

R Large, J Yang (UWindsor), S Bull, D Cooke, in collaboration with G Garven and M Simms (Johns Hopkins U)

This is a core project for Program 4 and is shared with Program 5 (see Project 5.1). The program of collaboration with Grant Garven (Johns Hopkins U) and Jianwen Yang (UWindsor) has continued to produce significant outcomes related to hydrothermal fluid flow in sedimentary basins.

- The Yang, Bull and Large

authorship team have had two papers published in 2004. One in Geofluids dealt with sensitivity analysis of basin permeability and fault parameters in a modeled section across the Batten Fault Zone. The other in Mineralium Deposita and examined the controls exerted by basin salinity distribution on hydrothermal fluid flow in sedimentary basins. The numerical modeling demonstrated the critical importance of fluid salinity in controlling the movement of dense brines deep in the basin to access the volcanic zinc-lead source rocks lateral aquifer system. Stratiform zinc-lead-silver mineralisation is favoured by the presence of evaporative sediment high the basin stratigraphy, enabling dense brines to sink and convect back to the surface under a moderate to high geothermal gradient.

- Mike Simms, a PhD student at Johns Hopkins University, is continuing his research on fluid flow related to zinc-lead-silver mineralisation in the McArthur basin. Mike presented a paper describing some aspects of his

work in the “Fluid flow and ore genesis” session of the 17th AGC in Hobart in February.

- Lyudmyla Koziy, PhD student at CODES, has developed a finite-element computer code coupling fluid flux, temperature and solute transport and successfully tested it against published models. The code is being used to simulate hydrothermal fluid flow related to the formation of sedimentary copper and zinc-lead-silver deposits.

Project 4.5 CORE

Textural and isotopic studies of sediment-hosted base metal deposits and their alteration haloes

R Large, P McGoldrick; PhD student R Maier

The main efforts in this project have been through Rod Maier’s PhD studies supervised by Peter McGoldrick and Ross Large. Rod spent July in Mt Isa logging and sampling core from the Bluebush prospect. The cores were in excellent condition and distinct alteration zones and highly diverse textures were evident. Whole-rock geochemical data was obtained from carefully selected samples for comparisons with other northern Australian zinc systems. McArthur River is the other deposit Rod is studying for the LA-ICPMS part of his research and during the second half of the year, a substantial part of the pyrite trace element halo work for McArthur River was completed. This involved LA-ICPMS analysis of primary textured pyrites in a series of drill holes, distal from the HYC deposit. Encouraging preliminary results suggest that elements including Co, Ni, Cu, Zn, As, Sb, Ba, Tl, Pb, Mo, Ag, Sn occur at anomalous levels in the pyrite. The exact controls on these anomalies is uncertain, however, some appear at the orebody equivalent stratigraphic level.

Peter McGoldrick commenced a LA-ICPMS study of pyrite

associated with the Mount Isa zinc-lead-silver and copper lodes and their barren and weakly mineralised stratigraphic equivalents. This research aims to understand the role of pyrite plays as a host for anomalous thallium seen in bulk rock samples distal from ore. It will also document how chalcophile trace elements behaved during recrystallisation of sedimentary pyrite.

A paper by Ireland, Large, McGoldrick and Blake “Spatial distribution patterns of sulfur isotopes, nodular carbonate and ore textures in the McArthur River (HYC) Zn-Pb-Ag deposit, Northern Territory, Australia” was published in the December 2004 issue of Economic Geology. It describes ore textures, carbonate nodules and sulfur isotopic results from HYC, and their implications for the processes involved in mineralisation. The data presented in the paper suggest that base-metal sulfides formed both in the water column and in the uppermost sediment pile. Biological and thermochemical sulfate reduction probably occurred simultaneously in different parts of a complex physicochemical system in which stratification of the marine environment is

Caption

seen as the primary control on the lateral distribution of the mineralised facies. The authors propose a stratified water body in which sharp internal chemical gradients separate a surficial oxic layer, an anoxic layer, and a basal hypersaline brine pool. Asymmetric metal zonation across the deposit reflects individual pulses of metalliferous fluid that were introduced into the basin as a bottom hugging dense current.

Project 4.6

Proterozoic sediment-hosted copper deposits (ARC Linkage-AMIRA P872)

D Selley, S Bull, P McGoldrick, R Scott, R Large, M Roach, M Hitzman (CSM) B Trudgill (CSM), M Nabighian (CSM); PhD students M Croaker, W Mackay, N Pollington, D Broughton (CSM)

The major highlight of this non-core CODES project was the commencement in the second half of the year of AMIRA P872 “Cu-Co mineralisation in the Congolese, Zambian and Central Australian Basins systems”. It builds upon the recently completed AMIRA-ARC Linkage P544 project (the primary focus of which



was the genesis of Zambian Copperbelt deposits), to progress understanding of geology and base metal mineralisation processes within the regional framework of the Lufilian Fold Belt of Central Africa. The project was successful in winning ARC Linkage funding for 2005-2007. The significant financial, logistical and data contributions from industry sponsor groups and the Australian Research Council (\$1,265,760 over three years) is a reflection of the vibrant interest in exploration for the renowned super-giant sediment-hosted copper systems of the Democratic Republic of the Congo (DRC), and similar styles of deposits worldwide.

P872 has nine sponsor companies:

- African Rainbow Minerals
- Anglo American
- Anvil Mining
- BHP Billiton
- CVRD
- Entreprise Generale Malta Forrest
- Equinox Minerals Limited
- Gecamines
- Phelps Dodge

The project continues the collaboration between CODES and Colorado School of Mines and maintains the world-class research team assembled for the AMIRA P544 project. In addition, the project is facilitated by highly experienced African-based collaborators from several sponsor companies. Gecamines and Entreprise Generale Malta Forrest staff members are notable in this regard. Collectively, these geoscientists have been instrumental in directing modern fundamental and applied research into regional and ore deposit geology of the DRC.

The project has five main objectives:

- To constrain the evolution of the outer portions of the Lufilian Fold Belt, from basin initiation to basin closure during Pan African orogenesis.
- To establish the roles of basin architecture and evolution in controlling hydrological

evolution and ultimate localisation of ore.

- To determine the roles of salt in influencing phases of basin growth and inversion, generation of hydrothermal brines and ore genesis.
- To understand the processes involved in the formation of the giant copper-cobalt systems of the Congo and Zambia, and to identify key ingredients of the mineralising system, that can be used as a guide to exploration of other sedimentary basins worldwide.
- To refine and further develop practical geochemical, mineralogical and geophysical vectors to ore, at regional and deposit scales.

In late 2004 David Selley, Stuart Bull and Robert Scott were involved a six-week reconnaissance and field mapping program in the DRC and northern Zambia. This work focussed on (1) developing new litho- and chemo-stratigraphic techniques for refining correlation between Zambia and the DRC, (2) analysis of regional map patterns throughout the eastern and northern Lufilian Fold Belt, and (3) preparation for petrological and geochemical analysis of three major deposits.

Project 4.8

Cu-Au-Fe oxide geology and geochemistry

G Davidson, D Cooke, R Berry, S Meffre, C Deyell (Utas), D Thorkelson (Simon Fraser U), T Baker (JCU), P Heithersay, M Schwarz (PIRSA), R Skirrow, E Bastrakov, O Holm, G Fraser (GA), K Barovich (U Adelaide), N Oliver (JCU); PhD students B Bowden, C McMahon (UTAS), J Hunt, L Marshall (JCU)

This non-core project is aimed at increasing understanding of the characteristics and controls upon IOCG deposits, and activities in 2004 mainly proceeded as student projects, some based at UTAS, and others at JCU. A

highlight was permission for Garry Davidson and Roger Skirrow (Geoscience Australia) to edit an IOCG special issue of Economic Geology. Several manuscripts have been reviewed and the issue is scheduled to appear in 2006.

The main field-based project is Bryan Bowden's PhD: "Alteration and genesis of the Prominent Hill IOCG deposit, Mt Woods Inlier, Australia". His work is supported by PIRSA, GA, Minotaur Resources, Oxiana NL, and Goldstream NL. GA is providing a very large in-kind component, including U-Pb and Ar-Ar dating expertise and facilities. Unfortunately a bad leg injury slowed Bryan's progress in 2004. However, first phase Ar-Ar dating was completed in collaboration with G Fraser, and geochemistry and petrography proceeded.

Several smaller projects touching on aspects of IOCGs include:

- A sulfate S isotope study of Mt Freda-style hydrothermal carbonate and a collaborative study of other Eastern Succession carbonates were prepared as manuscripts for publication (collaboration with JCU)
- Some work continued on measuring C-O and S isotopes from the Wernicke Mountains breccia pipes as part of a collaboration with Simon Fraser University and JCU (J Hunt, D Thorkelson, T Baker)
- Basic petrography was completed by Claire McMahon on the NICO Cu-Co-Au IOCG deposit, Great Bear Magmatic Province, Canada (collaboration with Robin Goad of Fortune Minerals).
- IOCG systems were a minor component of project 5.16 (Fluid mixing in hydrothermal systems). See Program 5.

Project 4.9 CORE
Development of novel laser and ICPMS techniques for microanalysis of trace elements and isotopes in sulfide mineralised samples

P McGoldrick, M Norman (RSES), LDanyushevsky, KHarris, SGilbert

The ability to analyse small quantities of minerals and rocks for trace elements and stable and radiogenic isotopes is fundamental to much of the work being carried out in CODES Programs 1, 3 and 4. Project 4.9 is focussed on further perfecting the analytical procedures for in situ analysis of sulfide minerals by LA-ICPMS.

Project 4.10 CORE
Microbes and the origin of Proterozoic Sedex zinc-lead-silver deposits

P McGoldrick, S Bull, R Large, T Lyons (UColumbia-Missouri); PhD student R Maier

This project has developed from work previously undertaken in Projects 4.1 and 4.5. It is aimed at recognising textural and isotopic (C and S) evidence for microbial activity associated with the northern Australian Proterozoic Sedex zinc-lead deposits. The work aims to determine if microbes played an active or passive role in the origin of these important deposits.

Rod Maier (see also Project 4.5) visited Mount Isa to re-log and sample core from the Bluebush prospect. A diverse array of 'crinkly' pyrite textures are present in the core and these are being compared with crinkly and nodular carbonate textures from other northern Australian Proterozoic zinc-lead deposits.

Peter McGoldrick convened a session at the 17th Australian Geological Convention called "Microbes and mineral deposits". He made two presentation in this session; one describing unusual macroscopic pyrite textures from the Sheep Creek copper deposit

in Montana, and the other summarises purported microbial features from several northern Australian Proterozoic sediment-hosted zinc-lead deposits.

Project 4.11
Giant Broken Hill-type (BHT) systems

R Large, G Davidson, S Bull, P McGoldrick, R Berry; PhD student T Webster; MSc students S Lewis and N Shah

No fieldwork was undertaken on this non-core project in 2004, with all work focussed in write up of student projects. These included the submission and acceptance of theses on Broken Hill (T Webster), Little Broken Hill (S Lewis), and Rampura Agucha, India, and surrounding gneiss terrain (N Shah). A highlight was the publication of results from Owen Hatton's thesis in Hatton & Davidson (2004). In this work the strongly phosphorus-manganese-rich character of Soldiers Cap Group iron formations is documented, as well as their relationship to subtle growth structures in the siliciclastic sediments. Their most important conclusion is the recognition that widespread dyking and mafic volcanism in the upper sequences of this Proterozoic basin (host to the giant Cannington BHT deposit) followed the expulsion of manganese-phosphorus-silica-iron chemical sediments, promoting the hypothesis that these fluids were released from overpressured hydrothermal aquifers early in extension, whereas mafic magmas were only tapped later by greater extension.

A major highlight of our Broken Hill research was the acceptance without modification of Tony Webster's PhD thesis. The thesis on the geology and structure of the Broken Hill Line of Lode represents a seminal contribution on the three-dimensional form, composition, zonation and structural environment of the ore bodies

Caption (bar = 1 cm)



at Broken Hill, that enables an unparalleled view of the 'anatomy' of this giant deposit. Tony's research at Broken Hill has shown that all significant macroscopic folds in the orebodies are south verging, suggesting that they are parasitic to, and lie within the north limb of a major regional antiform. The intensity of folding increases in the northeastern end of the field. They are granulite grade F2 structures, for which

there is abundant evidence. Intense high-grade D3 shearing is significant in the mining field but the whole Line of Lode is not a shear zone.

Tony's detailed documentation of the near-ore stratigraphy, the internal stratigraphy of the orebodies and the structures that have affected the mineralisation and its host sequence shows that the Broken Hill orebodies are largely in situ and were deposited with the surrounding metasediments. The mineralised rocks that form the orebodies and adjacent rocks preserve evidence of all of the structural events that have affected the region. Deformation has extensively modified the geometry of the orebodies but these effects are not profound. The ore system can be accurately reconstructed as a linear complex of ore lenses that are intercalated with their hosts and are partly associated with localised developments of unusual manganiferous sediments.

Tony Crawford is working with Barney Stevens (GSNSW) on the geochemistry and tectonic implications of amphibolites in the Broken Hill Block, evaluating the significance of iron-rich Palaeoproterozoic magmatism and its potential links with mineralisation. For further details, see Program 1's report.

Project 4.12

Origin and setting of the Zawar sediment-hosted zinc-lead deposits in Rajasthan, India

S Bull, P McGoldrick, H Bhattacharya (Presidency College, Calcutta)

This project represents an exciting initial collaboration between CODES and the active Indian geological research community. It commenced in September 2003, when Stuart Bull visited Professor Bhattacharya at Presidency College, and subsequently accompanied him on a field visit to the Palaeoproterozoic Zawar zinc deposits in Rajasthan. The

deposit visited (Balaria) comprises 15 Mt @ 6.07% Zn & 1.25% Pb as fracture-controlled veins/stringers of sphalerite and minor galena in massive silicified and sericitised carbonate. However, laminated stratiform sulfides are also present that are being studied for the first time. In addition to the mine visit, several regional transects were conducted to constrain the mineralisation within the context of the history of the host basin. Subsequent to the field component of the work Professor Bhattacharya spent four months at CODES from December 2003 to March 2004 interacting with CODES personnel. A substantial analytical program was undertaken on Zawar samples, including LA-ICPMS of sulfides, sulfur, carbon and oxygen isotopic analyses, and lead isotope analyses by solution ICPMS. This work is now being prepared for two publications, one on the basin setting of the mineralisation, and the other describing the zinc-lead mineralisation, in particular, the relationship between the veins/stringers and the stratiform occurrences. Apart from the nature and origin of the Zawar cluster of deposits, an important question in Rajasthan is their relationship, if any, to larger deposits such as Rampura Agucha 70 km to the northeast.

Project 4.13

Controls on the formation and sulfide trace element signatures of sediment-hosted gold deposits

R Large, R Scott, A Rae, L Danyushevsky, P Emsbo (USGS), V Maslenekov (Russian Academy of Science)

This project aims to use recent technologies pioneered at CODES to develop a new approach to terrane selection and deposit vectoring for sediment-hosted gold deposits.

Recent research utilising the LA-ICPMS system at CODES has shown that syndiagenetic

pyrite within Ordovician black shale host-rocks to the Victorian orogenic lode gold deposits are enriched in gold (up to 2.7 ppm) and contain other anomalous elements including As, Bi, Sb, Pb, Te and Se. A similar pattern of gold enrichment in sedimentary pyrite has been reported from Devonian strata in the Carlin district (Emsbo, 1999). These results raise the possibility that pre-concentration of gold-in-pyrite by syndiagenetic and syndiagenetic processes may be critical to the formation of world-class sediment-hosted gold deposits. Current metamorphic models for these deposits suggest the gold is sourced from well below the level of mineralisation (some unknown depth), however our work supports the exciting possibility that the gold is sourced from the very strata that host the deposits.

In collaboration with Poul Emsbo (USGS) and Valeriy Maslenekov (Russian Academy of Science) we plan to undertake a detailed study of the Victorian goldfields, the Carlin District and the Sukhoi Log District to test the source bed concept, and in doing so, develop strategies useful for exploration for sediment-hosted gold deposits. The research will address three themes;

- Theme 1: Testing the source bed concept to develop terrane evaluation criteria: evaluate both distribution of, and level of, gold enrichment, in syngenetic and diagenetic pyrite in the Victorian Goldfields, Carlin District and Lena Golfield. What type of sediments preferentially concentrate gold-in-pyrite. What is the variation in gold and other trace elements in pyrite between districts and at different stratigraphic levels within a gold province. How does the gold-enriched strata relate to the location of the ore deposits.
- Theme 2: sulfide trace element and sulfur, lead isotopic variations as vectors to ore: Are epigenetic gold deposits

surrounded by broad halos characterised by enrichment or depletion of gold-in-pyrite. Do sulfur and lead in pyrite show isotopic halos useful for exploration.

- Theme 3: fingerprinting the big deposits: Do the large sedimentary gold deposits, and their pyritic halos, show characteristic pyrite geochemistry and isotopes that are different from the small deposits.

The principal outcomes of our research will be a better understanding of the genesis of major gold provinces, and the development of improved exploration strategies and techniques for sediment-hosted gold deposits. Five gold exploration/mining companies have indicated a desire to provide cash support toward the project, and give access to their mine sites; Barrick, Placer, Newmont, Newcrest and Perseverance.

Broken Hill lead-zinc-silver deposit: British Mine (ML15) level plans showing distribution of massive rhodonite unit in 3 Lens. From Tony Webster's PhD thesis.

Application for ARC-Linkage funding was made in November 2004.

PhD Students in Program 4

Bryan Bowden: Iron oxide copper-gold related alteration history of the Mt Woods Inlier, South Australia, with special emphasis on the Prominent Hill prospect.

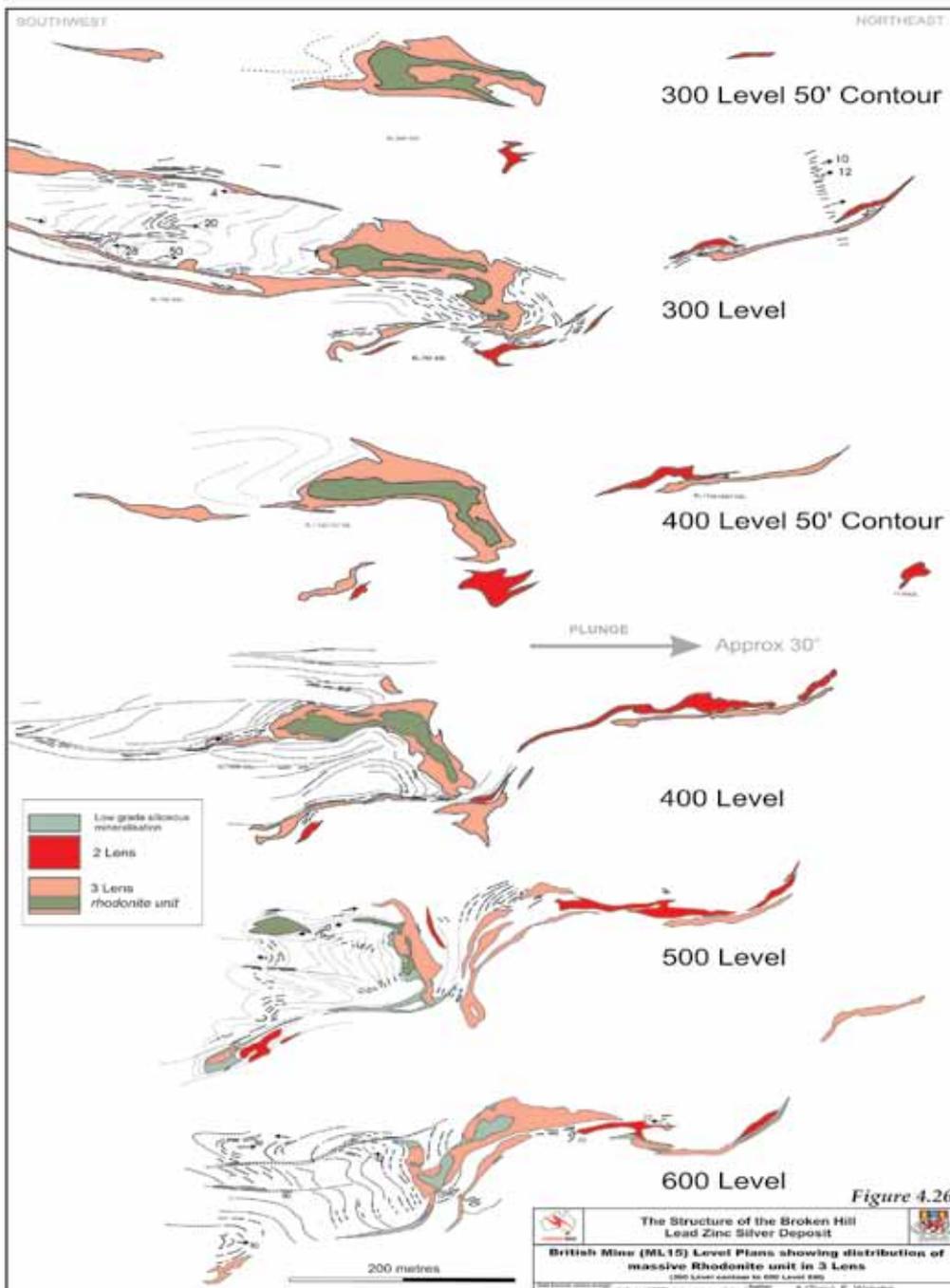
Mawson Croaker: Geology and genesis of the Nkana copper deposit, Zambia.

Wallace Mackay: Sedimentology and structure of the Curdimurka Subgroup, Willouran Range, South Australia.

Rod Maier: Pyrite and base-metal trace-element haloes in the northern Australian Zn-Pb-Ag deposits.

Nicky Pollington: Sedimentology, mineral paragenesis and geochemistry of the Konkola North copper deposit, Zambia.

Tony Webster: The structural evolution of the Broken Hill Pb-Zn-Ag deposit, New South Wales (graduated 2004).





Program 5

Hydrology and geochemistry of hydrothermal systems

Pre-feasibility drilling at the Antapaccay porphyrycopper-gold-molybdenum and skarn deposit on the Altiplano, southern Peru

Program 5 focuses on understanding fluid flow in volcanic arcs, backarc rifts and continental rifts and relating fluid chemistry, fluid flow and ore formation in these environments.

Objectives

- To investigate the hydrologic and chemical processes associated with ore transport and deposition in volcanic arcs, volcano-sedimentary basins and around granitoids.
- To develop coupled numerical simulations of fluid flow and chemical mass transfer for selected hydrothermal environments, in order to better understand the processes of ore formation.
- To develop a detailed understanding of the geology, hydrology and fluid chemistry of the selected study areas.

Highlights

Anthony Harris was awarded the 2004 Waldemar S. Lindgren Award from the Society of Economic Geologists for excellence in research by a young scientist in the field of economic geology.

David Cooke was awarded the Society of Economic Geologists Thayer Lindsley Travelling Lecturer award for 2005.

Peter Hollings, David Cooke and John Walshe won the Boldy award from the Mineral Deposits Division of the Geological Association of Canada for a presentation on the characteristics, distribution and controls of giant porphyry copper deposits. (Project 5.7)

Four publications in *Mineralium Deposita*, *Economic Geology* and *Geofluids* dealing with fluid flow and ore formation in the Northern Australian Zinc Belt. (Project 5.1)

Major field research programs initiated in Chile, Peru, the Dominican Republic, Indonesia and the Philippines as part of AMIRA project P765. (Project 5.18)

Core Projects

- 5.1 Nature, timing and significance of fluid flow and fluid chemistry in Proterozoic sedimentary basins, and relationship to stratiform zinc-lead-silver ore formation.
- 5.2 Fluid flow in the Mt Isa Basin. (AMIRA P552)
- 5.3 Software development.
- 5.5 Numerical modelling of precious metal transport and deposition in high- and low-sulfidation epithermal and subaerial geothermal systems.
- 5.7 Giant porphyry Cu deposits. (AMIRA P511)
- 5.8 Controls on hydrothermal fluid migration by volcanic facies architecture: implications for massive sulfide deposit formation.
- 5.14 Proterozoic sediment-hosted copper deposits. (AMIRA P544)
- 5.15 Fluid chemistry in porphyry copper-gold-molybdenum deposits
- 5.16 Fluid mixing in hydrothermal systems.
- 5.17 Hydrology and chemistry of mine drainage waters.
- 5.18 Transitions and zonation in porphyry-epithermal mineral districts. (AMIRA P765)
- 5.19 Sulfur isotopes and trace element geochemistry of sulfides as a discriminator of world-class early Proterozoic clode gold mineralisation.



Team Leader
David Cooke

Team Members

Stuart Bull, Bruce Gemmell, Cari Deyell, Anthony Harris, Ross Large, Andrew Rae and Zhaoshan Chang.

PhD Students

David Braxton, James Cannell, Mawson Croaker, Lee Evans, Peter Frikken, Tim Ireland, Ben Jones, Lyudmyla Koziy, Wallace Mackay, Glen Masterman, Nicole Pollington, Christian Schardt, Andrew Tyson

Collaborators

Johns Hopkins University, Unites States Geological Survey, University of Toronto, Lakehead University, Queens University, CSIRO Division of Exploration and Mining, Geoscience Australia, Monash University.



Project 5.1 CORE
Nature, timing and significance of fluid flow and fluid chemistry in Proterozoic sedimentary basins, and relationship to stratiform zinc-lead-silver ore formation

S Bull, R Large, D Cooke, P McGoldrick, R Scott, M Blake; G Garven (Johns HopkinsU) J Yang (WindsorU); PhD student M Simms (Johns HopkinsU),

This project is a joint Program 4 –Program 5 collaboration. Results are outlined under Program 4, project 4.2.

Project 5.2
Fluid flow in the Mt Isa Basin (AMIRA P552)

S Bull, R Large; P Southgate (GA); PhD student L Koziy; J Yang (WindsorU)

This collaborative AMIRA project has concluded and results are being written up in a series of papers for a Special Issue

Program 5 team: L to R, Cari Deyell, Ross Large, Paul Cromie, Anthony Harris, Zhaoshan Chang, Andrew Rae, David Braxton, Tim Ireland

of Economic Geology. A paper by Jianwen Yang, Ross Large & Stuart Bull on convective fluid flow at 1575 Ma along a north-south section of the Lawn Hill Platform, including the Century deposit was accepted for inclusion in the Special Issue. The results of this numerical modeling study have direct application to mineral exploration for base metal deposits in the Proterozoic sedimentary basins of northern Australia, and probably in sedimentary basins generally. The research suggests that exploration should concentrate on defining the major deep-penetrating, syn-sedimentary, often strike-slip faults that are rooted in the basement. The depth penetration and permeability of faults are major factors controlling maximum fluid discharge, and thus the location of major base metal ore deposits. Suitable basins also require a basin-wide clastic aquifer sequence with the capacity to transmit significant lateral fluid flow, overlain by a thick sequence of relatively impermeable fine-

grained sedimentary rocks (shales, siltstones or carbonates). The presence of volcanic or volcanoclastic source-rock units within or adjacent to the aquifer sequence is also considered to be a key factor. The modeling also suggests the presence of stacked aquifer sequences may create the framework to enhance fluid recharge deep into the basin centre, thus increasing metalliferous fluid discharge temperatures and velocities.

Project 5.3 CORE
Software development

R Large, D Cooke; PhD student L Koziy

Lyudmyla Koziy has finalised code for simulating two-dimensional migration of hydrothermal fluids in complex sedimentary structures. This included the development of three blocks that provide numerical solutions of the system from coupled equations for the hydraulic head, heat transport and mass transport. Features that distinguish the code from previously available software include an effective algorithm of the solution of a system of linear algebraic equations with a sparse matrix, which allows for a significant saving of computing time. The code also employs an 'upwind weighting' finite element technique to resolve the advection-dominated problem. The code can now deal with anisotropy effects from the rock matrix. It also has the capacity to simulate sources of heat within the section which allows the thermal effects of igneous intrusions to be simulated, and the ability to simulate local sources of solutes, which allowing modelling of the formation of dense brines by dissolution of salt sheets.

Extensive work on code validation has been undertaken during 2004. This has involved the construction of analytical solutions of the set of simplified problems and comparison with

the numerical solutions, a review of the available literature on results of experimental and numerical studies of free thermal and thermohaline convection in porous media and comparison of published data and published simulations with the newly developed code. This project is scheduled for completion in 2005.

Project 5.5 CORE
Fluid flow and fluid chemistry of high- and low-sulfidation epithermal and subaerial geothermal systems

D Cooke, B Gemmell, C Deyell, A Rae; R Rye (USGS), T. Bissig (U Concepcion). PhD student A Davies

Cari Deyell published a paper in SEG Special Publication 11 on landscape evolution, fluid flow and high-sulfidation mineralisation in the El Indio-Pascua gold-copper-silver belt of Chile, in collaboration with T. Bissig (now U of Concepcion) and R. Rye (USGS). She also gave a talk at the February 2004 Australian Geological Convention (Hobart) on enargite trace element geochemistry in the Lepanto high-sulfidation deposit (Philippines), with particular emphasis on the implications for recognising fluid flow patterns from the Far Southeast porphyry system, based on deposit-scale zonation patterns defined by the trace element compositions of enargite.

Andrew Rae published a paper in the Journal of Volcanology and Geothermal Research on the nature of magmatism at Palinpinon geothermal field and its implications for geothermal activity and regional tectonics. In February, Andrew Rae presented a paper at the 17th Australian Geological Convention in Hobart on the spatial and temporal relationships between intrusion emplacement and hydrothermal alteration assemblages at the Palinpinon geothermal system. Andrew Davies published a



paper on the Kelian epithermal gold deposit in CODES Special Publication 5, and gave an oral presentation on Kelian at the 24 Carat Gold workshop in Hobart (June 2004).

Project 5.7
Giant porphyry copper deposits (AMIRA P511)

D Cooke; J Walshe (CSIRO E&M), P Hollings (LakeheadU), A Clark (QueensU); PhD students J Cannell, P Frikken, G Masterman

AMIRA Project P511 (Giant Ore Deposit Systems) was an industry-funded project involving collaborative research between CODES, the CSIRO Division of Exploration and Mining and the Centre for Global Metallogeny (CGM - University of Western Australia). The project consisted of three modules, which focussed on Archean lode gold (CGM/CSIRO), PNG gold-copper (CSIRO) and Chilean porphyry copper-molybdenum deposits (CODES/CSIRO). The final AMIRA sponsors

Rosario open pit viewed from Cerro La Grande, Collahuasi, Chile

meetings were held in 2003, although research continued into 2004 through the work of the three CODES PhD students sponsored by this project.

Pete Hollings, David Cooke and John Walshe presented a paper on the tectonic controls on porphyry ore formation at the GAC-MAC meeting in May 2004. This paper won the Boldy award for the best economic geology paper presented at the meeting, and was published as an article in the Gangue newsletter in late 2004. David Cooke presented a keynote paper summarising the major findings of the central Chile research team at the PACRIM conference in Adelaide in September 2004. This presentation was reviewed in an article in Paydirt magazine in late 2004. Cooke, Masterman, Cannell and Walshe gave individual conference presentations at the AGC conference in Hobart (February 2004).

James Cannell submitted his PhD thesis in July 2004. This thesis provided new geological, structural, geochemical and geochronological data, which

formed the basis for a new model for the formation of porphyry copper- mineralisation at El Teniente. Peter Frikken completed the final corrections to his PhD thesis on the Río Blanco porphyry copper-molybdenum system in January 2004.

Glen Masterman and colleagues from CODES, Queens University and CSIRO Division of Exploration and Mining published a paper in Economic Geology on new geochronological data for the Collahuasi district. They

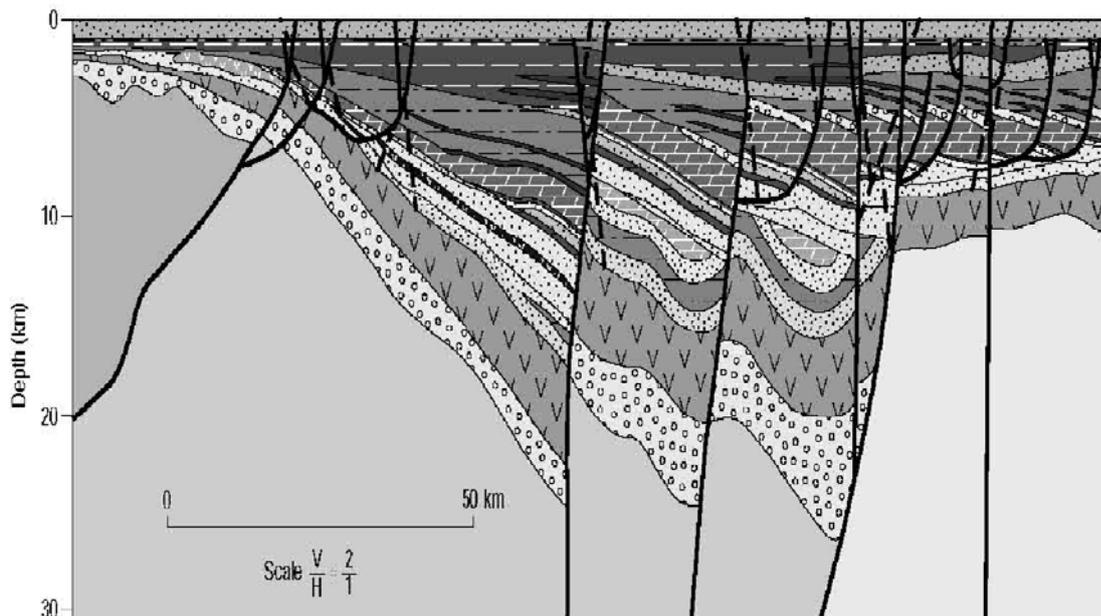
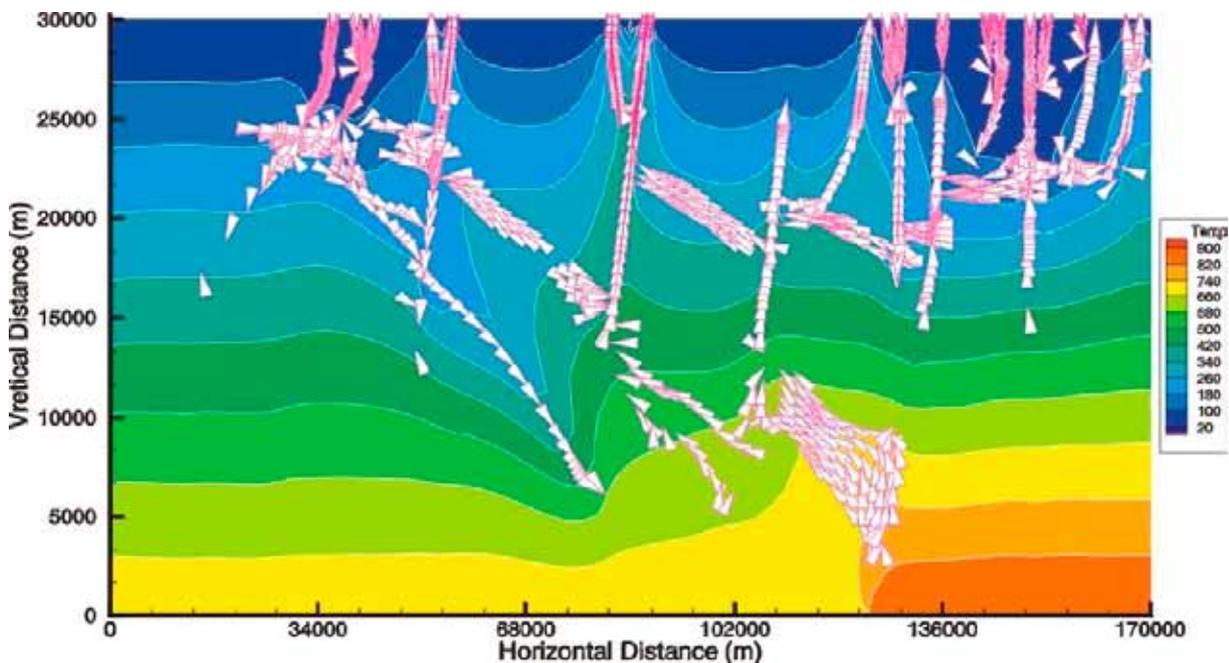
Caption

have also had a manuscript on the structural controls on superposition of high sulfidation epithermal mineralisation into the core of the Rosario porphyry system accepted for publication in Economic Geology in 2005. This is one of several manuscripts by CODES researchers and colleagues that will be published in a Special Issue of Economic Geology in mid-2005. The Special Issue summarises the results of research from AMIRA project P511.

Project 5.8 CORE Controls on hydrothermal fluid migration in submarine volcanic environments: implications for massive sulfide deposit formation

R Large, J McPhie; G Garven (Johns HopkinsU), J Yang, (U Windsor); PhD student C Schardt

Christian Schardt's PhD thesis was accepted in early 2004. This project is now completed. His



work involved finite difference numerical modelling to study buoyancy-driven heat and fluid transport in back-arc seafloor settings, using the Lau Basin, SW Pacific and the Panorama district, WA, as specific test sites. Results from the modelling suggest that the most important factors and processes controlling heat and fluid transport in submarine volcanic settings are fault and rock permeability, basement topography, and the nature of the heat source. Discharge temperatures are primarily controlled by rock permeability and range between 150°C and about 400°C. Discharge fluid velocities depend mostly on fault permeability variations and range between $\sim 1 \times 10^{-8}$ m/s and 4×10^{-6} m/s for individual fault structures, which equates to values of about 3 m/s for a typical seafloor black smoker chimney orifice. Both predicted discharge temperatures and fluid discharge velocities compare well with seafloor observations and theoretical calculations and do not require a thermal cracking front and associated constraints.

Heuristic mass calculations based on modeling results indicate that hydrothermal fluids with a 10 ppm base-metal content and dew deposition efficiency (10%) can form significant seafloor massive sulfide deposits (0.5 Mt of 10% Cu + Zn) within a time frame of about 6000 years. World-class or giant massive sulfide deposits (>4 Mt of Cu + Zn) require a convection system which runs for about 40,000 years or hydrothermal fluids with a much higher deposition efficiency and/or higher base-metal content. The spacing, distribution and potential size of base-metal deposits is predicted to depend primarily on the shape/extent of the heat source as well as the spacing and position of fault structures relative to the heat source.

Project 5.15 Core Fluid chemistry in porphyry copper-gold-molybdenum deposits

D Cooke, C Deyell, A Harris, A Rae, A Tunks, N White, C Ryan (CSIRO E&M), R Rye (USGS), E Petersen (UUtah), R Tosdal (MDRU-UBC); A. Berry, J Mavrogenes, M Norman, J Dunlap (ANU); P Reiners (Yale U). PhD students D Braxton, B Jones, V Lickfold, A Wilson; M Expl. Geosci. Student F Urzua; M Econ. Geol. Student A Ignacio

Anthony Harris has been awarded the Society of Economic Geologists Waldemar S. Lindgren Award for 2004. This award is offered annually by the society to a young scientist whose published research represents a significant contribution to economic geology. The award was made on the basis of his recent publications dealing with porphyry copper-gold deposits. During 2004, Anthony has continued his research into the magmatic-hydrothermal transition as preserved in rocks from porphyry ore deposits. This work is a collaborative effort with Program 1.

Anthony, together with Dima Kamenetsky, Noel White and David Steele (CSL) had a paper published in an invited special volume of *Resource Geology* that documents transitional quartz textures found in porphyries at Bajo de la Alumbrera. This work builds on the inclusion study published in *Science* in 2003, which documented the coexistence of melt and fluid inclusions in veins.

Anthony Harris, Leonid Danyushevsky and David Cooke are utilising the 213 nm laser ablation system at CODES, to analyse fluid inclusion populations in comb quartz layered textures preserved in porphyry ore deposits. These detailed microanalytical studies of fluid inclusions are helping to better constrain the physical models of volatile exsolution from silicic magmas.

Together with Andrew Berry and John Mavrogenes (ANU), Anthony Harris and Dima Kamenetsky were granted access to the Advanced Photon Source (Chicago), a state-of-the-art synchrotron facility, to study the transportation of copper in hydrothermal fluids. Anthony, together with Andrew Berry, John Mavrogenes and staff from the APS, ran experiments that measured the copper K-edge X-ray absorption near-edge structure (XANES) spectra from fluid inclusions heated to 600°C. The preliminary findings suggest the occurrence of CuCl_2^- at these high temperatures (confirming earlier work by Mavrogenes et al., 2002, *American Mineralogist* 87).

Geochronologic work on porphyry ore systems by Anthony Harris is ongoing. He has published in *Mineralium Deposita* his PhD LA-ICPMS uranium-lead zircon geochronologic data for the Farallón Negro Volcanic Complex, host to the classic Bajo de la Alumbrera porphyry copper-gold deposit. This work found that the regional magmatism associated with the porphyry was relatively long-lived (up to 2 m.y.) and that the porphyritic intrusions intimately associated with mineralisation were emplaced over this time. Ongoing thermochronologic work with collaborators at ANU and Yale, suggests that the Bajo de la Alumbrera hydrothermal system was sustained for millions of years, longer than could be expected by numerical simulations.

Cari Deyell was successful in gaining additional funding from the British Columbia and Yukon Chamber of Mines "Rocks to Riches" program for the second year of a study in collaboration with Richard Tosdal (MDRU-UBC) and David Cooke (CODES). This study is focused on the sulfur-isotope signature of sulfides in alkalic copper-gold deposits in British Columbia. Fieldwork and sampling was conducted at two deposits in north-central British Columbia in July-August and

sulfides were analysed at the USGS facility in Denver (USA) in collaboration with Rob Rye. Preliminary results from this study are reported in a paper submitted to the British Columbia Fieldwork volume, to be published in January 2005.

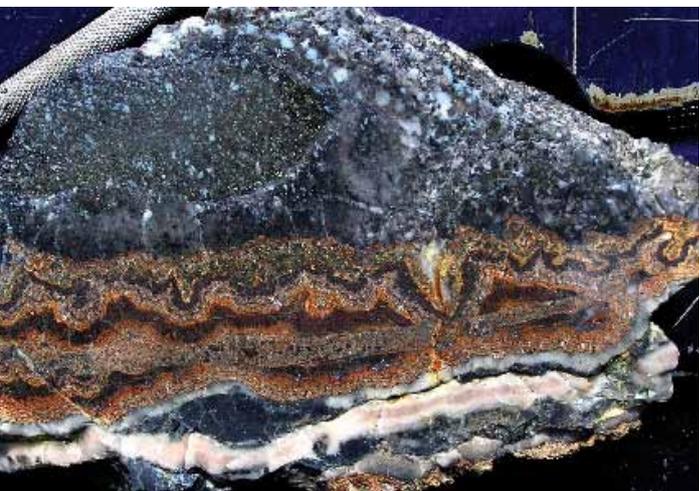
Alan Wilson, David Cooke, Ben Harper and Cari Deyell submitted a manuscript documenting sulfur isotopic zonation at the Cadia porphyry gold-copper deposits, for inclusion in a special issue of *Mineralium Deposita*. David Cooke gave an invited presentation on the characteristics of the alkaline porphyry province of NSW at a Geological Society of Australia symposium in Orange, NSW, in July 2004.

Andrew Rae travelled to the Boyongan porphyry copper-gold deposit (Philippines) in March 2004 to provide field supervision and guidance for PhD student David Braxton and Master of Economic Geology student Allan Ignacio. David Braxton completed his second field season (February-March) focusing on tectonic evolution and hypogene geochemistry of the Boyongan/Bayugo porphyry copper-gold deposits, in NE Mindanao (Philippines). Detailed paragenetic observations have documented cyclical patterns of alteration and vein formation spatially and temporally associated with discrete intrusive events. Ongoing petrographic and upcoming fluid inclusion studies will seek to identify the geochemical influences on mineralisation between fertile and unmineralised vein stages for the various intrusive events. In collaboration with Bob Rye (USGS) David has completed hydrogen and oxygen stable-isotope characterisation of the vein stages and principal alteration stages to characterise the origins and evolution of hypogene and supergene fluids. Studies constraining the timing of magma emplacement are ongoing in collaboration with Marc Norman (PRISE, ANU). Ongoing dating of late-stage

phyllitic and advanced argillic alteration in collaboration with Jim Dunlap (ANU) will constrain the timing of epithermal overprinting onto porphyry-style alteration. The cooling history and timing of exhumation and supergene oxidation (based on U-Th/He dating of apatite and zircon) is the subject of ongoing collaboration with Peter Reiners (Yale University). Allan Ignacio presented a poster on the supergene mineralisation at Boyongan at the SEG conference in Perth in October. Allan submitted a complete draft of his Masters thesis in November 2004, with the final version scheduled for submission in early 2005.

Ben Jones continued his BHP Billiton-supported PhD study of the Antapaccay porphyry copper-gold deposit during 2004. This project involves a detailed geological and geochemical investigation of hypogene porphyry and skarn mineralisation developed around three porphyry intrusive centres located on the western margin of the Altiplano in Southern Peru. The petrology and geochemistry of pre-mineral, mineralised, and post-mineral intrusive phases from Antapaccay and regional Abancay Batholith granitoids have been investigated by combined whole-rock geochemistry; lead, strontium and neodymium radiogenic isotope; and electron microprobe and LA-ICPMS mineral chemistry studies. Zircon and titanite LA-ICPMS U/Pb geochronology has been completed at the ANU (collaboratively with the Ore Genesis Group, RSES) and at CODES to determine the ages of magmatic events at Antapaccay and in the region. Field relationships and thin section petrography in conjunction with PIMA and XRD spectrometry (completed collaboratively with the University of Ballarat) have been used to construct an alteration, mineralisation and veinlet paragenesis. Re-Os molybdenite geochronology has been completed collaboratively with the Department of

Banded sphalerite-pyrite-quartz vein in pyrophyllite altered volcaniclastic sandstone, Pueblo Viejo, Dominican Republic



Geosciences, University of Arizona) and $^{40}\text{Ar}/^{39}\text{Ar}$ and K-Ar age determinations are being completed (collaboratively at the University of Melbourne and CSIRO Perth respectively) to determine the ages of hydrothermal biotite, orthoclase and sericite. Sulphide and sulphate $\delta^{34}\text{S}$, quartz and silicate δD and $\delta^{18}\text{O}$ (in collaboration with the Department of Geosciences, University of Arizona), and carbonate $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ stable isotope studies have been completed to investigate the sources of sulfur and water, and to better understand the significance of extensive Ca-Na alteration developed at Antapaccay. Apatite and zircon (U-Th)/He thermochronology is being completed (collaboratively with the CSIRO Perth) to investigate the cooling and uplift history of the system. Fluid and melt inclusion studies are underway and the project is scheduled for completion in 2005.

Felipe Urzua is in the final phases of completing his Master of Exploration Geoscience thesis on the Escondida copper-molybdenum porphyry district in northern Chile, under the supervision of Andrew Tunks and David Cooke, and through the sponsorship of BHP Billiton. Geochronological and geochemical studies were completed in 2004. The thesis is scheduled for submission in March 2005.

Project 5.16
Fluid mixing in hydrothermal systems

D Cooke, N Oliver, P Williams, B Fu (JCU), C Ryan (CSIRO), B Yardley (ULeeds)

This project is a collaboration between James Cook University, the University of Leeds and CODES. It aims primarily to determine the key processes that lead to fluid mixing in certain geological environments, and to determine the relative importance

of fluid mixing as an ore forming process with respect to other mineral depositional mechanisms. Originally the plan was for project completion by the end of 2004. However, this project has been extended into 2005 primarily because the postdoctoral research fellow, Bin Fu left JCU for U Wisconsin mid year. Thus expenditure was under budget and the work program did not advance as planned in 2004.

Project 5.17
Hydrology and chemistry of mine drainage waters

G Davidson, J Reid, D Cooke; PhD student: L Evans

In 2004, Lee Evans completed his third year of an environmental geology PhD entitled "Groundwaters in wet, temperate, sulphide mining districts: delineation of modern fluid flow and predictive modelling to improve management after mine closure (Rosebery, Tasmania)". This year concentrated on further construction and calibration of the numerical groundwater model, as well as work on the thesis chapters. Lee has taken 12-months leave of absence in 2005. The project is scheduled for completion in 2006.

Project 5.18
Transitions and zonation in porphyry-epithermal mineral districts (AMIRA P765)

D Cooke, B Gemmell, C Deyell, Z Chang, N White, J Reid, M Roach, J McPhie; J Hedenquist (CSM), P Hollings (Lakehead U); PhD students T Ireland, A Tyson; M Expl Geoscience Student R Gonzales; M Econ Geol student G Midgley

Porphyry-related mineral districts host many major ore deposits of diverse styles and metal associations. These include the porphyry (Cu-Mo-Au) deposits themselves, but also epithermal



Noel White examining a sphalerite-pyrite vein at Pueblo Viejo, Dominican Republic

copper-silver deposits, skarn copper-gold deposits, carbonate replacement zinc-lead-silver, and sediment-hosted gold. These districts continue to be major targets for both copper and gold explorers. Exploration in porphyry-related districts can be complicated by shallow-level alterations systems (e.g., lithocaps), differences in erosional levels and host lithologies, and structural complexities. It can be difficult to identify the productive ore zones that are interspersed between barren gaps within these large magmatic-hydrothermal systems. AMIRA project P765 is designed to test whether new advances in geochemical analyses can help to improve exploration success in porphyry-epithermal districts. We are developing and testing criteria that can be used by explorers to indicate prospective environments, discriminate

between mineralisation styles, and vector towards ore zones —betheyofporphyry,epithermal, and/or other peripheral styles. This is a collaboration between Program 3 (project 3.14) and Program 5.

2004 saw the initiation of major field programs in Baguio and Lepanto (Philippines), Batu Hijau (Indonesia), Colquijirca (Peru), Collahuasi (Chile) and Pueblo Viejo (Dominican Republic). Zhaoshan Chang joined the research team as a postdoctoral research fellow in June 2004, and is primarily responsible for research at the Indonesian and Philippine sites. Cari Deyell has taken responsibility for the South and Central American case studies. Sponsors field meetings were held at CODES in June and December 2004. Jeff Hedenquist participated in two Philippine field trips in 2004, and is coordinating the research program at Lepanto. Noel White completed field programs in the Philippines and the Dominican Republic. Pete Hollings undertook a geochemical sampling program in the Baguio district of the Philippines. Jocelyn McPhie

L to R: xxx, xxx, Peter Hollings, Zhaoshan Chang, xxx, xxx, David Cooke and xxx

initiated a volcanological study of the Pueblo Viejo deposit in the Dominican Republic.

Tim Ireland commenced a PhD on the structural and metallogenic evolution of the Collahuasi porphyry-epithermal district in northern Chile in January, under the supervision of David Cooke and Ron Berry, with logistical support from Anglo American. The project involves investigation of structural architecture and kinematics across various scales, and detailed district-wide mapping, which together will permit interpretation of an integrated geological history for the district as the context in which to better understand controls on porphyry- and related mineralisation. Two field seasons were completed between March-June and October-December, during which detailed structural mapping was completed at three of four porphyry deposits, 120 of a planned 150 km² were mapped at 1:5000, and 15 km of drill core was logged. Sampling was largely completed for petrological, palaeontological and geochronological purposes and laboratory work between

field seasons included U-Pb geochronology at CODES and trial palynology at the University of Adelaide in collaboration with Dr. Neville Alley. Further collaboration is planned for 2005 for Ar⁴⁰-Ar³⁹ geochronology at Queens University, Kingston, Canada, and for U-Th/He thermochronology at Yale University, Connecticut, USA, prior to a final field season in November.

Andrew Tyson commenced a PhD study early November. Andrew will undertake a geophysical PhD study, focussing on the geophysical responses of altered and mineralised rocks under the supervision of Mike Roach and James Reid. His initial field program will commence at Pueblo Viejo in February 2005.

Rene Gonzales is mapping the central Baguio district for his Master of Exploration Geoscience thesis. Mapping of much of the western half of the field area has been completed. 2005 will see the completion of the mapping program, and detailed investigations of the Mexico skarn deposit.

Gem Midgley joined the AMIRA P765 research team in late September. Gem is



completing a Master of Economic Geology thesis at CODES, and her research will evaluate the three-dimensional metal distribution and host rock controls on high-grade ore mineralisation at Pueblo Viejo.

Project 5.19

Sulfur isotopes and trace element geochemistry of sulfides as a discriminator of world-class lode gold mineralisation

C. Deyell, J. Walshe (CSIRO), P Neumayr (UWA)

This project has been investigating Archean lode gold deposits of Western Australia. In particular, it has focused on detailing the spatial distribution of hydrothermal alteration types and their mineralogical and chemical signals, and using these as a guide to interpreting fluid sources, ore transport and depositional processes. The results of 2004 research conducted in collaboration with P Neumayr (UWA) and J Walshe (CSIRO) in the St Ives camp was reported in an abstract presented by P Neumayr at the pmdCRC meeting in June 2004. A PhD study of West African Proterozoic gold mineralisation was terminated in mid-2004 when the PhD candidate accepted a full-time position in the minerals industry.

Lee Evans: Groundwaters in wet, temperate sulfide mining districts: Delineation of modern fluid flow and predictive modelling to improve management after mine closure (Rosebery, Tasmania).

Peter Frikken: Breccia-hosted Cu-Mo mineralisation at Rio Blanco, Chile. (graduated December 2004)

Tim Ireland: Geology and structural evolution of the Collahuasi District, Northern Chile.

Ben Jones: Genesis of the Antapaccay copper-gold porphyry deposit, Peru.

Lyudmyla Koziy: Numerical simulation of fluid flow and fluid chemistry in sedimentary basins.

Wallace Mackay: Sediment-hosted copper, Stuart Shelf, SA.

Nicole Pollington: Sedimentology, mineral paragenesis and geochemistry of the Konkola North copper deposit, Zambia.

Christian Schardt: Controls on hydrothermal fluid migration by volcanic facies architecture: implications for massive sulfide deposit formation. (graduated August 2004)

Andrew Tyson: Geophysical characteristics of porphyry and epithermal deposits.

PhD Projects in Program 5

David Braxton: Origin of the Boyongan porphyry copper-gold system, Philippines.

James Cannell: El Teniente porphyry copper-molybdenum deposit, Chile: geology, geochemistry and genesis. (thesis submitted July 2004)

Mawson Croaker: Geology and genesis of the Nkana copper deposit, Zambia.



Education

Objectives

To produce outstanding post-graduates who are able to identify and pursue new fundamental research initiatives and to lead industry exploration for new mineral resources.

To develop a high-quality post-graduate and post-doctoral program that integrates ore deposit and mineral province studies, concentrating on geological processes, geological environments and ore formation.

To enhance post-doctoral research career opportunities by actively involving research fellows in the planning, supervision and management of CODES research programs.

A classic selection from CODES 2004 PhD group: L to R, Blackwell Singoyi, Steve Lewis, Maya Kamenetsky, Tim Ireland, Kate Bull, Sofia Tetroeva, Paul Davidson, Mawson Croaker, Fiona Links, Brian Bowden, David Braxton.

Post-Doctoral and Research Fellows

- Sharon Allen began a five-year ARC Research Fellowship. Her research will focus on the products of explosive eruptions from felsic submarine volcanoes using data from the modern seafloor, numerical models and experimental simulations (Project 2.2).
- Cari Deyell completed the second year of her Canadian NSERC Fellowship. Cari has been a major player in the AMIRA project on epithermal-porphyry transitions led by David Cooke and Bruce Gemmell (Project 5.18). She undertook fieldwork for deposit studies in Chile, Peru, the Dominican Republic and Canada.
- Zhaoshan Chang joined CODES to work on epithermal-porphyry transitions, and AMIRA project led by David Cooke and Bruce Gemmell (Project 5.18). Zhaoshan undertook fieldwork for the project in Indonesia and the Philippines.
- Cathryn Gifkins devoted the year to completion of the latest CODES book, "Altered Volcanic Rocks", with co-authors Wally Herrmann and Ross Large (Project 2.1). The book will be ready for distribution early in 2005.
- Vadim Kamenetsky visited the Max-Planck Institute in Germany for six months in 2004, as part of his Humboldt Fellowship Bessel Award. Vadim worked on melt inclusions in magmas from diverse tectonic settings (Project 1.2). At the end of 2004, Vadim was successful in gaining a highly prestigious ARC Professorial Fellowship in recognition of his achievements in applying melt inclusion techniques in petrology and geochemistry.
- Rob Scott devoted much of 2004 to developing a new project entitled "Controls on the formation and sulfide trace element signatures of sediment-hosted gold deposits" (AMIRA P923) for Program 4. The project has attracted funding from five sponsors. Rob and David Selley are both involved in another new Program 4 project on Congolese Cu deposits that began at the end of 2004. This project is funded by AMIRA (AMIRA P872) and by an ARC Linkage grant. Stuart Bull contributed to both the sediment-hosted gold project and the Congolese copper project.
- Fernando Della Pasqua's research focused on collecting and compiling new anisotropy of magnetic susceptibility and petrofabric data for the analysis of source locations in the Gawler Range Volcanics (Project 2.9). He was also involved with Khin Zaw's work on the Loei Fold Belt (Project 1.8), the Houtoushan VHMS deposits in China, and LA-ICPMS analysis of sapphires from NE Tasmania (IRGS grant).
- Andrew Rae has been engaged in analysis of sulfides for trace elements using LA-ICPMS (Project 3.13) using samples from a variety of ore deposits.
- Leonid Danyushevsky continued to manage the LA-ICPMS facility, which is now widely used by staff and post-graduate students for numerous geochemical and geochronological applications.
- Khin Zaw began a three-year ARC Linkage project studying the geochronology, metallogenesis and deposit styles of the Loei Fold Belt in Thailand and Laos (Project 1.8). Zaw and Anthony Harris completed extensive fieldwork for the project and began analyses for the geochronology and deposit studies. Anthony is also involved in research on volatiles and metals in porphyry copper-gold hosting magmas (Project 1.1).
- Sebastien Meffre has devoted his time to developing the LA-ICPMS zircon dating technique in the CODES lab. He is also evaluating other minerals that may be suitable for dating by his technique.

PhD Program

There were eight PhD graduations in 2004, and two theses that were submitted in 2004 are currently under examination. CODES PhD students who submitted or graduated in 2004, and where they are now ...

James Cannell – Laos
Paul Davidson – CODES Program 1
Roman Leslie – Brisbane
Peter Frikken – Codelco, Chile
Owen Hatton – Lion Ore, WA
Neil Martin – Jaguar, WA
Christian Schardt – Johns Hopkins University, USA
Andrew Stewart – Ivanhoe Mines, Mongolia
Tony Webster – Perylia, Broken Hill
Andrew Wurst – Ivanhoe Mines, Mongolia

The new PhD students in 2004 are:

- Tim Ireland – Tim began a PhD project on the geology and structural evolution of the Collahuasi district in Chile, under the supervision of David Cooke and Ron Berry. Tim completed his undergraduate and Honours degree in 2001 at the University of Tasmania, and since then has been employed in mineral exploration.
- Claire McMahon – Claire's project involves a detailed study of trace elements in sulfide and oxide minerals of distal alteration zones and is supervised by Garry Davidson and Andrew Rae. Claire's

undergraduate and Honours degrees were undertaken at the University of Ballarat and she has an MSc degree from the University of Western Australia.

- Lee Robson – Lee is investigating the application of remote sensing techniques in geological mapping in western Tasmania. His project is supervised by Michael Roache and Ross Large. Lee has a BAppSc degree from James Cook University and an Honours degree from the University of Tasmania.

At the end of 2004, we welcomed two newcomers who will begin PhD projects at the beginning of 2005. Dinh Quang Sang, from Vietnam, will study the "Geological evolution of the northern suture zone of the Khontum Massif, central Vietnam". Sang's research will be supervised by Tony Crawford and Ron Berry. Weerapan Srichan, from Thailand, will also be supervised by Tony Crawford and Ron Berry. Weerapan (also known as Be) will undertake "Petrological-geochemical and tectonic studies of the Lampang volcanic belt, Thailand".

CODES had 28 PhD candidates at the end of 2004, very similar to the number in 2002-2003 but down from the all-time high of 37 in 2000. Recruitment of new PhD students within Australia has been challenging in the current extremely buoyant employment market for geologists, a situation that shows no sign of changing in the near future. As a result, CODES has invested additional effort in recruiting international candidates, several of whom are expected to commence new projects in 2005.

Former and current CODES students authored or co-authored 12 papers during 2004, with contributions from Michael Agnew, Leon Bagas, Robina Sharpe, Owen Hatton, Tim Ireland, Glenn Masterman, Nick Diren, Andrew Rae, Ali Raos, Andrew Stewart and Nick Williams. Our

PhD students were also well represented among presenters at national and international conferences, notably at the 17th Australian Geological Congress in Hobart and the Society of Economic Geologists' conference in Perth.

Master of Economic Geology Program

CODES Master of Economic Geology program is part of the National Masters Program supported by the Minerals Council of Australia.

Along with the boom in the minerals industry the Masters program has experienced something of a recruitment boom with ten new students joining the program. The mix of new students based in Australia includes Steve Groves (Newmont), Steve Brown (Randgott Exploration), Carl Jackman (Ivanhoe Mines), Alex Eaves (Robe River Mining), and Damian Jungman and Chris Gaughin who are both independent contractors. On the international scene we have seen the arrival of Bronto Sutupo (Newmont, Indonesia), Renee Gonzales (Anglo American, Phillipines), and Eggy Arbi and Allan Ketaren (Ivanhoe, Mongolia).

Continued strong interest from across the minerals industry indicates that 2005 should also be a good year for student recruitment.

As well as the new arrivals we have also seen some excellent theses completed, including those from:

- Steven Lewis – Structure and stratigraphy of the Harp Prospect, Broken Hill.
- Len Kolff – Iron oxide mineralisation at Semandou, Guinea, west Africa.
- Leon Bagas - Proterozoic evolution and tectonic setting of the northwest Paterson Orogen, Western Australia.

Leon submitted his thesis as a series of three papers,

one of which was published in *Precambrian Geology*. Together with an introductory chapter and conclusions, these works make up one of the best Master of Economic Geology theses submitted at CODES, and will be used as a model for other students wishing to publish as well as complete a thesis.

Several other students such as Mannie Mehu from Lihir Gold and Felipe Urzua from BHP Billiton have completed their coursework requirements and are now busily finishing their main thesis projects.

During the year, three Masters short-course modules were held. Jocelyn McPhie ran the usual superbly organised "Volcanology and mineralisation in volcanic terrains", a field-based course in New Zealand and western Tasmania. The "Ore deposit models" course was successfully combined with the three-day 24 Carat Gold Workshop. The combination of the ore-deposit models course with a topical workshop continues to be a great success and 111 delegates attended the workshop at the Wrest Point Casino, some of whom came from such far-flung places as Canada, USA, Phillipines, Indonesia and Ghana.

Nine delegates also took part in the pre-workshop field trip which visited Mount Lyell and Rosebery mines and included an underground visit to Henty. The conference presenters gave a range of up to date, informative discussions about a variety of styles of gold mineralisation including lode gold, porphyry copper-gold, low sulfidation epithermal gold, VHMS gold, high-sulfidation epithermal gold and carbonate replacement gold. Some of the highlights were talks from Guy Gosselin, Steve Kessler, Brian Levet, Doug Kirwin and Francois Robert, and from past CODES graduates Alan Wilson, Adrian Byass and Andrew Davies.

Thirteen of the workshop participants undertook the course as part of the Master in Economic

Geology degree, including four students from UWA doing the course under the National Masters umbrella.

Finally CODES unveiled its newest course, Brownfields Exploration, to a full house of 16 attendees. This course, led by Steve Walters, has been developed to cover a wide range of topics and exploration strategies designed to facilitate exploration in the data-rich environments close to operating mines. Guest presenters included Simon Gatehouse, Vic Wall lan Tedder and in-house staff including Steve Walters, Michael Roach, James Reid, Ross Large, PeterMcGoldrick, BruceGemmell, Kim Denwer and Andrew Tunks. The culmination of the course came during the "West Coast Challenge" which is a two-day data compilation and targeting exercise based on all the open file data from 50 years of exploration in the Mount Read Volcanic Belt of western Tasmania. Students could select which datasets they felt most relevant and plan a limited drilling program to test for VHMS-style mineralisation. Students were then required to submit and present in PowerPoint

their exploration programs to a panel of judges. The inaugural prize went to Steven Groves for his excellent targeting strategy.

Minerals Tertiary Education Consortium

CODES continued its close relationship with the Minerals Council of Australia through its Minerals Tertiary Education Consortium (MTEC). The support from MTEC is used to exchange students between universities both within the Honours and Masters programs.

This gives CODES students access to specialised courses that would not normally be available at UTAS. It also allows students from the mainland to travel to Tasmania to experience courses offered by CODES.

MTEC funding has also been used in the construction of a new CD focussed on recruiting quality postgraduate students to the Masters and PhD programs at CODES and the School of Earth Sciences.

Honours

The program was administered by Garry Davidson and Peter McGoldrick in 2004, with overall supervisory roles undertaken by 13 CODES staff members. The Honours student population (15) was again smaller than many previous years, including four students attracted from mainland Australian states and overseas. Subjects covered were very diverse, but broadly there was a clear move towards economic geology (10 students). In terms of geographic area, six Tasmanian projects were undertaken. However, in 2004, we had an unusually large number of projects overseas (4) compared to mainland Australia-based sites (5). This reflects the current strong activity in southeast Asia, in the major project lead by Khin Zaw. It also attests to the integration of undergraduate studies and research in the CODES scientific program. Of the calendar year group, an excellent outcome was the granting of five first-class Honours, with one result still unknown at the time of publication.

CODES postgraduate courses in the national MTEC Program 2004

Course Unit	Degree	Location	Number of Students	Leader
Volcanology	Master of Economic Geology	New Zealand, western Tasmania	15	J McPhie
Ore Deposit Models & Exploration Strategies	Master of Economic Geology	UTAS	16 + 80 industry	Andrew Tunks
Brownfields Exploration	Master of Economic Geology	UTAS	16	Steve Walters
Exploration Skills Mapping Camp	Honours	Western Tasmania	24	Andrew Tunks
Environmental Geology Field Techniques	Honours	UTAS	6	David Cooke
Ore Deposit Models for Mineral Exploration	Honours	University of Melbourne	9	Ross Large



teckcominco



Industry Links

CODES has developed an international reputation of undertaking research which is relevant to, and closely linked with, the minerals industry. In 2004 we were supported by twelve major corporate sponsors and were involved in research collaborations with over 40 national and international mining/exploration companies.

Strategy

There are five elements in our industry links strategy:

- CODES Corporate Sponsors program
- AMIRA research projects
- ARC Linkage projects
- Industry-linked student projects
- Short courses for industry.

CODES Corporate Sponsors in 2004

Anglo American
 AngloGold Ashanti
 Barrick
 BHP Billiton
 Gold Fields Australasia Pty Ltd
 Newcrest
 Newmont
 Rio Tinto
 Teckcominco
 WMC
 Xstrata
 Zinifex

Benefits of being a CODES Sponsor

- Association with, and first call on, world-class research team in ore deposit science.
- Membership of CODES Science Planning Panel.
- Access to scholarships for staff undertaking Masters courses.
- Fee reductions on regular short courses and special in-house courses.

Corporate Sponsors Program Sponsorships are vitally important in maintaining critical mass at CODES and to ensure the development, and nurturing, of strategic and applied research programs relevant to the exploration industry. We are grateful for the continuing support of the above sponsors, and look forward to signing up further corporate sponsors as the exploration climate continues to improve. During 2004, two new sponsors joined the sponsors program; Teckcominco and Zinifex.

AMIRA Research Projects

CODES is currently operating four projects under the AMIRA umbrella.

1. Project P765 'Transitions and zoning in porphyry-epithermal districts: indicators, discriminators and vectors' is funded by seven sponsors and an ARC Linkage grant, and has work programs in Chile, Peru, Dominican Republic, Indonesia and the Philippines. Further details are listed under the Research section (Project 3.14 and 5.18).
2. Project P843 "Geometallurgical Mapping and Mine Modelling – GEM^{III}" is funded by ten sponsors. An ARC Linkage grant application was submitted in late 2004. Further details are given on page 9.
3. Project P872 "Cu-Co mineralisation in the Congolese, Zambian and Central Australian Basin systems" has attracted nine sponsors and an ARC Linkage grant. Field work has begun

on the super-giant sediment-hosted copper systems of the Democratic Republic of the Congo (DRC) in the second half of 2004. Further details are listed under the Research section (Project 4.6).

4. Project P923 "Controls and formation and sulfide trace element signatures of sediment-hosted Au deposits" has attracted four sponsors. An ARC Linkage grant application was submitted in late 2004. Further details are listed under the Research section (Project 4.13).

ARC Linkage Projects

During 2004, CODES researchers held eight ARC-Linkage grants. Major Linkage projects include David Cooke and Bruce Gemmell's transitions and zonation in porphyry-epithermal mineral districts (Project 3.14), Khin Zaw's SE Asian-based project on the development and mineralisation potential of the Loei Fold Belt in Thailand (Project 1.8), and Garry Davidson and Mark Norman's project on trace element levels in sulfide minerals (Project 3.13). APAI-Linkage PhD projects include the Mt Oxide copper deposit, Queensland, the Jaguar VHMS deposit, Western Australia, the Mt Bischoff tin deposit, Tasmania and a tailings pile groundwater study at the Rosebery deposit Tasmania.

Industry Linked Student Projects

Some 65% of 2004 post-graduate students were working on projects with industry support and/or collaboration. This support varies from providing access and in-kind logistics assistance, through to full scholarship support.

The Tasmanian Government Mining Scholarship Scheme continues to support PhD and Honours students to undertake research, in collaboration with industry partners, which is directly relevant to the Tasmanian mining industry. In 2004, two PhD

students (Kim Denwer studying Mt Lyell and Singoyi Blackwell studying magnetite geochemistry) and five Honours students were funded by this scheme.

Short Courses and Workshops for Industry and Academic CODES holds a series of short courses and workshops each year to increase its national and international profile and transfer recent research results to fellow academics, government scientists and members of the exploration and mining industry.

The following courses were held in 2004 and involved the participation of CODES staff and invited national and international speakers:

- The Masters of Economic Geology field-based short course on "Volcanology and mineralisation in volcanic terranes" was led by Jocelyn McPhie and Bruce Gemmell in New Zealand and western Tasmania. Sixteen participants attended (14–28 March 2004).
- Ross Large and David Cooke ran a two-day short course on "Ore deposit models for mineral exploration" for 45 industry and postgraduate students at the University of Chile (17–18 March 2004).
- Ross Large, Bruce Gemmell, David Cooke, Steve Walters and Garry Davidson taught a five-day "Ore deposit models" short course for 10 VIEPS participants at the University of Melbourne (10–14 May 2004)
- Stuart Bull, David Cooke, Garry Davidson, Bruce Gemmell, Ross Large, Peter McGoldrick, David Selley, Andrew Tunks and Steve Walters presented portions of the Master of Economic Geology "Ore deposit models and exploration strategies", short course. This course included the highly successful 24 ct Gold workshop and attracted 84 industry and academic geologists (14–25 June 2004).
- David Cooke and Anthony

Harris led a three-day fieldtrip through central NSW as part of the "Tectonics to Mineral Discovery-Deconstructing the Lachlan Orogen" SGA-MORE-SGEG conference (4–9 July 2004).

- A short course entitled "Volcanology and VHMS deposits" was presented by Jocelyn McPhie and Bruce Gemmell at the University of Asmara in Eritrea. The course was sponsored by Sanu Resources, Sub-Saharan Resources and Nevsun, three mining companies operating in Eritrea. About 70 participants from mining companies, the University of Asmara and the national geological survey attended the 6-day lecture and field course (1–6 August 2004).
- Jocelyn McPhie and Wally Herrmann presented a four-day short course "Introduction to volcanology and hydrothermal alteration" to AngloGold Ashanti geologists at the Sunrise Dam Gold Mine in Western Australia (19–22 October 2004).
- James Reid, Mike Roach, Steve Walters and Bruce Gemmell taught portions of the Master of Economic Geology "Brownfields exploration" short course which attracted 16 industry participants (8–19 November 2004).
- The annual "Volcanic successions" short course run by Monash University was presented by Ray Cas, Jocelyn McPhie and Steve Beresford. The five-day course attracted 20 industry and survey participants (6–11 December 2004).

Finances

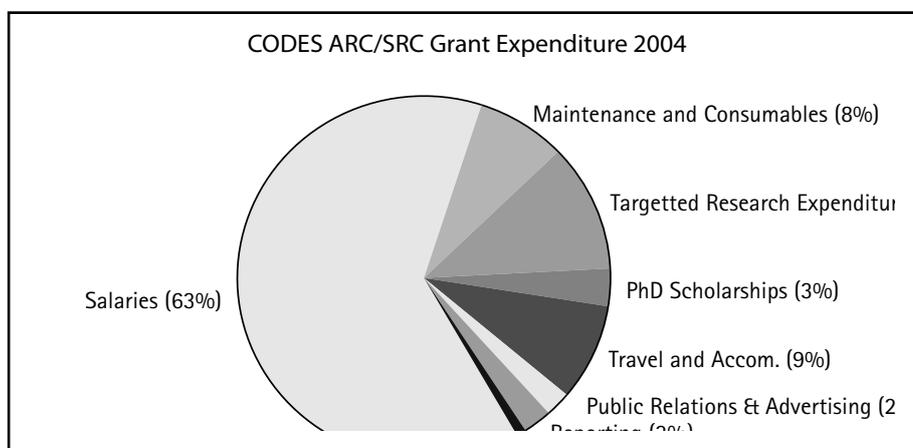
Total Income for 2004 from all sources was \$4.2 million - approximately 7% up on 2003. Income sources are shown in the pie chart.

University financial support increased by \$40,000. Industry funding was up \$200,000 overall, reversing last year's downward trend. The increase in Industry funding resulted from two large linkage projects which started in 2004 (continuing until 2006 and 2007), plus increased funding from MCA for the coursework Masters program. Contracts/Revenue Raising income increased by \$60,000 overall, mainly due to a successful Ore Deposit Workshop and an increase in book sales.

Although ARC funding remained stable overall, there were changes within the individual ARC income streams. There was a significant increase in Linkage, Discovery Grants and IRGs, however this was balanced by a similar decrease in Fellowship grants. The 70k decrease in State Government funds was due to the completion of a large MRT-funded research project in 2003. All other income streams remained stable.

CODES ARC/SRC Grant Expenditure 2004

INCOME	
SRC Grant	948,070
End of year balance brought forward from previous year	(7,207)
Misc income from refund of expenditures	3,909
Commitments brought forward from previous year (SRC a/c)	0
Total budget	944,772
EXPENDITURE	
Salaries	(625,996)
Equipment	(8,709)
Travel and Accommodation	(84,217)
Maintenance/consumables	(79,113)
Other	
PhD Scholarships	(32,966)
Public Relations and Advertising	(21,205)
Reporting	(25,236)
Targetted Research Expenditure	(112,738)
Total expend	(990,180)
Account balance at 31.12.04	(45,408)



Notes to and forming part of the Financial Statements for the year ended 31.12.2004

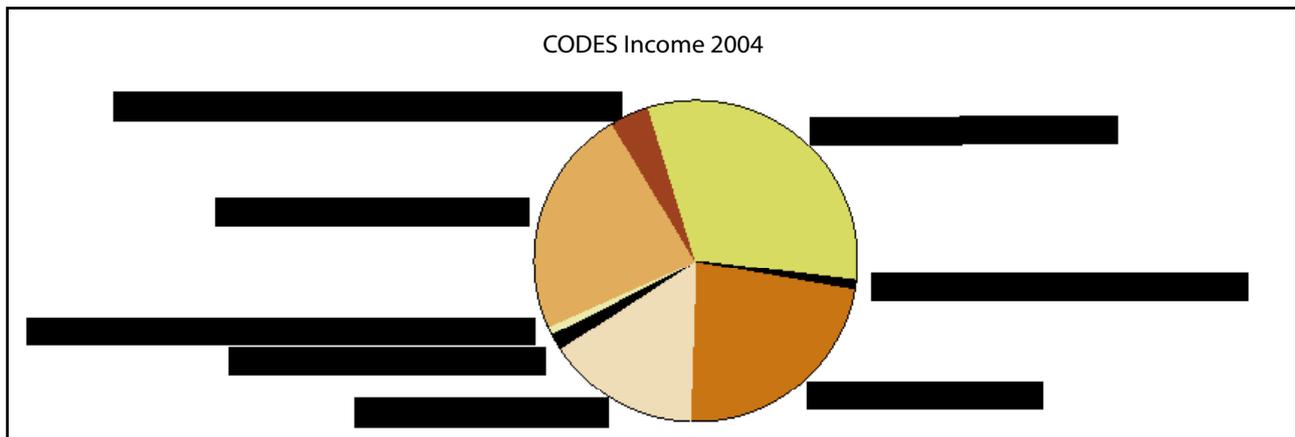
CODES financial data and reports for 2004 were prepared by Christine Higgins, CODES Finance Manager. Data was extracted from the University of Tasmania's Financial Management Information System and CODES Finance Databases. All reports shown here have been audited by the University of Tasmania.

The University operates under an accrual accounting system, therefore income figures shown here represent all income 'due' (invoiced) in 2004. Expenditure figures shown represent 'actual' expenditure in 2004.

In 2004 there have been no accounting changes, and income/expenditure categories are consistent with previous years (with the exception of some minor name changes which have been explained in the relevant Annual Report, in the notes to the Financial Statements).

CODES Income 2004

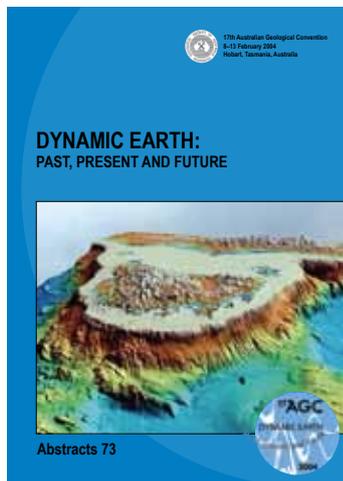
ARC - SRC Grant		948,070
Other ARC Grants		
Linkage Grants and Collaboratives	319,098	
Discovery Grants (previously called Large Grants)	273,099	
Fellowships	0	
Institutional Research Grants (previously called Small Grants)	45,254	
RIEF Grant	0	637,451
Other Commonwealth Government Funds		
Scholarships	0	
Miscellaneous	27,390	27,390
State Government Funds		
Tasmanian State Govt. - Scholarships (2003-2004)	68,000	
Directly funded research projects	9,769	
Miscellaneous	0	77,769
Local Government Funds		0
Industry/Private Funds		
AMIRA	182,987	
Industry - Other Projects	281,154	
Industry - Student Funded Projects	155,753	
CODES Industry Sponsors	140,000	
Minerals Council of Australia (MTEC)	173,590	
Miscellaneous	28,950	962,434
Contracts/Consultancies/Revenue Raising		
Short Courses	92,706	
Book Sales	31,744	
Consulting	0	
Miscellaneous	35,501	159,951
University of Tasmania - Host Institution Support		
University Support to Salaries	824,869	
General Operating Grant	113,759	
Infrastructure Grants (includes RIBG)	235,635	
University Strategic and Tasmanian Scholarship	83,178	
Faculty Scholarships	0	
Student Fee Income	60,000	
Research Excellence Grant	0	
Performance Pay	8,243	
Study Leave	0	
Minor Works Grant	0	1,325,684
Other Income Sources/Interest		
Miscellaneous	37,079	37,079
Grand Total		4,175,828



Publications

Edited Book

McPhie, J. and McGoldrick, P. (Editors), 2004. *Dynamic Earth: Past, Present and Future*, GSA Abstracts, vol. 73. Geological Society of Australia, Hobart, 312 pp.



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CODES Conference Contributions to the 17th AGC and SEG 2004

In 2004 CODES staff and students made major contributions to two high-profile international conferences. Early in the year the 17th Australian Geological Convention (the Geological Society of Australia's major biennial scientific meeting) was held in Hobart at Wrest Point Conference Centre. It was the first time in fourteen years that an AGC had been held in Hobart and over 700 people attended. Peter McGoldrick was the overall Technical Session convener and this part of the conference was organised around six main themes. Within these themes a number of the individual topical sessions were convened by other CODES staff. Out of a scientific program of around 600 papers more than 70 involved CODES staff or post-graduate students as authors or co-authors. In Theme 2 (Geology and Resources) alone, nearly a quarter of the papers had CODES authors.



In September, on the other side of the continent in Perth, CODES had a strong presence at the Society of Economic Geologists biennial scientific meeting. Many of the CODES delegates were post-graduate students supported by the SEG. Sixteen different papers or posters involved CODES authors and highlights were Ross Large's SEG presidential address "Ore deposit models, the deposit spectrum and hybrid ore deposits" and a student-prize winning poster by Nicky Pollington called "Sulfide mineral chemistry at Konkola North, Zambia".

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Field Guides

- Berry, R.F. and Bull, S.W., 2004. Geological Society of Australia Field Guide A2: A geological excursion

Appendices

CODES POSTGRADUATE STUDENTS 2004

Name	Supervisors	Project	Industry/Govt support
Bachelor of Science (Honours)			
Nathan Allen S	W Herrmann, G Davidson	Origin and features of Cambrian gold mineralization in the Elliott Bay area, Tasmania	Tasgold NL, TGMS
Derek Backhouse #	K Zaw, W Herrmann	Geological setting, alteration and nature of mineralization at the Phu Kham copper-gold deposit, Laos PDR	ARC Linkage
Adam Bath	DKamenetsky, ACrawford	Petrogenesis of the Gawler Range Volcanics from a melt inclusion perspective (provisional title; mid-2004 start)	
Michael Bavea	G Davidson	Groundwater delineation and chemistry of the Smithton Dolomite karst aquifer	DPIWE, MRT/TGMS
Kate Bromfield #	C Burrett, P Quilty	Palaeoenvironmental reconstruction of the Jurassic, using plant macrofossils from a site at Lune River, Southeast Tasmania	TGMS Great Southland Minerals
Richard Chopping	J Reid	High resolution geophysical pit mapping at the St Ives gold mine, WA	St Ives gold mine, Goldfields Ltd
Andy Crawford*	A Crawford	Origin of the Bond Range porphyry	SEG funds?
Grace Cumming	S Allen, J McPhie, K Zaw	Volcanic facies of the Chatree gold mine, central Thailand	ARC linkage
Nicholas Fitzpatrick #	A Harris, G Davidson	Controls on intrusive gold-related mineralization in the Lisle/ Golconda area, NE Tasmania	Tasgold NL
Kerrin Gale#	D Cooke, B Gemmell	Vein paragenesis of the Backdoor Prospect, Telfer District	Newcrest
Kate Godber*	G Davidson, M Roach	Ground magnetic mapping of the oceanic crust, Macquarie Island	AUSIMM scholarship
Jhana Hale*	J Reid	Geophysical investigation and interpretation of the Temma area, northwest Tasmania	MRT/TGMS, SEG
Ben Hey	M Roach	Geophysics of granite-hosted old mineralization beneath the Enterprise workings, NE Tasmania	Tasgold NL
Ned Howard	B Gemmell, W Herrmann	Alteration facies at the Darwin South orebody, Henty, Tasmania	MRT/TGMS, HentyGoldLtd
Teera Kamvong #	K Zaw, A Harris	Geochemistry and genesis of Phu Lon copper-gold skarn deposit, northeast Thailand	ARC Linkage
David Kratzman*	C Gifkins, J McPhie	Volcanology of the Sterling Valley volcanics, Mount Read Volcanics, Tasmania	TGMS
Emma Mathews*	S Allen, C Gifkins, C Reid	Stratigraphy and volcanology of a submarine apron from an offshore stratovolcano, Waitakere group, Muriwai, New Zealand	
Todd McGilvray*	P McGoldrick, C. Burrett	Geology and mineralisation of Oceana Zn-Pb deposit Zeehan area	Zeehan Zinc
Chris Parker*	J Reid, G Davidson	Vulnerability and aquifer potential of the Cowrie Siltstone aquifer around the Circular Head waste transfer site using geophysical, hydrogeochemical and hydrological methods	Australian Bulk Minerals and Circular Head Council
Lee Robson*	M Roach	A remote sensing and geophysical investigation of the central midlands, Tasmania	MRT/TGMS
Aaron Scollard *	M Roach, J Reid	Seismic investigation of the southern D'entrecasteux Channel, south Tasmania	
John Stephenson #	M Roach	A geophysical investigation of Frances Creek, Northern Territory	NTGS

Trent Strickland	D Cooke, C Deyell	Origin and significance of copper-bearing breccia at the E42 gold deposit, New South Wales	Barrick Gold
Hugh Tassell *	M Roach, R Coleman, J Reid	Seismic investigation into the ice thickness and seabed topography beneath the Amery Ice Shelf, Eastern Antarctica	ANARE
Brett Thomas*	A Tunks	Geology of the Minjar Project, Western Australia	Gindalbie Gold
Ian Wilson*	J Reid	HEM data levelling – The Clump, NW Tasmania	MRT/TGMS, SEG
Master of Economic Geology			
Abdul Arbi			Ivanhoe
Leon Bagas*	B Gemmell	Geology of the Paterson Orogen	GSWA
Stephen Brown			
Brett Butlin	A Tunks	Course work masters program	Barrick Gold of Australia
Andrew Dacey*		Course work masters program	Consultant
Adrian Fabris		Course work masters program	PIRSA
Christopher Gaughan			
Steven Groves	B Gemmell	Geology & Genesis of Moonlight Prospect, Patingo epithermal system	Newmont
Alan Ignacio	D Cooke	Boyongang porphyry system	Anglo American
Carl Jackman			
Anthony Johnston		Course work masters program	Geological Survey of NSW
Damian Jungmann			
Alan Ketaren			Ivanhoe
Lennard Kolff*	A Tunks	Seemandoo iron deposit, Guinea, West Africa	Rio Tinto
Steven Lewis*	W Herrmann	Structure and lithostratigraphy of the Harp Prospect, Broken Hill	Perilya
Mannie Mehu	B Gemmell, W Herrmann	Regional exploration around Lihir	Lihir Gold
Gem Midgley	D Cooke	Isotopic variations in Carlin-type gold deposits, Nevada	Anglogold
David Nixon	A Tunks	Gold mineralisation in the Tanami region	Barrick Gold of Australia
Dan Power		Gold mineralisation at Groundrush, Tanami	Newmont
Peter Pring			
Course work masters program			
Finlay Robertson			
Nalin Shah*	G Davidson	Geology and dating of the Mangalwar Complex, with reference to Rampura Agucha, Rajasthan, India	BHP Billiton
Bronto Sutopo	B Gemmell	Matarbe high-sulfidation epithermal deposit, Indonesia	Newmont
Simon VanDerWielen			
Master of Exploration Geoscience			
Albert Chong	B Gemmell, R Berry	Geology, mineralization, metal distribution and genesis of the Polymetallic Ridge and Marshall Zones, Battle Lake Camp, Vancouver Island, Canada	Boliden-Westmin
Rene Gonzales	D Cooke	Regional structure Boyongang	Anglo American
Matthew Hope*	P McGoldrick, S Bull	The Geological Evolution of the Norseman area, Western Australia	Central Norseman Gold
Terence Hoschke	R Large, M Roach	Geophysical signatures of gold-copper porphyry systems	Normandy
Kamonporn Kromkhun	K Zaw, D Cooke, A Harris	Geological setting, alteration, mineral paragenesis, & nature of ore fluids at 'H' zone, Chatree gold deposit, central Thailand	Pan Australia

Felipe Urzua	D Cooke, A Tunks	Regional geology of Escondida district, Northern Chile	Anaconda and BHP Billiton
Doctor of Philosophy			
Darren Andrews	J Reid, M Roach	Time-lapse geophysical monitoring of acid drainage at Savage River Mine, northwestern Tasmania	Goldamere Pty Ltd, DPIWE, Aust Bulk Minerals
Michael Baker	A Crawford, R Berry	Palaeoproterozoic magmatism in the Georgetown Block, N Queensland, and comparisons with Broken Hill block.	GSNSW, GSQ
Bryan Bowden	G Davidson, R Large	Iron oxide copper-gold related alteration history of the Mt Woods Inlier, SA, with special emphasis on the Prominent Hill prospect.	PIRSA Minotaur Resources, Goldstream Mining, Geoscience Aust
David Braxton	D Cooke, A Rae	Origin of the Boyongan porphyry Cu-Au system, Philippines	Anglo American
Katharine Bull	J McPhie, A Crawford	Facies architecture of the Ural volcanics, NSW	SEG, GSNW, ARC SRC
James Cannell	D Cooke, M Solomon	El Teniente porphyry Cu-Mo deposit, Chile: geology, geochemistry and genesis	Codelco, GODS AMIRA/ ARC Linkage
Dene Carroll	A Crawford, S Meffre	Tectono-magmatic evolution of eastern Viti Levu, Fiji.	NSW ARC Linkage
Mawson Croaker	D Selley, P McGoldrick	Geology and genesis of the Nkana copper deposit, Zambia.	AMIRA ARC Linkage
Paul Cromie	K Zaw, D Cooke, N White	Geological setting, geochemistry and genesis of the Sepon mineral district, Laos	OXIANA
Paul Davidson*	D Kamenetsky, A Crawford	Melt inclusions in porphyry Cu-Au-hosting magmatic systems	ARC SRC
Kim Denwer	R Large, W Herrmann	Mineralogical, geochemical and isotopic investigation of the Mount Lyell Cu-Au orebody and alteration system.	MRT/TGMS, Copper Mines of Tasmania
Gregory Ebsworth	J McPhie, A Crawford	Regional volcanic facies analysis of the Tyndall Group, Mount Read volcanics, Tasmania	MRT/TGMS
Lee Evans	G Davidson, D Cooke	Groundwaters in wet, temperate sulfide mining districts: Delineation of modern fluid flow and predictive modelling to improve management after mine closure (Rosebery, Tasmania).	Zinifex, ARC Linkage
Peter Frikken*	D Cooke, P Hollings, J Walsh (CSIRO)	Breccia-hosted Cu-Mo mineralisation at Rio Blanco, Chile	Codelco, AMIRA ARC Linkage
Russell Fulton	B Gemmell, R Berry	Geology and geochemistry of the hanging wall argillite, Greens Creek VHMS deposit, Alaska: implications for ore genesis and exploration.	Kennecott Greens Creek Mining
Owen Hatton*	G Davidson, S Bull	Basin configuration, sedimentology and volcanology of the Toole Creek Volcanics, Mount Isa region, Queensland	BHP Billiton, Aust Bulk Minerals, Savage River Mine, Goldstream
Tim Ireland	D Cooke, R Berry, B Gemmell	Geology and structural evolution of the Collahuasi District, Northern Chile.	Codelco, AMIRA/ARC Linkage
Ben Jones	R Large, A Crawford	Genesis of the Antapaccay Cu-Au porphyry deposit, Peru.	BHP World Minerals
Maya Kamenetsky	A Crawford, L Danyushevsky	Nature of primary melts in intracratonic settings: application of melt inclusions studies to kimberlites (Siberia)	ARC Discovery W. Paul project (A. von Humboldt Foundation)
Lyudmyla Koziy	R Large, D Cooke	Numerical simulation of fluid flow and fluid chemistry in sedimentary basins.	AMIRA P552
Roman Leslie	L Danyushevsky, A Crawford	Petrology and geochemistry of shoshonites in the southwest Pacific	ARC Discovery
Steven Lewis	G Davidson, R Berry	Sulfidic hydrothermal alteration in late brittle faults, Macquarie Island.	Aust. Aut Division, Aus IMM, SEG
Wallace Mackay	D Selley, S Bull	Sedimentology and structure of the Curdimurka Subgroup, Willouran Range, South Australia.	AMIRA/ ARC Linkage
Rodney Maier	P McGoldrick, R Large	Pyrite and base metal trace element haloes in the northern Australian Zn-Pb-Ag deposits.	ARC SRC Anglo American
Neil Martin*	R Large, S Bull	Genesis of the Rosebery VHMS deposit, western Tasmania.	Zinifex, ARC Linkage
Claire McMahon	G Davidson, A Rae	Controls on the geochemistry of hydrothermal pyrite in ore systems.	ARC Linkage
Nicole Pollington	P McGoldrick, S Bull	Sedimentology, mineral paragenesis and geochemistry of the Konkola North copper deposit, Zambia.	AMIRA/ ARC Linkage
Lee Robson	M Roach	Application of remote sensing for geological mapping in western Tasmania	MRT/TGMS

Carlos Rosa	J McPhie, B Gemmell, J Relvas	Submarine volcanic successions in the Iberian Pyrite Belt, Portugal	Portuguese Science and Technology (FCT) fund, Mining and Geological Institute (IGM) of Portugal
Christian Schardt*	R Large, J Yang, D Cooke	Controls on hydrothermal fluid migration by volcanic facies architecture: implications for massive sulfide deposit formation.	ARC SRC
Blackwell, Singoyi	G Davidson, K Zaw, R Large	Controls on the geochemistry of magnetite in hydrothermal fluids	MRT/ TGMS, Newcrest
Craig Stegman	R Large, R Scott	Geochemistry and structure of gold - basemetal mineralisation in the Cobar Gold Field, NSW	Rio Tinto
Andrew Stewart*	J McPhie	Volcanic facies architecture and evolution of Milos, Greece	Royal Gold and Midas SA
Sofia Tetroeva	L Danyushevsky, A Crawford	Petrology & geochemistry of adakites & related rocks from the Hunter Ridge, Southwest Pacific	ARC SRC
Andrew Tyson	M Roach, D Cooke	Geophysical characteristics of porphyry and epithermal deposits.	AMIRA/ ARC Linkage
Tony Webster*	R Berry, R Large	The structural evolution of the Broken Hill Pb-Zn-Ag deposit, New South Wales	ARC SRC
Andrew Wurst*	B Gemmell, D Cooke	Geology and genesis of the Permata-Batu Badinding-Hulubai and Kerikil Au-Ag low sulfidation epithermal deposits, Mt Muro, Kalimantan, Indonesia.	PT Indo Muro Kencana, AMIRA/ARC Linkage

* graduated 2004 § part-time/mid-year start # submitted 2004

AMIRA/ARC (Linkage) Projects 2004

Investigators	Project	Partners	Period	ARC Funding for 2004	Industry Funding for 2004
P McGoldrick, S Bull, D Selley, R Scott, D Cooke, R Large, M Blake, M Hitzman (CSM); PhD projects: D Broughton (CSM), N Pollington, M Croaker, W Mackay (CODES)	AMIRA P544: Proterozoic sediment-hosted Cu deposits: a comparison of Zambian and Australian environments (Project 4.6).	Anglo American (Zamanglo), AngloVaal Minerals, BHP Billiton, PIRSA, First Quantum-Mopani, Inco Exploration, Mount Isa Mines Exploration, Outokumpu, Phelps Dodge Exploration, Rio Tinto, Teck Corporation, WMC	2000-2004	\$23,886	\$18,287
D Cooke, JB Gemmell, C Deyell, N White	AMIRA P765. Transitions and Zoning in Porphyry-Epithermal Districts: Indicators, Discriminators, and Vectors	Anglo American, Anglo Gold Ashanti, Goldfields, Newcrest, Newmont, Placer, Teckcominco	2004-2006	\$112,574	\$164,700
D Selley, S Bull, M Hitzman, D Broughton, R Scott, R Large, P McGoldrick, M Roach	AMIRA P872 Sediment-hosted Cu-deposits of Congolese, Zambian & Central Australian basin systems	African Rainbow Minerals, Anvil Mining, CVRD, Equinox Minerals Limited, Anglo American, BHP Billiton, Enterprise Generale Malta Forrest, Phelps Dodge Exploration Corporation	2004-2007		\$64,780

ARC (Linkage) Projects 2004

Investigators	Project	Partners	Period	ARC Funding for 2004	Industry Funding for 2004
G Davidson, D Cooke, J Yang (PhD project: L Evans)	Ground waters and fluid flow predictive modelling for management after mine closure	Zinifex	2001-2004	\$11,943	
GJ Davidson, Norman M	What Controls Trace Element Levels in Ore Sulfides? A Laser-ICPMS Perspective	Anglo American; AngloGold; BHP Billiton Ltd; Newcrest Mining Limited; Newmont Exploration Pty Ltd; Placer Dome	2003-2005	\$78,589	\$13,000
Zaw, K; Meffre, S; Herrmann, W; Golding, SD; Harris A		Kingsgate Consolidated NL; Oxiana Resources NL; Pan Australian Resources NL	2004-2006	\$92,106	\$60,000

ARC Discovery Grants 2004

Investigators	Project	Period	ARC Funding for 2004
L Danyushevsky	Role of melting of oceanic crust	2003-2005	\$41,904
J McPhie	Volcanology of voluminous felsic lava	2003-2004	\$50,285
A Crawford	Tectonic paradox of the eastern margin of the Australian Plate, 120-45 Ma	2003-2005	\$78,570
S Allen	Submarine Explosive Eruptions of Silicic Magma: Constraints on Products and Processes from Modern Sea-floor Examples, Ancient Successions and Experiments	2004-2008	\$102,340

Other Research Grants 2004

Investigators	Project	Funding Body	Partners	Period	Funding for 2004
D Cooke, A Rae (PhD project: D Braxton)	Boyongan Porphyry Copper-Gold Deposit, Surigao, Philippines	Anglo American Exploration		2003-2005	\$35,633
W Herrmann, R Large	Sunrise-Cleo Sulfide Trace-element, SWIR and volcanic facies vectors	AngloGoldAustralasia		2003-2004	\$56,500
B Gemmell (PhD project: R Fulton)	Geology and geochemistry of the Hangingwall Argillite, Greens Creek VHMS deposit, Alaska: implications for ore genesis and exploration	Kennecott Greens Creek Mining Company		2001-2004	\$36,178
K Zaw, D Cooke, N White, C Ryan (PhD project: P Cromie)	Geological setting, geochemistry and genesis of the Sepon mineral district, Laos	Oxiana Resources NL		2003-2005	\$14,700
G Davidson (PhD project: B Bowden)	Mt Woods Inlier project	Primary Industry and Resources, South Australia	Geoscience Australia, Goldstream Mining N.L, Minotaur Resources	2003-2005	\$3,750
L Danyushevsky	Trace element analysis, of fish otoliths by LA-ICPMS	Falkland Islands Government		2003-2004	\$45,000
JB Gemmell, R 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	\$40,262
M Roach	Georange Project 8125	Georange Sweden		2003-2004	\$17,156
G Davidson	Bicentennial Gold 88 End	AUSIMM		2004-2005	\$2,000
L Danyushevsky	Analysis of otoliths	Faulkland Island Government		2004	\$20,000

COLLABORATIONS WITH CODES 2004

International institutions			
Institution	Researcher	CODES collaborators	Project
Akara Mining Limited (Thailand)		S Allen, J McPhie, A Harris, K Zaw	Volcanic facies architecture of the central Loei Belt, Thailand
Cardiff University	David Rickard	P McGoldrick, R Large	Pyrite textures from the McArthur River Zn-Pb-Ag deposit
Colorado School of Mines	M Hitzman, B Trudgill, D Broughton, M Nabighian.	D Selley, S Bull, R Scott, P McGoldrick, R Large, M Roach.	Sedimentary Cu deposits in Zambia and the Democratic Republic of Congo
Colorado School of Mines	J Hedenquist	D Cooke, Z Chang, C Deyell	Lepanto mineral district, Philippines
Columbia University (USA)	C Small	L Danyushevsky	Magmatic and tectonic processes along the Hunter Ridge, SW Pacific
Department of Mineral Resources (Thailand)	Somboon Khositantont	S Allen, J McPhie, A Harris, K Zaw, G Cumming	Volcanic facies architecture of the central Loei Belt, Thailand
Duke University	J Karson	G Davidson	Macquarie Island tectonics to contain fluid flow
Free University (The Netherlands)	M Elburg	D Kamenetsky	Origin of low-Ca olivine in enriched, subduction-related picrites.
GFZ Potsdam (Germany)	R Thomas	D Kamenetsky	Determination of water in glasses using laser Raman spectroscopy
Geological Survey of Sweden	Magnus Ripa	S Bull	Regional stratigraphy, basin evolution and setting of Zn-Pb-Cu-Ag-Au deposits in Bergslagen district, Sweden
GEOMAR, Germany	Armin Freundt	S Allen	Experimental simulations of submarine volcanoclastic mass-flows
Geomarine Research (New Zealand)	Bruce Hayward	S Allen, B Hayward	Facies characteristics of volcanoclastic mass-flow deposits
Hefei University (PR China)	Taofa Zhou	K Zaw	Skarn Cu-Au deposits in Lower Yangtze River Region
Institute for Frontier Research on Earth Evolution (IFREEE, Japan)	Yoshihiko Tamura	S Allen	Submarine volcanoes of the Izu-Bonin Arc
Institute of Geology and Mineral Exploration (Athens, Greece)	Georges Vougioukalakis	J McPhie, A Stewart	Volcanic geology of Milos, Greece
Instituto Geológico y Minero, Salamanca	Fernando Tornos, Carmen Conde	M Solomon	The origin of the Tharsis massive sulphide deposit
Instituto Geológico y Minero, Lisbon; Eurozinc Mining Corporation	Carlos Inverno	M Solomon	The origin of the Feitais (Aljustrel) massive sulphide deposit
Institute of Mineralogy, Miass, Russia	Prof V Maslennikov	R Large	Geochemistry of pyrite in sediment hosted gold deposits
Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing	Hou Zengqian	K Zaw	VHMS deposits in China
John Hopkins University	Grant Garven, Michael Simms	R Large, S Bull, D Cooke	Fluid flow in sedimentary basins
Laboratoire Pierre Sue, CEA-CNRS (France)	N Metrich	D Kamenetsky	Primitive melts of Mt Etna: implications for parental magmas of modern eruptions
Lakehead University	P Hollings	D Cooke	Geodynamic setting and tectonic evolution of the northern Philippines
Lulea University	Rod Allen	S Bull	Regional stratigraphy, basin evolution and setting of Zn-Pb-Cu-Ag-Au deposits in Bergslagen district, Sweden
Max-Planck Institute for Geochemistry (Germany)	A Sobolev	M Kamenetsky, L Danyushevsky, D Kamenetsky	Composition and origin of the Udachnaya pipe kimberlite
Max-Planck Institute for Geochemistry (Germany)	A Sobolev, A Gurenko, D Kuzmin, A Hoffmann	D Kamenetsky	Recycled oceanic crust in the origin of mid-ocean rift basalts and komatiites.
Max-Planck Institute for Geochemistry (Germany)	W Sun	D Kamenetsky	Behavior of Re, Au and Cu during magmatic fractionation and degassing.
Max-Planck Institute for Geochemistry (Germany)	V Batanova	D Kamenetsky	A link between ultramafic shoshonites and Alaskan-type intrusions in the Far East Russia

Mineral Deposit Research Unit, University of British Columbia	R. Tosdal	C Deyell, D Cooke	Sulfur Isotopic Zonation in Alkalic Porphyry Cu-Au Systems: Applications to Mineral Exploration in British Columbia
Nanjing University, Nanjing	Gu Lianxing	K Zaw	Stratabound base metal deposits in China
National Institute for Engineering, Technology and Innovation (INETI, Lisbon, Portugal)	Luis Martins	J McPhie, C Rosa	Character and setting of volcanic successions that host massive sulfide ore deposits in the Iberian Pyrite Belt, Portugal
Niigata University (Japan)	Katsuki Kurokawa	S Allen	Characteristics and origin of pumiceous mass-flow units in submarine volcanic successions
Presidency College, Calcutta	H Bhattacharya	P McGoldrick, S Bull	Origin and setting of the Zawar sediment-hosted Zn-Pb deposits in Rajasthan, India
Russian Academy of Science	Valeriy Maslennikov	R Scott, R Large, A Rae	Controls on the formation and sulfide trace element signatures of sediment-hosted gold deposits
Simon Fraser University	Derek Thorkelson	G Davidson	Cu-Au Fe-oxide deposits geology and geochemistry
Smithsonian Institution (USA)	Richard Fiske	S Allen	Eruption mechanisms and characteristics of submarine felsic pumice
Somincor Ltd; Instituto Geológico y Minero, Lisbon	C Inverno, A Ferreira, P Caetano, and N Pacheco	M Solomon	The formation of the Lombador and Neves Norte ore lenses, Neves Corvo
Swedish Geological Survey		S Bull	Regional stratigraphy, basin evolution and setting of Zn-Pb-Cu-Ag-Au deposits in Bergslagen district, Sweden
Unites States Geological Survey	Poul Emsbo	R Large, R Scott, A Rae	Pyrite geochemistry of Carlin deposits
Unites States Geological Survey	C Finn	G Davidson	Macquarie Island magnetics to define former hydrothermal flow patterns
University of Arizona	Erik Seedorff	A Harris	Porphyry Ore Deposit Geology
University of Arizona	M Barton	G Davidson	Oxygen isotope systematics of Tasmanian west coast alteration adjacent to Cambrian ores
University of Chicago/ GSE-CARS	Matt Newville, Steve Sutton	A Harris	Synchrotron-Copper speciation in magmatic-hydrothermal fluids
University of Geosciences, Wuhan, China	Xinbuao Lu	K Zaw	Gold-copper deposits in China
University of Lisbon (Portugal)	Jorge Relvas	J McPhie, C Rosa	Character and setting of volcanic successions that host massive sulfide ore deposits in the Iberian Pyrite Belt, Portugal
Universidade de Lisboa	Paulo Fonseca	M Solomon	The tectonics of the SW Iberian Variscan collision
University of Michigan	J Alt	G Davidson	Macquarie Island isotopic systematics as a window into VHMS district fluid circulation.
University of Missouri-Columbia (USA)	Tim Lyons	P McGoldrick	Proterozoic ocean chemistry and sedimentary zinc-lead deposits
University of Oregon (USA)	Kathy Cashman	S Allen	Physical properties of submarine-erupted felsic pumice
University of Pisa (Italy)	P Fulignatti, P Marianelli, A Sbrana.	D Kamenetsky	Liquid immiscibility processes in the formation of Mt Vesuvius skarn.
University of Pisa (Italy)	M Pompillio	D Kamenetsky	Primitive melts of Mt Etna: implications for parental magmas of modern eruptions
University of Southampton	D Teagle, R Coggan	G Davidson	Sulfur isotope systematics of altered ocean floor on Macquarie Island
University of Windsor, Canada	Jianwen Yang	R Large, S Bull	Numerical fluid flow modeling of hydrothermal systems
Vernadsky Institute of Geochemistry, Moscow, Russia	N Sushchevskaya, V Naumov	D Kamenetsky	Studies in immiscibility and geochemical variations in mafic and felsic magmas
Vernadsky Institute of Geochemistry, Moscow, Russia	A Ariskin.	L Danyushevsky	Modelling of mantle melting processes
Vanuatu Geological Survey	Douglas Charlie	S Allen, F Della Pasqua	Plagioclase ultraphyric lavas and caldera-related pyroclastic deposits on Tanna, Vanuatu
Volcanic Resources, Sweden	Rod Allen	J McPhie, C Gifkins	Textural and compositional effects of alteration in volcanic rocks

Yale University	Peter Reiners	A Harris, D Braxton, T Ireland	Thermochronologic analyses of porphyry systems to constrain their uplift and exhumation histories.
Yale University	Scott Bryan	A Harris	Volcanology of Farallon Negro Volcanic Complex
National Institutions			
Australian Museum, Sydney	Lin Sutherland	K Zaw	Origin of sapphire deposits in Tasmania
Australian National University	Andrew Berry, John Mavrogenes	A Harris, D Kamenetsky	Synchrotron-Copperspeciation in magmatic-hydrothermal fluids
Australian National University	Jim Dunlap, Charlotte Allen, Ian Campbell	A Harris	Geochronology - Porphyry Ore Deposits
Australian National University	Mark Fanning	A Harris	Geochronology - Gawler Range Volcanics
Australian National University	G Yaxley	D Kamenetsky, M Kamenetsky	Origins of compositional heterogeneity in olivine-hosted melt inclusions from the Baffin Island picrites
Australian National University	R Arculus	D Kamenetsky	Petrology and geochemistry of the Solomon Islands picrites
CSIRO Exploration & Mining	John Walshe	D Cooke	Porphyry copper genesis
Geological Survey of New South Wales	Simon Meakin, Gary Colquhoun	J McPhie, K Bull	Early Devonian volcanic successions in the western Lachlan Fold Belt
Geoscience Australia	Terry Mernagh	A Harris, K Zaw, D Kamenetsky, P Davidson	Laser Raman Fluid gas geochemistry
Geoscience Australia	Roger Skirrow	B Bowden, G Davidson	Alteration and genesis of the Prominent Hill IOCG deposit
Geoscience Australia	D Huston	G Davidson	Sulfur isotope geochemistry of the Archean Panorama VHMS district
Geoscience Australia	Roger Skirrow	G Davidson	Iron oxide Cu-Au deposit genesis
CSIRO	Chris Ryan	A Harris, K Zaw, D Kamenetsky, P Davidson	PIXE - Fluid inclusions geochemistry
James Cook University	Nick Oliver	D Cooke	Fluid flow in hydrothermal systems
James Cook University	N Oliver, Tim Baker, Julie Hunt	G Davidson	Cu-Au Fe-oxide deposits geology and geochemistry
James Cook University	Karen Volp	G Davidson	Stable isotopes, history of Archean Brazilian near-granite Cu-Au systems
James Cook University	L Marshall, N Oliver	G Davidson	Earth succession carbonate isotope compositions
James Cook University	Tim Baker, Julie Hunt	G Davidson	Genesis of the Wernecke Mountain IOCG like breccias
JKMRC	T Napier-Munn	S Walters, R Large	Development of P843 GeM project
McArthur Ore Deposit Assessments Pty.	Garry McArthur	R Large, JB Gemmell	Alteration model for Hellyer
Macquarie University	Mark Lackie	J McPhie, F Della Pasqua	AMS analyses of voluminous felsic lavas in the Gawler Range Volcanics
Mineral Resources Tasmania	Geoff Green	C Gifkins, W Herrmann, B Kimber, J McPhie	Distribution of volcanic centres, alteration zones and ore deposits in the Mount Read Volcanics, western Tasmania
Mineral Resources Tasmania	A Brown, D Green, G Green	G Davidson	Hydrothermal geology at Macquarie Island ocean crust; Isotope geochemistry of mineralized Cambrian hydrothermal systems in the Mount Read Volcanics, Tasmania
Monash University	David Giles	A Crawford	Mafics in BHT terrains
Primary Industries and Resources South Australia	Michael Schwarz,	J McPhie, S Allen, F Della Pasqua	Voluminous felsic lavas in the Gawler Range Volcanics
Primary Industries and Resources South Australia	Wolfgang Preiss, Stuart Robertson	W Mackay, S Bull, D Selley	Geology and Cu mineralization in the Willouran Ranges
Primary Industries and Resources South Australia	Michael Schwarz	B Bowden, G Davidson	Alteration and genesis of the Prominent Hill IOCG deposit
RSES-PRISE	Marc Norman	G Davidson, A Rae, R Large, P McGoldrick	Trace element analysis of sulfides by LA-ICPMS: new applications for exploration vector chemistry
University of Adelaide	K Barovich	G Davidson	Cu-Au Fe-oxide deposits geology and geochemistry
University of Adelaide	J Foden	R Large	Strontium isotopes in northern Australian SEDEX Zn-Pb systems
University of Melbourne	R Maas	M Kamenetsky, D Kamenetsky	Composition and origin of the Udachnaya pipe kimberlite
University of Queensland	Sue Golding	A Harris, K Zaw	K-Ar geochronology and D/H isotope geochemistry

University of Western Australia Centre for Global Metallogeny	Mark Barley	K Zaw	SHRIMP geochronology, Loei ARC-Industry Linkage Project
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VISITORS TO CODES 2004

Academic and government (international)

Ariskin	Alexei A.	Professor	Vernadsky Institute of Geochemistry, Moscow, Russian Academy of Sciences	Modelling of mantle melting processes using experimental data generated at UTAS high-pressure experimental laboratory, L Danyushevsky	Feb-April
Ballhaus	Chris	Professor	Institute of Mineralogy, University of Munster Germany	Collaborative work on Solomon Islands primitive magmas with D Kamenetsky	Feb
Battacharya	H.N. (Bappa)	Professor	Presidency College, Calcutta India	Collaborative work with S Bull and P McGoldrick on Zavar sedimentary Zn deposits	Jan
Elburg	Marlina	Research Fellow	Max Planck Institute for Chemistry, Mainz Germany	Experimental work with melt inclusions with D Kamenetsky	Jan-Feb
Emsbo	Poul	Dr	Geological Survey of USA Denver	Present results of Carlin district work and discussion on Collaboration P923	June
Gillerman	Virginia	Dr	Idaho Geological Survey		Dec
Hedenquist	Jeff	Assoc Prof.	Colorado School of Mines	Collaboration for AMIRA P765 ARC Linkage Project	June
Kesler	Steve	Prof	University of Michigan	Present results of Carlin district research	June
Lyons	Tim	Assoc Prof	University of Missouri Columbia	Keynote speaker, 17th Australian Geological Convention	Feb
Oehler	Dorothy	Dr	NASA	Discussions with P McGoldrick and S Bull about HYC microbes	Sept
Price	John	Dr	Nevada Bureau of Mines	Field work with JB Gemmell	Oct
Russell	Mike	Professor	University of Glasgow, Scotland	Seminars on Origin of Life, and Origin of the Pb-Zn ores of Ireland	Sept
Seedorff	Erik	Prof	University of Arizona	Discussions with D Cooke, A Tunks and JB Gemmell about Masters programs	Oct
Taranik	Jim	Director	Newmont Denver	Discussion on operation of research centres	August
Zürcher	Lukas		University of Arizona	Discussions with D Cooke, A Tunks and JB Gemmell about Masters programs	Oct

ACADEMIC and Government (National)

Arculus	Richard	Professor	Head of Dept of Earth & Marine Science, ANU	Discussions on Solomon Island picrites results geochemistry	Feb
Beresford	Steve	Lecturer	Monash University	Presented seminar on magmatic-Ni	Oct
Berry	Mark	Research Manager	CSIRO Division of Exploration & Mining	Discussion on collaborative research	August
Caprarelli	Graziella		University of Technology Sydney	Discuss potential melt inclusion projects with L Danyushevsky and A Crawford	
Cas	Ray	Professor	Monash University	Centre collaborations	Feb
Cox	Steve	Professor	ANU	Collaboration discussions	May
Healy	Tom	Director	Advanced Mineral Products SRC University of Melbourne	Centre of Excellence proposal meeting	Aug/Oct
Heithersay	Paul	Director	PIRSA	Science Planning Panel	April

Kennett	Brian	Professor	Research School of Earth Sciences ANU	Present the ANSIR lecture on National Seismic Imaging Resource, and discuss Tasman Line tectonics with A Crawford	August
Lineweaver	Charlie	Deputy Director	Planetary sciences institution ANU	Seminar "Are we alone"	Oct
Maas	Roland	Dr	Manager, Isotope Geochemistry laboratory School of Earth Science, University of Melbourne	Isotope studies of MORB, kimberlites and carbonatites with D Kamenetsky	Feb
Macnae	Jim	Professor of geophysics	RMIT University, Melbourne	Centre of Excellence proposal meeting	Sept
Marshal	Craig	Post doctoral Research Fellow	Australian Centre for Astrobiology, Macquarie University	McArthur River deposit workshop	Dec
O'Sullivan	Kerry	Project Manager	AMIRA International	Data metallogenica	Sept
Phillips	Neil	Chief	CSIRO Exploration and Mining	Collaboration discussions	Feb
Pigram	Chris	Chief of Mines	Geoscience Australia	Science Planning Panel, Advisory Board	April
Sara	Vicki	Consultant		Centre of Excellent discussions	August
Ulrich	Thomas	Research Fellow	RSES, ANU	Analysis of fluid inclusions in quartz by laser-ablation ICPMS, L Danyushevsky	Nov
Walshe	John	Senior Principal Research Geologist	CSIRO Exploration and Mining	Collaborative research	August
Walter	Malcolm	Professor	Australian Centre for Astrobiology, Macquarie University	Seminar on early life and discussions with P McGoldrick about McArthur River & McArthur River deposit Workshop	Oct & Dec
Industry					
Alan	Andrew		Anglo American	Discussion on sedimentary Zn & Cu deposits with S Bull and D Selley	Feb
Andrew	Ross	Consultant	RioTinto	Science Planning Panel, Advisory Board	April
Audet	Marc Antoine		Falconbridge New Caledonia	Microprobe work on New Caledonian ophiolite, with A Crawford and S Meffre	
Child	Ralph	General Manager Geology	Pan Australian Limited	Loei ARC-Industry Linkage Project	Nov
Dow	John	Managing Director	Newmont Australia Ltd	Research Centre discussions	August
Everard	John	Geologist- Metallic Minerals	Mineral Resources Tasmania	Discuss results arising from fieldwork with A Crawford on the St Mary Triassic basalts in eastern Tasmania	
Foster	Jeff		Geodiscovery Brisbane	Present a day workshop on Ni mineralisation in magmatic rocks	Oct
Franey	Nick	VP Exploration	AngloAmerican	Science Planning Panel, Advisory Board	April
Fullagar	Peter	Director	Fullagar Geophysics Pty Ltd Brisbane	Fields modelling & inversion visit, Centre of Excellence proposal meeting	July
Gahlot	Brijendra		Anglo American, India	Discussion about sedimentary Zn and Masters course	Dec
Hammond	John	Consulting Geologist	Newmont Exploration	AMIRA meeting, Advisory Board	April
Hannington	Mark	Research Geologist	Geological Survey of Canada	Discussion about new VHMS research project	June
Holliday	John	Principal Geologist	Newcrest Mining Limited	AMIRA meeting	July
Hronsky	Jon		WMC Ltd	Science Planning Panel	April

James	Ron		Akara Mining Limited	Loei ARC-Industry Linkage Project	Nov
Kennedy	Tim		Anglo American	P544 Shortcourse	Feb
Lu	Xinbio		University of Geoscience, Wuhan, China	Skarn deposits in South China	Feb
Macdonald	James	Chief Geologist	BHP Billiton	Science Planning Panel, Advisory Board	April
McArthur	Gary	Principal Consultant	McArthur Ore Deposit Assessments Ltd	Geometallurgy discussions	Sept
Megwhal	Shailendra Kumar		Anglo American, India	Discussion about sedimentary Zn and Masters course	Dec
Mills	Stuart		Anglo American	Discussion on sedimentary Zn & Cu deposits with S Bull and D Selley	Feb
Pritchard	Peter		GSA Victoria Division	Meeting with A Crawford	
Robert	Francois	Chief Geologist	Barrick Gold	SEG International Lecturer, discussions in gold research	Feb, March
Rogers	Jamie		Placer	Loftus-Hills memorial lecture	Sept
Smith	Stuart		Oxiana Limited	Loei ARC-Industry Linkage Project	Nov
White	Noel	Consulting Economic Geologist		AMIRA meeting	Jan
Wilson	John	Director	Corstor, South Africa	Discuss joint development of a new method for obtaining structural data from oriented drill cores	Dec
Withnall	Ian		Geological Survey of Queensland	Work with A Crawford on N Qld Palaeozoic tectonics	