Centre for Ore Deposit Research

An ARC Special Research Centre

at the University of Tasmania

• Australia •

Annual Report 2003

Established and supported by the Australian Research Council's Special Research Centres Program

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Director's Report

Following the very positive ARC review in 2002, CODES moved into the final triennium as a Special Research Centre with two major aims:

- to consolidate and maintain our position as one of the global leaders in ore deposit and exploration research, and
- to commence planning and implementation of a strategy to bid successfully in late 2004 for a new life as an ARC-funded Centre of Excellence.

For the latter, we have been talking widely with industry sponsors, other research groups, and State and Federal Government agencies to ensure that we are well positioned to make the bid for a Centre of Excellence. We have been encouraged by the inclusion in the Federal Government's research National Priorities of 'Deep Earth Resources', and also the emphasis accorded to ore deposit and exploration geoscience in the new blueprint for Australian Earth Sciences, released in October 2003 by the Australian Academy of Sciences ('Geoscience – Unearthing our Future').

During 2003 we continued out strategy to integrate basic research activities funded by the ARC with applied research focused on industry collaborative projects. An important development in this regard has been the successful installation of the new Cameca electron microprobe in the Central Science Laboratory, funded by an ARC Linkage Infrastructure and Equipment Fund grant of $750,000, backed up by funds from the University and CODES. This facility underpins much of the geochemical and mineralogical research we undertake, and when complemented by microscale trace-element analysis enabled by the CODES-funded LA-ICPMS, we have a very powerful suite of analytical tools available for ore deposit research. Excellent progress has been made in the LA-ICPMS laboratory, with trace element analysis of minerals and glasses routinely providing world-class low-level data, and U-Pb dating of zircons becoming increasingly efficient, accurate and widely used. Furthermore, through careful testing and selection of appropriate standards, CODES researchers have pioneered analysis of trace elements in sulfides, and the many applications of this development are receiving strong interest from the exploration industry.

During 2003, CODES researchers produced 38 refereed publications in a broad range of international journals, including papers in the high-impact journals *Science* (1), *Nature* (1) and *Geology* (3), as well as *Economic Geology* (3), *Chemical Geology*, *Journal of Volcanology and Geothermal Research*, *Journal of the Geological Society (London)*, *Tectonics*, *Geofluids*, and chapters in several new books on Australian geology. Together with the completion of 77 reports for industry groups, many involving AMIRA projects, these outcomes reflect well on the calibre and performance of the CODES research team and demonstrate that we are hitting our targets as a government- and

industry-funded Special Research Centre. At the Society for Geology Applied to Mineral Deposits meeting in Athens and the International Geochemical Exploration Symposium in Dublin, both in August 2003, CODES researchers presented 17 papers, with Ross Large and David Cooke delivering invited keynote papers.

A highlight of the year was the presentation to CODES Program 3 Leader Bruce Gemmell and his team of a Research Excellence Award from the University of Tasmania Faculty of Science Engineering & Technology. The award recognised the major research achievements of the Program 3 team over the past five years, including publication of 45 refereed papers and 89 industry reports, receiving over $3 million in external research funding from ARC and industry, and editing a Special Issue of *Economic Geology* based on results from a recent CODES AMIRA-ARC Linkage project.

Increasing vigour in the exploration industry in 2003 was reflected in CODES in a number of ways. First, undergraduate enrolments in Earth Sciences nearly doubled (due largely to the efforts of Mike Roach, Andrew Tunks, Mike Blake, and the team responsible for production of the 'WHY GEOLOGY?' CD distributed to Grade 12 science students in Tasmania). Second, despite a bumper crop of PhD completions, all our new doctorate graduates seeking employment in the exploration industry were successful and are currently working across the globe, including three in Western Australia, several in South America (Chile and Peru), and several in Mongolia.

The major AMIRA-funded project P544 ('Proterozoic sediment-hosted copper deposits') was completed in 2003, with presentations of final reports to sponsors at well-attended meetings in Hobart and Zambia. This was a highly succcessful project, funded by 12 international mining companies, that brought together a team of researchers from CODES and the Colorado School of Mines in a comprehensive geological and geochemical study of the Proterozoic copper provinces in Zambia and South Australia. We are presently assembling industry funding for a new project to build on P544, especially with respect to the Zambian and Congo deposits. A new AMIRA-funded Project P765 'Transitions and zonation in porphyry-Cu epithermal mineral districts' commenced in the second half of 2003, with funding obtained from seven industry sponsors. This project is designed to test how new advances in alteration mapping and geochemical analysis can improve exploration success in porphyry-epithermal districts. A major new ARC-Linkage project on the Cu-Au deposits of the Loei Belt, Thailand, with funding provided by three industry partners, also commenced in late 2003. It is planned that this project will be the fore-runner of a series of field-based research projects in the mineralised fold belts of SE Asia.

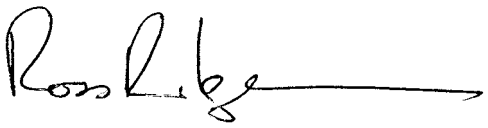
A fruitful collaboration involving CODES researchers Cathryn Gifkins and Wally Herrmann, Mineral Resources Tasmania and the pmd*CRC led to production of new interactive GIS maps of the Mount Read Volcanics, western Tasmania, highlighting the links between volcanic centres, alteration zones and massive sulfide ore deposits. This map will be of great value to the exploration industry in western Tasmania.

Excellent news towards the end of 2003 was that Dr Sharon Allen had been awarded an ARC five-year post-doctoral fellowship to continue her studies on modern and ancient submarine-emplaced pumice breccia deposits. Also, Dr Dima Kamenetsky was awarded a prestigious Bessell Award of the Humboldt Foundation to spend two periods of six months to conduct collaborative research at the renowned Max-Planck Institute of Chemistry in Germany.

The major downturn in the minerals discovery rate in Australia over the last five years has lead to several government and industry reports (Prosser Report, Bowler Report, Exploration Action Agenda) focussed on the need to increase exploration activity and minerals-related research. It is now well accepted by government and industry that in order to increase mineral discovery rates, we need focussed research to develop new and better ore deposit models and innovative exploration methods. The increase in metals prices toward the end of 2003 is a good sign that a period of increased exploration activity is on the way. CODES is now well-positioned to work closely with the minerals industry, during a new period of exploration growth and contribute to some major new mineral discoveries.

An exciting example of how postgraduate student research can contribute to mineral discovery was revealed in 2003 by CODES Masters student Dan Olberg, working with Newcrest in Kalimantan. Follow-up drilling of an area revealed by Dan's research on exploration vectors for epithermal gold in the Gosowong district, led to the discovery of the Kencana gold deposit by Newcrest.

In conclusion, 2003 has been a successful and rewarding year for CODES. Our international profile as a leading ore deposit research group is well founded, and continues to be based on a strong multidisciplinary team effort. I take this opportunity to thank all the CODES staff, our energetic graduate students and our sponsors, for their commitment, achievements and support.



Ross R Large

Management

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

Advisory Board
Advisory Board members represent major industry sponsors, University of Tasmania senior management, and other key national geoscience organisations. The Board meets annually to review progress of the Centre and to advise on future directions. Stuart Mills (Anglo American) joined the board in 2003.

Science Planning Panel
The Science Planning Panel has a wider membership than the Advisory Board and includes a representative from all sponsor companies. The Panel meets annually for a one-day forum of presentations concerning the Centre's scientific research progress and to discuss potential new research projects. This forum is designed to provide industry with an opportunity to influence future research directions.

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

Staff
CODES employs 25 research staff and 14 administrative and technical staff who are funded by the SRC grant, industry support and the university. Eleven of the academic staff and seven of the general staff are joint appointments between CODES and the School of Earth Sciences. No new research staff joined CODES in 2003, and Dr Robina Sharpe left for industry employment in western Africa. Kylie Kapeller replaced Lynne Vaudrey as Personal Assistant to the Director. Dr Cari Deyell was awarded a Canadian NSERC post-doctoral fellowship to remain at CODES for a further two years.

ADVISORY BOARD	
Chair: Andrew Glenn	Pro Vice-Chancellor (Research), University of Tasmania
Jim Reid	Dean – Faculty of Science, Engineering & Technology, University of Tasmania
Ross Large	Director, CODES
Ray McLeod	General Manager Exploration – Australia, Newcrest Mining Limited
James Macdonald	Global Geoscience Leader, BHP Billiton – Minerals Exploration
Chris Pigram	Chief, Minerals and Geohazards Division, Geoscience Australia
Alan Goode	Research Coordinator, AMIRA International
Tony Brown	Director of Mines, Mineral Resources Tasmania
David Groves	Director, Centre for Global Metallogeny, University of Western Australia
Ian Willis/Stuart Mills	Principal Geologist – Asia Pacific, Anglo American
Noel White	Consultant
Tony Crawford	Deputy Director, CODES
Ron Berry	Head, School of Earth Sciences, University of Tasmania
Jocelyn McPhie	Program 2 Leader, CODES

EXECUTIVE COMMITTEE	
Chair: Ross Large	Director, CODES
Tony Crawford	Deputy Director, Program 1 Leader
Jocelyn McPhie	Program 2 Leader
Bruce Gemmell	Program 3 Leader
Peter McGoldrick	Program 4 Leader
David Cooke	Program 5 Leader
Christine Higgins	Finance Manager
Kylie Kapeller	Personal Assistant to the Director
June Pongratz	Publications Manager

SCIENCE PLANNING PANEL	
Geoff Green	Managing Geologist, Metallic Minerals and Geochemistry, Mineral Resources Tasmania
David Groves	Director, Centre for Global Metallogeny, University of Western Australia
Stuart Mills	Principal Geologist – Asia Pacific, Anglo American
Ray McLeod	General Manager Exploration – Australia, Newcrest Mining Limited
Noel White	Consultant
James Macdonald	Global Geoscience Leader, BHP Billiton – Minerals Exploration
Ian Scott	Group Manager, Geoscience Technologies, WMC Resources
Jon Hronsky	Team Leader – Project Generation, WMC Resources
Nigel Radford	Consulting Geochemist, Newmont
Keith Hannan	Principal Geochemist, Xstrata (formerly MIM Exploration)
Alan Goode	Research Coordinator, AMIRA International
Rob Rutherford	Senior Geologist, Phelps Dodge Australasia
Paul Heithersay	Branch Manager – Geological Survey, Primary Industries & Resources South Australia
John Holliday	Regional Exploration Manager, Newcrest Mining Limited
Roric Smith	Chief Geologist – China & Australia, AngloGold Exploration Australasia

OPPOSITE: CODES Program Leaders. L to R, David Cooke, Tony Crawford, Bruce Gemmell, Jocelyn McPhie, Peter McGoldrick, Ross Large (Director)

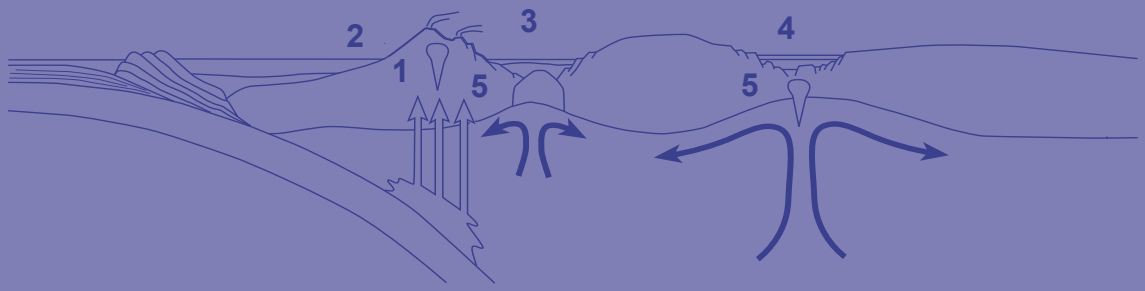
CODES STAFF 2003		% in CODES
Director, Professor Ross Large, BScHons (UTAS), PhD (UNE)	Volcanic-hosted and sediment-hosted massive sulfides	100
Deputy Director, Assoc. Prof. Tony Crawford, BScHons, PhD (MelbU)	Petrology, geochemistry and tectonics of volcanic arcs	50

Academic Staff		
Dr Sharon Allen, BSc (MasseyU), MSc (AucklandU), PhD (MonashU)	Volcanic facies analysis	100
Dr Ron Berry, BSc, PhD (FlindersU)	Structure of mineralised provinces and CHIME dating	50
Dr Stuart Bull, BScHons, PhD (MonashU)	Clastic and carbonate sedimentology, and volcanology	100
Dr David Cooke, BScHons (LaTrobeU), PhD (MonashU)	Fluid–rock interaction and hydrothermal geochemistry	50
Dr Leonid Danyushevsky, PhD (Vernadsky Inst.)	Petrology, geochemistry and application of melt inclusions	50
Dr Garry Davidson, BScHons (ANU), PhD (UTAS)	Sulfur isotope geochemistry and Cu-Au ores	50
Dr Fernando Della Pasqua, PhD (UTAS)	Petrology and geochemistry	50
Dr Cari Deyell, BSc (QueensU), PhD (UBC)	Geochemistry and mineralogy of hydrothermal systems	100
Associate Professor Bruce Gemmell, BSc (UBC), MA, PhD (Dartmouth)	VHMS deposits and epithermal Au-Ag	50
Dr Cathryn Gifkins, BScHons (MonashU), PhD (UTAS)	Volcanology and alteration in volcanic rocks	100
Dr Anthony Harris, BScHons, PhD (UQld)	Ore deposit geology and geochemistry	100
Mr Wally Herrmann, BScHons (MonashU), MEconGeol (UTAS)	Alteration and exploration in volcanic settings	100
Dr Dima Kamenetsky, PhD (Vernadsky Inst.)	Petrology and geochemistry of melt inclusions	50
Dr Peter McGoldrick, BScHons, PhD (MelbU)	Geochemistry of ore deposits and their alteration halos	75
Associate Professor Jocelyn McPhie, BAHons (MacquarieU), PhD (UNE)	Volcanic facies architecture and volcanic textures	50
Dr Sebastien Meffre, BScHons, PhD (SydneyU)	Petrology and tectonics of the SW Pacific	50
Dr Andrew Rae, MSc (UOtago), PhD (UTAS)	Ore deposit geology and hydrothermal processes	100
Dr Michael Roach, BScHons (NewcastleU), PhD (UTAS)	Electrical geophysical responses of sulfide ores	50
Dr Robert Scott, BScHons, PhD (MonashU)	Structural geology	100
Dr David Selley, BScHons (UAdelaide), PhD (UTAS)	Structural geology and basin analysis	100
Dr Robina Sharpe, BSc Hons (UTas) PhD (UTAS)	Ore deposit geology and geochemistry	100
Dr Michael Solomon, MSc, PhD (UTas), DSc (ULondon)	Geochemistry and genesis of mineral deposits	25
Dr Andrew Tunks, BScHons (MonashU), PhD (UTAS)	Structural geology and Masters Coordinator	100
Dr Khin Zaw, BSc (YangonU), PhD (UTAS)	Fluid inclusions and SE Asian metallogenesis	100

Technical/Administrative Staff		
Mr Michael Blake, BSc (UTAS)	Research Assistant	100
Mr Alistair Chilcott, BComp (UTAS)	Computer Systems Officer	70
Mr Peter Cornish	Laboratory Manager	100
Ms Sarah Gilbert, BScHons (UTAS)	Research Assistant	100
Ms Christine Higgins, GradCertManagement (UTAS)	Finance Manager	50
Ms Nilar Hlaing, BSc (Yangon U)	Research Assistant; Publications Officer	20
Ms Kylie Kapeller	Personal Assistant to Director (from June 2003)	100
Ms Loreto Lazcano-Frikken, BSocSci (GabrielaMistralU)	Administrative Assistant (to April 2003)	100
Mrs Katie McGoldrick	Laboratory Assistant	80
Ms June Pongratz	Publications Manager	50
Mr Phil Robinson	Analytical Services Manager	70
Mrs Dianne Steffens	Finance Assistant	100
Mr Simon Stephens, BSc (UTAS)	Manager, Lapidary Services	50
Ms Lynne Vaudrey, BA (USydney), BAHons (UTAS)	Administrative Officer (to March 2003)	100
Ms Isabella von Lichtan, BScHons (UTAS)	Curator	20

CODES Administrative and Technical Staff 2003. Upper stairs, L to R: Sarah Gilbert, Di Steffens, Peter Cornish, Katie McGoldrick. Lower stairs, L to R: Izzy von Lichten, Alistair Chilcott, Nilar Hlaing, Kylie Kapeller, Christine Higgins, June Pongratz, Simon Stevens, Phil Robinson.

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 Industry–CODES Collaboration Projects

CODES is committed to developing and maintaining strong collaborative links with the mining and exploration industry at all levels of our research and teaching operations, from Honours projects to large multi-disciplinary, multi-sponsor research projects. Projects >$50,000 pa are shown.

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 An interactive volcanic facies and alteration map of the Mount Read Volcanics, western Tasmania

Investigators: Cathryn Gifkins, Wally Herrmann, Bronwyn Kimber

Partners: Mineral Resources Tasmania, pmd*CRC

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

Investigator: Wally Herrmann

Partner: AngloGold

4 AMIRA P765: Transitions and zoning in porphyry-epithermal districts: indicators, discriminators and vectors (commences Jan 04)

Investigators: David Cooke, Bruce Gemmell, Cari Deyell, Noel White

Partners: AMIRA International, AngloGold, Placer Dome, TeckCominco, Goldfields, Newcrest Mining, Anglo American, Newmont

5 Geochronology, metallogenesis and deposit styles of the Loei Fold Belt in Thailand and Laos PDR (commences Jan 04)

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

Partners: Kingsgate Consolidated, Pan Australian Resources, Oxiana Resources

6 AMIRA P544: Proterozoic sediment-hosted Cu deposits: a comparison of Zambian and Australian deposits

Investigators: Peter McGoldrick, Stuart Bull, David Selley, Rob Scott, David Cooke, Ross Large, Michael Blake: Murray Hitzman (CSM): PhD students N Pollington, M Croaker, W Mackay: D Broughton (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

7 Geology of the Escondida district

Investigators: Andrew Tunks. Masters student: Felipe Urzua

Partner: BHP Billiton

A BUMPER PhD CROP

During 2002–2003, 18 CODES students were awarded PhD degrees. Of these, six were overseas students (from Canada, Germany, South Africa, New Zealand (2) and Scotland), and only two had done their undergraduate training and Honours year at University of Tasmania. Other Australian universities that provided these students included Monash University, University of Melbourne, James Cook University, Macquarie University, University of Queensland, University of Technology Sydney, and the University of Wollongong. These pages feature our 2002–2003 PhD graduates.

Michael Agnew came to CODES after completing his Honours degree at the University of Queensland. His PhD project involved a study of the Lewis Ponds massive sulfide deposit near Orange, in the Siluro-Devonian section of the Lachlan Fold Belt near Orange in NSW. The project was sponsored by TriOrigin Minerals. Upon completion, Mike was awarded a CODES writing-up scholarship to complete several papers derived from his thesis, and he has recently taken a contract position with Anglo American in Western Australia.

Steven Bodon did an MSc at Monash University before coming to CODES to undertake a PhD on the setting and genesis of the Broken Hill-type mineralisation at Cannington in the Mt Isa Inlier, originally sponsored by a BHP Billiton/ARC SPIRT scholarship. Following submission of his PhD thesis, Steve moved to South Africa. Steve is presently employed as a contract geologist in southern Africa.

Darryl Clark is from Queensland, and completed an Honours degree at James Cook University. His PhD project focused on the origin of the Mammoth mineralisation at the Gunpowder sediment-hosted copper deposit in NW Queensland, sponsored by Western Metals. After completing his PhD, Darryl took up an exploration position with Ivanhoe Mines in Mongolia before moving to a position with AngloGold in WA.

Paul Davidson is a University of Tasmania graduate who came to geology relatively late in life compared to most other PhD students. Paul's thesis details a novel study of late magmatic fluid phase immiscibility in felsic magmas, both mineralized (Rio Blanco-Los Bronces, Chile) and unmineralised (Okataina rhyolite, Taupo Zone, NZ). This project, sponsored by CODES, has already yielded several papers in international journals. Paul has commenced post-doctoral research in CODES on fluid evolution associated with the Batu Hijau porphyry Cu-Au deposit in Indonesia.

Andrew Davies came to CODES after graduating from the University of British Columbia and working in industry for several years. His PhD project led him to the challenging (logistically and geologically) giant Kelian gold deposit in Kalimantan, Indonesia, where he developed particular expertise in the interpretation of igneous- and alteration-related breccias. This project was sponsored by Rio Tinto Indonesia. Since completing his PhD, Andrew has been working for AngloGold in copper-gold exploration in Peru.

Peter Frikken moved to CODES after completing an Honours year at the University of Wollongong. His PhD project, sponsored by Codelco, involved a study of the geology, geochemistry and genesis of the giant breccia-hosted Cu-Au deposit at Andina in Chile. Peter married Loreto Lazcano in Chile, and moved back to Chile following his PhD to work for Codelco at El Salvadore.

Owen Hatton is the first University of Technology Sydney Honours graduate to come to CODES for a PhD. His projec centred on basin configuration, sedimentology and volcanology of the Toole Creek Volcanics (Mt Isa Inlier), with support from BHP Billiton. Owen now works in exploration for Jubilee in Western Australia.

Oliver Holm completed his Honours degree at Macquarie University before working in the coal industry for several years. As part of his PhD studies at CODES, Ollie took on a project in remote NW Tasmania examining the structural and metamorphic history of the poorly understood Arthur Lineament, sponsored by Mineral Resources Tasmania. Several papers have emerged from this study already. Ollie presently works for Geoscience Australia in Canberra.

Sarah Jones is a New Zealander who did her Masters degree at the University of Otago before moving on to several exploration appointments in Western Australia. Sarah came to CODES for a project based on Vancouver Island, British Columbia, in which she studied the 'caprocks' above the Myra Falls VHMS deposit. This project was sponsored by Boliden-Westmin. She is presently employed in regional mapping for the Geological Survey of Western Australia.

Vanessa Lickfold came to CODES following completion of an MSc and industry experience in South Africa. Her PhD project, sponsored by Rio Tinto, involved detailed mapping and laboratory studies aimed at documenting the intrusive history and fluid evolution of the Endeavour porphyry Cu-Au deposits in the Goonumbla district near Parkes, NSW. Upon completion of her thesis, Vanessa returned home to South Africa to take up an exploration job with Kumba Resources.

Glen Masterman graduated with Honours from the University of Melbourne and worked in gold exploration in Western Australia for several years before moving to CODES to undertake a PhD. Glen's project was based at high altitude (4000 m) in the Collahuasi district in northern Chile, and focused on the Rosario Cu-Mo porphyry and associated high sulfidation Cu-Au veins. Glen now works in exploration with Placer Gold, based in Kalgoorlie in Western Australia.

Karin Orth completed an Honours degree at Monash University, and worked in regional mapping with the Geological Survey of Victoria before moving to CODES, where her PhD project centred on the Palaeoproterozoic Koongie Park Formation and associated base metal mineralisation in the Kimberley district of NW Australia. This PhD was originally supported by Billiton and Acacia Resources. Since graduating with a PhD, Karin has taken up a CODES writing up scholarship, and has several papers published or in press derived from her thesis work.

Andrew Rae is a graduate from the University of Otago, New Zealand. He worked for three years in industry doing ore deposit petrography before undertaking a PhD at CODES. His PhD project entailed a study of the Palimpinon geothermal field on Negros Island in the Philippines, focusing on alteration systematics and mineralisation potential. This project was funded by Inmet, Newcrest and BHP Billiton. Having developed keen analytical and mineragraphic skills, Andrew has stayed on as a post-doctoral fellow at CODES, managing the laser ablation sulfide trace element study that currently has six industry sponsors.

David 'Rowdy' Rawlings graduated from the University of Wollongong and moved to the regional mapping section of the Geological Survey of the Northern Territory. Rowdy undertook a PhD at CODES to study the sedimentology, volcanology and geodynamic evolution of a key section of the McArthur Basin in northern Australia, sponsored by Rio Tinto. Post-PhD, Rowdy moved back to the NT Geological Survey, but has recently taken a position in uranium exploration with Cameco.

Christian Schardt did his undergraduate work in Germany, and moved to CODES to carry out a numerical modeling PhD project examining controls on hydrothermal fluid migration by volcanic facies architecture, and implications for VHMS mineralisation. Despite the departure of his main supervisor, Dr Jianwen Yang, for Canada, Christian completed his PhD in good time, and is currently traveling for a year before seeking employment in academia in Europe.

Andrew Stewart completed an Honours degree at Macquarie University, and worked for several years in exploration before moving to CODES. His PhD area, the envy of many staff and colleague students, was on the Greek island of Milos, and his project focused on the facies architecture and mineralisation of the felsic lavas and plugs making up much of the island. The project was supported by an ARC research grant to his supervisor, Dr J McPhie. One of the few PhD students to complete his thesis within a 3-year time frame, Andrew has moved to an exploration position with Ivanhoe Mines in Mongolia, almost as far away as you can get from Milos.

Alan Wilson, a Scotsman with almost 10 years experience in exploration in South America, was selected by Newcrest to carry out a PhD on the complex and diverse Cu-Au mineralisation at Cadia, near Orange in NSW. Alan's thesis was awarded a Dean's Medal of Excellence. He now works in exploration for Newcrest, based in Western Australia.

Rohan Wolfe is a home-grown University of Tasmania graduate whose PhD project was based around the DinkiDi Cu-Au porphyry in the Didipio region of Luzon in the Philippines, and sponsored by Climax-Arimco. Rowan managed to work several contract jobs looking for porphyry Cu deposits in Iran between blocks of thesis preparation, and is another of our graduates working for Ivanhoe Mines, based primarily in Mongolia.

BELOW: L to R, David Cooke, Darryl Clarke, Michael Agnew, Andrew Tunks, Glen Masterman, Ross Large, Alan Wilson and Bruce Gemmell.

Laser Ablation ICPMS Microanalysis – a new CODES research direction in ore deposit studies

Thirty-five years ago in the School of Earth Sciences at UTAS, Geoff Loftus-Hills attempted to use pyrite trace element compositions (Ni, Co, Se) to elucidate the origin of diverse orebodies in western Tasmania. To do so, an attempt was made to collect ultra-clean separates from diverse orebodies and their host rocks, and analyse them using (mainly) atomic absorption spectrophotometry. Although some useful relationships were discovered, problems with sample purity, zoning of individual grains, and relatively insensitive analytical procedures all conspired to diminish the usefulness of this technique.

The development of new in-situ micro-analytical tools such as the LA-ICPMS has opened doors wide to new directions in ore deposit research, building upon the same philosophy that underpinned Loftus-Hills' work. In 1999, CODES purchased an Agilent HP4500 quadrupole ICPMS, and a Merchantek LUV266X laser; the latter was up-graded to a New Wave UP213 nm Nd:YAG laser in 2002. Since then, CODES researchers have been developing new procedures using the LA-ICPMS facility to measure the trace element compositions of different sulfides, for innovative and cost-effective application in diverse exploration and ore genesis studies. With a beam resolution as low as 5 mm, low detection limit microanalysis of a wide range of elements is made possible for very fine-grained sulfides (e.g., Carlin, McArthur River), and element zoning in individual sulfide grains can be accurately measured.

A first step in the process that has enabled such studies was the development of a suitable range of primary standards, since standards commonly used for analysis of silicate phases are not well characterised for chalcophile elements. Since natural materials are either heterogeneous or do not carry a useful range of elements at sufficient concentrations to make them useful as primary calibration standards, doped glass standards were developed and repeatedly analysed by both solution- and LA-ICPMS. Second, it was necessary to evaluate analytical errors caused by matrix-dependent laser-induced fractionation, which when carefully determined, will allow quantitative correction factors to be introduced for analysis of each sulfide mineral. Finally, optimum operating conditions for the laser had to be determined for each sulfide.

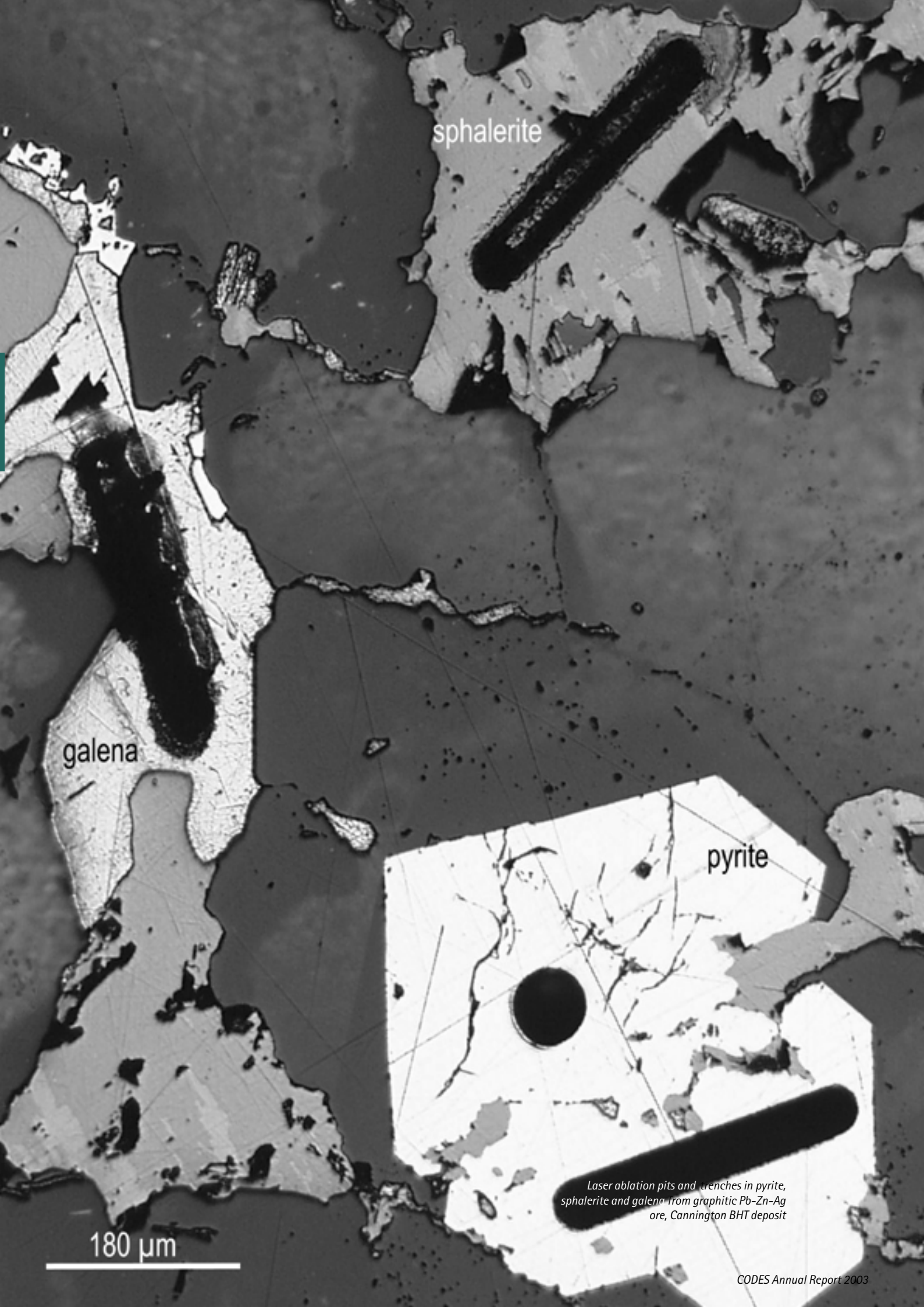
These non-trivial pre-requisites have been successfully achieved — for example, the paper by Norman, Robinson and Clark (2003) 'Major- and trace-element analysis of sulfide ores by laser ablation ICP-MS, solution ICP-MS and XRF: new data on international reference materials' (*The Canadian Mineralogist* 41).

Confident that this analytical system was delivering quality data, CODES researchers have developed a number of new applications, including microanalysis of:

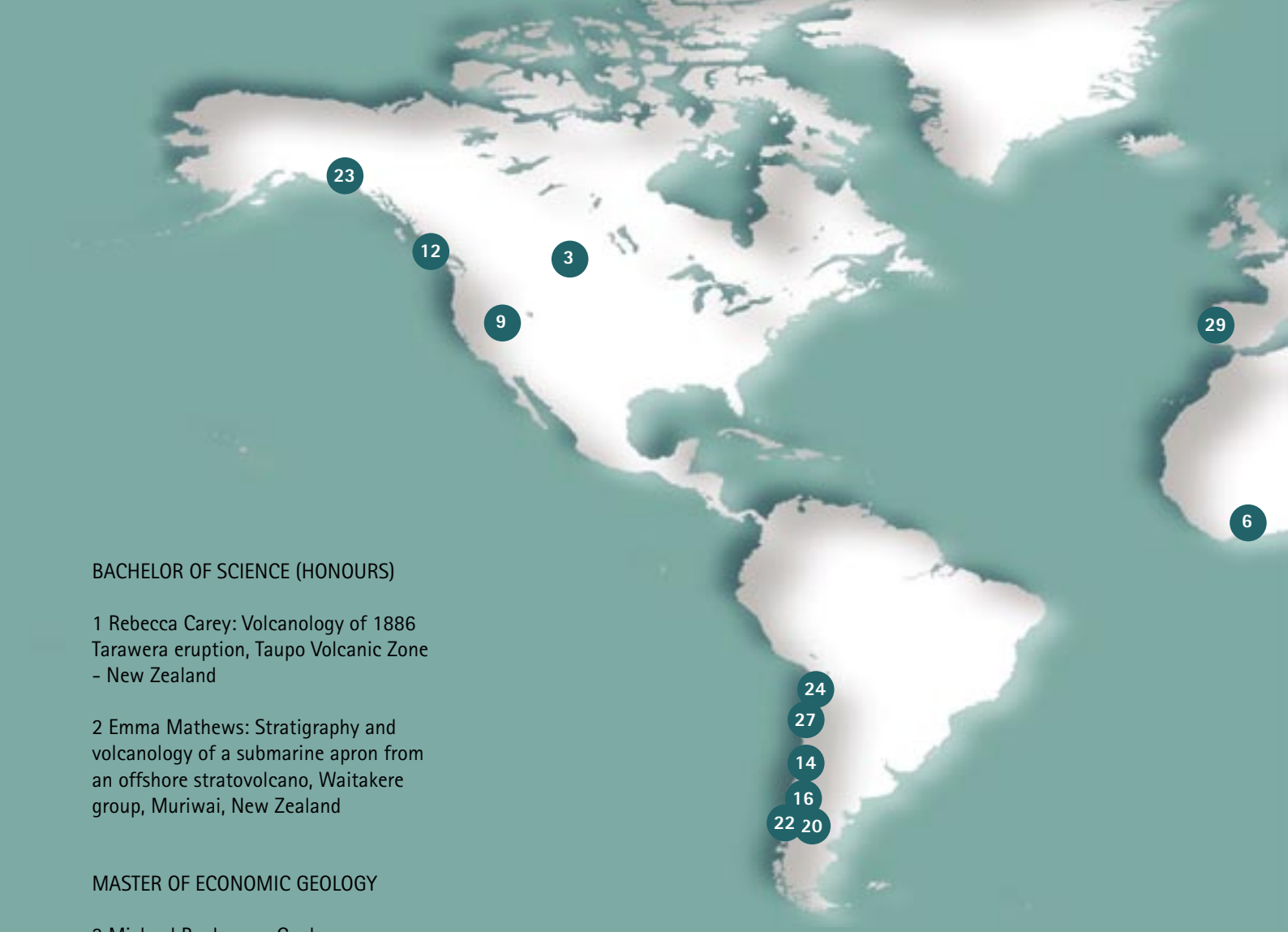
- Fine-grained pyrite from the Deep Star Carlin-type deposit in Nevada, to determine the residence site(s) of gold (Rae et al.)
- Chalcocites from the Mammoth (Gunpowder) deposit, to distinguish primary from supergene mineralisation (Clark et al.)
- Pyrite in Victorian lode gold deposits, to compare gold contents of pyrite in different parageneses, including pyrite associated with marker beds, in the host metasediments and in the ores (Large et al.)
- Enargites from the Lepanto high-sulfidation deposit (Philippines), to evaluate spatial compositional zoning outwards from the main Far Southeast porphyry host and correlations with fluid salinities determined by infra-red microthermometric studies of the same grains (Deyell et al.)
- Pyrite and chalcopyrite in the Rosebery VHMS system in western Tasmania, to distinguish Cambrian mineralisation from later, less economically important mineralisation associated with nearby Devonian granite emplacement (Neil Martin & Ross Large)
- Pyrite from Kanowna Belle, Cadia Far East and Sunrise Dam, to evaluate the potential and usefulness of trace-element compositions as vectors to mineralisation (Andrew Rae, Garry Davidson & Wally Herrmann).

Mainly via the ARC Linkage project mechanism, more than ten sponsor companies are presently involved in CODES core and non-core projects based on LA-ICPMS of sulfides, and the range of applications of this exciting methodology is increasing monthly. The CODES LA-ICPMS sulfides team includes Garry Davidson, Andrew Rae, Leonid Danyushevsky, Ross Large, Peter McGoldrick, Sarah Gilbert, and Marc Norman now at PRISE (ANU). Two PhD students are working directly on LA-ICPMS applied to sulfides (Claire McMahon) and oxides (Singoyi Blackwell).

ABOVE: Andrew Rae, Sarah Gilbert and Leonid Danyushevsky; The Agilent HP4500 quadrupole ICPMS and Merchantek LUV266X laser operational at CODES.



Laser ablation pits and trenches in pyrite, sphalerite and galena from graphitic Pb-Zn-Ag ore, Cannington BHT deposit



BACHELOR OF SCIENCE (HONOURS)

1 Rebecca Carey: Volcanology of 1886 Tarawera eruption, Taupo Volcanic Zone - New Zealand

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

MASTER OF ECONOMIC GEOLOGY

3 Michael Buchanan: Geology, geochemistry and genesis of the Harmin/ Fenton Zone VHMS prospects, Snow Lake, Manitoba, Canada

4 Richard Cotton: Geology of the Ross alluvial Au deposit, New Zealand

5 Alan Ignacio: Geology of the Boyongan porphyry deposit, Mindanao, Philippines

6 Lennard Kolff: Seemandoo iron deposit, Guinea, West Africa

7 Ian Laurent: Geophysical interpretation of the Svartliden Au deposit, Sweden

8 Mannie Mehu: Regional exploration around Lihir, PNG

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 Spencer Summers: Sekatak project, northeast Kalimantan, Indonesia

MASTER OF EXPLORATION GEOSCIENCE

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

13 Kamonporn Kromkhun: Geological setting, alteration, mineral paragenesis, and nature of ore fluids and 'H' zone, Chatree gold deposit, central Thailand

14 Felipe Urzua: Geology of the Escondida district, Chile

DOCTOR OF PHILOSOPHY

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

16 James Cannell: Geology, geochemistry and genesis of the El Teniente porphyry Cu-Mo deposit, Chile

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

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

19 Paul Cromie: Geological setting, geochemistry and genesis of the Sepon Cu-Au deposit, Laos

20 Paul Davidson: Melt inclusions in porphyry Cu-Au-hosting magmatic systems

INTERNATIONAL STUDENT PROJECTS 2003

21 Andrew Davies: Geology and genesis of the Kelian gold deposit, East Kalimantan, Indonesia

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

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

24 Ben Jones: Antapaccay porphyry Cu-Au system, Peru

25 Maya Kamenetsky: Primary melts of kimberlites, and Emeishan flood basalts, China

26 Roman Leslie: Petrology and geochemistry of shoshonites, SW Pacific, especially Fiji

27 Glen Masterman: Genetic relationships between the Rosario porphyry Cu-Mo deposits and the high-sulfidation Cu-Au veins, Collahuasi district, Chile

28 Nicki Pollington: Sedimentology mineral paragenesis and geochemistry of the Konkola North copper deposit, Zambia

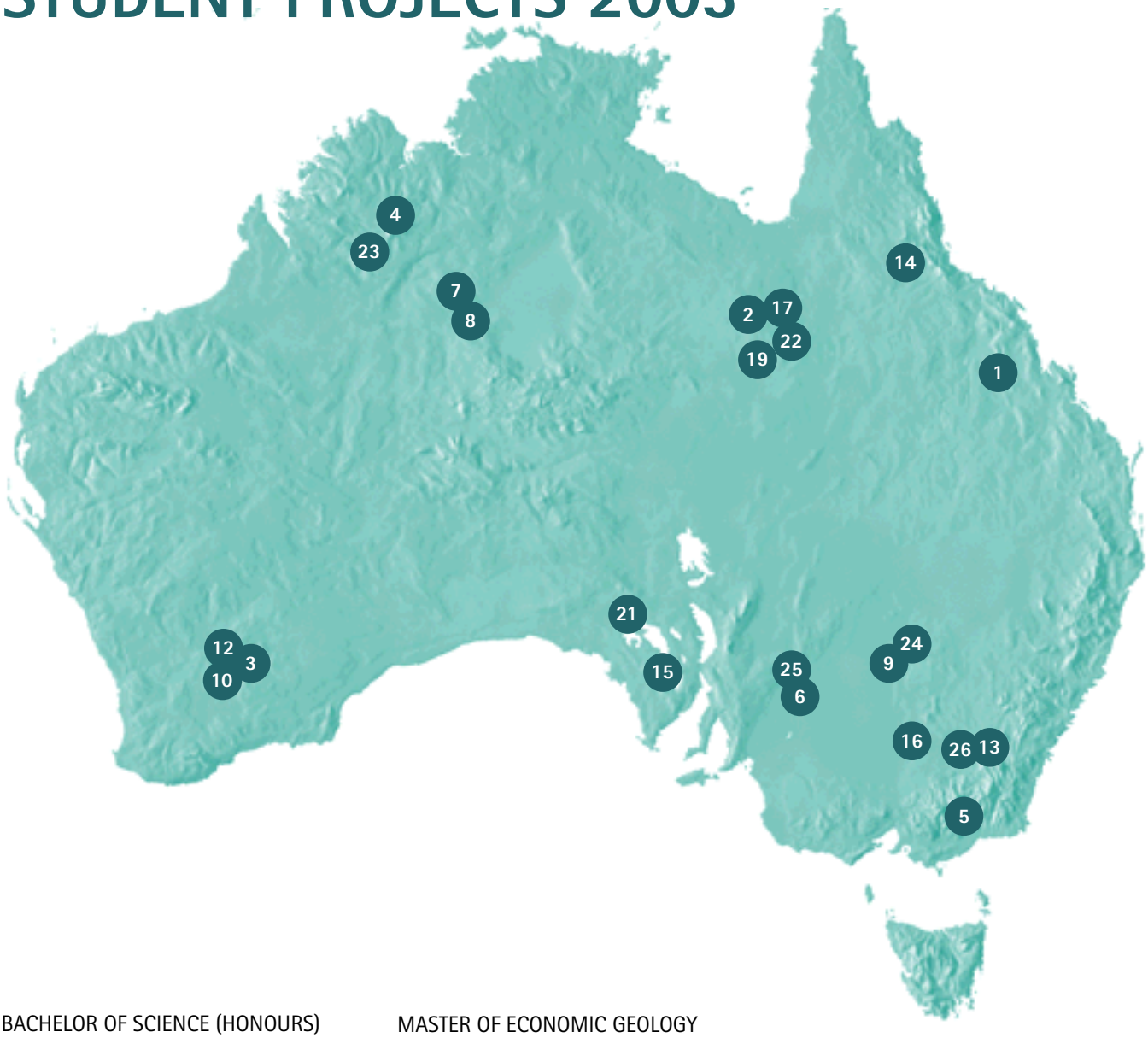
29 Carlos Rosa: Submarine volcanic successions in the Iberian Pyrite Belt, Portugal

30 Andrew Stewart: Facies architecture of an arc volcanic island - Milos, Greece

31 Sofia Tetroeva: Petrogenesis of adakitic lavas in modern SW Pacific settings, particularly in Fiji

32 Andrew Wurst: Mineralisation and alteration of the Kerikil and Serujan Lode systems: implications for ore genesis and exploration, Mt Muro, Indonesia

MAINLAND AUSTRALIA STUDENT PROJECTS 2003



BACHELOR OF SCIENCE (HONOURS)

1 Joe Booth: Genesis and alteration vectors around the Bimurra epithermal deposit, Drummond Basin , Qld

2 Anthia Pittas: Geology and genesis of the Esperanza South Copper mineralisation in the Gunpowder area, Qld

3 Brett Thomas: Geology of the Minjar Project, WA

MASTER OF ECONOMIC GEOLOGY

4 Leon Bagas: Geology of the Paterson Orogen, WA

5 Julian Bartlett: Alteration within the Barkly River greenstones, Whisky Knob Window, E Vic

6 Steven Lewis: Structure and lithostratigraphy of the Harp Prospect, Broken Hill, NSW

7 David Nixon: Gold mineralisation in the Tanami region, NT

8 Dan Power: Gold mineralisation at Groundrush, Tanami

9 Michael Priestly: Perseverance gold prospect, Cobar, NSW

MASTER OF EXPLORATION GEOSCIENCE

10 Matthew Hope: Geology of the Mount Kirk Formation, Norseman, WA

11 Terry Hoschke: Geophysical signature of Au-Cu porphyry systems

12 Pamela Italiano: A study of the petrology and petrophysics of the Black Swan komatiite, Eastern Goldfields, WA

DOCTOR OF PHILOSOPHY

13 Michael Agnew: Geology and genesis of the Lewis Ponds massive sulfide deposits, NSW

14 Michael Baker: Geochemistry of the mafic rocks in the Precambrian Georgetown Block, N Qld

15 Bryan Bowden: Iron Oxide Copper-Gold related alteration history of the Mt Woods Inlier, South Australia, with special emphasis on the Prominent Hill prospect

16 Katharine Bull: Facies architecture, geochemistry and tectonic implications of the central Lachlan Fold Belt, NSW

17 Darryl Clark: Geology and genesis of the Mammoth Copper Deposit, Mt Isa Inlier, W Qld

18 Andrew Fitzpatrick: Scale-dependent electrical properties of sulfide rocks

19 Owen Hatton: Basin configuration, sedimentology and volcanology of the Toole Creek Volcanics, Mt Isa region, Qld

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

21 Wallace MacKay: Sediment-hosted copper, Stuart Shelf, South Australia

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

23 Karin Orth: Geology and mineralisation of the Koongie Park Pb-Zn deposit, WA

24 Craig Stegman: Geochemistry and structure of gold–base metal mineralisation in the Cobar goldfield, NSW

25 Tony Webster: Structural evolution of the Broken Hill Pb-Zn-Ag deposit, NSW

26 Alan Wilson: The geology, genesis and exploration context of the Cadia gold-copper porphyry deposits, NSW

TASMANIA

BACHELOR OF SCIENCE (HONOURS)

Darren Andrews: Hobart seismic microzonation

John Bedi: Reservoir and source rock potential of the Upper Parmeener Supergroup – Tasmania Basin

Mary Bessell: Groundwater and salinity of the Swan River Tertiary Basin, Tasmania

Andrew Crawford: Origin of the Bond Range porphyry, NW Tasmania

Kate Godber: Ground magnetic mapping of the oceanic crust, Macquarie Island

Jhana Hale: Geophysical investigation and interpretation of the Temma area, NW Tasmania

David Hartney: Comparison of metamorphism and structure of metamorphic inliers, NE Tasmania

John Hooper: Firetower prospect geology and genesis, NW Tasmania

David Kratzmann: Volcanology of the Sterling Volcanics, W Tasmania

Paul Lane: The Longford Sub-basin architecture and economic potential based on seismic, potential field and drill-hole data

Todd McGilvray: Geology and genesis of a Pb-Zn system in the Zeehan area, W Tasmania

Sophie Osterloh: Origin of the Maydena silica flour and bedrock silicification, Tasmania

Monica Osuchowski Land stability of the Knights Creek catchments and control upon the turbidity of the Knights Creek Reservoir

Cynthia Palfreyman Hydrogeology of the Dolphin Sands sand spit, Tasmania

Chris Parker: Vulnerability and aquifer potential of the Cowrie Siltstone aquifer around the Circular Head waste transfer site using geophysical, hydrogeochemical and hydrological methods

Lee Robson: A remote sensing and geophysical investigation of the central midlands, Tasmania

Aaron Scollard: Geophysical investigations of the D'Entrecasteaux channel

Luke Wallace: Aqueous geochemistry of the constructed wetlands treating AMD, Rosebery, Tasmania

GRADUATE DIPLOMA OF SCIENCE

Stuart Dawes: Morphology and compositional variation of alluvial gold from Tobacco Creek, NE Tasmania

MASTER OF ECONOMIC GEOLOGY

Steven Richardson Geology and geochemistry of the Que River footwall alteration zone, W Tasmania

DOCTOR OF PHILOSOPHY

Darren Andrews: Time-lapse geophysical monitoring of acid mine drainage at Savage River mine, NW Tasmania

Kim Denwer: Genesis of the Mount Lyell deposits, W Tasmania

Greg Ebsworth: Tyndall Group, Mt Read Volcanics, W Tasmania

Steven Lewis: Hydrothermal processes and facies in slow spread oceanic crust, Macquarie Island

Neil Martin: Origin of the Rosebery VHMS deposit, W Tasmania

Christian Schardt: Heat and fluid flow simulations in submarine terrains

Blackwell Singoyi: Hydrothermal magnetite textures and trace element chemistry

PROGRAM 1
Tectonics, magmas and fluids

Research within Program 1 is divided between three broad themes: 1 - using the geochemical signatures of magmatic rocks 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; 2 - using both melt and fluid inclusions in minerals to elucidate and compare the magmatic-hydrothermal transition in mineralised and unmineralised systems; 3 - using modern geochemical and petrological techniques to address fundamental problems in the genesis of magmatic rocks.

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 Cu-Au, and high-sulfidation epithermal Au/Ag 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 Archaean) 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 SE Asian terrains.**

ABOVE Program 1 team — L to R, back row: Roman Leslie, Leonid Danyushevsky, Tony Crawford (Program Leader), David Steele, Ron Berry, Phil Robinson; front row: Ben Jones, Dima Kamenetsky, Sebastien Meffre, Maya Kamenetsky, Sofia Tetroeva, Fernando Della Pasqua.

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, Patricia Durance-Sie (part-Monash University), Ben Jones, Maya Kamenetsky, Roman Leslie, Sofia Tetroeva

Collaborators
Australia: CSL (UTAS), Geoscience Australia, CSIRO E&M, Geological Survey of NSW, Geological Survey of Victoria, Australian Crustal Research Centre (Monash University), University of Adelaide, Research School of Earth Sciences ANU, Centre for Strategic Minerals UWA
International: Lamont Doherty Earth Observatory USA, University of Naples (Italy), Lakehead University (Canada), University of New Caledonia, Max Planck Institute for Chemistry (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.

Highlights

1 Program 1 researchers and their collaborators authored 23 publications in a wide range of peer-reviewed international journals in 2003, including papers in *Nature*, *Science*, *Geology*, *Chemical Geology*, *Economic Geology*, *Geochimica Cosmochimica Acta*, *Geostandards Newsletter: Journal of Geostandards and Geoanalysis*, *Australian Journal of Earth Sciences*, *Lithos*, *Canadian Mineralogist*, *Ore Geology Reviews*, *Geofluids*, *Contributions to Mineralogy and Petrology*, *Tectonics*, and *Journal of the Geological Society (London)*.

2 Successful LIEF bid ($750,000) for funding of a new electron microprobe, and installation and routine operation of the new Cameca probe in the Central Science Laboratory.

3 Routine operation of laser ablation for U–Pb dating of zircons across a wide range of CODES projects, and for low-level determination of trace elements in sulfide minerals.

4 The prestigious Bessel Research Award of the Alexander von Humboldt Foundation to Dima Kamenetsky to spend six months in 2003 at the renowned Max Planck Institute for Chemistry in Germany.

5 Submission of Paul Davidson's PhD thesis in November, and commencement of new PhD students Michael Baker ('Palaeoproterozoic magmatism in the Georgetown Block, N Queensland') and Sofia Tetroeva ('Petrogenesis of adakitic magmas').

6 Successful completion of the first cruise, to the Norfolk Ridge region, of Australia's new National Research Facility R/V *Southern Surveyor*, with Tony Crawford (Chief Scientist), Sebastien Meffre, Patrick Quilty, Mike Baker, and colleagues from New Zealand and New Caledonia. This cruise attracted widespread media coverage, including articles in *The Australian* newspaper, a number of segments on ABC radio and TV, and on local and national commercial TV.

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

V Kamenetsky, A Harris, A Crawford, D Cooke, L Danyushevsky, T Mernagh (GA), D Steele (CSL), C Ryan and E von Achterbergh (CSIRO E&M), Dr S Garwin, Dr N White (consultant); PhD students P Davidson, B Jones, R Leslie

The key aim of this program is 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.

In the proceedings of an international conference in Italy on applications of melt inclusion studies, Dima Kamenetsky authored a paper 'Magmatic inclusions in the search for natural silicate–salt melt immiscibility; methodology and examples'. Application of this methodology to fluid evolution in the late magmatic history of the Bajo de la Alumbrera led to an important paper by Anthony Harris, Dima Kamenetsky and colleagues in *Science*, detailing the magmatic-hydrothermal transition and the exsolution of late magmatic vapour and fluids in a mineralised felsic magmatic system. The fluids released were found to be strongly enriched in Cu, and to be appropriate precursors to the hydrothermal fluids responsible for the Alumbrera alteration system and ore deposit.

Late in the year, Paul Davidson submitted his PhD thesis in which he compared melt and fluid inclusions in quartz phenocrysts from the mineralised Rio Blanco-Los Bronces porphyry Cu deposit 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 silicate melt and hydrosaline brine cotrapped in quartz phenocrysts, and that the brines are strongly enriched in Cu. Paul continues his porphyry-related studies, applying his skills to a project examining the nature of late magmatic fluid evolution in quartz phenocrysts from a number of other porphyry systems.

PhD student Ben Jones continued his PhD study of the Antapaccay porphyry Cu deposit in Peru. During the year, Ben completed a detailed U-Pb in zircon geochronological study of the various pre-, syn- and post-mineralisation intrusive phases in this deposit. Ben also assembled (and presented to his project sponsors) a thorough overview of the geological and tectonic evolution of Peru and N Chile; this will constitute the early chapters of Ben's thesis.

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

The original philosophy of this research project was that melt inclusions trapped in olivine phenocrysts in diverse magma types preserve a record of the volatile and chalcophile element abundances of primitive basaltic magmas before these were modified by fractionation, degassing and hybridisation. This provides a new method to determine the volatile and chalcophile element compositions of primitive magmas in different tectonics settings, enabling an evaluation of the controls on these features by mantle source composition and melting conditions. On this basis, we assembled suites of olivine-bearing lavas from different tectonic settings, including mid-ocean ridge and backarc basin spreading centres, intra-oceanic and continental magmatic arcs, intraplate alkaline basalts, and large igneous provinces (flood basalts). Detailed melt inclusion studies on olivines from these suites have demonstrated unexpected and remarkable complexities in the magmatic evolution of most of the suites studied (Danyushevsky et al., 2003; Sun et al., 2003; Lima et al., 2003). Significant magmatic interactions with mantle and lower crustal wallrock, and with cumulates in the base of arc crust, are now well documented, and force a revision of our early concepts. A paper documenting these complexities has been submitted to *Journal of Petrology* (Danyushevsky, Leslie, Crawford & Durance) and will be published in 2004. Nevertheless, work in mid-ocean ridge basalts, arc basalts from the Taupo Volcanic Zone, and shoshonites from Fiji, has shown that careful melt inclusion studies can indeed provide very useful data about magmatic volatile and chalcophile element budgets. For example, primitive olivines in Taupo basalts carry melt inclusions with remarkably high Cl contents (>1%), with correspondingly high Cu abundances (>1000 ppm).

Roman Leslie's PhD study of primitive shoshonitic magmas associated with the Emperor epithermal gold deposit in Fiji is nearing completion. Roman has shown that most melt inclusions in primitive olivine phenocrysts ($Fo_{>86}$) in these lavas have unusual compositions recording the aforementioned wallrock interaction processes. However, more evolved olivines have melt inclusions with compositions representative of the evolving melt, and probably recording melt volatile compositions. Surprisingly, despite Cl contents up to 6000 ppm, these melt inclusions have very low H_2O contents of (<0.1%), raising concerns about the viability of current models for shoshonite petrogenesis, and the evolutionary pathways of H_2O in such magmatic systems.

Leonid Danyushevsky has commenced cosupervision of MonashU PhD student Patty Durance, whose PhD project involves the petrogenesis of primitive arc tholeiite magmas from the Hunter Ridge in the SW Pacific. The melt inclusion and LA-ICPMS components of this study are being carried out in CODES laboratories, and Monash cosupervision involves Dr Ian Nicholls.

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)

During 2003, development of diverse applications of the CODES-funded LA-ICPMS continued, with several excellent outcomes. Following careful attention to development of appropriate standards (Norman et al., 2003), routine microanalysis of sulfide grains became achievable, leading to a major multi-sponsored industry project and related contract work for the laboratory. Drs Meffre and Danyushevsky continued improvement of the analytical procedure to use the LA-ICPMS to date zircons via U-Pb micro-isotopic analysis. This had led to applications as diverse as dating Palaeoproterozoic zircons from the Mount Isa Inlier, Mesoproterozoic zircons from the Stuart Shelf, Late Neoproterozoic and Palaeozoic zircons from Ordovician rocks in the Macquarie arc of the Lachlan Fold Belt, and Tertiary zircons from various SW Pacific arc basement suites. In another development, Yu, Norman and Robinson (2003) described a method for rapid trace-element analysis of silicate rocks using fused lithium borate discs such as those prepared for wholerock analysis by XRF.

Following the successful ARC LIEF application (Crawford, Large et al.), a Cameca SX100 microprobe has been installed in the Central Science Laboratory. The new instrument has considerably improved capabilities for imaging and analysis. It includes a cathodoluminescence

spectrometer that enables imaging of the internal structure of phases such as zircon, a vital prerequisite to the successful dating using LA-ICPMS. Drs Berry and Steele developed a new microanalytical system for the accurate dating of monazite using the new microprobe, and Dr Steele visited the School of Earth Sciences at UAdelaide to install this system on their microprobe.

Philip Robinson, the School of Earth Sciences and CODES analyst, was invited to co-write a major review paper on sample preparation for analysis of geological samples, and this large paper was published (Potts and Robinson, 2003) in the new volume of Wilson and Wilson's *Comprehensive Analytical Chemistry*. Phil was also asked to stay on as an Editorial Board member of the journal *Geostandards Newsletter – Journal of Geostandards and Geoanalysis*, which, with an impact factor of 2.36, is among the ten most highly cited earth sciences journals.

Waves breaking over the bow of Australia's newly refitted research vessel R/V Southern Surveyor *during the Norfolk'n Around cruise to the Norfolk Ridge in February–March 2003.*

Swimming below the MOHO: Sebastien Meffre and Tony Crawford sampling mantle peridotites in Yate Gorge, New Caledonia.

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

A Crawford, D Cooke, W Herrmann, S Meffre, R Scott (CODES); D Glen, I Percival, J Watkins and L Barron (Geol. Survey NSW); C Simpson (Consultant), M Fanning (PRISE-ANU)

This collaborative project with 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 will be published as the last issue in 2004.

Project 1.5
Modern and ancient fold belt volcanics

A Crawford, S Meffre, L Danyushevsky, D Kamenetsky, P Quilty; R Herzer and N Mortimer (Institute of Geological and Nuclear Sciences – NZ), P O'Brien & N Exon (Geoscience Australia), C Laporte and M Allenbach (U New Caledonia), P Hollings (LakeheadU, Canada), R Glen (GS NSW); PhD students M Baker, D Carroll, P Durance, O Holm, S Tetroeva

Modern Settings

A major new Program 1 research effort in the SW Pacific commenced in 2003, hosted by an ARC Discovery Grant ('Tectonic Paradox of the Eastern Margin of the Australian Plate, 120 Ma–45 Ma') to Tony Crawford. The geological and tectonic history of the eastern margin of Australia is apparently well preserved in the marginal seas and ridges extending out as far as Fiji and Tonga, but a major paradox exists. All available geological evidence suggests that from 120 Ma until the modern phase of subduction commenced around 45 Ma, the eastern margin of the Australian plate was undergoing strong extension. In contrast, all plate kinematic reconstructions demand significant convergence, and therefore subduction (and attendant island arc magmatism) along this margin in the same time interval. The problem with the hypothesis of long-lived subduction east of Australia from at least Early Cretaceous to Palaeocene is that arc magmatism of 120–45 Ma age is unknown in the Australian (including offshore continental ribbons) sector of eastern Gondwanaland. The reason for the apparently poorly represented or absent arc-type magmatic products associated with the hypothesised Cretaceous–Palaeocene subduction, and the paradox concerning the nature of the plate boundary, is a first-order problem for studies of the geodynamic evolution of the SW Pacific. As it is widely accepted that 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. A paper synthesising the tectonic development of the SW Pacific and its importance to establishing a better understanding the geology of eastern Australia was published (Crawford, Meffre and Symonds, 2003) in the new book, 'Evolution and Dynamics of the Australian Plate', co-published by the Geological Society of Australia and the Geological Society of America late in 2003.

To address this problem, the ARC Discovery Grant enabled the first cruise of the newly fitted-out Australian National Research Facility R/V *Southern Surveyor*, in the Three Kings Rise–Norfolk Ridge region in February 2003. During the 21-day cruise, in which Tony Crawford (Chief Scientist), Sebastien Meffre, Pat Quilty and Mike Baker from UTasmania all took part, 35 dredges were deployed, some 30 of which yielded useful rocks for the study. Detailed laboratory geochemical and geochemical studies of the dredged rocks are underway. This cruise attracted significant media attention involving radio and TV interviews, and a feature article in *The Australian* newspaper.

A successful ARC Discovery Grant to Leonid Danyushevsky, commencing in 2003, supports a new study of the petrogenesis of the unusual but relatively widespread adakitic and high-Mg andesite magmas in the Hunter Ridge part of the SW Pacific. These mainly felsic and andesitic magmas are thought to be generated in abnormally hot subduction zones by partial melting of the subducting

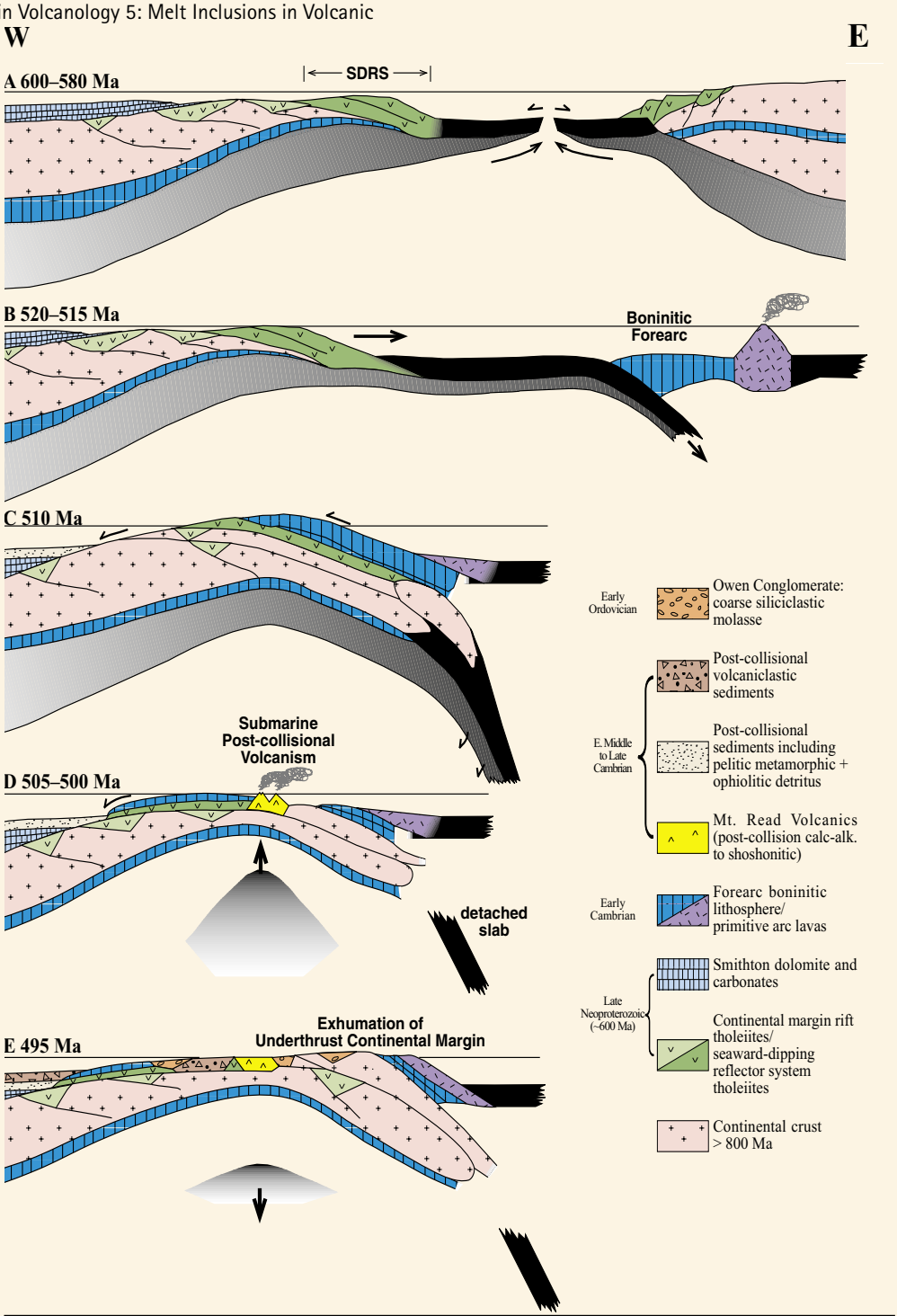
slab rather than the overlying mantle wedge. Adakitic magmas have been increasingly implicated in the formation of major porphyry-Cu orebodies in the Andes, and have been recently shown to have anomalously high Au contents. With new PhD student Sofia Tetroeva, Leonid will use detailed melt-inclusion studies to determine the nature of the parental magmas to erupted adakitic lavas, and evaluate existing models for the genesis of these rocks.

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

- A paper by Sun, Bennett, Eggins, Kamenetsky and Arculus (*Nature*) on the geochemical behaviour of rhenium during magmatic processes, with important implications for the interpretation of Re-Os isotopic data.
- A paper by Small and Danyushevsky (*Geology*) explaining the origin of mid-ocean-ridge depth discontinuities.
- A paper by Lima, Danyushevsky, De Vivo and Fedele (in the book 'Developments in Volcanology 5: Melt Inclusions in Volcanic Systems') detailing the results of post-doctoral work Annamaria Lima carried out in CODES in 2002 on the Vesuvius magmatic system.

Fold Belt Studies

The tectonic development of fold belts and construction of continental crust is a key research direction for Program 1, guided by own work in modern active W Pacific-style subduction-related settings. Nick Direen (CODES PhD graduate, now lecturing at the University of Adelaide) and Tony Crawford published two papers concerned with the Tasman Line, the much debated and poorly understood geophysical lineament purported to mark the eastern limit of the Australian cratonic crust. On the same theme, Oliver Holm (CODES PhD 2002, now at GA), Crawford and Berry described metabasic rocks from the Arthur Lineament in NW Tasmania, demonstrating the existence of an allochthonous fault slice containing rift tholeiites dated at around 777 Ma, possibly associated with the main breakup of Rodinia. A synthesis of the Neoproterozoic and Cambrian rocks



Hypothetical tectonic development of Tasmanian basement, 600–495 Ma (Crawford, Meffre and Symonds, 2003).

in Victoria was completed by Tony Crawford and colleagues (largely from the Geological Survey of Victoria) to form Chapter 3 of the 'Geology of Victoria', published in 2003 by the Geological Society of Australia.

A new project in north Queensland commenced in September 2003, with funding from a University of Tasmania Internal Research Grant. This project, involving Tony Crawford, David Giles (Australian Crustal Research Centre at Monash University) and Ian Withnall (Geological Survey of Queensland), aims to document the outcropping northern extremity of the Tasman Line, where it outcrops around Greenvale, inland from Charters Towers. Complex slices of ultramafic and mafic rocks, schists, phyllites and more felsic volcanics were mapped by Withnall almost 20 years ago, and we aim to use detailed petrological-geochemical, geochronological and structural studies to determine the tectonic setting of eruption of the volcanic rocks, and their structural-metamorphic history. In one of these structural slices, serpentinised ultramafic rocks of the Gray Creek Complex host the Greenvale Ni deposit.

Sebastien Meffre continued his regional geological and geochemical study of the Tumut region, sponsored by the Geological Survey of NSW. Sebastien and colleagues Kamenetsky, Crawford and others have submitted a paper to *Precambrian Geology* describing the geochemistry and setting of Late Neoproterozoic picrites on King Island, part of the 600 Ma seaward dipping reflector sequence proposed in Direen and Crawford (2003).

Late in 2003, Tony Crawford carried out fieldwork with Barney Stevens (Geological Survey of NSW) in the Broken Hill block, sampling amphibolites from across the region and across the established litho-stratigraphy. This work is the first phase of a project that saw a Linkage Grant submitted in the November 2003 round, aimed at establishing the regional nature, timing, and significance for mineralisation of the mafic magmatism in the Broken Hill and Georgetown Blocks (for the latter, PhD study by Michael Baker is underway). Colleagues involved include Massimo Raveggi from the ACRC at Monash University, and Karen Barovich from the University of Adelaide, in addition to geologists from the geological surveys of South Australia (Colin Conor), NSW (Barney Stevens) and Queensland (Ian Withnall).

Foldbelt-related publications in 2003 included:

- A paper by Holm, Crawford and Berry (*Australian Journal of Earth Sciences*) on the geochemistry and tectonic implications of metabasic rocks of the Arthur Lineament in NW Tasmania.
- A paper (Crawford, Meffre & Symonds: 120-0 Ma tectonic evolution of the SW Pacific, and analogous geological evolution of the 600– 220 Ma Tasman Fold Belt System) in the new joint Geological Society of Australia–Geological Society of America volume 'The Evolution and Dynamics of the Australian Plate'.
- A chapter, by Tony Crawford and colleagues in the book 'Geology of Victoria', on the Neoproterozoic and Cambrian rocks in Victoria.
- A paper by Nick Direen and Tony Crawford (*Journal of the Geological Society (London)*) interpreting the Late Neoproterozoic basalts of SE Australia as seaward-dipping reflectors of a ~600–570 Ma volcanic passive margin.
- A paper by Direen and Crawford (*Australian Journal of Earth Sciences*) evaluating the history and significance of the Tasman Line, one of the most profound and puzzling large-scale geophysical lineaments on the Australian continent.

Ongoing petrology-geochemistry research projects include:

- A study of the early magmatism and geological development of Fiji by PhD student Dene Carroll is nearing completion. During 2003, Dene finished most chapters of his thesis, and is carrying out some LA-ICPMS zircon dating of key units to round off the section relating to the geological evolution of the SW Pacific.
- An isotopic study of the felsic rocks in the Cambrian Mount Read Volcanics of western Tasmania forms the basis for a paper in preparation (Tony Crawford, Peter Hollings, David Whitford) examining the tectonic setting of mineralisation within this important belt. The paper will be part of a Special Issue of *Economic Geology* focussing on volcanic-hosted mineralisation.

Project 1.8
Geochronology, metallogenesis and deposit styles of the Loei foldbelt in Thailand and Laos PDR

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

The ARC Linkage project was initiated in 2004 with funding from three sponsor companies, Oxiana Limited, Kingsgate Consolidated Limited and Pan Australian Resources NL. The Loei volcanic-plutonic belt occurs between the Shan-Thai and Indochina terranes in mainland SE Asia. Although several skarn type Cu-Au and porphyry related epithermal gold deposits are distributed along the belt these deposits are not well documented and their metallogenic relationships are poorly understood. This project will study the age, origin and styles of Cu-Au mineralisation and their exploration significance to the discovery of world class Cu–Au resources in the region. Several higher degree Australian and SE Asian students will be involved in the project. The following projects are already being undertaken:

Grace Cumming: Volcanic setting and mineralisation at Khao Sai-Chon Dean district, central Thailand.

Teera Kamvomp: Genesis and geochemistry of Phu Lon Cu-Au skarn deposit, Loei district, northern Thailand.

Kamonporn Kronkhun: Geological setting, alteration and mineral paragenesis of H lens, Chatree gold deposit, central Thailand.

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 (thesis submitted November 2003).

Patricia Durance-Sie: Melt, fluid and solid inclusion studies on phenocrysts from two submarine volcanoes at the southern termination of the North Fiji backarc basin.

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.

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.

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 Cu-Au and epithermal Au-Ag ore deposits.**
- **To clarify the primary textural characteristics and textural evolution of fresh, glassy volcanic facies through syn-depositional, diagenetic and hydrothermal alteration stages.**

ABOVE Program 2 team — L to R: Stuart Bull, Fernando della Pasqua, Kate Bull, Carlos Rosa, Cathryn Gifkins, Wally Herrmann, Jocelyn McPhie (Program Leader)

Team Leader
Jocelyn McPhie

Team Members
Sharon Allen, Stuart Bull, Fernando Della Pasqua, Cathryn Gifkins, Wally Herrmann, Carol Simpson; Rod Allen (Volcanic Resources)

PhD Students
Michael Agnew, Katharine Bull, Gregory Ebsworth, Karin Orth, Carlos Rosa, Andrew Stewart

Collaborators
Macquarie University, Lulea University (Sweden), University of Lisbon (Portugal), Niigata University (Japan), Institute for Frontier Research on Earth Evolution (IFREE, Japan), Smithsonian Institution (USA), Institute for Geology and Mining (Lisbon, Portugal), Institute of Geology and Mineral Exploration (Athens, Greece), Mineral Resources Tasmania, Geological Survey of New South Wales, Primary Industries and Resources South Australia, Geological Survey of Sweden (Sweden), Anglo Gold (Australia), Geomarine Research (New Zealand), Silver and Baryte SA (Greece), Boliden Mineral AB (Sweden), SOMINCOR (Portugal)

Core Projects in Program 2
2.1 Facies architecture models for submarine volcanic successions that host seafloor massive sulfide 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.

Highlights

1 Results of CODES Volcanology research were featured at an international field workshop and conference on Milos, Greece.

2 New research collaborations were established with volcanologists at Niigata University and IFREE in Japan, and at the Smithsonian Institution in the USA.

3 A new project began to establish source vent positions of extensive rhyolites in the Gawler Range Volcanics.

4 Interactive GIS maps of the Mount Read Volcanics, western Tasmania, were produced, highlighting the links between volcanic centres, alteration zones and massive sulfide ore deposits.

Project 2.1 CORE
Facies architecture models for submarine volcanic successions that host seafloor massive sulfide ore deposits and other deposit types in arc environments

S Allen, S Bull, C Gifkins, W Herrmann, J McPhie; R Allen (Volcanic Resources), Y Goto (Muroran Institute of Technology), N Fujibayashi (NiigataU), K Kobayashi (NiigataU), S Meakin (GS-NSW), J Relvas (ULisbon); PhD students M Agnew, K Bull, G Ebsworth, K Orth, 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 successions. The work is carried out in the context of PhD projects and projects undertaken by Research Fellows, Sharon Allen, Stuart Bull, Cathryn Gifkins and Wally Herrmann. In 2003, this project included six PhD projects (summarised below), two of which were completed. Several of these projects combine volcanic facies architecture and textural studies with investigations of alteration related to massive sulfide mineralisation (Project 3.5). Study areas included:
Anson Formation at Lewis Ponds, New South Wales
Ural Volcanics, New South Wales
Mount Read Volcanics in western Tasmania
Eastern Goldfields, Western Australia
Iberian Pyrite Belt, Portugal
Milos, Greece
Bergslagen , Sweden
Green Hills Volcanics, northwestern Tasmania

Michael Agnew completed his PhD thesis on the geology and genesis of the Lewis Ponds polymetallic massive sulfide deposits, central western New South Wales. Lewis Ponds is unusual in that base-metal sulfides occur in thick units of poorly sorted, limestone-bearing volcanic breccia, deposited from mass flows around the flanks of a high-level intrusive dacite centre. This observed spatial association provides a basis for new exploration targets in New South Wales as many small massive sulfide deposits occur in marine successions containing fossiliferous limestone lenses and felsic volcanic rocks.

Michael has recently submitted a paper to the *Australian Journal of Earth Sciences* on the volcanic and sedimentary setting of the massive sulfide lenses entitled, 'Facies architecture of the Lewis Ponds carbonate and volcanic-hosted massive sulfide deposits, central western New South Wales'.

Kate Bull completed a second field season, working on the Early Devonian submarine volcanic successions in central western New South Wales. Her main PhD project area is in the Ural Volcanics around Lake Cargelligo, but has been extended to include the Mount Hope Volcanics farther north where she has completed sampling and facies analysis of an east-west stratigraphic section. Kate's project is conducted in collaboration with the Geological Survey of New South Wales. Major results of her work in the Ural Volcanics, including a new 1:10,000 scale geological map, have been summarised in a manuscript submitted to the *Quarterly Notes of the Geological Survey of New South Wales*. Kate was very successful in gaining additional funding for her research, being awarded a Hugh McKinstry student research grant by the Society of Economic Geologists. She also received travel grants from the American Geophysical Union and from the International Association for Volcanology and Geochemistry of the Earth's Interior to present papers at international conferences (the IUGG conference in Sapporo, Japan, and the South Aegean Active Volcanic Arc conference on Milos, Greece).

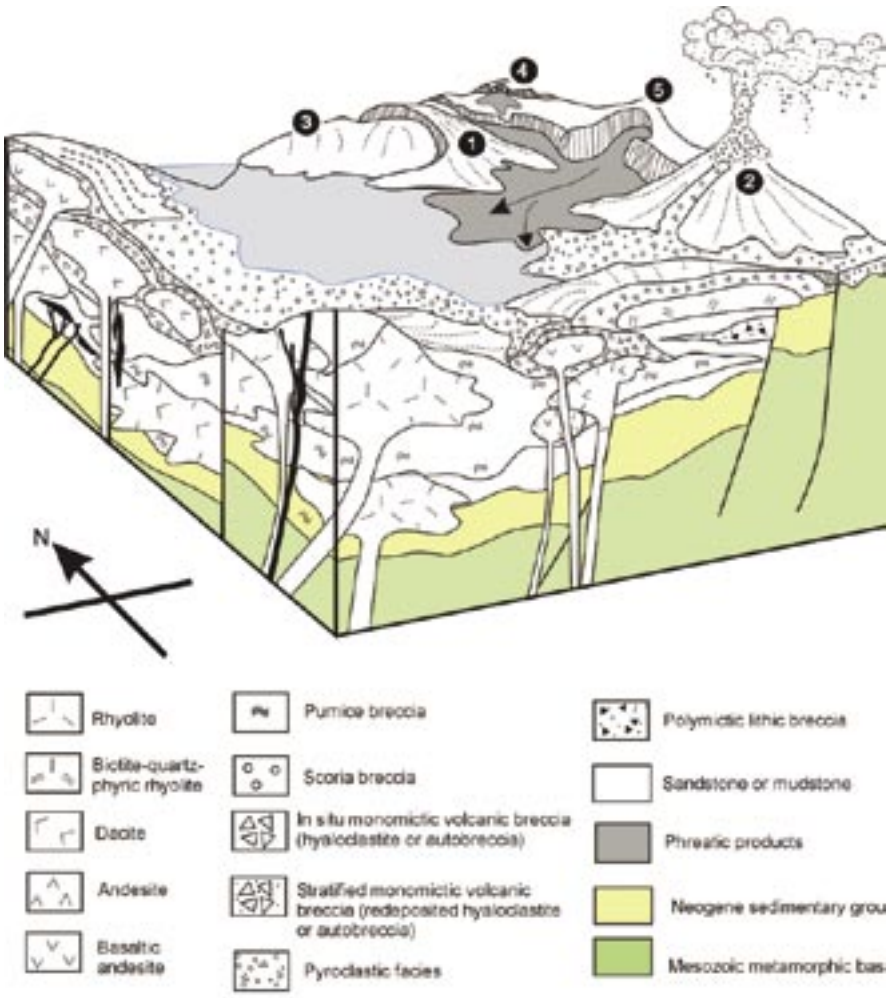
Greg Ebsworth is in the final year of his PhD project on regional variations in the internal stratigraphy of the Tyndall Group and its correlates in western Tasmania. The Tyndall Group is the youngest part of the Mount Read Volcanics, and hosts the Henty gold deposit and several important base-metals prospects. Greg has generated new stratigraphic logs and comprehensive data on textures, whole rock geochemistry, detrital mineral chemistry and biostratigraphic ages for all major areas of the Tyndall Group and its correlates, mainly focussing on the lower, highly prospective part of the group. The results of his research will help to constrain the position of Cambrian mineralisation in the Mount Read Volcanics, and greatly advance current understanding of the late Middle Cambrian palaeogeography and tectonic setting of western Tasmania.

Carlos Rosda, Kate Bull and Andrew Stewart on Milos, Greece

Karin Orth's PhD thesis was accepted and she graduated in 2003. Karin studied the volcanic and sedimentary setting of massive sulfide prospects in the Palaeoproterozoic Koongie Park Formation, Western Australia. Karin clarified the stratigraphy and structure of the succession and showed how the volcanic and mineralising hydrothermal processes were interrelated. A paper (Orth and McPhie) on cooling and crystallisation of a rhyolitic sill in the Koongie Park Formation was published in the *Journal of Volcanology and Geothermal Research*. Karin is currently preparing additional manuscripts on the facies architecture and on carbonates associated with the massive sulfide deposits.

Carlos Rosa made significant progress on his PhD research in the Iberian Pyrite Belt, Portugal. Carlos completed a second field season, mapping sections through the volcanic succession that hosts the massive sulfide ore deposits for which the Iberian Pyrite Belt is world-famous. One area of very good outcrop (Albernoa), and drill core sections through the host succession at the Neves Corvo mine, have been studied in detail. Carlos has recognised two major associations: one association is dominated by submarine felsic lavas and the other is mainly composed of felsic pumice breccia. This research is jointly supervised by Dr Jorge Relvas at the University of Lisbon and receives support from the Portuguese Science and Technology Fund, the Institute for Geology and Mining of Portugal, and SOMINCOR mining company.

In 2003, Andrew Stewart submitted his PhD thesis on the volcanic facies architecture of Milos, Greece, and it is under examination. The 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. Milos has a volcanic history beginning about 3 million years ago and continuing to historical times. Much of the early volcanism was submarine and explosive, generating spectacular beds of giant pumice. The island also features complete cross-sections through submarine-emplaced cryptodome volcanoes, accessible only by boat. The volcanic evolution and transition from shallow submarine to subaerial settings have been established with the help of new U-Pb in zircon dates, obtained in collaboration with Dr Marc Norman at the Research School of Earth Sciences (ANU). The new dates also constrain the age of Au- and Ag-rich epithermal quartz veins. This research has been 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. A paper describing a large dacitic cryptodome (Stewart and McPhie, *Journal of Volcanology and Geothermal Research*) and a field guide (McPhie and Stewart) were published. Another paper that deals with the origin of extremely coarse, submarine pumice breccia is in press (Stewart and McPhie, *Bulletin of Volcanology*). A third manuscript on the volcanic facies architecture of Milos is in preparation. Andrew joined Ivanhoe Mines Mongolia Inc. as a Senior Exploration Geologist leading one of their exploration campaigns in Mongolia.



A three-year collaborative project (also Project 4.4) based in Sweden, between CODES (Stuart Bull), the Swedish Geological Survey (Magnus Ripa), Luleå University (Rod Allen) and Boliden Mineral AB (R Jonsson and Hans Christoffersson), was completed in 2003. This project involved field-based facies analysis and structural interpretation of metamorphosed Palaeoproterozoic volcanic and sedimentary formations in the Bergslagen district of southern Sweden where there are important Zn-Pb sulfide deposits. The project clarified the origin and exploration significance of carbonates interbedded with the volcanic units. The carbonates are in fact tabular to lensoidal, microbial limestone reefs, variably affected by hydrothermal alteration, metamorphic recrystallisation and deformation. The project also involved a detailed structural, stratigraphic and facies analysis of the Garpenberg Norra Zn-Pb-Ag deposit, resulting in a new model for the volcanic setting and ore genesis. The achievements of the project have been documented in detail in the final report. Stuart and Rod are also preparing a manuscript on their new facies model for carbonates in this unique, volcanic-dominated setting.

Cathryn Gifkins, Wally Herrmann, Bronwyn Kimber and Jocelyn McPhie participated in a collaborative project with Mineral Resources Tasmania, the pmd*CRC at the University of Melbourne, and Fractal Technologies, aimed at producing a comprehensive database on Tasmanian geology that would stimulate mineral exploration. Their contribution involved compilation and analysis of both published and unpublished data on the Mount Read Volcanics in western Tasmania, specifically focussing on the volcanic facies architecture and alteration. The project generated interactive GIS maps 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. A major outcome is the recognition that all known massive sulfide ore deposits and most hydrothermal alteration zones are spatially associated with proximal volcanic facies that delineate near-vent locations. One implication is that a combination of alteration and volcanic facies information can be used to define prospective areas, provide vectors to ore and discriminate among different deposit types.

Wally Herrmann is investigating the facies architecture of the Archaean volcanic succession at the Sunrise Dam Gold Mine area, in the Eastern Goldfields of Western Australia, as part of a project sponsored by AngloGold Australia. The project aims to integrate research on sulfide trace-element compositions, short wavelength infrared spectrometry and volcanic facies to develop a set of criteria and ore vectors that will assist exploration of potential depth extensions of gold ore bodies at Sunrise Dam. Despite their Archaean age, the textures of the host rocks are remarkably well preserved and much has already been revealed by an intensive 3-week session of drill-core logging. The dominance of porphyritic andesite, coarse monomictic volcanic breccia and volcanic sandstone grading to magnetite-rich siltstone indicates effusive-intrusive emplacement of andesite in a relatively deep (below wave base) subaqueous setting. Laterally discontinuous dome-like andesitic units and extensive dolerite sills have important implications for local stratigraphic and structural interpretations.

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 focuses on alteration associated with VHMS deposits, and incorporates many of the outcomes of AMIRA project P439 ('Studies of VHMS-related alteration: geochemical and mineralogical vectors to ore'). Processes commonly responsible for alteration in submarine volcanic successions are reviewed and complemented by a series of case studies. Substantial progress was made during 2003 and the book is nearing completion.

Sharon Allen initiated a new collaborative project in Japan, funded by the Australian Academy of Science and the Japanese Society for the Promotion of Science. She worked with colleagues Dr Norie Fujibayahsi and Dr Kenta Kobayashi on a well-exposed Miocene submarine rhyolitic lava. The surface morphology of the lava is almost perfectly preserved, including large- and small-scale ropey wrinkles. Field data on orientations of flow bands, lineations and folds, fold geometry and size, and locations and orientations of extension fractures will be used to determine the emplacement mechanisms and rheology, allowing comparisons with subaerial rhyolites and with submarine lavas of different composition. Collaboration between Dr Yoshi Goto (Muroran Institute of Technology, Japan) and Jocelyn McPhie in research on submarine lavas, especially pillow lavas, came to completion in 2003. A detailed field study of Tertiary basaltic lavas at Stanley in northwestern Tasmania revealed a strong genetic link between pillow lavas and sheet lavas. A paper (Goto and McPhie) presenting a new model for pillow lava propagation is in press in the *Journal of Volcanology and Geothermal Research*.

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

S Allen, J McPhie; R Allen (Volcanic Resources), 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; Greece), Tertiary (Vanuatu) and Palaeozoic (Cambrian, western Tasmania; Early Devonian, New South Wales) pumice breccias.

In 2003, Sharon Allen was awarded a joint grant from the Australian Academy of Science and Japanese Society for the Promotion of Science to support six weeks of travel and research into submarine pumiceous pyroclastic deposits in Japan. Sharon spent the first three weeks with the Institute for Frontier Research on Earth Evolution (IFREE) as a Research Scientist aboard the research vessel *Kaiyo*. Sharon was involved in deep-tow camera and geophysical surveys of modern sea-floor volcanoes along the Izu-Bonin Arc. A direct result of this cruise is a new collaborative study on giant pumice deposits generated by submarine eruptions, with Dr Yoshihiko Tamura (Group Leader, IFREE) and Dr Richard Fiske (Senior Volcanologist, Smithsonian Institution, USA). The new study will use the data on the giant pumice deposits obtained during the cruise, and vesicularity and textural data on dredge samples recovered from Sumisu volcano, to fully describe these deposits and constrain the eruptive style and depositional processes.

Several team members contributed to *American Geophysical Union Monograph* Number 27, published in 2003. The monograph focuses on explosive subaqueous volcanism, and is based on a Chapman Conference devoted to the same topic that was held in 2002. The monograph includes papers by Sharon Allen, Rod Allen, Jocelyn McPhie, Alison Raos (graduated 2001) and Andrew Stewart, covering submarine successions in Greece, Vanuatu and western Tasmania. These successions are all dominated by thick, submarine, felsic pumice breccia units generated by explosive eruptions. In detail, the facies characteristics differ significantly, reflecting variations in eruption mechanisms, in transport and depositional processes, and in proximity to source vents.

Ancient pumice breccias commonly display a bedding-parallel foliation defined by fiamme and interpreted to result from early diagenetic compaction and alteration of glassy pumice. The Early Devonian Ural Volcanics, New South Wales, include extensive and thick units

of submarine pumice breccia intercalated with rhyolitic and dacitic lavas. Kate Bull has mapped and logged pumice breccias that include conspicuous fiamme (juvenile clasts that define a pre-tectonic fabric) and has also recognised apparently similar fiamme in a variety of other facies. Part of Kate's PhD research will involve detailed examination of these fiamme.

Program 2 made a major contribution to an international conference on the volcanology, tectonics and ore deposits in the southern Aegean volcanic arc, Greece. The conference was held on Milos in September 2003 and attracted academic, survey and industry geologists with an interest in the region. Prior to the conference, Jocelyn McPhie and Andrew Stewart led a field workshop presenting some of the results of their research on the submarine pumice breccias that make up much of the lower part of the succession. The workshop was sponsored by the IAVCEI Commission on Explosive Volcanism and involved a series of lectures followed by field days inspecting some of the spectacular coastal outcrops. At the conference, Andrew gave a paper on the facies architecture and evolution of Milos. Kate Bull has recognised submarine pumice-rich facies in the Early Devonian Ural Volcanics in New South Wales that are similar to those on Milos, and also presented a paper on this aspect of her PhD research at the conference.

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 Program 2 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 but output has continued since then. A Thematic Issue of the *Australian Journal of Earth Sciences* devoted to the results of the project is due for publication as the last issue in 2004. It will include a paper (Squire and McPhie) on the facies architecture of the Forest Reefs Volcanics and constraints on tectonic interpretations, based on the PhD study by Rick Squire (graduated 2001). Carol Simpson has prepared a paper (Simpson, Crawford & Scott) on her research into the character and setting of the Cargo Volcanics. Carol and Rick have contributed to a number of other papers in the Thematic Issue, dealing with aspects of the Ordovician volcanism, tectonics and porphyry Cu mineralisation. Wally Herrmann conducted a detailed study of alteration styles associated with the Ordovician porphyry Cu mineralisation, and presented results in a paper (Cooke and Herrmann) accepted for the Thematic Issue.

Project 2.4
Facies architecture of the Mesoproterozoic Gawler Range Volcanics in South Australia

S Allen, J McPhie, C Simpson, V Kamenetsky; S Daly (PIRSA)

The Volcanology Program has included a volcanological study of the Mesoproterozoic Gawler Range Volcanics in South Australia, supported by the Australian Research Council and Primary Industries and Resources South Australia. Although major research activity has ceased, output continued in 2003. A paper (Allen, Simpson, McPhie and Daly) on the stratigraphy and geochemistry of the three main widespread felsic units was published in the *Australian Journal of Earth Sciences*. Another manuscript on the volcanology of the Yardea Dacite is currently in preparation. The team also presented a paper at the IUGG conference in Sapporo, Japan, in a session on Large Igneous Provinces. Total output from the project comprises six papers in international refereed journals, five abstracts and a new 1:250,000 scale geological map of the Gawler Range Volcanics. These publications caught the attention of the media, resulting in Sharon Allen being interviewed on ABC Radio. A new project in the Gawler Range Province (Project 2.9) began in 2003.

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

S Allen, V Kamenetsky, J McPhie; 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.

Facies analysis in ancient volcanic successions, especially those that are altered and deformed, relies on the assumption that phenocryst populations in lavas differ significantly from those in crystal-rich volcaniclastic facies. In particular, we assume that phenocrysts in the coherent parts of lavas (and shallow intrusions) are dominantly euhedral, evenly distributed and uniform in mineralogy and size. However, there are surprisingly few quantitative data on phenocryst populations in felsic lavas so the validity of this assumption has not been assessed. Models for fractionation processes in arc magmas also rely on an understanding of phenocryst populations and of phenocryst-melt relationships. Although considerable attention has been paid to fractionation processes in mafic and intermediate porphyritic magmas, much less is known about porphyritic felsic magmas. There is increasing recognition that such magmas contribute significantly to mineralising hydrothermal systems (Project 1.1).

Forty-six samples of fresh, mainly rhyolitic, porphyritic lavas and 12 samples of rhyolitic ignimbrites were collected from the Taupo Volcanic Zone, New Zealand, and the southern Aegean volcanic arc, Greece. The phenocryst populations have been investigated by computer-aided image analysis, yielding data on the total phenocryst content and the proportion of phenocryst fragments in each sample. The data confirm that fragments are much less abundant in lavas than in pyroclastic deposits: on average, fragments in lavas amount to ~5% of the total phenocryst population, or ~0.5 modal%, regardless of the total phenocryst content. The results have been summarised in a paper published in the *Journal of Volcanology and Geothermal Research* by Sharon Allen and Jocelyn McPhie.

Paul Davidson submitted his PhD thesis on the transition between magmatic and hydrothermal fluids, using melt and fluid inclusion studies, of which an important component was a study of 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. Heating experiments on some melt inclusions resulted in the in situ exsolution of hypersaline aqueous globules enriched in metals and volatiles. In other samples, naturally exsolved one- and two-phase aqueous globules in glass inclusions were discovered. The difference between samples which exsolved hypersaline fluid globules during heating, and those which exsolved lower salinity globules naturally, could be a reflection of the pressure and temperature conditions of trapping, and the exact cooling path. These results are important in understanding the transfer of metals from fractionating arc magmas to hydrothermal systems. The melt inclusions in the New Zealand rhyolites have also provided useful information regarding decrepitation behaviour in melt inclusions.

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

S Allen; B Hayward (Geomarine Research), N Fujibayashi and K Kurokawa (Niigata U), A Freundt (GEOMAR); Honours student Emma Mathews

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 features 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. The field research was the focus in 2003 and involved volcanic successions in New Zealand and Japan. Her work in New Zealand involved submarine volcaniclastic mass-flow deposits in the Miocene Waitemata Group, in collaboration with Dr Bruce Hayward, Geomarine Research, Auckland. Sharon has 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. The main changes are increases in matrix proportions, bed thickness, and in the non-volcanic component, and decreases in the proportion of coarse volcanic clasts. The results are summarised in a paper in press in the *New Zealand Journal of Geology and Geophysics*. Emma Mathew's Honours thesis has also contributed to this project. Emma mapped part of the Miocene Waitakere Group on the western coast of the North Island near Auckland. The Waitakere Group includes a variety of mass-flow facies, reflecting growth and denudation of dominantly andesitic volcanic islands formerly located farther west.

Fieldwork in Japan was based at Niigata University under the guidance of Professor Katsuki Kurokawa and Dr Norie Fujibayashi, and funded by the Australian Academy of Science and the Japanese Society for the Promotion of Science. Sharon logged and sampled a number of submarine pumice-rich units that record large explosive eruptions sourced from volcanoes on land. The field data will provide a framework for interpreting the textural characteristics of analogue deposits generated by experimental simulations.

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 associated with formation of a 4-km-wide caldera.

There are few well-described examples of trachyandesitic pyroclastic deposits even though they are probably common in arc volcanic successions. The examples in the Siwi Group are unusual in being composed of both non-vesicular spatter and highly vesicular pumice. Lateral and vertical facies variations are particularly marked in the Siwi Group pyroclastic deposits, reflecting the importance of syn-eruptive agglutination and welding of hot, low-viscosity pyroclasts. Sharon Allen completed a detailed volcanological study of the trachyandesitic pyroclastic deposits of the Siwi Group and submitted a manuscript to the *Bulletin of Volcanology*. The pyroclastic deposits could result from catastrophic degassing of the high-volatile-content, plagioclase ultraphyric magma.

Project 2.9
Volcanology and source-vent locations of voluminous felsic lavas: Mesoproterozoic Gawler Range Volcanics in South Australia

S Allen, J McPhie, F Della Pasqua; M Lackie (Macquarie U); M Schwartz (PIRSA)

This new 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 are typical of many continental intraplate volcanic provinces in including voluminous (>10^2 km^3) felsic volcanic units. The previous project demonstrated that the voluminous felsic units in the upper part of the succession are lavas rather than ignimbrites as had previously been assumed. However, the location and nature of the source vents are unknown. Such information is critical for calculations of outflow distances and eruption rates, and for inferences regarding magma rheology. It is also of interest for mineral exploration. The new project 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 is one of three voluminous (>500 km^3) and widespread felsic lavas recently recognised in the Gawler Range Volcanics. We have comprehensive data on textures, mineralogy, composition, overall geometry and internal variations (Allen and McPhie 2002 *Geological Society of America Bulletin*, Allen et al. 2003 *Australian Journal of Earth Sciences*). In addition, some internal variations and the overall geometry suggested that the Eucarro Rhyolite may have been erupted from an east-west striking fissure (Allen and McPhie 2002 op. cit.). Hence, this unit has been selected for a further study that will test the east-west fissure hypothesis.

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. This technique has been used successfully overseas for a variety of rock types (sedimentary rocks, pyroclastic deposits, lavas, shallow intrusions) but there have been only a few published Australian studies. The AMS measurements will be performed by Dr Mark Lackie at Macquarie University. Either, and perhaps both, techniques may produce consistent results that can be used to determine outflow directions, and hence, source vent locations.

Sharon Allen and Fernando Della Pasqua measuring the axes of elongate phenocrysts in the Eucarro Rhyolite.

Other achievements

Sharon Allen is on the Editorial Boards of both the *Australian Journal of Earth Sciences* and the *Journal of Volcanology and Geothermal Research*.

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.

Sharon Allen is Chair and Greg Ebsworth is the Treasurer of the Geological Society of Australia's Specialist Group in Volcanology.

Sharon Allen was interviewed by ABC Radio in February 2003 following publication of Gawler Range Volcanics research (*Geological Society of America Bulletin* and *Australian Journal of Earth Sciences*). The interview focussed on new interpretations.

Jocelyn McPhie spoke on ABC Radio in August 2003 for the 120th Anniversary of the Krakatau eruption (26 August 1883).

PhD projects in Program 2

Michael Agnew: The Lewis Ponds Au-Ag-rich massive sulfide deposit, New South Wales. Graduated 2003.

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.

Karin Orth: Style and setting of massive sulfide mineralisation at Koongie Park, Halls Creek, Western Australia. Graduated 2003.

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. Thesis submitted in 2003.

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.

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 Cu-Pb-Zn and epithermal Au-Ag in modern and ancient, subaerial and subaqueous environments in Australia and the Pacific Rim.

ABOVE Program 3 team — L to R, back row: Bruce Gemmell (Program Leader), Andrew Rae, Russell Fulton, Ben Jones, Andrew Wurst, Rob Scott; front row, Garry Davidson, Wally Herrmann, Mike Solomon, Cathryn Gifkins, Cari Deyell

Team Leader
Bruce Gemmell

Team Members
Michael Blake, David Cooke, Garry Davidson, Cari Deyell, Wally Herrmann, Dima Kamenetsky, Ross Large, Jocelyn McPhie, Michael Roach, Michael Solomon, Khin Zaw

PhD Students
Michael Agnew, Andrew Davies, Kim Denwer, Russell Fulton, Steve Lewis, Neil Martin, Thomas Monecke (FreibergU), Karin Orth, 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 Espana, Geological Survey of Japan, Chinese Academy of Geological Sciences, Nanjing University, British Geological Survey, Instituto Geológico e Mineiro (Portugal), Istanbul Technical University

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 Cu–Pb–Zn–Ag–Au deposits in volcanic arc settings.
3.8 Subaqueous epithermal mineralisation, Conical Seamount, Tabar-Feni island chain (Papua New Guinea).

Highlights

1 CODES Program 3 team received Faculty of Science, Engineering & Technology Research Excellence Award for 2003.

2 Graduation of four PhD students: Michael Agnew, Andrew Davies, Thomas Monecke and Karin Orth.

3 Initiation of AMIRA-ARC Linkage project (P765): 'Transitions and zonation in porphyry-Cu epithermal mineral districts'.

4 Organising and co-convening 'Modern and Ancient Mineralising Seafloor Hydrothermal Systems' session for the Society of Economic Geology at the GSA meeting in Seattle, USA.

Research excellence award

Bruce Gemmell, leader of CODES Program 3, was presented with a University of Tasmania Faculty of Science and Engineering Research Excellence Award. The purpose of the Award is to recognise and reward research programs which reflect the Faculty of Science, Engineering & Technology's research strengths and areas of research excellence.

The award was based on the major achievements of the Program 3 team over the last five years, including:

• Publication of 43 refereed papers, one book, 69 conference abstracts and 89 industry reports.

• Obtaining $3,063,375 in external funding – $1,570,975 (51%) from ARC and $1,492,400 (49%) from industry.

• Editing and publishing a special issue of *Economic Geology* in 2001, containing 14 papers based on an AMIRA-ARC collaborative research project.

• Organising and convening an international conference, 'Volcanic Environments and Massive Sulfide Deposits' and associated field trips in 2000.

• Accepting 17 invitations to deliver keynote papers at international conferences, 13 invitations to convene or chair sessions at international conferences and 14 invitations to teach external short courses.

• Graduating 15 Honours, 10 Masters and 5 PhD students in the 'Ores in Volcanic Arcs' program.

• Collaborating with 20 minerals companies in research on how to improve mineral exploration success rates in volcanic successions.

• Adoption by mining companies of our exploration models and methodologies in their exploration, in particular the geological and geochemical vectors developed for both VHMS and epithermal deposits.

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)

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 a collaborative research project (with Weidong Sun, Vickie Bennett, Richard Arculus and Steve Eggins at ANU) concerning metal (Re, Cu, Au) behaviour during the origin and crystallization of arc and backarc magmas. Using LA-ICPMS analyses of melt inclusions in high-Mg olivines from subaerial arc picritic basalts (Aoba, Vanuatu) and submarine backarc basalts with clear arc characteristics (Eastern Manus Basin and Valu Fa Ridge), these authors (Sun et al., 2003) demonstrated significant Re volatility during degassing. Also, it was shown that previously established low Re concentrations in subduction-related volcanics may be a sampling artefact, particularly as the effects of Re loss through magma degassing are likely to be more pronounced in these volatile-rich magmas. These results indicate strong enrichment of Re in un-degassed arc rocks, and consequently the continental crust, which results in a crustal estimate of 2 ppb Re, as compared to previous estimates of 0.4–0.2 ppb. Melt inclusions in volcanic glass and olivine from Valu Fa Ridge seamounts, on both sides of the propagating tip of the Lau Basin, were investigated to determine the capacity of slab-derived melts and fluids to transport Re into the mantle wedge (Sun et al., submitted to *Earth and Planetary Science Letters*). This research shows that Re enrichment in arc magmas is likely due to addition of Re via fluids released from subducted slabs. Another paper (Sun et al., submitted to *Nature*) reports on the systematics of Au behaviour in a suite of pressure-quenched, submarine arc glasses ranging from basalt (including olivine-hosted melt inclusion compositions) to rhyolite from the eastern Manus Basin. Gold, Cu and Re abundances decrease dramatically in melts of 58 wt% SiO_2, most likely because of significant magma degassing. This may help to explain the origin of some magmatic gold ore deposits in this region and their intimate association with arc andesite-dacite rocks.

Khin Zaw continued research on the ore fluid chemistry of ancient and modern VHMS systems, using PIXE, LRS and microthermometry. Results from research on the Mt Chalmers VHMS deposit, Queensland, were published in *Chemical Geology* (Zaw et al., 2003). An integrated collaborative research project on the Devonian Mt Morgan deposit in Queensland (particularly on the newly delineated zinc-rich Car Park mineralisation) has continued, involving Khin Zaw and researchers at the University of Queensland and Perilya Mine NL. The project adopts a multi-disciplinary approach including studies on textural relations, mineral paragenesis, isotopic composition and variations in the concentration of volatile and trace elements in fluid inclusions in order to understand the style of mineralisation, the source(s) of ore-forming fluids, and the mechanism of ore deposition.

Project 3.3 CORE
Active base and precious metal–rich massive sulfide deposition associated with submarine volcanism

JB Gemmell, R Sharpe, D Kamenetsky, Khin Zaw; 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). Robina Sharpe and Ray Binns (CSIRO Exploration and Mining) continued 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.

Bruce Gemmell participated in the German CONDRILL oceanographic cruise aboard the R/V *Sonne* (SO-166) in late 2002 (see project 3.8) in collaboration with Peter Herzig (Freiberg University, Germany) and Mark Hannington (Geological Survey of Canada). A portion of this cruise was devoted to using the British Geological Survey's Rockdrill to test the top 5 m of the Roman Ruins site at PACMANUS. Technological, geological and geochemical results of this drilling were published in three papers (Herzig et al., 2003a; Herzig et al., 2003b; Petersen et al., 2003). Drilling retrieved massive sulfides ± barite, nodular sulfide-anhydrite breccias, resedimented sulfides, as well as clay-altered dacite from depths up to 5 m. Preliminary analyses reveal high Au and base metal concentrations throughout the cores, locally reaching up to 58 g/t Au over 20 cm of core length. The longest core recovered 2.2 m grading 11.3 g/t Au, 156 g/t Ag, 2.4 wt.% Cu, 26.5 wt.% Zn, and 0.9 wt.% Pb. Gold enrichment is clearly related to sphalerite-rich sections of the core. Laser ablation S-isotope studies of this sulfide mineralisation are continuing with the aim of determining the source of the sulfur and a better understanding of the sulfide precipitating processes.

Okinawa Trough, Japan: International collaboration between Khin Zaw and researchers from Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing and Geological Survey of Japan is directed towards understanding the importance of magmatic input of ore fluids and metals in a modern seafloor hydrothermal system. This research has focussed on the JADE site, Okinawa trough, Japan and a paper detailing the fluid inclusion and isotope geochemistry has been submitted to *Mineralium Deposita*.

Middle Valley, Juan de Fuca Ridge, Canada: Collaborative research on the nature and chemical composition of Middle Valley ore fluids between researchers from Geological Survey of Canada (Jan Peter) and Khin Zaw, Ross Large and Bruce Gemmell progressed this year. A paper from 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 Cu–Pb–Zn–Ag–Au deposits in volcanic arc settings

JB Gemmell, R Large, M Solomon, Khin Zaw, J McPhie; PhD students M Agnew, K Denwer, R Fulton, S Jones, N Martin, T Monecke (FreibergU), K Orth, 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 (Zn–Pb–Cu–Ag–Au) deposits, through sub-seafloor shallow-water, replacement Au-rich epithermal styles, to deep sub-volcanic intrusion-related Cu–Au-rich styles. To improve our understanding of the

Modern and Ancient Mineralising Seafloor Hydrothermal Systems

At the 2003 Geological Society of America annual meeting in Seattle, USA, Bruce Gemmell and Cornel de Ronde (IGNS, New Zealand) co-convened the Society of Economic Geology day-long Special Session entitled 'Modern and Ancient Mineralising Seafloor Hydrothermal Systems'. Invited speakers compared recent research results on modern submarine mineralising hydrothermal systems in a variety of plate tectonic settings (e.g., backarcs, intra-oceanic and island arcs, seamounts, sediment-free ridges and sedimented ridges) to ancient volcanic and sediment-hosted ore deposits.

The morning session started with an overview paper by Mark Hannington (GSC) discussing the fluids in the VHMS environment concentrating on the relative role and importance of magmatic vs seawater fluids in seafloor hydrothermal systems. The diversity of modern hydrothermal systems on sediment-free ridges by Sven Petersen (FreibergU) and ultramafic-hosted systems by Debra Kelley (UWashington) was compared to ancient ophiolite-hosted deposits by Randy Koski (USGS). Presentations on the massive sulfide deposits formed in modern (Wayne Goodfellow, GSC) and ancient (Jan Peter, GSC) sedimented rift settings set the scene for a comparison, by Ross Large, of the ancient sediment-hosted McArthur River (HYC) and modern Atlantis II Deep deposit in the Red Sea.

In recent years, much of the modern seafloor research and exploration has concentrated on intra-oceanic backarcs and forearcs, and the afternoon session concentrated on these environments. Cornel de Ronde (IGNS) presented the recent results of mapping of the submarine volcanoes and associated hydrothermal systems along the Tonga-Kermadec arc, and Garry Massoth (IGNS) discussed the hydrothermal plumes and their characteristics from these hydrothermal systems. Three talks concentrated on the results of drilling programs on the modern seafloor: PACMANUS in the eastern Manus basin, PNG by Ray Binns (CSIRO); Suiyo Seamount in the Izu-Bonin arc, Japan by Jun-ichiro Ishibashi (KyushuU); and the epithermal-like, Au-rich system at Conical Seamount, Tabar-Feni fore-arc, PNG by Sven Petersen (FreibergU). Two examples of the diversity and spectrum of VHMS deposits in ancient submarine volcanic belts were presented — Richard Herrington (British Museum of Natural History) discussed the South Urals area in Russia and Bruce Gemmell discussed the Mount Read volcanic belt in Tasmania.

The session was attended by over 150 academic and industry geologists and generated lively discussion on the parallels between modern, active seafloor hydrothermal systems and their ancient analogues.

ABOVE: Delegates to the SEG Special Session (L to R): Bruce Gemmell, Ross Large, Cornel de Ronde, Ray Binns, Sven Petersen, Jan Peter, Mark Hannington, Wayne Goodfellow, Gary Massoth, Richard Herrington, Randy Koski. Absent: Deborah Kelly, Jun-ichiro Ishibashi

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.

During 2003, research was undertaken on the following deposits: Rosebery, Hellyer, Mount Lyell (Tasmania), Waterloo, Mount Morgan, Mount Chalmers (Queensland), Koongie Park (WA), Lewis Ponds (NSW), Greens Creek (Alaska), Yaman Kasi, Alexandrinka (southern Urals, Russia) 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 is nearing completion of his PhD study at the Rosebery mine, Tasmania. Because of its very low limits of detection, laser ablation trace element study on sulfides was successful in determining trace element associations and patterns where electron microprobe studies have failed previously. These results have been an aid in distinguishing the primary Cambrian volcanogenic sulfides from the Devonian metasomatic overprint. Trace element and associated morphological changes in the sulfides also give some indication of changes in physicochemical conditions during ore formation.

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 3-D alteration model has been 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 3-D 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.

A manuscript on the Hellyer VHMS deposit by Mike Solomon, with contributions from Bruce Gemmell and Khin Zaw, has been accepted by *Ore Geology Reviews*. This paper attempts to reconstruct the geology at depth below the deposit, and the nature and source of the fluids and likely flowpaths involved in mineralisation. It uses previously published and new data on fluid inclusions, and stable and radiogenic isotopes in ore and footwall rocks. 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 began a PhD project in 2003 to determine how the giant Mount Lyell Cu-Au orebody formed. He will be undertaking the first system-wide investigation aimed at delineating the altered facies, distribution of sulfide assemblages, and stable isotopic variations. It is anticipated that Kim's research will provide insights into the composition/s of the mineralising fluid/s for the entire Mount Lyell field and the processes that led to the various styles of mineralisation.

Michael Agnew was awarded a PhD for his thesis on the geology and genesis of the Lewis Ponds polymetallic massive sulfide deposits in central western New South Wales. Michael's textural and mineralogical study of the massive sulfide provided new evidence for a syngenetic, sub-sea floor replacement origin. The well-preserved vuggy, framboidal, botryoidal and bladed textures observed at Lewis Ponds are commonly found in carbonate-hosted replacement and seafloor exhalative massive sulfide deposits. Michael worked on two papers on this topic after completion of his PhD: one has been accepted in the *Australian Journal of Earth Sciences*, the other is still in preparation.

Karin Orth was awarded her PhD for research on the style and setting of massive sulfide bodies at Koongie Park (Halls Creek, WA). Refer to project 2.1 for further details.

International
Sarah Jones was awarded her PhD thesis on the siliceous 'cap rocks' associated with VHMS deposits at Myra Falls (British Columbia, Canada). Her study characterised the geologic and structural setting of the 'cap rocks' environment, including reconstruction of the palaeo-seafloor topography at the time of mineralisation. She described the mineralogy, textures, paragenesis and metal zoning as well as the geochemical characteristics of the fluid inclusions, trace elements and stable isotopes of the 'cap rocks'. Her model for the genesis of the 'cap rocks' has led to the development of new criteria for exploration in the Myra Falls district.

Russell Fulton continued his PhD research on the geology and geochemistry of the hangingwall argillite, and its implications for ore genesis and exploration at the Greens Creek Zn–Pb–Ag–Au deposit on Admiralty Island in southeastern Alaska. The major portion of the hangingwall sequence comprises the Mine Argillite — discrete 5 to 50 cm-thick beds of ladder veined, dark grey, massive dolomite (MA) separated by strongly foliated, siliceous, organic-rich, variably calcitic, black slaty argillite (SA). The dolomite interbeds are less common up-section.

The SA is a dark gray to black, sooty phyllite comprising quartz, calcite, dolomite and muscovite with lesser pyrite and organic matter and minor apatite, chlorite, albite, orthoclase, paragonite, rutile, barite, sphalerite, galena and magnesite. The MA (excluding quartz-carbonate veins) consists of dolomite, quartz and lesser muscovite with minor pyrite, apatite, calcite, paragonite and lesser organic matter, chlorite, orthoclase, albite, pyrrhotite, rutile, sphalerite, barite, galena and magnesite.

Mineralogical indicators of proximity to mineralisation within the MA include the presence of cymrite, sphalerite, tetrahedrite, galena and Ba-rich white micas. Russell also presented a poster at the GAC-MAC-SEG conference held in Vancouver, Canada.

A collaborative research program on VHMS deposits in China with Khin Zaw and researchers from the Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing (Prof. Hou Zhengqian) and Nanjing University (Prof. Gu Lianxing and Ni Pie) continued this year. The results of the project on VHMS mineralisation in the Jinshajiang Orogenic Belt, southwestern China and the metallogenic relations of the Sanjiang Tectonic Domain, western China, were published in *Ore Geology Reviews* (Zengqian et al) and in the proceedings of the SGA Conference in Athens, Greece (Zengqian et al., 2003).

Valeriy Maslennikov of the Institute of Mineralogy (Miass, Russia) presented the results of collaborative research (Maslennikov et al., 2003) with Ross Large on the Siluro-Devonian massive sulfide deposits of the southern Urals at the SGA meeting in Athens. A detailed study of the trace element zonation in sulfide chimneys from the Yaman Ksay and Alexandrinka deposits, utilising the CODES LA-ICPMS, demonstrated a systematic variation in a range of trace elements, in particular Mn, Tl, As, Au, Pb, Te, Ag and Bi, from the central conduit to the outer rim of the chimneys. Khin Zaw and Maslennikov continued investigating the temperature and chemistry of ore fluids as deduced from fluid-inclusion studies of selected minerals in the chimney fragments. This research will apply PIXE, LRS and IR techniques to understand the nature and source of ore fluids, and mixing and boiling processes during sulfide chimney formation.

Mike Solomon has continued studies of the massive sulfide ores of the Iberian pyrite belt, 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, 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. A preliminary isotopic, trace element and textural study of selected Neves Corvo samples has led to a more detailed sampling of the Lombador and Norte orebodies; the former is the least deformed body in the Neves Corvo field. Much of this ore is clearly sedimented.

Mike Solomon and Cecilio Quesada (Instituto Geológico y Minero de Espana) published a paper in *Geology* (Solomon and Quesada, 2003) suggesting that brine-pool type VHMS deposits occur in collisional arcs, whereas black smoker- type VHMS deposits form in backarc and/or arc basins.

Project 3.6
Studies of VHMS-related alteration: development of geochemical and mineralogical vectors to mineralisation (AMIRA P439)

JB Gemmell, P Herzig (FreibergU), PhD student T Monecke (FreibergU)

In a collaborative study with Freiberg University (Germany), Thomas Monecke was awarded his PhD for the investigation of the Waterloo VHMS prospect in the Mount Windsor Subprovince (Queensland). This study was originally part of the AMIRA P439 project and concentrated on the geology, alteration mineralogy and wholerock geochemistry of the Waterloo deposit. Thomas used volcanic facies architecture of the host succession to unravel the temporal and spatial relationships between volcanism and massive sulfide formation. He also investigated the complexities of hydrothermal alteration on hand specimen, thin section and XRD scales, in particular the use of quantitative X-ray diffraction analysis by the Rietveld method. Thomas presented a paper on the volcanic facies architecture of the Waterloo deposit at the SGA meeting (Monecke et al., 2003) in Athens. He also submitted a paper to *Geochimica and Cosmochimica Acta* proposing a dynamic model for the metasomatic enrichment of base and precious metals based on the truncated fractal frequency distribution of element abundance data. Thomas was awarded the highest honour in the German academic system for his PhD research – magna cum laude. Thomas was supervised by Professor Peter Herzig (Freiberg) and Bruce Gemmell (CODES).

Project 3.7
Sulfur geochemistry of hydrothermally altered volcanic terrains

G Davidson, M Roach, R Berry; PhD student S Lewis; Honours student K Godber; J Alt (UMichigan); J Karson, P Rivazzigno (DukeU); A Brown (MRT); D Teagle and PhD student Rozz Coggan (USouthampton)

Garry Davidson and Michael Roach continued collaborations on aspects of hydrothermal activity in oceanic crust on Macquarie Island with Duke University (Jeff Karson), the USGS (Carol Finn), the University of Michigan (Jeff Alt), and the University of Southampton (Damon Teagle and PhD student Rozz Coggan). Two main projects underway are: ASAC Grant 2409, which is aimed at employing magnetic methods to delineate hydrothermal architecture; and a PhD project with student Steven Lewis (Ron Berry additional supervisor),

focussed on characterising and understanding the controls on sulfidic hydrothermal alteration in a range of late brittle faults. In project 2409, partly supported by a Bicentennial Gold '88 grant, Honours student Kate Godber magnetically mapped a 4 x 5 km area of the island. The field area included elements of the mantle, lower and upper oceanic crust, and indicated that all of these are magnetically distinct. Moreover, the geometry of a major fault zone separating the upper crust from the lower crust section was shown to be sub-vertical, which constrains tectonic models for its origin. The survey provided excellent delineation of non-magnetic hydrothermal alteration, and identified several hitherto unrecognised east-west altered domains that now require field investigation. Steve Lewis completed his fieldwork in March, producing detailed maps of spaced high-temperature alteration along the Major Lake, Caroline Cove and Sellick Bay faults, as well as studies of adjacent regional alteration zones. Follow-up analyses include major and minor element geochemistry and fluid inclusion characteristics. This work will shed light on the nature of fluid circulation in oblique slip fault regimes. Steve's project will lead to an increased understanding of the hydrothermal processes and products associated with oblique slip-fault systems in mid-ocean ridge environments. Collaborative research on O and Sr isotope profiles of the oceanic crust continued with the Michigan and UK groups. Academic output included a paper in *Geology* (Alt et al., 2003) and two conference abstracts.

Erika Greiner, Russell Fulton, Andy West, Brian Erickson and John Proffett on Mammoth Ridge, Admiralty Island, SE Alaska. Gallagher Ridge is in the background.

Kate Godber acquiring ground magnetic data on Macquarie Island.

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 Mark Hannington of the Geological Survey of Canada, completed an investigation of the sulfur isotope characteristics of subaqueous epithermal samples collected by dredging at Conical Seamount, Tabar-Feni island chain, Papua New Guinea. Polymetallic veins and associated pyritic stockwork occur on the summit of the seamount, a subaqueous alkaline volcano south of Lihir Island. This prospect is a unique new type of seafloor mineral deposit, with epithermal-like characteristics. A paper outlining the results of this research was submitted to *Economic Geology*.

Bruce Gemmell participated in the German CONDRILL oceanographic cruise aboard the RV *Sonne* (SO-166) in late 2002, in collaboration with Peter Herzig (FreibergU)

and Mark Hannington (GSC). The aim of this cruise was to test the top 5 m of the mineralised zone at Conical Seamount using the British Geological Survey's Rockdrill. Technological, geological and geochemical results of this drilling were published in two papers (Herzig et al., 2003a; Herzig et al., 2003b). Drilling of 39 holes at the summit plateau of Conical seamount indicated that the previously discovered epithermal-style gold mineralisation reaches a depth of at least 4.5 m below seafloor with gold concentrations of up to 14.2 g/t Au over a core interval of 30 cm. This discovery significantly extends the known surface extent of gold mineralisation (up to 230 g/t Au) on Conical seamount. Laser ablation S-isotope studies of pyrite associated with the gold mineralisation are continuing.

Project 3.9
Epithermal Au–Ag deposits: geological, geochemical and isotopic vectors to target major deposits (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

The results of the P588 research project are to be published in a special issue of *Economic Geology*, with papers to be written and reviewed in 2004. Overall, this project made major advances in the understanding and interpretation of alteration related to low sulfidation epithermal deposits, in particular Cerro Vanguardia, Argentina, Gosowong and Mt Muro, Indonesia, Ladolam, Papua New Guinea and Bimurra and Twin Hills, Queensland. We have determined the distribution, mineralogy, mineral chemistry, whole-rock geochemistry and isotope (O, C-O, S,) characteristics of hydrothermal alteration as well as gaining an improved understanding of volcanic facies architecture, structure and fluid flow at these epithermal Au-Ag districts and deposits. This project was supported by AngloGold and Cerro Vanguardia SA, Aurora Gold, AurionGold, Barrick Gold of Australia, Lihir Management, Newcrest Mining, Newmont Exploration, University of Auckland, CODES, University of Tasmania, AMIRA and the Australian Research Council.

Based on the research result of P588, Robina Sharpe and Bruce Gemmell were invited to participate in an exploration workshop at Cerro Vanguardia, Argentina in February. The aim of workshop was to synthesize current geological knowledge of the district and formulate an exploration strategy and program.

Project 3.10
Global comparisons of VHMS deposits

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); Namik Çagatay (Istanbul Technical University)

This multi-national research project is being led by Rod Allen from Lulea University, Sweden. Volcanic-hosted massive sulfide (VHMS) deposits are important sources of zinc, copper, lead, silver and gold. However, traditional exploration methods are not replacing the declining ore reserves in many VHMS districts and, despite extensive research on individual deposits and districts, the features that control the locations of VHMS deposits are not well understood. This multi-disciplinary international project 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 VHMS deposits; and thereby develop new criteria for locating these ore deposits. VHMS deposits form at specific times (in specific stratigraphic intervals) in volcanically active, extensional marine basins. The key global issue to be addressed is the connection between VHMS ore formation, magmatism and extensional tectonics. The project aims to develop criteria to recognise this connection in the field; i.e., how we identify the volcanic intervals that are likely to host major ore deposits in any given district. This problem requires comparison of several districts, so that the fundamental features essential to formation of major ore deposits (features that occur in all districts), such as the evidence for short-lived intense crustal extension, can be distinguished from features that are not essential (occurring only in specific districts), such as submarine calderas and subsidence structures. The approach includes: (1) defining the main styles of VHMS deposits, (2) defining the character and stratigraphic position of the ore horizons in 5-10 major VHMS districts, (3) assessing how far these horizons can be followed and how they change with distance from ore, (4) assessing whether the VHMS horizons are part of one or two specific basin-wide favourable stratigraphic intervals, (5) interpreting the significance of these favourable stratigraphic intervals in terms of basin evolution, and (6) testing the results and hypotheses on 4-5 less well known VHMS districts. This project promotes scientific exchange among developed and less developed nations, and aims to provide new knowledge that will promote mineral exploration, investment and employment in these nations. The project has commenced in Sweden and Spain and will involve over 50 senior scientists from about 20 nations. A major field program involving CODES researchers will take place in 2004.

Project 3.11
Epithermal deposits of the Pacific Rim

JB Gemmell, D Cooke, C Deyell; PhD students A Davies, A Wurst

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.

Andrew Wurst is in the final year of his PhD research into the Permata-Batu Badingding-Hulubai (PBH) and Kerikil low-sulfidation Au–Ag epithermal deposits at Mount Muro in central Kalimantan, Indonesia. 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 a 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. Hydrothermal fluids have been able to boil, cool and mix with ground waters through enhanced permeability created by repeated sealing, brecciation and re-brecciation of the coherent host rocks. These two systems provide important information on the processes and mechanisms of metal deposition in the epithermal realm of ore deposits.

Andrew Davies was awarded his PhD for research on the Kelian deposit, east Kalimantan, Indonesia. Kelian is a late Miocene base metal-rich epithermal gold deposit associated with an extensive maar-diatreme and phreatic breccia complex. The breccia complex and ore deposit formed due to rhyolitic intrusion into a shallow level (1–2 km), weakly mineralised hydrothermal system. Interaction of rhyolitic magmas with the convecting hydrothermal system resulted in widespread phreatomagmatic, phreatic, hydraulic and tectonic brecciation, coupled with high-grade ore deposition. The end result

of this complex interplay of magmatism, brecciation, structure and geochemistry was a giant, carbonate- and base-metal-rich epithermal gold deposit of low sulfidation character. Andrew presented the results of his study in a paper (Davies et al., 2003) at the SGA conference in Athens.

Project 3.12
Stable and radiogenic isotope applications to ranking prospects in volcanic terrains

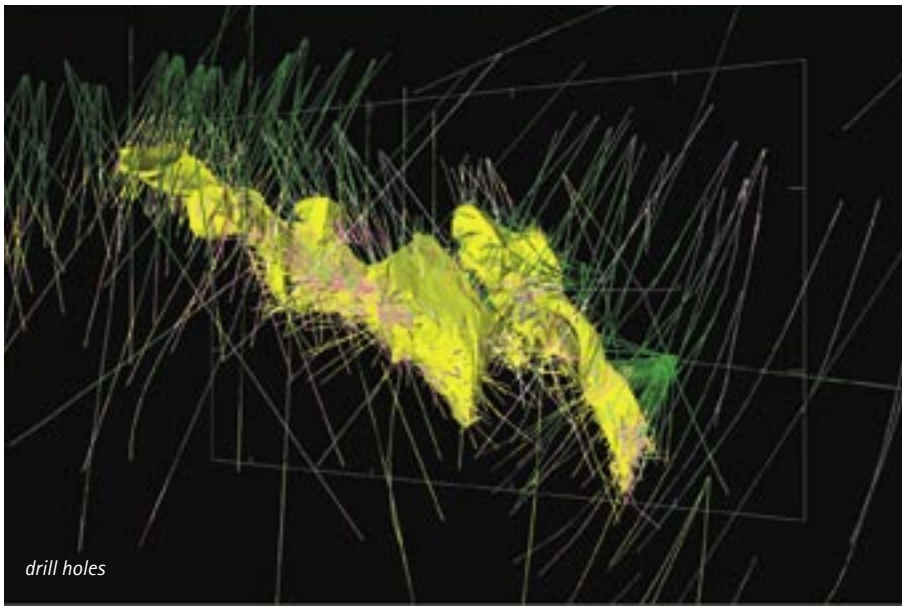
G Davidson, W Herrmann, M Solomon, M Blake, R Large, (UTasmania), M Barton (UArizona), D Huston (GA), D. Groves (UWA); D Green, G Green, M McLenaghan, J Taheri (MRT); students: S Dreiberg (UWA)

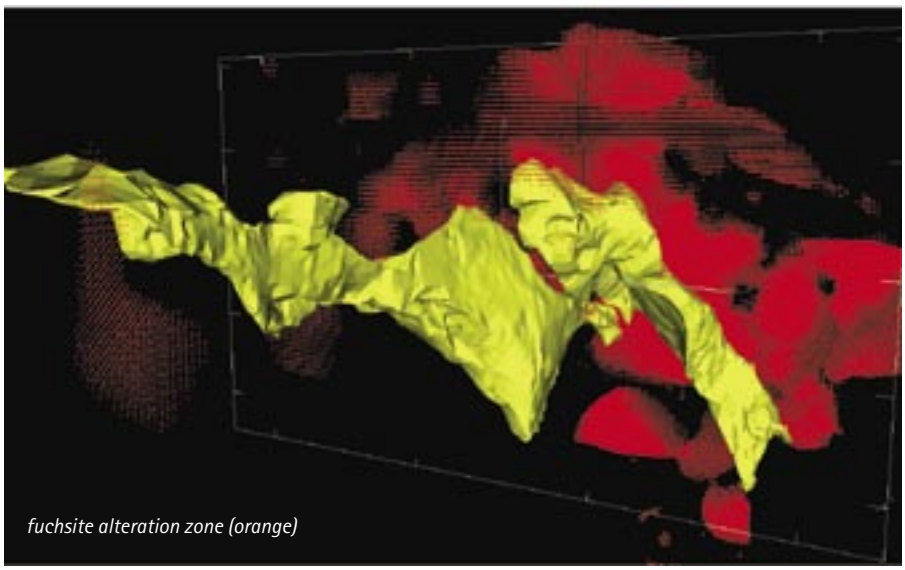
This project evaluates isotopic vectors and signatures of deposits and alteration facies in submarine volcanic terrains. Following the major, but currently confidential, study that finished in 2002 (one paper has been released for publication in *Economic Geology* - Williams & Davidson, in press), laboratory work has focussed on a collaboration with UWA and GA to determine the sulfur isotope structure of the Archean Panorama volcanic belt. This area offers a rare opportunity to analyse the alteration products of a major VHMS hydrothermal system, from within an underlying stratabound granitic intrusion, through 3 km of layered volcanic stratigraphy, to overlying palaeo-seafloor sulfide mineralisation manifested as Cu-Zn deposits such as Kangaroo Caves. The region was also the subject of hydrothermal modelling in Christian Schardt's PhD thesis completed in 2003 at CODES. Our previous S isotopic work focussed on the deposits and their alteration haloes. However, in the 2003 phase, analyses were undertaken using existing samples from transects established by Carl Brauhart. The wholerock soluble sulfide extraction facility at CODES was employed for the work. Sufficient S was available for analysis, and the results were part of S Dreiberg's PhD studies, with publications currently in preparation with Davidson and Huston.

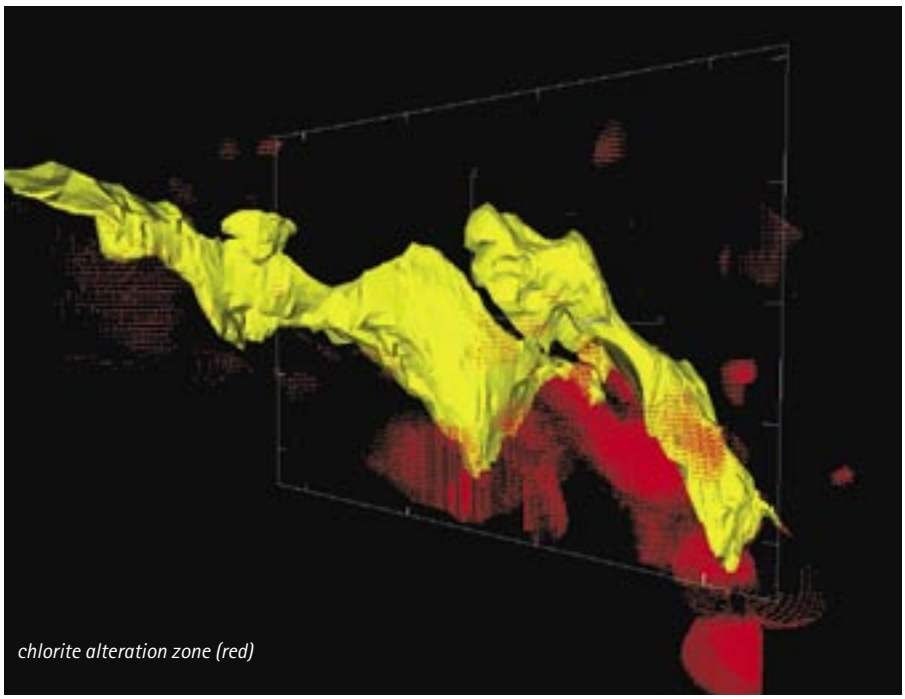
Project 3.13
Trace element analysis of sulfides by LA-ICPMS: new applications for exploration vector geochemistry

G Davidson, A Rae, L Danyushevsky, R Large, P McGoldrick; M Norman (ANU)

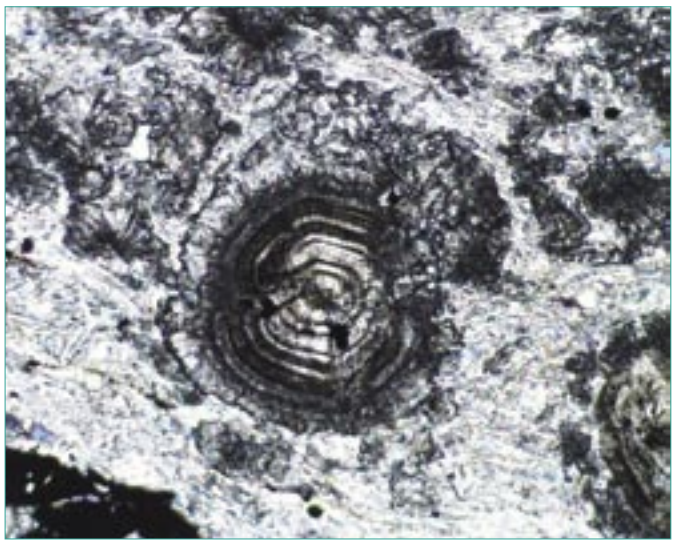
The ARC-Linkage grant 'What controls trace element levels in ore sulfides? A laser-ICPMS perspective' commenced in 2003, supported by Newmont Mining, BHP Billiton, Anglo American, AngloGold, Placer Mining and Newcrest Mining. Led by Garry Davidson (CODES) and Marc Norman (ANU), this was an evolution of a 2002 industry project

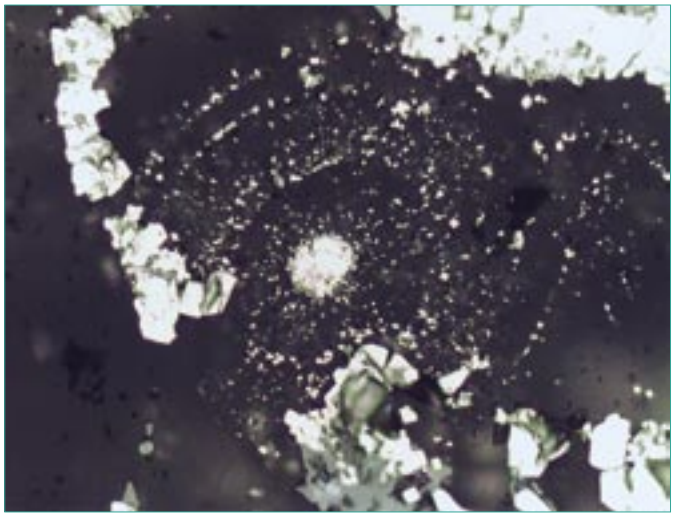


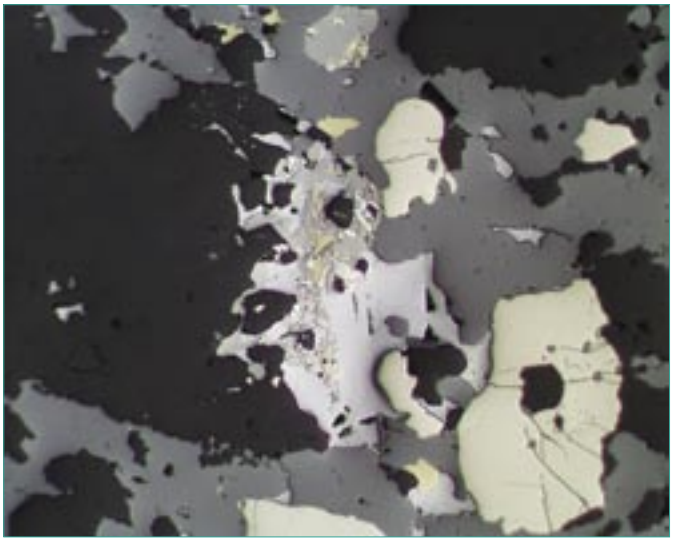




Hellyer 3D models, developed in collaboration with Gary McArthur (MODA) , for exploring the "second layer" of the Mount Read Volcanics







Textures from the Rosebery VHMS deposit. TOP: Con centrically zoned carbonate spheroid in sericite-quartz altered pumice breccia flow top (mineralisation-related alteration). MIDDLE: Concentrically and radially distributed fine-grained pyrite in quartz with framboidal core (primary mineralisation). BOTTOM: Tetrahedrite, chalcopyrite and arsenopyrite in galena-shalerite-pyrite (annealed primary mineralisation).

'Microanalysis to Enhance Exploration Success'. The project includes an APAI student scholarship, which was only taken up by Claire McMahon in late December 2003. This project aims to determine the source of metals in sulfides in the distal haloes of ore alteration systems. This study requires radiogenic and oxygen isotope analyses as well as background characterisation of LA-ICPMS pyrite compositions. Our major case study in 2002 at Cleo-Sunrise Dam lode gold deposit was used to guide our 2003 approach to detailed studies at Kanowna Belle (WA lode gold deposit), and Cadia Hill (NSW Cu-Au-Mo porphyry). The work included major petrographic studies at each site by post-doctoral fellow Andrew Rae, prior to analysis of 30–40 samples at 6–10 LA-ICPMS pyrite spots each. Limited work was also completed at Cannington (BHT system) using samples from Steve Bodon's PhD collection (this work is refocussing upon magnetite and will be undertaken by PhD student Singoyi Blackwell in 2004). A sponsors' meeting was held in December 2003. Due to the confidential nature of the research, no publications were produced during the year.

Project 3.14
Transitions and zoning in porphyry–epithermal districts: indicators, discriminators and vectors (collaboration with Program 5, project 5.18)

D Cooke, JB Gemmell, C Deyell, N White; J Hedenquist (CSM)

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 Au-Ag deposits, skarn Cu-Au deposits, carbonate replacement Zn-Pb-Ag, and sediment-hosted Au. These districts continue to be major targets for both copper and gold explorers.

The purpose of this project, 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. We will develop and test criteria that can be used by explorers to indicate prospective environments, discriminate between mineralisation styles, and vector towards ore zones — be they of porphyry, epithermal, and/or other peripheral styles. Study areas include Lepanto, and Baguio, Philippines, Batu Hijau, Indonesia, Collahuasi, Chile, Pueblo Viejo, Dominican Republic, Colquijirca, Peru, El Indio, Chile and other possible sites.

This project began during the second half of 2003 with AMIRA funding from AngloGold Australia Limited, Placer Dome Inc, Teck-Cominco, Gold Fields Ltd, Newcrest Mining Ltd, Anglo American (Philippines) and Newmont. In late 2003 we were successful in obtaining ARC funding through the Linkage grant scheme. Preliminary sponsors' meetings were held in June and December.

Project 3.15
Petrophysical characterisation of ore and alteration types in the Skellefte District, Sweden

Michael Roach, Per Nilsson (Raycon, Sweden)

This project is funded through the Georange program, an initiative of the European Union Regional Development Fund. It is one component of a broader research program to evaluate the volcanology, structure and detailed features of the mineral deposits of the Skellefte District, Sweden. The project aims to characterise the geophysical characteristics of a range and important ore and alteration types by

a combination of laboratory and in-situ measurements together with down-hole geophysical logging. This new information will be used to help plan and interpret surface geophysical exploration.

Measurements have been conducted in two ore systems that represent end-members in the diverse continuum of Skellefte deposits: Mauliden a low Zn-grade, moderate tonnage VHMS system comprising a core of massive pyrite within an extensive zone of silica-pyrite alteration and Storliden a small high Zn- and Cu-grade epigenetic deposit with a little associated alteration. Laboratory measurements of chemical, petrographic and petrophysical properties are currently in progress and this information, in conjunction with in-situ measurement,s will be used to create forward models of the ore systems to evaluate the most effective geophysical exploration strategies.

PhD Projects in Program 3

Michael Agnew: Volcanic setting, lithogeochemistry and genesis of the Lewis Ponds massive sulfide deposits, NSW. PhD awarded December 2003.

Andrew Davies: Geology and genesis of the Kelian Au deposit, east Kalimantan, Indonesia. PhD awarded December 2003.

Kim Denwer: Mineralogical, geochemical and isotopic investigation of the Mount Lyell Cu-Au orebody and alteration system. Commenced in 2003.

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

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

Neil Martin: Genesis of the Rosebery VHMS deposit, western Tasmania.

Thomas Monecke: Geology, host rock succession, and hydrothermal alteration of the Waterloo volcanic-hosted massive sulfide deposit, northern Queensland, Australia. Based at Freiberg University, Germany. PhD awarded June 2003.

Karin Orth: Setting of the Palaeoproterozoic Koongie Park Formation and carbonate-associated base metal mineralisation at Koongie Park, northwestern Australia. PhD awarded August 2003.

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

Kim Denwer (PhD student) and Wally Herrmann discussing Mount Lyell geology . The Linda Valley and Lake Burbury in the background.

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

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.

ABOVE Program 4 team — L to R, back row: David Cooke, Rod Maier, Mawson Croaker, Robert Scott, Wallace McKay,; Front row: Cari Deyell, Bryan Bowden, Stuart Bull, David Selley, Ross Large, Garry Davidson. Peter McGoldrick (Team Leader) absent.

Team Leader
Peter McGoldrick

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

PhD Students
Bryan Bowden, Darryl Clark, Mawson Croaker, Owen Hatton, Wallace Mackay, Rod Maier, Nicky Pollington, Tony Webster

Collaborators
Colorado School of Mines, Geoscience Australia, Luleå University, Swedish Geological Survey, Johns Hopkins University, Boliden Mineral AB, University of Adelaide, PIRSA, RSES-PRISE, Simon Fraser University, James Cook University, University of Western Australia, 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.
4.4 Regional stratigraphy, basin evolution and setting of Zn-Pb-Cu-Ag-Au deposits in the Bergslagen district (Sweden).
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 sulfide mineralised samples.
4.10 Microbes and the origin of Proterozoic Sedex Zn-Pb-Ag deposits.

Highlights

1 Successful completion of our largest industry-funded research project: AMIRA/ARC P544 'Proterozoic sediment-hosted copper deposits', a collaboration between CODES and CSM. Final AMIRA meetings held in Hobart and Kitwe, Zambia, in July. Final report (three CDs) circulated to sponsors in December.

2 Bergslagen project completed with final report incorporating a new model for carbonate sedimentation in volcanic basins and geochemical methods of discriminating ore related to regional alteration.

3 PhD theses accepted: Owen Hatton 'Basin configuration, volcanology, sedimentology and pre-deformational alteration of the Toole Creek Volcanics, Mt Isa Inlier, northwest Queensland'; and Darryl Clark 'Mineral paragenesis and geochemistry of the Mammoth Cu deposit, Gunpowder, northwest Queensland'.

4 Presentation by Leonid Danyushevsky at Goldschmidt Conference describing secondary sulfide standards used for monitoring LA-ICPMS analysis of unknown sulfide minerals (joint Program 1–Program 4 project).

Project 4.1 CORE
Geological environment of stratiform Zn–Pb 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:

- CODES researchers presented a two-day workshop in February 2003 to staff of the Northern Territory Geological Survey on 'Basin Evolution and Hydrothermal Systems for Zinc, Lead and Copper'.
- Large, McGoldrick, Bull and Cooke contributed a chapter to a book on 'Sediment-hosted Lead-Zinc Sulfide Deposits: Attributes and Models of Some Major Deposits in India, Australia and Canada'. The book was edited by Mihir Deb and Wayne Goodfellow, and will be published in early 2004. It is the outcome of research presented at an international workshop on ore deposit models held in New Delhi and field locations in Rajastan.
- A paper by CODES Honours student Tim Ireland with Stuart Bull and Ross Large, on the sedimentology and significance of the inter-ore sedimentary breccias at the McArthur River Zn-Pb-Ag deposit was accepted by *Mineralium Deposita*, and has appeared in the first issue for 2004. It provides documented proof that the stratiform sulfide lenses formed on or just below the seafloor.
- Ross Large was invited to coordinate a paper for the 100th Anniversary volume of *Economic Geology*, on the geology and genesis of Proterozoic stratiform/strabound Zn-Pb-Ag deposits of northern Australia. The manuscript is in preparation.

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

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

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.

- Mike Simms, a PhD student at Johns HopkinsU, has undertaken finite element modelling of different fault scenarios of the McArthur Basin in order to determine controls on convective hydrothermal fluid flow related to the McArthur River deposit located adjacent to the Emu Fault.
- Yang, Bull and Large have had a paper accepted by *Geofluids* relating to a sensitivity analysis of basin permeability and fault parameters in a modelled section across the Batten Fault Zone. A second paper by these authors on the controls by basin salinity distribution on hydrothermal fluid flow has been submitted to *Mineralium Deposita*.
- A paper (Yang, Large and Bull) on convective fluid flow at 1575 Ma along a north-south section of the Lawn Hill Platform, including the Century deposit, has been submitted for inclusion in a Special Issue of *Economic Geology*.
- Lyudmyla Koziy, PhD student at CODES, has undertaken finite element modelling to test several fluid flow scenarios along an east-west seismic-controlled line in the northern sector of the Lawn Hill platform. This work has emphasised the effect by basement highs and related marginal faults, in controlling the temperature and velocity of sedimentary basin fluid flow.

Project 4.4 CORE
Regional stratigraphy, basin evolution and setting of Zn–Pb–Cu–Ag–Au deposits in Bergslagen district, Sweden

S Bull, R Allen (Luleå University), R Jonsson and H Christoffersson (Boliden Mineral AB), M Ripa (Swedish Geological Survey).

The Bergslagen district of southern Sweden contains historically important and currently mined Zn-Pb deposits hosted in metamorphosed pelitic and calcareous metasediments within a thick Palaeoproterozoic felsic volcanic and volcaniclastic succession. This project, completed in 2003, was a three year collaboration between CODES, the Swedish Geological Survey (SGU), Luleå University and Boliden Mineral AB. It was based on detailed fieldwork involving facies analysis and structural interpretation of volcanic and sedimentary strata to determine deposit settings and provide a framework for lithogeochemical studies. The project was extremely successful in terms of interaction between the involved parties, with all participants acquiring new skills and insights. Its outcomes have direct applications for base metal exploration in Bergslagen and similar deformed and metamorphosed mineralised successions, and wider implications in terms of a new facies model for carbonate units in volcanic-dominated Proterozoic basins.

The final report for the project was submitted to the project sponsors in May 2003. In addition, Rod Allen gave an oral presentation summarising the results at the annual SGU seminar series in Uppsala in March, and led a short field trip for Boliden geologists in September. The final report contains two main sections. The first addresses the origin and regional setting of the marble units and correlative skarns sporadically interbedded with the volcaniclastic rocks throughout Bergslagen. These range from thin intercalations of limited lateral extent to regionally extensive horizons, and they are important foci for various styles of mineralisation. The genesis of the marbles has been variously interpreted in the literature, with stromatolites noted previously at some localities, but units in other areas interpreted as hydrothermal in origin. Increasing degrees of hydrothermal alteration, metamorphic recrystallisation and deformation progressively destroy evidence of the stromatolitic origin of the Bergslagen marbles. However, evidence of a microbial origin in the form of locally preserved microbial layering and bulbous-lobate bed tops representing stromatolite heads are preserved to lower-middle amphibolite facies.

The $\delta^{13}C$ and $\delta^{18}O$ isotope values of microbially laminated carbonate samples provide an accurate measurement of the primary C and O isotopic signature of the Bergslagen carbonates (18.8–21.7‰ $\delta^{18}O$, 0.1–1.1 ‰ $\delta^{13}C$) and confirm their marine sedimentary origin. The C isotopic values are retained in the more recrystallised and deformed carbonates, but the O data is spread towards lighter values. Importantly, regional depletion in $\delta^{18}O$ occurs in carbonates in the intensely mineralised Garpenberg area, and $\delta^{13}C$ depletion occurs in the dolomite close to ore, providing a potential method for discriminating regional from ore-related dolomites.

Marble and skarn beds interpreted to represent isolated, low aspect ratio, reef structures occur sporadically throughout the Bergslagen stratigraphy. However, in the upper part of the volcanic succession during periods of reduced volcanic activity and/or in areas distal from felsic caldera vents, these units amalgamated to form thick, regionally extensive carbonate accumulations similar in scale to modern barrier reef systems. Integrated analysis of these successions has led to the development of a new facies model for carbonates in this unique, volcanic-dominated setting that is being prepared for publication.

The second section of the final report deals specifically with the Garpenberg Norra Zn-Pb-Ag deposit. In summary, it is interpreted to be a volcanogenic hydrothermal ore deposit formed mainly by stratabound replacement below the sea floor within the caldera vent of a large shallow marine rhyolite-dacite volcano. In this model, hot metal-bearing

hydrothermal solutions moved up through the volcaniclastic succession within the volcanic centre and spread laterally to form extensive zones of sub-conformable alteration. The main limestone unit represents a stromatolitic limestone reef buried below the sea floor by the caldera forming eruption, thus forming both a barrier and a chemically reactive trap that focused precipitation of metals along the base of the limestone.

The Garpenberg Norra mine lies on the northwestern limb of a regional F_2 syncline and displays a complex pattern of parasitic F_2 folds and post-F_2 shears and faults. As a result, the distribution of ore bodies is controlled by a combination of stratigraphy and structure and four tectono-stratigraphic scenarios have been identified for the development of economic orebodies within Garpenberg-type systems. Overall, Garpenberg-type mineralization is characterised by relatively high Mn, and especially Mn/Fe, compared to the regional skarns and iron ore skarns. A Zn versus Mn/Fe diagram can be used to discriminate the prospective Garpenberg-type skarns from these regional skarns and iron ore skarns, at least in the Garpenberg region. These may prove to be useful exploration guides to sulphide ores in Bergslagen.

Participants in the P544 Zambia final meeting photographed in Mindola open cut.

Project 4.5 CORE
Textural and isotopic studies of sediment-hosted base metal deposits and their alteration haloes

R Large, S Bull, M Blake, P McGoldrick PhD student: R Maier; Honours student: T McGilvray

Ireland, Large, Bull and McGoldrick had a paper accepted for publication in Economic Geology: Utilising spatial variations in textures and S-isotopes to better understand sulfide depositional processes in the number 2 and 4 lenses of the McArthur River deposit.

Rod Maier started a PhD project in 2003, supported by Anglo American and McArthur River Mining. This project aims to document pyrite trace element chemistry in the halo of the McArthur River deposit and the Bluebush prospect. This work will complement previous halo studies at HYC by CODES researchers. Bluebush is a large, sub-economic Zn-Pb accumulation hosted in pyritic and manganese carbonate-bearing siltstones of the Upper McNamara Group (see also Project 4.10).

Todd McGilvray completed an Honours project documenting the sedimentology, ore textures and host rock alteration at the Oceana carbonate-replacement Zn deposit in western Tasmania.

Project 4.6
Proterozoic sediment-hosted Cu deposits

S Bull, D Selley, P McGoldrick, R Scott, , D Cooke, R Large; M Hitzman (CSM); PhD students M Croaker, W Mackay, N Pollington, L Koziy, D Broughton (CSM), G Dawson (UWA)

The major highlight of Program 4 research in 2003 was the successful completion of this AMIRA ARC-Linkage funded project. Since its inception in July 2000, the project has demonstrated effective collaboration between researchers with diverse skills and experience, and actively contributing industry geologists, hallmarks of the CODES research philosophy. Moreover, it has established strong links between two world class economic geology research centres, CODES and the Colorado School of Mines, a relationship which will be maintained for continuing studies of sediment-hosted Cu deposits within the Democratic Republic of the Congo.

Research was undertaken as a series of parallel studies of Cu-bearing Proterozoic sedimentary basins in Zambia, South Australia and Western Australia. Although broadly similar in age and tectonic setting, these three systems were selected due to their significantly different levels of known metal endowment and basin configuration. Through both regional and deposit scale studies, the project has significantly improved our understanding of how the structural and stratigraphic development of basins impact upon hydrological evolution, generation and passage of brines with metal carrying capacity, and trapping of metals. Lithogeochemical and geochemical modelling studies provided new insights to the nature, origin and signature of basin fluids involved in the formation of the diverse deposit types of the Zambian Copperbelt. Important advances were made in the development of practical exploration techniques in other basin systems.

Major outcomes of the project:

- Development of a regionally applicable stratigraphy for the Zambian Copperbelt, and recognition of the role of the 'hangingwall' packages in basin hydrological evolution.
- Integration of regional stratigraphic studies with 10 deposit-specific studies to determine the structural and sedimentological evolution of the host sequence in Zambia. This work has demonstrated a systematic and predictable relationship between basin architecture and ore position.
- Integrated petrographic, lithogeochemical and geochronological studies have placed important constraints on the history and scale of hydrothermal alteration involved in the Zambian Copperbelt. Geochemical modelling based on elements of these studies have defined a range of conditions necessary for the transport and precipitation of metals.
- Numerical fluid flow modelling studies of the Zambian Copperbelt have indicated the roles of salt dissolution and basin-controlling master fault systems in determining fluid migration, interaction

with metal sources, and highlighted the potential for alternative styles of ore deposits at other structural/stratigraphic sites.
- Basin architecture studies in the Adelaide Fold Belt have demonstrated a catastrophic phase of basin collapse associated with evacuation of salt from deep stratigraphic levels. This event is considered to have had an important impact on the hydrological development of the basin system and its potential for Cu mineralisation.

A synthesis of results from the three-year work program and continuing PhD studies was presented to sponsors at final meetings in Hobart and Kitwe, Zambia, in July. The Kitwe meeting followed the IGCP 450 conference and field trip in the Democratic Republic of the Congo, ensuring strong sponsor attendance and providing the opportunity to discuss important results with the aid of mine exposures and drill core. It also allowed involvement of Zambian-based industry sponsors, whose guidance and logistical support were fundamental to the success of the project.

The final report (three CDs comprising 24 individual new reports and previous Annual Reports) was distributed to sponsor groups in December 2003.

The project was supported by: Anglo American, Anglovaal Mining, BHP Billiton, First Quantum Minerals, INCO, MIM Exploration, Mopani Copper Mines, North Ltd, Outokumpu Mining Australia, Phelps Dodge Exploration, Primary Industries & Resources South Australia, Rio Tinto, Straits Resources, Teck Cominco, WMC Resources, AMIRA International and the Australian Research Council.

David Selley and David Broughton (CSM) were invited to contribute a chapter on the Zambian Copperbelt to the forthcoming 100th Anniversary volume of *Economic Geology*.

Project 4.8
Cu-Au-Fe oxide geology and geochemistry

G Davidson, D Cooke, R Berry, D Thorkelson (Simon FraserU); T Baker (JCU); P Heithersay, M Schwarz (PIRSA); R Skirrow, E Bastrakov (GA); K Barovich (UAdelaide), N Oliver (JCU), M Norman (ANU); PhD students B Bowden, J Hunt; L Marshall (JCU), L Rutherford (UAdelaide)

A non-core element of our research in deformed and undeformed sedimentary basins is advancing knowledge of the characteristics and genesis of the iron oxide copper-gold deposits (IOCG). These deposits attest to deposition from oxidised high temperature fluids, but the circumstances of the development of such fluids in these settings have been a major source of discussion in economic geology literature in recent years. Our research on this question in 2003 has been, in part, undertaken at UTAS, and partly through collaborative links with researchers at other Australian and international centres. Our aim is to broaden our research base through these collaborative links. These research links will then be very useful for expanding our IOCG research in the future. The following studies in 2003 advanced our IOCG research in several areas:

- Understanding the nature and timing of IOCG alteration. Mt Woods Inlier, Australia (Bowden, UTAS PhD) with special emphasis on the new discovery at Prominent Hill. PIRSA, GA, Minotaur Resources and Goldstream NL have collaborated to support this project financially, with GA providing a very large in-kind component. Bryan Bowden's work at Prominent Hill took place in the first half of 2003; family illness deprived the project of his services in the second half of that year. Work in 2003 focussed on laboratory analysis of samples collected in 2002, with a phase of whole rock lithogeochemistry, petrography, and selection and submission of zircon-bearing igneous rocks for dating.
- Source of fundamental fluid components in IOCG districts and deposits. We are collaborating with several different groups in the analysis of S, C, Sm and Nd isotopes in a number of districts. The isotopic compositions of these elements are good guides to the source of fluids. Our group is variously contributing samples, expertise, and analytical resources to this effort.
  - Eastern Succession, Queensland, Australia. In 2003, this project focussed on novel analyses of the isotopic composition of hydrothermal carbonate, funded by a UTAS IRGS grant. This work is providing a new tool for elucidation of the isotopic composition of oxidised sulfur in IOCG and other oxidised hydrothermal systems. A second area of collaboration was the compilation by L Marshall (JCU student) of carbonate isotope geochemistry of the Eastern Succession (paper submitted to *Mineralium Deposita*; Marshall, Oliver & Davidson); this research has brought together most of the available C-O isotope data for the Eastern Succession, and constrained C sources for the IOCG deposits and their voluminous alteration haloes.
  - Gawler Craton, South Australia. UTAS work here focussed on the write-up of past research at the U-Cu Oak Dam prospect, as well as new Sm-Nd and S isotope analyses (Skirrow, Bastrakov & Davidson) from a large number of Gawler Craton prospects. The latter analyses were undertaken both by conventional and laser methods at UTAS, and were briefly reported in a 2003 abstract to the SGA conference in Athens. This work is contributing to GA's major project on the Gawler Craton IOCG prospectivity, with a particular focus being the source of metals in the giant Olympic Dam deposit, compared to the numerous other smaller deposits scattered across the Stuart Shelf.
  - Wernecke Mountains, Canada (collaboration with Derek Thorkelson, Tim Baker and Julie Hunt on geochemical assessment of several large breccia pipes). Carbonate C-O and conventional S analyses were undertaken at UTAS, and will initially be reported in Julie's PhD thesis, due in May 2004. The Wernecke Mountain breccias do not host economic IOCG deposits, but have long been of interest as an end-member manifestation of IOCG fluid activity. They were included as part of the original Hitzman et al. (1992) paper that defined the IOCG deposit group.
- Controls on trace element levels in IOCG deposits. Great Bear Magmatic Province, Canada (collaboration with Robin Goad of Fortune Minerals). This project is now proceeding as a case study within the LA-ICPMS determination of trace elements in sulfide minerals project (see Program 3). In 2003, a sample set was acquired from the Cu-Co-Au NICO deposit, which is proceeding through feasibility; the sample set will be analysed in 2004 and 2005 by Claire McMahon as part of her PhD studies.

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, L Danyushevsky, K Harris, F della-Pasqua

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 SRC 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.

A series of 'secondary' sulfide standards were prepared by the ultra-fine grinding of mixtures of common natural sulfides, which permit a realistic estimation of analytical uncertainty for individual chalcophile elements in a range of sulfides. Leonid Danyushevsky presented the results of this work at the Goldschmidt Conference in Japan in September.

Project 4.10 CORE
Microbes and the origin of Proterozoic SEDEX Zn-Pb-Ag deposits

P McGoldrick, S Bull, R Large, T Lyons (U Columbia-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 Zn-Pb deposits. The work aims to determine if microbes played an active or passive role in the origin of these important deposits.

An important part of Rod Maier's PhD project (see also Project 4.5) at Bluebush will involve description and interpretation of pyrite and base metal sulfide textures. Crinkly and laminated pyrite, and crinkly and nodular carbonate textures similar to those at McArthur River and other northern Australian Proterozoic Zn-Pb deposits are present at Bluebush.

In collaboration with Tim Lyons from University of Missouri–Columbia, samples from the hangingwall and footwall of the Lady Loretta deposit are being analysed for carbonate-associated sulfate S isotopes. This approach will allow us to document secular trends in late Palaeoproterozoic ocean S chemistry.

Project 4.11
Giant Broken Hill-type (BHT) and SEDEX Zn-Ag-Pb systems

R Large, S Bull, G Davidson; W Goodfellow, J Peter (GSC); PhD student: T Webster; MSc student: S Lewis

Considerable effort was expended in 2003 to develop a major AMIRA-funded collaborative project with the Geological Survey of Canada to study aspects of BHT and SEDEX Zn-Pb-Ag deposits. However, due to the record low zinc price, very little zinc exploration is currently being undertaken world-wide and the required industry support was not realised. A moderate level of research is continuing on BHT ore systems:

- A collaborative project with Perilya has been developed to support a Masters student, Steven Lewis, to undertake a geological and geochemical study of the Little Broken Hill prospect. The project involves surface mapping, drill core logging and geochemical studies to place Little Broken Hill in the context of the main Broken Hill lode system.
- Tony Webster is nearing completion of his PhD research on the morphology and structure of the Broken Hill deposit. This very comprehensive study of the various lode systems at Broken Hill clearly demonstrates that the ore bodies are pre-deformation and have been folded along with the enclosing host rocks and alteration facies.
- Ross Large, Garry Davidson, Steve Bodon and Tony Webster were invited to contribute to an in-house BHP Billiton conference on Broken Hill-type deposits. The conference involved an exchange of ideas from researchers from Monash, JCU and CODES involved in BHT research.
- Ross Large presented a Keynote address to the 2003 Broken Hill Exploration Initiative Conference where he discussed the genesis of BHT deposits within the spectrum of statiform/stratabound sediment-hosted Zn-Pb-Ag deposits.

Project 4.12
Origin and setting of the Zawar sediment-hosted Zn-Pb deposits in Rajasthan, India

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

This project commenced in September, when Stuart Bull visited Professor Bhattacharya at Presidency College, and subsequently accompanied him on a field visit to the Palaeoproterozoic Zawar Zn deposits in Rajasthan. Professor Bhattacharya has been working on the mineralisation for some time, in terms of both its basin setting and the nature and origin of the sulfides. 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. Apart from the nature and origin of the Zawar cluster of deposits, the main question in Rajasthan is their relationship, if any, to the higher grade (in all senses) and more economically viable deposits such as Rampura Agucha 70 km to the northeast. This project represents an exciting initial collaboration between CODES and the active Indian geological research community, and Professor Bhattacharya will visit CODES for four months in 2004 to interact with CODES personnel and utilise the analytical facilities.

PhD Students in Program 4

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

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

Darryl Clark: Mineral paragenesis and geochemistry of the mammoth Cu deposit, Gunpowder, north-west Queensland (graduated 2003).

Owen Hatton: Basin configuration, volcanology/sedimentology and pre-deformational alteration of the Toole Creek Volcanics, Mt Isa Inlier, northwestern Queensland (submitted & accepted 2003).

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.

PROGRAM 5
Hydrology and geochemistry of hydrothermal systems

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.**

ABOVE Program 5 team — L to R, Ross Large, Andrew Rae, Paul Cromie, David Cooke (Program Leader), Ben Jones, Lee Evans, Cari Deyell, James Cannell.

Team Leader
David Cooke

Team Members
Stuart Bull, Bruce Gemmell, Cari Deyell, Anthony Harris, Ross Large, Andrew Rae, Jianwen Yang

PhD Students
David Braxton, James Cannell, Mawson Croaker, Andrew Davies, Lee Evans, Peter Frikken, Tim Ireland, Ben Jones, Lyudmyla Koziy, Vanessa Lickfold, Wallace Mackay, Glen Masterman, Nicole Pollington, Christian Schardt, Ruth Shepherd, Alan Wilson

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

Core Projects

5.1 Nature, timing and significance of fluid flow and fluid chemistry in Proterozoic sedimentary basins, and relationship to stratiform Zn-Pb-Ag ore formation.
5.2 Fluid flow in the Mount 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 lode gold mineralisation.

Highlights

1 **A total of $110K per annum in ARC Linkage funding awarded to AMIRA project P765 ('Transitions and zoning in porphyry-epithermal mineral districts'). Project 5.18**

2 **Invited keynote conference presentations by David Cooke on the porphyry copper deposits of Central Chile, and on epithermal ore deposits. (Projects 5.7 and 5.5)**

3 **Commencement of a new NSERC-funded postdoctoral study by Cari Deyell on the sulfur isotope systematics of alkalic porphyry deposits. (Project 5.15)**

4 **Final reporting of the results of numerical modelling of fluid flow and chemical mass transfer for the Zambian copper deposits. (Project 5.14)**

5 **Publication of a paper in SEG Reviews by Andrew Rae documenting the relationships between fluid flow and hydrothermal alteration assemblages at the Palinpinon geothermal system, and presentations of these results at GAC-MAC (Vancouver) and the Goldschmidt conference in Japan. (Project 5.5)**

Project 5.1 CORE
Nature, timing and significance of fluid flow and fluid chemistry in Proterozoic sedimentary basins, and relationship to stratiform Zn–Pb–Ag ore formation

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

In 2003, Cooke, Bull and Large published a paper dealing with chemical aspects of stratiform Pb-Zn ore formation in the Journal of Geochemical Exploration. Chemical modelling was used to test the viability of exhalation and wall rock replacement as ore-forming mechanisms. It highlighted that reaction with sour gas in a Century-style petroleum reservoir had the potential to form massive sulfide mineralisation, provided that acidification could be prevented during H_2S gas condensation into the mineralising brine. This paper was also given as an oral presentation at the Geofluids conference in the Netherlands in May 2003.

Ross Large and David Cooke taught a two-day post-conference workshop on fluid chemistry and fluid flow in hydrothermal systems at the International Geochemical Exploration Symposium in Dublin in September 2003. Particular emphasis was placed on fluid flow and ore formation in stratiform Pb-Zn systems. A one-day visit to the Lisheen Pb-Zn mine was completed in conjunction with this workshop.

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)

The results from this collaborative AMIRA project have major implications for the formation of stratiform Zn-Pb-Ag deposits in the Mt Isa Basin. Numerical modelling, undertaken in collaboration with Jianwen Yang (Windsor University, Canada) has investigated the relative importance of a number of basin parameters, including: (1) the permeability and thickness of potential aquifers; (2) their depth in the basin; (3) the presence of stacked aquifer sequences; and (4) the relationship between aquifers and syn-sedimentary faults. Probably the most important conclusion from the modelling is the significance of the depth penetration of major faults. Deep penetrating faults have an over-riding influence on fluid flow and heat flow patterns in the basin. They are the principal discharge faults and create temperature anomalies that maintain consistently higher temperature and higher velocity fluid flow relative to faults of lesser depth penetration and/or permeability. The Termite Range, Fish River and Elizabeth Creek Faults are interpreted to be major deep faults in the northern Mt Isa Basin that have controlled basin-wide convective fluid flow, and the location of major base metal deposits.

A manuscript has been submitted for a Special Issue of *Economic Geology* due to appear in 2005.

As part of her on-going PhD study, Lyudmyla Koziy has continued to numerically model coupled fluid flow and heat transport on a geological section (P3) through the Lawn Hill Platform that was generated by the AMIRA research team. Lyudmyla's work has involved finite element mesh construction, mesh digitisation, input data collection and preparation of input files. She has undertaken simulations of five different fluid-flow scenarios on this section, and is continuing to analyse her results and to refine her numerical models.

Project 5.3 CORE
Software development

D Cooke, R Large; PhD student L Koziy

Lyudmyla Koziy's PhD study on fluid flow in sedimentary basins has required that she undertake significant software development in 2003. She has written FORTRAN code to enable flexible mesh adjustment, and has subsequently tested the mesh influence by undertaking three simulations using varied meshes. Supplementary software has also been written which enables analysis of discharge conditions. This has been applied to five case studies from Project 5.2. Lyudmyla has also finalised writing the required algorithms and is now developing software that will simulate 2-D migration of hydrothermal fluid in complex geological structures. This work should be completed during 2004.

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), G. Dipple (MDRU-UBC); PhD students A Davies, G Masterman

Cari Deyell submitted a manuscript to *Economic Geology* on the stable isotope systematics of the Pascua-Lama high sulfidation epithermal gold deposit, Chile, in which she used chemical modelling to explain the conditions of alunite and gold deposition. This manuscript is currently being revised and should be published in 2004. Cari also was invited to present a paper on mineralisation in the El Indio district at the SEG symposium on Andean Metallogenesis at the Chilean Congresso in Concepcion (October 2003) and has submitted a paper to the companion volume (SEG Special Publication)., She has also submitted a paper in collaboration with G. Dipple (MDRU-UBC) on the alunite-natroalunite stability relationships in epithermal systems and gave a talk on the mineralogical and stable isotope systematics of the Kelly epithermal vein (Philippines) at the SGA meeting in Athens (August 2003). The stable isotope study has been conducted in collaboration with Dr Bob Rye (USGS).

David Cooke gave a keynote address at the 2003 Athens SGA meeting that summarised a template for describing epithermal mineralisation, and how it can be used in conjunction with the results of chemical modelling to infer conditions of ore formation. A paper summarising some of the results of Andrew Davies' PhD study of the Kelian deposit (also part of SRC project 3.11) was presented by Bruce Gemmell at the same meeting.

Andrew Rae gave presentations on the Palinpinon geothermal system at the GAC-MAC conference in Vancouver (May 2003) and at the Goldschmidt conference in Japan (August 2003). His manuscript describing the spatial and temporal relationships of alteration assemblages at Palinpinon was published in the *Society of Economic Geologists Special Publication* 14 (the Giggenbach memorial volume). A paper that summarises the petrology and tectonic setting of the Palinpinon geothermal field will be published in the *Journal of Volcanology and Geothermal Research* in 2004.

Project 5.7
Giant porphyry Cu 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 Archaean lode Au (CGM/CSIRO), PNG Au-Cu (CSIRO) and Chilean porphyry Cu-Mo deposits (CODES/CSIRO). The final AMIRA sponsors meetings were held in 2003, although research will continue in 2004 through the work of the three CODES PhD students sponsored by this project. A keynote paper summarising the major findings of the research team in central Chile was presented by David Cooke at the SGA meeting in Athens in August 2003.

Glen Masterman submitted his PhD thesis in July 2003. It was accepted in October 2003 and Glen graduated in December. Glen's thesis integrated new geological, structural, geochemical and geochronological data into an integrated model for the formation, exhumation and preservation of porphyry copper and superimposed high sulfidation epithermal mineralisation in the Collahuasi district, Chile. Glen also finalised corrections to a paper for *Economic Geology* that documents the geochronology of porphyry and high sulfidation epithermal mineralisation at Collahuasi. This paper is scheduled for publication in 2004.

Peter Frikken submitted his PhD thesis on the Río Blanco porphyry Cu-Mo system in March 2003. Due to Peter's work commitments in Chile, corrections to this thesis were not finalised until January 2004. The thesis uses mineralogical and stable isotopic zonation to propose a new genetic model for the formation of breccia-hosted mineralisation at Río Blanco.

James Cannell continued his research into the El Teniente porphyry Cu-Mo system. Results of the Re-Os geochronological study undertaken in collaboration with Holly Stein were presented at the Athens SGA meeting in August 2003.

A Special Issue of *Economic Geology* that summarises the results of the porphyry-related research in AMIRA project P511 is scheduled for publication late in 2004. Most of the papers submitted to this volume by CODES staff and students have now been reviewed, and are currently being revised in preparation for publication.

Project 5.8 CORE
Controls on hydrothermal fluid migration by volcanic facies architecture: implications for massive sulfide deposit formation

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

Christian Schardt's PhD study was completed in October 2003 and is currently being examined. This study used finite difference numerical modelling to study buoyancy-driven heat and fluid transport in submarine volcanic environments. Modelling of fluid flow in the Archaean Panorama VHMS district in Western Australia and the modern-day Lau basin was conducted in order to gain insights into potential ore-forming processes. The study emphasised that the most important factors controlling heat and fluid transport in submarine volcanic settings are: the fault and rock permeabilities, basement topography and the nature of the heat source. Recharge-discharge patterns are affected by the nature of the heat source and the fault and facies architecture of the numerical model, whereas discharge velocities depend mostly on fault permeability variations. The modelling results have shown that hydrothermal fluids that contain as little as 10 ppm base metals can potentially form massive sulfide deposits with >0.5 Mt of 10% Cu+Zn ore in as little as 6000 years. World-class deposits probably require hydrothermal activity to extend beyond 40,000 years.

Baguio district, Mexico: Zig Zag Formation

Project 5.14
Proterozoic sediment-hosted copper deposits (AMIRA P544)

P McGoldrick, S Bull, D Selley, R Scott, R Large, D Cooke, M Blake; M Hitzman (Colorado School of Mines); PhD students M Croaker, W Mackay, N Pollington, L Koziy (CODES), D Broughton (CSM)

This collaboration between Programs 4 and 5 is outlined in detail in project 4.6. The AMIRA project finished in July 2003 with sponsor meetings in Hobart and Zambia. The key contributions of Program 5 to the final report were numerical simulations of fluid flow and chemical mass transfer.

Lyudmyla Koziy completed numerical simulations of fluid flow, salinity and heat transfer on a geological section through the Zambian Copperbelt. Eight different simulations were implemented, with the results highlighting the importance of salinity, structure and stratigraphy in controlling the nature of fluid flow in the Zambian basin.

David Cooke undertook simulations of water–rock interaction to test genetic hypotheses for the footwall, arenaceous and ore shale-type orebodies that occur in the Zambian Copper Belt. The results of these simulations showed that our speculations regarding ore-forming processes for each deposit type were chemically viable, provided that inferences regarding the permeability architecture, fluid compositions and timing of mineralisation were correct. Chemical modelling was also used to test hypotheses concerning the formation of associated regional-scale sodic and potassic alteration assemblages.

Project 5.15
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)PhD students D Braxton, B Jones, V Lickfold, A Wilson; M. Expl. Geosci. Student F Urzua; M. Econ. Geol. Student A Ignacio

Several industry-supported PhD studies at CODES are incorporating investigations into fluid chemistry at porphyry copper-gold deposits. The research methods and aims are broadly compatible with Project

5.7, with the principal techniques of determining fluid compositions being petrographic analyses, fluid inclusions and stable and radiogenic isotopes. These PhD studies are linked with Program 1, because each study also contains a component of igneous petrology, geochemistry and tectonics.

Cari Deyell was successful in gaining NSERC funding from the Canadian government for a postdoctoral study of the sulfur isotope systematics of alkalic porphyry copper-gold deposits in Canada and Australia. This project commenced in mid-2003, with a sampling trip to several deposits in British Columbia in collaboration with R Tosdal (MDRU-UBC). A brief sampling program was also conducted at the Lake Cowal Au deposit in NSW. Preliminary results of this two-year study are being presented at the Cordilleran roundup meeting in Vancouver in January 2004. Sulfur isotope analyses are being completed in collaboration with Dr Bob Rye at the USGS laboratory in Denver.

Anthony Harris has continued his postdoctoral studies at CODES concentrating on an investigation into the magmatic-hydrothermal transition as preserved in rocks from Bajo de la Alumbrera, NW Argentina. This is a collaboration with Program 1. Anthony, together with Dima Kamenetsky, Noel White and Chris Ryan, has published a paper in *Science* that documents melt inclusions and coexisting fluid inclusions found in hydrothermal veins at Alumbrera. A second manuscript documenting melt and fluid inclusions in phenocrystic quartz from different porphyritic intrusions at Bajo de la Alumbrera has been submitted to *Resource Geology*. *Mineralium Deposita* has accepted Anthony's manuscript on the longevity of volcanism in the district. He has also submitted a manuscript on the stable isotopic systematics of alteration assemblages at Bajo de la Alumbrera to the Special Issue of *Economic Geology* dealing with giant ore deposits. These manuscripts are scheduled for publication in 2004.

David Braxton commenced a PhD on the Boyongan porphyry Cu-Au deposit (Philippines) in July 2003, supervised by David Cooke and Andrew Rae, and supported by Anglo American (Philippines). This project involves a detailed investigation of the geological and geochemical aspects of hypogene mineralisation at Boyongan, and will attempt to explain deposit formation within the framework of the tectonic evolution of the region. An initial field season was completed in August-September, and subsequent lab work has included petrological and sulfur isotope studies at CODES, and XRD investigations at the University of Utah, in collaboration with Dr Erich Petersen. A second field season is planned for February 2004.

Allan Ignacio is undertaking research on the supergene mineralisation at Boyongan as part of his Masters of Economic Geology degree, supported by Anglo American (Philippines). Allan has completed documentation of the zonation of supergene mineralisation at Boyongan using core logging, PIMA and petrological studies, and is now investigating mineral compositions and the stable isotope systematics of the supergene carbonate minerals. This project is scheduled for completion in mid-2004.

In July 2003, Alan Wilson completed his PhD study of the four porphyry Au-Cu deposits of the Cadia district, NSW. This thesis was passed without corrections in September 2002. Alan and co-workers published a paper documenting the geology, alteration, mineralisation and fluid inclusion systematics of the Ridgeway porphyry Cu-Au deposit in *Economic Geology* in December 2003. This paper documents how mineralisation at Ridgeway is related to high temperature, highly saline fluids that have not undergone phase separation before metal deposition. Alan Wilson and David Cooke gave a two-day workshop to geologists from Newcrest Mining Ltd in December 2003, which summarised the findings of the PhD study, and compared them to the characteristics of the alkalic porphyry Cu-Au deposits of British Columbia, Canada.

Vanessa Lickfold completed her PhD in 2002. She published a paper from her thesis in *Economic Geology* in December 2003. This paper summarises the intrusive history and fluid chemistry at four porphyry Cu-Au deposits in the Goonumbla district. A second manuscript, summarising the igneous geochemistry and isotope systematics of the intrusions, is being submitted to a Special Issue of the *Australian Journal of Earth Sciences* scheduled for publication in 2004. A paper summarising the characteristics of comb quartz layers and their melt inclusions at Goonumbla and Cadia, written in collaboration with Alan Wilson, Anthony Harris and David Cooke, was presented by Vanessa at the SGA meeting in Athens (August 2003).

Ben Jones continued his BHP Billiton-supported PhD study of the Antapaccay porphyry Cu-Au deposit (Peru) during 2003. Most of the work completed to date consists of U-Pb geochronological studies of the local and regional intrusions, and literature reviews of the tectonics of the Andean margin, and of the geochemistry of intrusions related to porphyry deposits. Research on this project will continue throughout 2004.

Felipe Urzua is undertaking a detailed structural mapping project of the Escondida Cu-Mo porphyry district in northern Chile, under the supervision of Andrew Tunks and David Cooke, and through the sponsorship of BHP Billiton. Felipe completed mapping the district in October 2003. Geochronological investigations of selected units are now underway. This project is scheduled for completion in 2004.

Project 5.16
Fluid mixing in hydrothermal systems

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

CODES research activities in this James Cook University-based ARC Discovery Grant-funded project involved a two-week field visit to Cloncurry, Mt Isa and Townsville, where samples were collected in order to test for geochemical signatures diagnostic of fluid mixing. Bin Fu continued his PIXE and Laser Raman studies of fluid inclusions from El Teniente and Grasberg, detecting high CO_2 concentrations in the El Teniente fluid inclusions.

Project 5.17
Hydrology and chemistry of mine drainage waters

D Cooke, G Davidson, J Reid, S Gilbert, P Hollings (LakeheadU); PhD student: L Evans

CODES and SES staff at the University of Tasmania have continued their investigations of acid drainage at active and abandoned mine sites in Tasmania. In 2003, Lee Evans completed his second 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 involved the construction and calibration of a groundwater model for the catchments containing the Rosebery mine and related infrastructure. The model incorporated mine workings, fracture data, major faults, geology and utilised a representative water balance. Aqueous geochemistry was expanded to include major ion and stable isotope analyses of drainage waters.

Sarah Gilbert, together with David Cooke and Peter Hollings, published a paper in *Environmental Geology* in mid-2003. It summarised the results of column leach experiments designed to test the stability of hardpan layers in the Renison Bell tailings dam. Laboratory experiments were conducted under a variety of conditions likely to be encountered after mine closure, in order to evaluate whether hardpan

formation was advantageous or deleterious with regards to drainage water quality emanating from the dam.

An ARC-Linkage proposal was submitted in November 2003 in an attempt to secure an APAI scholarship for a new PhD study on the geochemistry and microbiology of acid drainage waters at the abandoned Mount Bischoff tin mine in western Tasmania. If successful, this project will be conducted in collaboration between CODES, the School of Earth Sciences and the School of Agricultural Sciences at the University of Tasmania. Financial support for the project will be provided by the Department of Primary Industries, Water and the Environment (DPIWE) and by Mineral Resources Tasmania.

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

D Cooke, B Gemmell, C Deyell, N White, J Reid; PhD student T Ireland

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 Au-Ag deposits, skarn Cu-Au deposits, carbonate replacement Zn-Pb-Ag, and sediment-hosted Au. These districts continue to be major targets for both copper and gold explorers. Exploration in porphyry-related districts can be complicated by shallow-level alteration 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 mineralization styles, and vector towards ore zones — be they of porphyry, epithermal, and/or other peripheral styles. This is a collaboration between Program 3 (project 3.14) and Program 5.

This project commenced in the second half of 2003, with funding obtained from a total of seven industry sponsors (Anglo American Philippines, AngloGold, Gold Fields, Newcrest, Newmont, Placer, Teck-Cominco). The project was successful in winning $110,000 per annum in linkage funding in October 2003. Preliminary sponsors meetings were held in April, July and December. Sites selected by the sponsors for detailed field study are Lepanto and Baguio (Philippines), Batu Hijau (Indonesia), Collahuasi (Chile) and Pueblo Viejo (Dominican Republic). Negotiations are underway to gain access to other sites for comparison studies.

Project 5.19
Sulfur isotopes and trace element geochemistry of sulfides as a discriminator of world-class Early Proterozoic lode gold mineralisation

D Cooke, R Berry, A Tunks; PhD student R Shepherd

The principal objective of this proposed PhD project is to develop discriminators that identify multi-million-ounce Precambrian lode gold deposits buried under cover in West Africa and Australia. This will be achieved using laser ablation sulphur isotope and ICPMS trace element analyses of pyrite. Research undertaken will be carried out on a range of strategically selected deposits that represent a spectrum from world-class, multi-million-ounce deposit to smaller low tonnage deposits. Ruth Shepherd commenced her studies in September 2003 and has been collecting samples from a number of West African deposits.

Project 5.20
Geology and geochemistry of gold and lead-zinc mineralisation in Nunavut, Canada.

Cari Deyell, Ross Sherlock (Geological Survey of Canada)

This project has involved geochemical investigations into the origins and characteristics of gold mineralisation in Proterozoic banded iron formations in the Committee Bay area, Nunavut. Also being studied is MVT-style Pb-Zn mineralisation at Nanisivik. Results of the 2003 research program have been reported in the Geological Survey of Canada current research volume.

PhD Projects in Program 5

David Braxton: Origin of the Boyongang porphyry Cu-Au system, Philippines.

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

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

Andrew Davies: Geology and genesis of the Kelian Au deposit, east Kalimantan, Indonesia. (completed and graduated 2003)

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. (completed 2003)

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

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

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

Vanessa Lickfold: The intrusive history and volatile evolution of the Endeavour porphyry Cu-Au deposits, Goonumbla district, New South Wales. (completed and graduated 2003)

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

Glen Masterman: Genetic relationships between the Rosario porphyry Cu-Mo deposits and the high-sulfidation Cu-Au veins, Collahuasi district, Chile. (completed and graduated 2003)

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. (completed 2003)

Ruth Shepherd: Structure and geochemistry of gold mineralisation, Abosso, Ghana.

Alan Wilson: The genesis and exploration context of porphyry Cu-Au deposits in the Cadia district, NSW (completed and graduated 2003).

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 an international 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.

ABOVE CODES PhD students — L to R, back row, Paul Cromie, Rod Maier, Russell Fulton, Carlos Rosa, Kim Denwer, Wallace Mackay, Neil Martin, Andrew Stacey; middle row, James Cannell, Ben Jones, Darren Andrews, Mawson Croaker, Len Kolff , Steve Lewis; front row, Fiona Links, Sofia Tetroeva, Maya Kemenetsky, Singoyi Blackwell, Brian Bowden, Mike Baker.

Post-Doctoral and Research Fellows

- Robina Sharpe moved to employment in Ghana in 2003, leaving 14 post-doctoral and research fellows at CODES.
- Good news came in the form of a five-year ARC post-doctoral fellowship awarded to Sharon Allen, and a two-year Canadian NSERC fellowship to Cari Deyell. Sharon will continue her work on submarine-erupted pumice breccias in modern and ancient systems, and Cari will study S isotope characteristics of mineralised alkalic porphyries.
- Dima Kamenetsky was awarded a prestigious Humboldt Fellowship Bessell Award to travel to the Max-Planck Institute in Germany for six months in 2003 and again in 2004, to work on melt inclusions in magmas from diverse tectonic settings.
- AMIRA- and related industry-funded projects based in CODES are driven by post-doctoral fellows who are also closely involved in the supervision of PhD students in these projects. David Selley, Stuart Bull and Rob Scott contribute to the Zambian sediment-hosted copper project, and Andrew Rae manages the analytical component of the trace elements in sulfides project.
- Leonid Danyushevsky has made exceptional progress in developing the LA-ICPMS facility, which is now widely used by staff and post-graduate students for numerous geochemical and geochronological applications.
- Sebastien Meffre divided his time between improving the laser ablation zircon U-Pb dating system, working on SW Pacific tectonics (including a 21-day research cruise on the R/V *Southern Surveyor*), and ground-truthing regional mapping and geophysical data interpretation for the Geological Survey of NSW.
- Cathryn Gifkins and Wally Herrmann completed a contract project funded by Mineral Resources Tasmania and the pmd*CRC to produce new interactive maps of the Mount Read Volcanics in western Tasmania to aid mineral exploration.
- Post-docs Anthony Harris, Dima Kamenetsky and colleagues published a paper in *Science* describing melt inclusions in quartz veins at the Alumbrera porphyry-Cu deposit in Argentina.
- Khin Zaw and his SE Asia research group had an extremely productive year, publishing seven papers in refereed journals, and successfully establishing another ARC Linkage project in SE Asia for 2004–2006.
- During 2002, CODES post-doctoral and research fellows authored or co-authored 24 of CODES 38 papers in scholarly journals.

PhD Program

There were nine PhD theses submitted during 2003. Of these, eight were awarded the degree, and the last and most recently submitted of these is still under examination. New PhD students in 2003 include:

- Darren Andrews, another UTAS graduate, whose project focuses on time-lapse geophysical monitoring of acid mine drainage at Savage River, western Tasmania.
- Michael Baker, who completed BSc(Hons) at USydney; Mike's PhD focuses on the magmatism in the Palaeoproterozoic Georgetown Block in north Queensland. (principal supervisor Tony Crawford)

CODES PhD students who submitted or graduated in 2003, and where they are now ...

Michael Agnew – Anglo American, WA

Andrew Davies – AngloGold, Peru

Peter Frikken – Codelco, Chile

Owen Hatton – LionOre, WA

Glen Masterman – Placer Dome, WA

Alan Wilson – Newcrest, WA

Christian Schardt – Johns Hopkins University, USA

Andrew Stewart – Ivanhoe Mining, Mongolia

Paul Davidson – CODES Program 1

- David Braxton who comes from the USA and has worked in Peru and Utah; David is working on the Boyongan porphyry-Cu deposit in the Philippines, and his project is funded by Anglo American (Philippines). (Principal supervisor David Cooke)
- Paul Cromie, who studied in Victoria and worked in industry in SE Asia; Paul is working on the Sepon gold deposit in Cambodia. (Principal supervisor Khin Zaw)
- Kim Denwer, after 10 years in industry, tackles the genesis of the Mount Lyell mineral field in western Tasmania. (Principal supervisor Ross Large)
- Rod Maier, a BSc(Hons) graduate from UNewcastle, who is working on trace elements in sulfides as vectors to ore in northern Australian sediment-hosted Pb-Zn deposits. (Principal supervisor Peter McGoldrick)
- Ruth Shepherd, a CODES graduate who has spent several years working in Ghana, is studying the structure and mineralisation of the Abosso gold field, Ghana. (Principal supervisor David Cooke)
- Blackwell Singoyi, from Zambia, is working on the trace-element signatures of hydrothermal magnetites from different styles of mineralisation. (Principal supervisor Garry Davidson)
- Craig Stegman, who has upgraded from an MExpGeosci ('Structural and geochemical controls on mineralisation at the New Occidental gold deposit, Cobar, New South Wales, Australia') into a PhD. (Principal supervisor Rob Scott)
- Sofia Tetroeva from University of Moscow, Russia, whose project on SW Pacific magmatism and adakite petrogenesis is supported by University International Post-graduate student scholarship. (Principal supervisor Leonid Danyushevsky)

The number of CODES PhD candidates during 2003 levelled out at 29 students. An impediment to recruiting new PhD students within Australia is the recent tendency by most mainland universities to 'corral' their own Honours students to do a PhD in their 'home' institutions. Currently, only 25% of the CODES-Earth Sciences PhD

cohort completed their Honours degree at the UTAS, and of these, all but two have spent 3-10 years in exploration post-Honours before returning to take on a PhD.

Current or recently completed CODES PhD students authored or co-authored 12 papers during 2003, with contributions from Andrew Stewart (2), Karin Orth, Alison Raos, Oliver Holm, Nick Direen (2), Zongshu Yu, Paul Cromie, Darryl Clark, Andrew Rae and Phisit Limtrakun. Our PhD students were also well represented among presenters at national and international conferences, notably at the 7th Biennial SGA conference in Athens.

Masters Program

It was a year of consolidation for the Masters program with the majority of new enrolments coming from international students. During the last year, we are pleased to have been joined by Mannie Mehu from Lihir Gold, Steven Lewis completing a project for Perilya at Broken Hill, Len Kolff studying a new iron ore discovery in western Africa, and Kamonporn Krumpkhun researching a gold deposit in Thailand.

A number of excellent theses were submitted during the year, including those from:

Pamela Italiano – Ni mineralisation at Black Swan, Western Australia
Mike Buchanan – Geochemistry of the Fenton Creek zone, Canada
Ian Laurent – Geophysics of the Svartliden Project, Sweden.

Congratulations also to Andrew Dacey and Simon Henderson, who completed their Masters via the coursework option.

Two successful short courses were completed during the year. David Cooke ran the 'Geochemistry of Hydrothermal Systems' course in June, which was well-attended by both students and industry professionals. The second 'Ore Deposits of South America' trip was run in November. This field-based course, which visits mines in Peru and Chile, was a great success, attracting students and industry representatives from around the globe. Some of the highlight visits were Pierina and Colquircia in Peru, and El Teniente, Rio Blanco and Chuquicamata in Chile. This trip provides a great opportunity to see some of the world's largest mines and also some of the 'hottest' exploration ground. Invariably, such big and complex systems keep the groups debating the pros and cons of genetic models and exploration strategies far into the night.

2004 is shaping up as another solid year for the Masters program, with increased enrolments and three high-quality courses being offered.

As reported in *Ore Solutions*, follow-up drilling of an area revealed by CODES Masters student Dan Olberg's research on exploration vectors for epithermal gold in the Gosowong district, led to the discovery of the Kencana gold deposit by Newcrest.

ore solutions

Newsletter of the Centre for Ore Deposit Research, an ARC Special Research Centre at the University of Tasmania

Master of Economic Geology Research Leads to Exploration Success

Follow-up drilling to research by Newcrest exploration geologist and CODES student, Dan Olberg, has led to an exciting new epithermal discovery in Indonesia. Dan completed his Master of Economic Geology thesis entitled 'Ore shoot targeting in the Gosowong Vein Zone, Halmahera, Indonesia' in late 2001.

Dan Olberg examining outcrop in the Gosowong district.

Gosowong is located in the Maluku province of eastern Indonesia, on the north arm of the island of Halmahera. It is a classic example of a volcanic-hosted, low-sulfidation, epithermal quartz vein deposit. Gold mineralisation at Gosowong was discovered by Newcrest Mining Limited geologists in May of 1994 as a result of a ground reconnaissance program in northern Halmahera, targeting porphyry style gold-copper mineralisation. The mineralised structure is known as the Gosowong Vein Zone (GVZ) and has been traced along strike for 2 km, though the Gosowong deposit encompasses only a 400 m section of the total strike length. Economic mineralisation is predominantly hosted in two gently south-plunging ore shoots along an east-dipping normal fault that contain quartz–adularia–electrum and quartz–chlorite–electrum styles of epithermal mineralisation.

Newcrest geologist at the Kencana discovery hole monument.

The Gosowong resource at the commencement of mining in 1999 was estimated at 0.99 Mt at 27 g/t Au and 38 g/t Ag for a total of 870 000 ounces Au, using a cut-off grade of 2 g/t Au. Mining of the Gosowong deposit finished in early 2002, however milling of both high-grade and low-grade stockpiles continued into 2003.

Dan worked as a senior exploration geologist at Gosowong during the course of his Master of Economic Geology studies. The primary aim of Dan's study was to identify additional high-grade ore-shoots along the GVZ. A multi-faceted approach was implemented incorporating structure, stratigraphy, vein textures, alteration zoning, fluid inclusions, and metal zoning, with the ultimate aim being to construct a model for predictive targeting of high-grade ore-shoots along the GVZ.

Dan created a Gosowong specific 'prospectivity matrix' based on the sum total of the relative prospectivities of each of the components analysed in his study. This matrix indicated that the most prospective area of the GVZ was deep and to the south of the deposit.

In May Newcrest Mining Limited announced (Market Release 23/05/03) that drilling has resulted in the discovery of a significant zone of mineralisation at the Kencana prospect, on a separate structure to the GVZ, south of the original Gosowong

continued on page 2

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EXPLORATION SUCCESS from page 1

mine. This newly discovered mineralisation lies 1 km south of the original Gosowong mine and in an envelope approximately 250 m long, 100 m down-dip with a thickness ranging from 3 to 20 m. It remains open along strike and at depth. Some of the drilling intersections reported include: 10.55 m @ 20 g/t Au, 23.45 m @ 110 g/t Au, 13.5 m @ 29 g/t Au, 3.5 m @ 105 g/t Au, 10.4 m @ 34 g/t Au, and 10.4 m @ 130 g/t Au.

The discovery hole at Kencana was targeted on the southern zone on the Gosowong structure which Dan identified as highly prospective. Dan reports that "the Gosowong vein structure was intercepted as planned, but another high-grade epithermal vein was intersected in the hangingwall". The Kencana vein strikes NW and is located adjacent to the intersection between the Gosowong structure and the NW Kencana structure and does not crop out at surface. The Kencana vein has the same characteristics as Gosowong deposit, with both quartz-adularia style and quartz-chlorite styles of veining.

Understandably, Dan says "I'm ecstatic that my thesis actually turned out to be useful in discovering an ore deposit, which was really my whole objective in writing it". Newcrest Mining Limited reports that drilling is continuing on this new discovery. Dan was supervised by Associate Professor Bruce Gemmell.

Honours Program

In what was a relatively tough year for the exploration industry, the number of students participating in the Honours program was down from previous years, but nevertheless 15 students progressed through the year, including mid-year finishers, mid-year starters, and the main calendar year group. Four student projects were in economic geology, seven in geophysics (of which four had economic geology applications and three were in environmental geology), two in volcanology, one in petroleum geology, and one in igneous petrology (see following table). Four of the projects had field components outside mainland Tasmania, including sites at Mount Isa, the Western Australian goldfields, Macquarie Island, and New Zealand. Twelve CODES staff members were involved in project supervision. The high academic standards of 2002 were maintained in 2003, with six students receiving first class Honours, three are still being examined, and the remainder receiving H2A results.

A group of rock-salt carvings from the Wieliczka Salt Mine, a UNESCO World Heritage area in Poland. Legend says that the salt mines in Wieliczka were part of the dowry of the Hungarian princess, Kinga, when she wed Boleslaw the Shy over 700 years ago. Within the mine are many carvings of historical and legendary tales from the area, as well as entire chapels. Taken during the University of Tasmania SEG Student Chapter Poland field trip to the Kupferschiefer and the Silesian Zn-Pb field.

Minerals Tertiary Education Council Consortium

CODES has continued its role as a founding member of the MTEC consortium. Our major role is coordinating the MCA National Masters Program, a joint venture between UTAS, JCU and UWA with support from CRCLEME and VIEPS. The program encourages exchange of students between the participating Tertiary institutions to provide a world-class Masters education program in minerals exploration and mining geology. CODES and Earth Sciences at UTAS are also participating in the MCA National Honours program coordinated by VIEPS. In 2003 CODES ran two Honours-level courses for students from Melbourne, Monash, ANU and UTAS.

Toward the end of 2003, following a major review of the MTEC program, the MCA agreed to continue the program for another three years with CODES as one of the major contributors. The program will continue to support both the salary and costs associated with the MTEC Senior Lecturer Dr Andrew Tunks. Furthermore, additional MTEC funds will be used to support the transfer of students both within the Masters and Honours programs ensuring that CODES students can access the best available course across the country. Naturally many students from the mainland have also used the travel subsidies to attend CODES courses in Tasmania, giving them opportunites to look closely at Tasmanian geology and to take advantage of specialised orebody expertise not available at their home insitutions.

MTEC has also helped facilitate exciting new collaborative developments which are in the planning stage and are likely to have a big impact on the Master of Economic Geology degree. These new developments will be announced throughout 2004 as details are finalised.

SEG Student Chapter

The Society of Economic Geologists Student Chapter at CODES is an active and dynamic group involved in a range of academic, educational and social activities. Highlights for 2003 included:

1. A week-long field trip to important mining districts of Poland, including the famous copper deposits of the Kupferscheifer. This field trip was a collaborative effort involving the University of Tasmania SEG student chapter, the Colorado School of Mines and the Institute of Geological Sciences at Jagiellonian University in Krakow.
2. Providing financial support to help fund a series of presentations to first-year geology students, highlighting the many benefits of a career in the earth sciences.
3. Planning for a field trip around Tasmania for post-graduate students attending the 17th Australian Geological Convention in Hobart during February 2004.
4. Liaising with the SEG headquarters in Colorado to arrange for the Thayer-Lindsley travelling lecturer, Francois Robert from Barrick Gold, to visit CODES in early 2004 and present several seminars to the Student Chapter and academic staff.
5. Kate Bull, a CODES PhD student and the 2003 Student Chapter committee secretary, being awarded a US $1500 bursary from the SEG (the Hugh E. McKinstrey student research award) for her project on the facies architecture of the Early Devonian Ural Volcanics in NSW. Kate used her award to help subsidise participation in an international field workshop on explosive volcanism that was held on the Greek island of Milos in September 2003.
6. Participation by several students in conferences and workshops including the 7th Biennial SGA meeting in Athens and the 17th Victorian Universities Earth Science Conference in Melbourne.
7. Assisting in the organisation of a CODES wine-tasting night and the annual CODES Christmas BBQ.
8. Producing a 2004 calendar showcasing photos taken by Student Chapter members; and producing a crucial piece of geological field equipment — the Tasmanian Geologists' Hand-Warmer (aka a stubby-holder).

Sincere thanks are extended to the academic, technical and administrative staff at CODES who have all supported the Student Chapter throughout the year. The Student Chapter appreciates the excellent efforts of Dr Zbigniew Sawlowicz and his students, who were such gracious hosts during the Polish field trip. We are particularly grateful for the generous financial assistance provided by the SEG Foundation, CODES and the Tasmanian Minerals Council (with particular thanks to Mr Terry Long). This funding made it possible for Student Chapter members to participate in the many field trips, conferences, and workshops held throughout 2003.

Industry Links

CODES has developed an international reputation of undertaking research which is relevant to, and closely linked with, the minerals industry. In 2003 we were supported by ten major corporate sponsors and were involved in research collaborations with 45 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

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

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

There were several changes to corporate sponsors in 2003. Gold Fields Australasia Pty Ltd and Xstrata joined as new sponsors, the latter taking over MIM Exploration's sponsorship role. 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.

AMIRA Research Projects

With the completion of the P511 'Giant Ore Deposit Systems' project in late 2002, and of P544 'Proterozoic sediment-hosted Cu deposits' late in 2003, the only CODES project currently operating under the AMIRA umbrella is the recently commenced P765 'Transitions and zonation in porphyry-epithermal mineral districts'. This project, funded by seven sponsors and an ARC Linkage grant, has work programs in South America, the Dominican Republic and the Western Pacific.

CODES is presently involved in a major effort to generate several new AMIRA-linked research projects, including one on mineralised breccias (with MonashU), and another following up and building on the very successful P544 'Proterozoic stratiform Cu' project.

ARC Linkage Projects

During 2003, CODES researchers held two ARC-Linkage grants and two APA(I) Linkage PhD projects. Two new Linkage projects, 'Transitions and zonation in porphyry-epithermal mineral districts' which is linked to David Cooke and Bruce Gemmell's major AMIRA project (see above), and Khin Zaw's new SE Asian-based Linkage project on the development and mineralisation potential of the Loei Fold Belt in Thailand, will both commence in January 2004.

Industry Linked Student Projects

Some 65% of 2003 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 2003, one PhD student and five Honours students were funded by this scheme. A new PhD project on the geology and genesis of the Mount Lyell deposit has been funded by a Tasmanian Government Mining Scholarship awarded to Kim Denwer, and Anglo have funded a new PhD project for David Braxton on the Boyongan porphyry-Cu system in the Philippines.

Short Courses and Workshops for Industry and Academe

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 2003 and involved the participation of CODES staff and invited national and international speakers:

Jocelyn McPhie and Ray Cas (Monash U) ran the popular 'Modern and ancient volcanic successions' short course at Merimbula, New South Wales, 23–30 November 2003.

Jocelyn McPhie and Andrew Stewart presented a workshop 'Products of submarine explosive eruptions: the Milos case' at Milos, Greece, 15–17 September 2003, as part of the IAVCEI Commission on Explosive Volcanism Volcanology Program-sponsored international conference on the volcanology, tectonics and ore deposits in the southern Aegean volcanic arc, Greece.

Ross Large and David Cooke ran a two-day post-conference workshop on fluid chemistry and fluid flow in hydrothermal systems at the Exploration Geochemistry conference in Dublin, 4–5 September 2003.

Alan Wilson and David Cooke presented a two-day workshop to geologists from Newcrest Mining Ltd in December 2003, which summarised the findings of Alan's PhD study at Cadia, and compared Cadia with the alkalic porphyry Cu-Au deposits of British Columbia, Canada.

Robina Sharpe and Bruce Gemmell were invited to participate in an exploration workshop at Cerro Vanguardia, Argentina, in February 2003 at which they synthesised the current geological knowledge of the district and participated in the formulation of an exploration strategy and program.

Ross Large, Stuart Bull, David Cooke and Dave Selley presented a two-day workshop in February 2003 to staff of the Northern Territory Geological Survey on 'Basin evolution and hydrothermal systems associated with zinc, lead and copper mineralisation'.

In November 2003, Andrew Tunks, David Cooke and others led the exciting 'Ore deposits of South America' field-based course for a second time (see Education section), with a strong representation by industry geologists.

A workshop on 'Ore deposit geochemistry, hydrology and geochronology' was presented by David Cooke, Ross Large and colleagues from UMelbourne, from 30 June to 11 July 2003.

2003 Masters shortcourse, South America

2003 Masters shortcourse, New Zealand

Collaborations

A major objective of the ARC's Special Research Centres program is for Centres to develop strong collaborative research projects with other well-recognised national and international research groups and individuals in areas of core research activities.

All collaborations across each of CODES' five research programs are referred to in the individual program reports, and listed in the Appendix. Major collaborative links involving researchers from CODES during 2003 include:

Links with other Australian universities:

Collaborative links with researchers at Monash University have been strengthened during 2003 with the commencement of two new joint projects. With funding from a UTAS internal research grant, Tony Crawford has begun a study of the northern limit of the Tasman Line, around Greenvale in north Queensland, with David Giles from the Australian Crustal Research Centre at Monash, and Ian Withnall from the Geological Survey of Queensland. David Cooke, Jocelyn McPhie and Cathryn Gifkins from CODES have begun a joint project with Monash volcanologist, Ray Cas, and Rick Squire from UMelbourne, to study the diverse occurrences of mineralisation in breccias, ranging from diamond-bearing kimberlitic breccias, to porphyry-Cu/Au-hosting diatremes and breccias. In addition, Monash PhD student Patti Durance-Sie spent more than three months at CODES during 2003 using the melt-inclusion facilities, under Leonid Danyushevsky's guidance, to gather new data for her studies on lavas from the SW Pacific arcs.

David Cooke is co-leader of an ARC Discovery Grant, with Nick Oliver, Bin Fu and Pat Williams at James Cook University, Townsville, focussed on fluid mixing in hydrothermal systems. In a second project, CODES researchers Garry Davidson, Ron Berry and David Cooke are collaborating with JCU researchers Tim Baker and Nick Oliver, and University of Adelaide geochemist Karen Barovich in a study of the geology and geochemistry of Fe oxide-Cu-Au deposits.

CODES volcanologists Jocelyn McPhie and Fernando Della Pasqua are working with Macquarie University geophysicist Mark Lackie, using anisotropy of magnetic susceptibility to better define volcanic fabrics and vent locations in the Proterozoic Gawler Range Volcanics in South Australia. Marc Norman (PRISE, ANU) is collaborating with Jocelyn McPhie in dating young volcanics from Milos in the Aegean arc. Marc has also been involved in the LA-ICPMS sulfide study at CODES since its inception, working with Garry Davidson, Andrew Rae and Leonid Danyushevsky.

Dima Kamenetsky maintains productive links with UMelbourne's Roland Maas, the latter contributing his expertise in the collection and interpretation of radiogenic isotope data. Dima's melt inclusion expertise also contributed to a paper in *Nature* by an RSES (ANU) group led by Vickie Bennett and Weidong Sun on the behaviour of rhenium as a guide to how other volatile metals might behave in magmatic systems.

Links with Australian Government agencies

CODES maintains a number of strong links with Geoscience Australia (GA). In SW Pacific marine geoscience, the first cruise of the newly refitted R/V *Southern Surveyor*, led by Tony Crawford as Chief Scientist, was strongly supported, and partly funded by GA, with the active involvement of GA marine geologists Neville Exon, Phil O'Brien and GA technical support staff. GA geochemist Terry Mernagh continues to provide quality FTIR data for CODES researchers in Programs 1 and 5, especially focussing on the partitioning of chalcophile metals during late magmatic fluid evolution. Roger Skirrow and Evgeniy Bastrakov from GA are collaborating with CODES researchers Garry Davidson, Ron Berry and David Cooke on aspects of the geology and geochemistry of Fe oxide-Cu-Au deposits, and Peter Southgate's work with CODES researchers on the north Australia basins is currently being prepared for publication.

Primary Industry and Resources South Australia (PIRSA) continue to provide support for a collaborative project involving PIRSA's Michael Schwartz and CODES volcanologists aimed at identifying vent locations for the Gawler Range Volcanics. Working with PIRSA's Manager of the Geological Survey, Paul Heithersay, and geologist Michael Schwartz, the CODES Fe oxide-Cu-Au deposits research team maintains a strong interest in South Australian deposits, part of which involves Bryan Bowden's PhD project on Prominent Hill.

Mineral Resources Tasmania contribute significantly to CODES via Tasmanian Government Mining Scholarships, which support Honours and PhD students working in the State. MRT's Geoff Green has been working with CODES researchers Wally Herrmann, Garry Davidson, Cathryn Gifkins and others on diverse aspects of mineralisation, geochemistry and volcanic facies analysis of the Mount Read Volcanics. Tony Brown and John Everard from MRT are involved with CODES researchers Garry Davidson, Tony Crawford and Dima Kamenetsky on several studies of magmatism and hydrothermal alteration of Macquarie Island crust.

On-going collaboration between Tony Crawford and geologists from the Geological Survey of Victoria led to production of the Neoproterozoic–Cambrian chapter of *Geology of Victoria*, and Tony and David Giles (MonashU) are working with Ian Withnall from the Geological Survey of Queensland on the regional geology of the northern end of the Tasman Line, along the eastern edge of the Proterozoic Georgetown Block. A team from the Geological Survey of New South Wales (Dick Glen, Ian Percival and Larry Barron) is currently involved with researchers from CODES, Tony Crawford, Dave Cooke, Sebastien Meffre and Rob Scott, in assembling papers for a Thematic Issue of *Australian Journal of Earth Sciences* to be published in 2004, reporting outcomes of the joint CODES–GS-NSW SPIRT project on the Ordovician Macquarie arc and its mineral deposits in central western NSW.

CODES maintains several productive links with CSIRO Exploration and Mining researchers. In 2002-2003, CODES researchers published four papers in collaboration with CSIRO E&M PIXE probe geochemists Chris Ryan and Esme van Achterbergh. In particular, the PIXE probe

collaboration provided remarkable spatial element distribution and concentration data for melt and fluid inclusion studies of metal partitioning during volatile phase exsolution from magmas. Bruce Gemmell's work with CSIRO E&M's Tim McConaghy and Ray Binns on active sulfide deposition on the seafloor during submarine volcanism continued during 2003, and CODES' David Cooke and his team of postgraduate students maintained on-going collaboration with E&M's John Walshe on the giant porphyry Cu systems in Chile.

International Collaborations

Several important collaborations between researchers from CODES and a number of North American groups continued to provide valuable outcomes. In particular, Johns Hopkins University's Grant Garven furthered his research on fluid flow modelling in sedimentary basins and volcanic piles, working with Ross Large and PhD students Christian Schardt (CODES) and Mike Simms (Johns HopkinsU), with input by Jianwen Yang, formerly from CODES now at UWindsor in Canada. The other major CODES-North American collaboration is with Murray Hitzman's ore deposit research group at Colorado School of Mines (CSM), which is focussed on Proterozoic sediment-hosted mineralisation, particularly in Zambia. This collaborative effort has been co-funded by industry (via AMIRA) and ARC Linkage grants. Collaborations with CSM will increase in 2004 with the funding of a new AMIRA-ARC Linkage project on porphyry-epithermal transitions, led by David Cooke and Bruce Gemmell (CODES) and involving Jeff Hedenquist (CSM).

CODES has established a number of European links with research groups in Greece (volcanology), Russia (ore deposit mineralogy and geochemistry), Sweden (Bergslagen and Skellefte districts), Germany (seafloor mineralisation), England (S isotope geochemistry of altered oceanic crust), and Italy (melt inclusion studies). A strong link with the Max-Plank Institute of Geochemistry in Germany (Mainz) has been established, with CODES' Dima Kamenetsky being awarded the Bessell Fellowship. Dima spent six months at Max-Planck in 2003, and will do so again in 2004. This fellowship supports Dima's work in melt inclusion studies of volatile exsolution in magmatic systems, a core element of the Program 1 research effort. Collaborative links with ore deposit geologists (via Mike Solomon at CODES) and volcanologists (via Jocelyn McPhie) in Portugal have proved very beneficial to CODES, leading to a Lisbon-funded PhD project at CODES by Portuguese volcanologist Carlos Rosa.

Links between CODES researchers and Japanese groups are developing. Sharon Allen was involved in a research cruise funded by Japan's Institute for Frontier Research in Earth Evolution research cruises in the West Pacific, investigating the formation of pumice breccias in submarine arc volcanoes. A CODES collaboration with India commenced in 2003 with a visit by Stuart Bull to Professor Harendra Nath Bhattacharya at Presidency College in Calcutta, and a subsequent field trip to investigate the setting and origin of the Zawar sediment-hosted zinc deposits in Rajasthan. Prof. Bhattacharya subsequently spent four months at CODES collecting analytical data for the same project. Finally, CODES maintains strong links with New Zealand geologists. Tony Crawford is collaborating with Dick Price (UWaikato) and Ian Smith (UAuckland) on the origin and significance of basalts in the Taupo Volcanic Zone, and with Dick Price on the tectonic significance of the Pentecost ophiolite in Vanuatu.

Ross Large and Professor Harendra Nath Bhattacharya (Presidency College, Calcutta)

Finances

Total Income for 2003 from all sources was $3.9 million – approximately 5% down on 2002.

University financial support increased by $160,000. Industry funding was down $430,000, due to several large AMIRA projects finishing in 2003. This trend will reverse in 2004 with three large AMIRA and linkage projects planned to commence. All other income streams remained stable.

INSTITUTIONAL SUPPORT
Research performance earnings through the Institutional Grants Scheme and the Research Training Scheme are partially returned to CODES to help support academic research salaries, general staff salaries and funding for postgraduate students. Six academic salaries and four general staff salaries in CODES are funded in this way.

NOTES TO AND FORMING PART OF THE FINANCIAL STATEMENTS FOR THE YEAR ENDED 31 DECEMBER 2003

CODES financial data and reports for 2003 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.

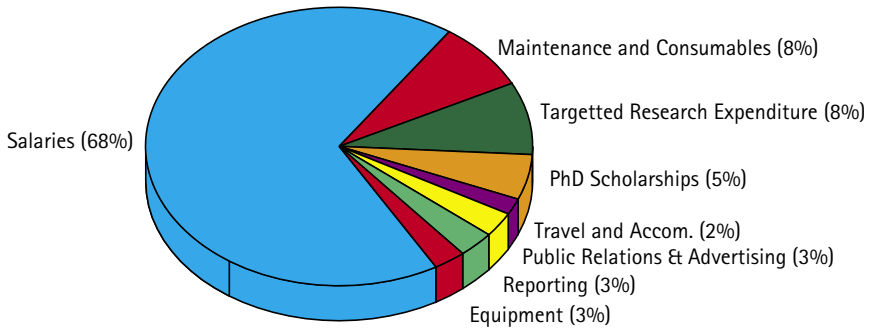
The University operates under an accrual accounting system, therefore income figures shown here represent all income 'due' (invoiced) in 2003. Expenditure figures shown represent 'actual' expenditure in 2003.

In 2003 there have been no other accounting changes, and income/expenditure categories are consistent with previous years (with the exception of some minor name changes, etc., which have been explained in the relevant Annual Report, in the notes to the Financial Statements).

SRC Grant 2003

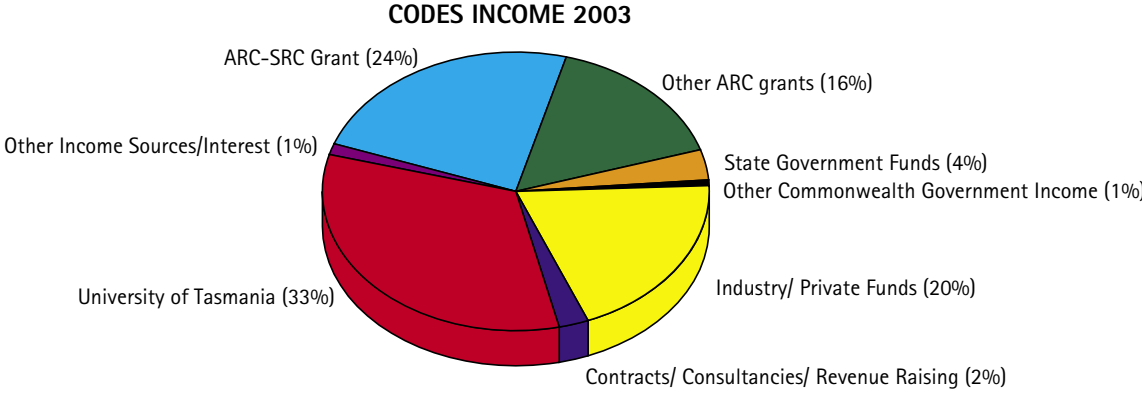
INCOME		
SRC Grant	926,393	
End of year balance brought forward from previous year	(10,372)	
Misc income from refund of expenditures	936	
Commitments brought forward from previous year (SRC a/c)	0	
Total budget		916,957
EXPENDITURE		
Salaries	(628,024)	
Equipment	(24,857)	
Travel and Accommodation	(17,343)	
Maintenance/Consumables	(73,229)	
Other		
PhD Scholarships	(48,689)	
Public Relations and Advertising	(26,361)	
Reporting	(28,085)	
Targetted Research Expenditure	(77,576)	
Total Expend		(924,164)
		(7,207)
Commitments unspent to be carried forward to next year		0
Account balance at 31.12.2003		(7,207)

CODES ARC/SRC GRANT EXPENDITURE 2003



Summary of all CODES Income in 2003

ARC – SRC Grant			926,393
Other ARC Grants			
Linkage Grants and Collaboratives	246,607		
Discovery Grants (previously called Large Grants)	176,067		
Fellowships	168,425		
Institutional Research Grants (previously called Small Grants)	34,500		
RIEF Grant	0		625,599
Other Commonwealth Government Funds			
Scholarships	0		
Miscellaneous	25,255		25,255
State Government Funds			
Tasmanian State Govt Scholarships (2003-2004)	68,000		
Directly funded research projects	70,000		
Miscellaneous	102		138,102
Local Government Funds			0
Industry/Private Funds			
AMIRA	124,720		
Industry - Other Projects	163,656		
Industry - Student Funded Projects	232,129		
CODES Industry Sponsors	135,000		
Minerals Council of Australia (MTEC)	100,000		
Miscellaneous	11,276		766,781
Contracts/Consultancies/Revenue Raising			
Short Courses	62,030		
Book Sales	26,708		
Consulting	0		
Miscellaneous	8,696		97,434
University of Tasmania – Host Institution Support			
University Support to Salaries	796,830		
General Operating Grant	138,359		
Infrastructure Grants (includes RIBG)	245,500		
University Strategic and Tasmanian Scholarship	99,051		
Faculty Scholarships	0		
Research Excellence Grant	5,000		
Performance Pay	2,000		
Study Leave	0		
Minor Works Grant	0		1,286,740
Other Income Sources/Interest			
Miscellaneous	51,207		51,207
		Grand Total	3,917,511



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Scott, R., 2003. Architecture and evolution of the Yeneena Basin, Paterson Orogen, W.A. AMIRA/ARC Project P544 Proterozoic sediment-hosted copper deposits Final Report (October 2003), 6.1-6.8.

Scott, R., 2003. Arenite-hosted copper mineralisation east of the Kafue Anticline: a comparison of tectono-stratigraphic, mineralogical, geochemical and C- and O-isotopic characteristics of small and large depsoits. AMIRA/ARC Project P544 Proterozoic sediment-hosted copper deposits Final Report (October 2003), 16b.1 - 16b.12.

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Scott, R., 2003. Stratigraphy, alteration history and copper mineralisation at Ndola West, Zambian Copperbelt. AMIRA/ARC Project P544 Proterozoic sediment-hosted copper deposits Final Report (October 2003), 16.1 - 16.20.

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PhD and Masters Theses

Agnew, M., 2003, Geology and genesis of the Lewis Ponds massive sulphide deposits NSW, Australia. University of Tasmania, Hobart, PhD thesis.
Buchanan, M., 2003, Geology and geochemistry of the Fenton Creek Zone, Canada. University of Tasmania, Hobart, MSc (Economic Geology) thesis.
Clark, D., 2003, Geology and genesis of the Mammoth copper deposit, Mt Isa Inlier, Australia. University of Tasmania, Hobart, PhD thesis.
Davies, A.G.S., 2003, Geology and genesis of the Kelian gold deposit, East Kalimantan, Indonesia. University of Tasmania, Hobart, PhD thesis, 360 p.
Italiano, P., 2003, A study of the petrology and petrophysics of the Black Swan Komatiite, Eastern Goldfields, Western Australia. University of Tasmania, Hobart, MSc (Exploration Geoscience) thesis.
Laurent, I., 2003, A geological and geophysical synthesis of the Svartliden Project, Sweden and its application in defining gold exploration targets. University of Tasmania, Hobart, MSc (Economic Geology) thesis.
Masterman, G.J., 2003, Structural and geochemical evolution of the Rosario copper-molybdenum porphyry deposit and related copper-silver veins, Collahuasi district, Northern Chile. University of Tasmania, Hobart, PhD thesis, 253 p.
Orth, K., 203, Setting of the Palaeoproterozoic Koongie Park Formation and carbonate-associated base metal mineralisation, at Koongie Park, northwestern Australia. University of Tasmania, Hobart, PhD thesis.
Wilson, A.J., 2003, The geology, genesis and exploration context of the Cadia gold-copper porphyry deposits, New South Wales, Australia. University of Tasmania, Hobart, PhD thesis, 335 p.

Appendices

CODES graduate students 2003

Name	Supervisors	Project	Industry/Govt support
BACHELOR OF SCIENCE (HONOURS)			
Darren Andrews*	M Roach	Hobart seismic microzonation	Aust. E'quake Eng. Society
John Bedi*	C Burrett, C Reid	Reservoir and source rock potential of the Upper Parmeener Supergroup – Tasmania Basin	TGMS
Mary Bessell*	G Davidson, M Roach	Groundwater and salinity of the Swan River Tertiary Basin, Tasmania	Glamorgan Spring Bay Council, Landcare groups
Joe Booth*	B Gemmell, R Sharpe	Genesis and alteration vectors around the Bimurra epithermal deposit, Drummond Basin	AMIRA project
Rebecca Carey*	J McPhie, S Allen	Volcanology of 1886 Tarawera eruption, Taupo Volcanic Zone - New Zealand	
Andy Crawford#	A Crawford	Origin of the Bond Range porphyry	
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	TGMS
David Hartney*	R Berry	Comparison of metamorphism and structure of metamorphic inliers, NE Tasmania	
John Hooper*	W Herrmann, M Solomon	Firetower Prospect geology and genesis, Tasmania	Auriongold
David Kratzmann§	J McPhie, C Gifkins	Volcanology of the Sterling Volcanics, western Tasmania	TGMS
Paul Lane*	C Burrett, M Roach	The Longford Sub-basin architecture and economic potential based on seismic, potential field and drill-hole data	Great Southland Minerals 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	Geology and genesis of a Pb-Zn system in the Zeehan area	Great Southland Minerals
Sophie Osterloh*	G Davidson, W Herrmann	Origin of the Maydena silica flour and bedrock silicification, Tasmania	Macdonald Mining and Sons
Monica Osuchowski*	G Davidson, M Roach, J Reid	Land stability of the Knights Creek catchments and control upon the turbidity of the Knights Creek Reservoir	Hobart Water Governor's Env Schol TGMS
Cynthia Palfreyman*	G Davidson, M Roach, J Reid	Hydrogeology of the Dolphin Sands sand spit, Tasmania	Glamorgan Spring Bay Council, Landcare groups
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
Anthia Pittas	B Gemmell	Geology and genesis of the Esperanza South Copper mineralisation in the Gunpowder area, Qld	Western Metals
Lee Robson#	M Roach	A remote sensing and geophysical investigation of the central midlands, Tasmania	TGMS
Aaron Scollard§	M Roach	Geophysical investigations of the D'Entrecasteaux Channel	
Brett Thomas#	A Tunks	Geology of the Minjar Project, Western Australia	
Luke Wallace*	D Cooke, G Davidson, J Reid	Aqueous geochemistry of the constructed wetlands treating AMD, Rosebery, Tasmania	Pasminco Rosebery
Ian Wilson#	J Reid	HEM data levelling – The Clump, NW Tasmania	TGMS

Name	Supervisors	Project	Industry/Govt support
GRADUATE DIPLOMA OF SCIENCE			
Stuart Dawes*	P McGoldrick	Morphology and compositional variation of alluvial gold from Tobacco Creek, northeastern Tasmania	
MASTER OF ECONOMIC GEOLOGY			
Leon Bagas	B Gemmell	Geology of the Paterson Orogen	GSWA
Julian Bartlett#	W Herrmann	Alteration within the Barkly River greenstones, Whisky Knob Window, E Vic	
Michael Buchanan*	B Gemmell, R Berry	Geology, geochemistry and genesis of the Harmin/Fenton Zone VHMS prospects, Snow Lake, Manitoba, Canada	Hudson Bay Exploration, Anglo American Exploration
Brett Butlin	A Tunks		Barrick Gold of Australia
Adrian Byass		Course work masters program	Siberia Gold
Richard Cotton	B Gemmell, R Berry	Geology of the Ross alluvial Au deposit, New Zealand	L&M Mining
Andrew Dacey		Course work masters program	Consultant
Adrian Fabris			PIRSA
Simon Henderson*		Coursework masters program	
Alan Ignacio	D Cooke	Boyongang porphyry system	AngloAmerican
Anthony Johnston			Geological Survey of NSW
Lennard Kolff§	A Tunks	Seemandoo iron deposit, Guinea, West Africa	Rio Tinto
Ian Laurent*	M Roach	Geophysical interpretation of the Svartliden Au deposit, Sweden	Viking Gold
Steven Lewis	R Large	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
Michael Priestly	R Scott	Perseverance gold prospect, Cobar, NSW	Rio Tinto
Steven Richardson	B Gemmell	Geology and geochemistry of the Que River footwall alteration zone, W Tas	Consultant
Nalin Shah	G Davidson	Geology and dating of the Mangalwar Complex, with reference to Rampura Agucha, Rajasthan, India	BHP Billiton
Spencer Summers	K Zaw	Sekatak project, northeast Kalimantan, Indonesia	Indochina Goldfields, Jakarta
MASTER OF EXPLORATION GEOSCIENCE			
Albert Chong§	B Gemmell, R Berry	Geology, mineralisation, metal distribution, and genesis of the polymetallic Ridge and Marshall Zones, Battle Lake Camp, Vancouver Island, Canada	Boliden-Westmin
Matthew Hope#	P McGoldrick, S Bull	Geology of the Mount Kirk Formation, Norseman, WA	Central Norseman Gold
Terry Hoschke§	R Large, M Roach	Geophysical signature of Au-Cu porphyry systems	Normandy
Pamela Italiano*	M Roach, B Gemmell	A study of the Petrology and Petrophysics of the Black Swan komatiite, eastern Goldfields, Western Australia	Mining Project Investors

CODES graduate students 2003

Name	Supervisors	Project	Industry/Govt support
Kamonporn Kromkhun	K Zaw, D Cooke	Geological setting, alteration, mineral paragenesis, and nature of ore fluids and 'H' zone, Chatree gold deposit, Central Thailand	
Felipe Urzua	A Tunks	Geology of the Escondida District, Chile	Anaconda and BHP Billiton

DOCTOR OF PHILOSOPHY

Darren Andrews§	J Reid, M Roach	Time-lapse geophysical monitoring of acid mine drainage at Savage River mine, NW Tasmania	Australian Bulk Minerals and DPIWE
Michael Agnew*	S.Bull, R Large	Geology and genesis of the Lewis Ponds massive sulphide deposits NSW, Australia	Triorigin
Michael Baker§	A Crawford, R Berry	Geochemistry of the mafic rocks in the Precambrian Georgetown Block, North Queensland	
Bryan Bowden	G Davidson, R Large	Iron Oxide Copper-Gold related alteration history of the Mt Woods Inlier, South Australia, with special emphasis on the Prominent Hill prospect (Minotaur- BHP Billiton)	Minotaur Resources, Goldstream, PIRSA, Geoscience Australia
David Braxton§	D Cooke, A Rae	Origin of the Boyongang porphyry Cu-Au system, Philippines	Anglo American
Katharine Bull	J McPhie, A Crawford	Facies architecture, geochemistry and tectonic implications of the Central Lachlan Fold Belt, NSW	GSNSW
James Cannell	D Cooke, M Solomon, J Walshe, CSIRO	El Teniente porphyry Cu-Mo deposit, Chile: geology, geochemistry and genesis	Codelco
Dene Carroll	A Crawford, S Meffre	Tectono-magmatic evolution of eastern Viti Levu, Fiji	
Darryl Clark*	B Gemmell, P McGoldrick	Geology and genesis of the Mammoth Copper Deposit, Mt Isa Inlier, Australia	Western Metals
Mawson Croaker	D Selley, P McGoldrick	Geology and genesis of the Nkana copper deposit, Zambia	AMIRA P544
Paul Cromie§	K Zaw, N White	Geological setting, geochemistry and genesis of the Sepon Cu-Au deposit, Laos	Oxiana Ltd
Paul Davidson#	V Kamenetsky, A Crawford	Melt inclusions in porphyry Cu-Au-hosting magmatic systems	
Andrew Davies*	D Cooke, B Gemmell	Geology and genesis of the Kelian gold deposit, East Kalimantan, Indonesia	PT Kelian Equatorial Mining, Rio Tinto Indonesia
Kim Denwer§	R Large, W Herrmann, K Corbett	Genesis of the Mount Lyell deposits, Tasmania	Tas Govt Mining Scholarship
Greg Ebsworth	J McPhie, A Crawford, R Large	Tyndall Group, Mount Read Volcanics, W Tasmania	Tas Govt Mining Scholarship
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)	Pasminco
Andrew Fitzpatrick	M Roach, J Reid	Scale-dependent electrical properties of sulfide rocks	Normandy, Western Metals, Rio Tinto, MIM, ARC
Peter Frikken#	D Cooke, P Hollings J Walshe (CSIRO)	Breccia-hosted Cu-Mo mineralisaton at Rio Blanco, Chile	Codelco
Russell Fulton	B Gemmell, R Berry	Geology and geochemistry of the hangingwall argillite, Greens Creek VHMS deposit, Alaska: Implications for ore genesis and exploration	Kennecott Greens Creek Mining Company
Owen Hatton#	G Davidson, S Bull	Basin configuration, sedimentology and volcanology of the Toole Creek Volcanics, Mount Isa region, Qld	BHP Billiton
Ben Jones	R Large, A Crawford, N White	Antapaccay porphyry Cu-Au system, Peru	BHP Billiton

Name	Supervisors	Project	Industry/Govt support
Maya Kamenetsky	A Crawford, L Danyushevsky	Primary melts of kimberlites, and Emeishan flood basalts, China	
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	
Steven Lewis	G Davidson, R Berry	Hydrothermal processes and facies in slow spread oceanic crust – Macquarie Island	ASAC Grant
Wallace MacKay	D Selley, S Bull	Sediment-hosted copper, Stuart Shelf, South Australia	AMIRA P544
Rod Maier§	P McGoldrick, R Large	Pyrite and base metal trace element haloes in the northern Australian Zn-Pb-Ag deposits	Xstrata and Anglo American
Neil Martin	R Large, S Bull	Origin of the Rosebery VHMS deposit, W Tasmania	Pasminco
Glen Masterman*	D Cooke, R Berry	Genetic relationships between the Rosario porphyry Cu-Mo deposits and the high-sulfidation Cu-Au veins, Collahuasi district, Chile.	Compania Minera Dona Ines De Collahuasi
Karin Orth*	J McPhie, P McGoldrick	Geology and mineralisation of the Koongie Park Pb-Zn deposit, WA	
Nicki Pollington	P Mc Goldrick, S Bull	Sedimentology mineral paragenesis and geochemistry of the Konkola North copper deposit, Zambia	AMIRA P544
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	Heat and fluid flow simulations in submarine terrains	
Blackwell Singoyi§	K Zaw, R Large, L Danyushevsky	Hydrothermal magnetite textures and trace element chemistry	
Craig Stegman	R Large, R Scott	Geochemistry and structure of gold – base metal mineralisation in the Cobar goldfield, NSW	Rio Tinto
Andrew Stewart#	J McPhie	Facies architecture of an arc volcanic island - Milos, Greece	
Sofia Tetroeva§	L Danyushevsky, A Crawford	Petrogenesis of adakitic lavas in modern SW Pacific settings, particularly in Fiji	
Tony Webster	R Berry, R Large	Structural evolution of the Broken Hill Pb-Zn-Ag deposit, NSW	
Alan Wilson*	D Cooke, R Large, J Holliday	The geology, genesis and exploration context of the Cadia gold-copper porphyry deposits, NSW, Australia	Newmont
Andrew Wurst	B Gemmell, D Cooke	Mineralisation and alteration of the Kerikil and Serujan Lode systems, Mt Muro, Indonesia: implications for ore genesis and exploration	PT Indo Muro Kencana, AMIRA P588

Fellowships: Queen Elizabeth II/Australian Post-doctoral /Industry 2003

Principal Investigator	Project	Period	Total ARC Funds
D Kamenetsky	Novel applications of melt inclusion studies: insights into the magmatic history of porphyry Cu-Au deposits and provenance of volcaniclastic sediments.	1999-2003	$313,970
S Allen	Experimental simulations and textural analysis of submarine volcaniclastic mass flow deposits that result from large scale eruption and failure events	2001-2003	$183,261

ARC Linkage Projects: APA-I 2003

Investigators	Project	Partners	Period	ARC Funding for period	Industry Funding for period
G Davidson, D Cooke, J Yang (PhD project: L Evans)	Ground waters and fluid flow predictive modelling for management after mine closure	Pasminco	2001-2004	$69,882	$15,000
JB Gemmell	Geologic, genetic and exploration implications of syndeformational, structurally-controlled, sediment-hosted copper deposits: investigation of the Mount Oxide deposit, Queeensland	Western Metals Limited	2003-2006	$69,099	$30,000

AMIRA/ARC (Linkage) Projects 2003

Investigators	Project	Partners	Period	ARC Funding for period	Industry Funding for period
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	2000-2003	$393,000	$1,092,000

ARC (Linkage) Projects: Large Collaborative Projects 2003

Investigators	Project	Partners	Period	ARC Funding for period	Industry Funding for period
G Davidson, M Norman	What controls trace element levels in ore sulfides? A LA-ICPMS perspective	Anglo American; AngloGold; BHP Billiton; Newcrest; Newmont; Placer Dome	2003-2004	-	$150,000

ARC (LIEF) Projects 2003

Investigators	Project	Partners	Period	ARC Funding for period
A Crawford, R Large, R Berry, L Danyushevsky, G Davidson, B Gemmell, V Kamenetsky	An electron probe microanalysis system to replace an existing 14-year-old instrument		2003	$750,000

ARC Discovery Grants 2003

Investigators	Project	Partners	Period	ARC Funding for period
L Danyushevsky	Role of melting of oceanic crust		2003-2005	$110,000
J McPhie	Volcanology of voluminous felsic lava		2003-2004	$96,000
A Crawford	Tectonic paradox of the eastern margin of the Australian Plate, 120-45 Ma		2003-2005	$224,000

Other Research Grants 2003

Investigators	Project	Funding Body	Partners	Period	Funding for period
D Cooke, A Rae (PhD project: D Braxton)	Boyongang Porphyry Copper-Gold Deposit, Surigao, Philippines	Anglo American		2003-2005	$113,688
W Herrmann, R Large	Sunrise-Cleo Sulfide Trace-element, SWIR and volcanic facies vectors	AngloGold		2003-2004	$56,500
A Tunks (Masters project: F Urzua)	Geology of the Escondida District, Chile	BHP Minerals		2002-2003	$190,000
A Tunks	Abosso Goldfields Mine	Gold Fields of South Africa		2002-2003	$54,000
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	$131,300
K Zaw, N White, C Ryan (PhD project: P Cromie)	Geological setting, geochemistry and genesis of the Sepon mineral district, Laos	Oxiana Resources NL		2003-2005	$44,100
W Herrmann, R Large (MSc project: S Lewis)	Structure and lithostratigraphy of the Hard Prospect, Little Broken Hill, New South Wales	Perilya Broken Hill Limited		2003	$7000
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	$17,850
A Crawford	Ancient oceanic crust in Northeastern Australia: keystone in understanding breakup of the Rodinia supercontinent and evidence for Proterozoic plate tectonics	University of Tasmania – Institutional Research Grant		2003	$15,000
C Gifkins, W Herrmann	An interactive volcanic facies and alteration map of the Mount Read Volcanics, Western Tasmania	Mineral Resources Tasmania	pmd*CRC	2003	$70,000
R Large (PhD project: B Jones)	Antapaccay porphyry Cu-Au system, Peru	BHP Billiton		2001-2003	$47,400
P McGoldrick (PhD project: R Maier)	Pyrite and base metal trace element haloes in the northern Australian Zn-Pb-Ag deposits	Anglo American		2003	$7,000
J Reid	Electrical conductivity of sea ice	Australian Antarctic Science		2003	$1,931
G Davidson	GIS Macquarie Island	Australian Antarctic Science		2003	$3,219

Collaborations with CODES 2003

INTERNATIONAL INSTITUTIONS

Institution	Researcher	CODES collaborators	Project
Chinese Academy of Geological Sciences, Beijing	H Zhengqian	Bruce Gemmell, Ross Large, Mike Solomon, Khin Zaw, Jocelyn McPhie	The nature, diversity and genesis of ancient massive sulfide Cu-Pb-Zn-Ag-Au deposits in volcanic arc settings
Colorado School of Mines	Murray Hitzman, David Broughton	Peter McGoldrick, Stuart Bull, Dave Selley, Rob Scott, David Cooke, Michael Blake	Proterozoic sediment-hosted copper deposits
Colorado School of Mines	Jeff Hedenquist	David Cooke, Bruce Gemmell, Cari Deyell, Noel White	Transitions and zoning in porphyry-epithermal districts: indicators, discriminators and vectors
Colorado State University	Holly Stein	David Cooke, James Cannell, Alan Wilson	Giant porphyry Cu deposits
Department of Mineral Resources, Thailand	S Khositanont, T Rodmanee, P Chaodumrong	Khin Zaw, Sebastien Meffre, Wally Herrmann, Anthony Harris	Geochronology and metallogenesis of the Loei belt
DNRE, Bathurst Canada	S McCutcheon	Ross Large, Bruce Gemmell, Garry Davidson	Global comparisons of VHMS deposits
Duke University	Jeff Karson, P Rivazzigno	Garry Davidson, Ron Berry	Sulfur geochemistry of hydrothermally altered volcanic terrains
Freiburg University	Peter Herzig	Bruce Gemmell	Studies of VHMS-related alteration: development of geochemical and mineralogical vectors to mineralisation
Freiburg University	Peter Herzig	Bruce Gemmell	Subaqueous epithermal mineralisation, Conical Seamount, Tabar-Feni island chain, Papua New Guinea
Freiburg University	Peter Herzig	Ross Large, Bruce Gemmell, Garry Davidson	Global comparisons of VHMS deposits
Freiburg University	Thomas Monecke, Peter Herzig	Bruce Gemmell	Waterloo VHMS prospect, Mount Windsor
GEODE, Royal Holloway College, London	Derek Blundell	Ross Large, Bruce Gemmell, Garry Davidson	Global comparisons of VHMS deposits
Geological Survey of Canada	Mark Hannington, Ian Jonasson	Bruce Gemmell	Subaqueous epithermal mineralisation, Conical Seamount, Tabar-Feni island chain, Papua New Guinea
Geological Survey of Canada	Mark Hannington	Bruce Gemmell	Kidd Creek argillite sulfur isotope study
Geological Survey of Canada	Jan Peter	Bruce Gemmell, Dima Kamenetsky, Khin Zaw	Active base and precious metal-rich massive sulfide deposition associated with submarine volcanism
Geological Survey of Canada	Ross Sherlock	Cari Deyell	Geology and mineralisation of banded iron formations in Nunavut, Canada
Geological Survey of Sweden	Magnus Ripa	Stuart Bull	Regional stratigraphy, basin evolution and setting of Zn-Pb-Cu-Ag-Au deposits in Bergslagen district, Sweden
Geomarine Research (New Zealancd)	Bruce Hayward	Sharon Allen	Facies characteristics of volcaniclastic mass-flow deposits
Institute for Frontier Research on Earth Evolution (Japan)	Yoshihiko Tamura	Sharon Allen	Origin and significance of giant pumice breccias in submarine arc volcanoes
Institute of Geology and Mineral Exploration IGME, Greece	Georges Vougioukalakis	Jocelyn McPhie	Volcanic geology of Milos, Greece
Institute of Mineralogy, Miass, Russia	Valeriy Masslenikov	Bruce Gemmell, Ross Large, Mike Solomon, Khin Zaw, Jocelyn McPhie	The nature, diversity and genesis of ancient massive sulfide Cu-Pb-Zn-Ag-Au deposits in volcanic arc settings

Institute of Mineralogy, Miass, Russia	Valeriy Masslenikov	Ross Large, Bruce Gemmell, Garry Davidson	Global comparisons of VHMS deposits
Institution	**Researcher**	**CODES collaborators**	**Project**
Instituto Geologica Minerio (IGM), Lisbon	Luis Martins	Jocelyn McPhie	Character and setting of volcanic host successions to massive sulfide deposits in the Iberian Pyrite Belt, Portugal
Instituto Geologica Minerio (IGM), Lisbon	Carlos Inverno	Bruce Gemmell, Ross Large, Mike Solomon, Khin Zaw, Jocelyn McPhie	The nature, diversity and genesis of ancient massive sulfide Cu-Pb-Zn-Ag-Au deposits in volcanic arc settings
Instituto Geologico y Minero de Espana, Salamanca	F Tornos, C Quesada	Bruce Gemmell, Ross Large, Mike Solomon, Khin Zaw, Jocelyn McPhie	The nature, diversity and genesis of ancient massive sulfide Cu-Pb-Zn-Ag-Au deposits in volcanic arc settings
Instituto Tecnologica Geominero de Espana	F Tornos	Ross Large, Bruce Gemmell, Garry Davidson	Global comparisons of VHMS deposits
Istanbul Technical University	Namik Cagatay	Ross Large, Bruce Gemmell, Garry Davidson	Global comparisons of VHMS deposits
Johns Hopkins University	Grant Garven, Mike Simms	Ross Large, David Cooke, Stuart Bull, Peter McGoldrick, Rob Scott, Michael Blake	Fluid flow modelling in sedimentary basins
Johns Hopkins University	Grant Garven	Ross Large, Jocelyn McPhie, Christian Schardt	Controls on hydrothermal fluid migration by volcanic facies architecture: implications for massive sulfide deposit formation
Lakehead University, Canada	Peter Hollings	David Cooke	Giant porphyry Cu deposits
Laurentian University, Canada	Harold Gibson	Ross Large, Bruce Gemmell, Garry Davidson	Global comparisons of VHMS deposits
Lulea University, Sweden	Rod Allen	Stuart Bull	Regional stratigraphy, basin evolution and setting of Zn-Pb-Cu-Ag-Au deposits in Bergslagen district, Sweden
Lulea University, Sweden	Rod Allen, P Weihed	Ross Large, Bruce Gemmell, Garry Davidson	Global comparisons of VHMS deposits
Mineral Deposit Research Unit, UBC	Dick Tosdal	Cari Deyell, David Cooke	Geochemistry of alkalic porphyry deposits
Mineral Deposit Research Unit, UBC	Greg Dipple	Cari Deyell	Geochemistry and mineralogy of high sulfidation epithermal systems
Muroran Institute of Technology (Japan)	Yoshihiko Goto	Jocelyn McPhie	Propagation mechanisms of pillow and sheet lavas
Nanjing University	Gu Lianxing, Ni Pie	Bruce Gemmell, Ross Large, Mike Solomon, Khin Zaw, Jocelyn McPhie	The nature, diversity and genesis of ancient massive sulfide Cu-Pb-Zn-Ag-Au deposits in volcanic arc settings
Natural History Museum, UK	Richard Herrington	Ross Large, Bruce Gemmell, Garry Davidson	Global comparisons of VHMS deposits
Niigata University (Japan)	Norie Fujibayashi, Katsuki Kurokawa	Sharon Allen	Characteristics and origin of pumiceous mass-flow deposits in submarine volcanic successions
Niigata University (Japan)	Norie Fujibayashi, Kenta Kobayashi	Sharon Allen	Structure and emplacement mechanisms of submarine rhyolitic lavas
Porto	O Gaspar	Bruce Gemmell, Ross Large, Mike Solomon, Khin Zaw, Jocelyn McPhie	The nature, diversity and genesis of ancient massive sulfide Cu-Pb-Zn-Ag-Au deposits in volcanic arc settings
Queens University	Alan Clark	David Cooke	Giant porphyry Cu deposits
Simon Fraser University	Derek Thorkelson	Garry Davidson, Ron Berry	Cu-Au-Fe oxide geology and geochemistry
Smithsonian Institution (USA)	Richard Fiske	Sharon Allen	Origin and significance of giant pumice breccias in submarine arc volcanoes

United States Geological Survey	Robert Rye	Cari Deyell, David Cooke, David Braxton	Stable isotope geochemistry of epithermal and porphyry deposits
University of Antofagasta, Chile	Thomas Bissig	Cari Deyell	High sulfidation epithermal ore deposits
University of Arizona	Mark Barton	Garry Davidson, Wally Herrmann, Mike Solomon, Michael Blake, Ross Large	Stable and radiogenic isotope applications to ranking prospects in volcanic terrains
University of Auckland	Stuart Simmons	Jocelyn McPhie, Bruce Gemmell, Robina Sharpe, Wally Herrmann, Michael Blake, Rob Scott	Epithermal Au-Ag deposits: geological, geochemical and isotopic vectors to target major deposits
University of Columbia-Missouri	T Lyons	Peter McGoldrick, Stuart Bull, Ross Large	Microbes and the origin of Proterozoic Sedex Zn-Pb-Ag deposits
University of Leeds	Bruce Yardley	David Cooke	Fluid mixing in hydrothermal systems
University of Lisbon	Jorge Relvas	Jocelyn McPhie	Character and setting of volcanic host successions to massive sulfide deposits in the Iberian Pyrite Belt, Portugal
University of Michigan	J Alt	Garry Davidson, Ron Berry	Sulfur geochemistry of hydrothermally altered volcanic terrains
University of Southampton	Dick Teagle	Garry Davidson, Ron Berry	Sulfur geochemistry of hydrothermally altered volcanic terrains
University of Toronto	Steve Scott	Bruce Gemmell, Robina Sharpe, Dima Kamenetsky, Khin Zaw	Active base and precious metal-rich massive sulfide deposition associated with submarine volcanism
University of Utah	Erich Peterson	David Cooke, David Braxton	Mineralogy of porphyry deposits
University of Windsor	Jianwen Yang	Stuart Bull, David Cooke, Ross Large	Nature, timing and significance of fluid flow in Proterozoic sedimentary basins, and relationship to stratiform Zn-Pb-Ag ore formation
University of Geosciences, Wuhan	Xinbiao Lu	Bruce Gemmell, Ross Large, Khin Zaw, Mike Solomon	Stratabound base-metal deposits in China

NATIONAL INSTITUTIONS

Institution	Researcher	CODES collaborators	Project
Australian Museum, Sydney	Lin Sutherland	Khin Zaw, Fernando Della Pasqua	Fluid/melt inclusion constraints on genesis of sapphires in NE Tasmania
Australian National University	W Sun, V Bennett, R Arculus and S Eggins	Bruce Gemmell, Dima Kamenetsky, Khin Zaw, Mike Solomon, Ross Large	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.
Central Science Laboratory, University of Tasmania	David Steele	Dima Kamenetsky, Dima Kamenetsky, Tony Crawford	Volatiles elements and chalcophile elements in magmas from different supra-subduction zone tectonic settings
Central Science Laboratory, University of Tasmania	David Steele	Dima Kamenetsky, Anthony Harris, Tony Crawford, David Cooke, Leonid Danyushevsky	Volatiles and chalcophile elements in porphyry Cu-Au-hosting magmas
Central Science Laboratory, University of Tasmania	David Steele	Leonid Danyushevsky, P Robinson, M Norman, Sebastien Meffre, Ron Berry, Andrew Rae, Garry Davidson	Development of analytical techniques
Consultant	Dr S Garwin	Dima Kamenetsky, Anthony Harris, Tony Crawford, David Cooke, Leonid Danyushevsky	Volatiles and chalcophile elements in porphyry Cu-Au-hosting magmas

Consultant	Carol Simpson	Tony Crawford, David Cooke, Wally Herrmann, Sebastien Meffre, Rob Scott, Jocelyn McPhie	Origin and metallogenesis of Ordovician volcanic belts in central western New South Wales
Consultant	Noel White	Dima Kamenetsky, Anthony Harris, Tony Crawford, David Cooke, Leonid Danyushevsky	Volatiles and chalcophile elements in porphyry Cu-Au-hosting magmas
CSIRO E&M	Ray Binns, Tim McConaghy	Bruce Gemmell, Dima Kamenetsky, Khin Zaw	Active base and precious metal-rich massive sulfide deposition associated with submarine volcanism
CSIRO E&M	John Walshe	David Cooke	Giant porphyry Cu deposits
CSIRO E&M	Chris Ryan	David Cooke, Cari Deyell, Anthony Harris, Andrew Rae, Andrew Tunks, Noel White	Fluid chemistry in porphyry copper-gold-molybdenum deposits
CSIRO E&M	Chris Ryan	David Cooke	Fluid mixing in hydrothermal systems
CSIRO E&M	Chris Ryan and Esme van Achterbergh	Dima Kamenetsky, Anthony Harris, Tony Crawford, David Cooke, Leonid Danyushevsky	Volatiles and chalcophile elements in porphyry Cu-Au-hosting magmas
Geological Survey of NSW	Simone Meakin, Roger Cameron	Jocelyn McPhie	Early Devonian volcanic successions in the Lachlan Fold Belt
Geoscience Australia	David Huston	Garry Davidson, Wally Herrmann, Mike Solomon, Michael Blake, Ross Large	Stable and radiogenic isotope applications to ranking prospects in volcanic terrains
Geoscience Australia	Terry Mernagh	Dima Kamenetsky, Anthony Harris, Tony Crawford, David Cooke, Leonid Danyushevsky	Volatiles and chalcophile elements in porphyry Cu-Au hosting magmas
Geoscience Australia	Peter Southgate	Ross Large, Stuart Bull	Fluid flow in the Mt Isa Basin
Geoscience Australia	Roger Skirrow, E Bastrakov	Garry Davidson, Ron Berry, David Cooke	Cu-Au-Fe oxide geology and geochemistry
GSNSW	Dick Glen, Ian Percival, J Watkins, Larry Barron	Tony Crawford, David Cooke, Wally Herrmann, Sebastien Meffre, Rob Scott, Jocelyn McPhie	Origin and metallogenesis of Ordovician volcanic belts in central western New South Wales
James Cook University	Bin Fu, Nick Oliver, Pat Williams	David Cooke	Fluid mixing in hydrothermal systems
James Cook University	T Baker, M Norman, N Oliver, J Hunt	Garry Davidson, Ron Berry, David Cooke	Cu-Au-Fe oxide geology and geochemistry
Macquarie University	Mark Lackie	Jocelyn McPhie, Fernando Della Pasqua	Volcanology and source-vent locations of voluminous felsic lavas: Mesoproterozoic Gawler Range Volcanics in South Australia
Mineral Resources Tasmania	Tony Brown	Garry Davidson, Ron Berry	Sulfur geochemistry of hydrothermally altered volcanic terrains
Mineral Resources Tasmania	Geoff Green	Cathryn Gifkins, Wally Herrmann, Jocelyn McPhie, Bronwyn Kimber	Distribution of volcanic centres, alterations zones and ore deposits in the Mount Read Volcanics, western Tasmania
Mineral Resources Tasmania	D Green, Geoff Green, M McLenaghan, J Taheri	Garry Davidson, Wally Herrmann, Mike Solomon, Michael Blake, Ross Large	Stable and radiogenic isotope applications to ranking prospects in volcanic terrains
MODA	Gary McArthur, Steve Richardson	Ross Large, Michael Blake, Bruce Gemmell	Computer-based 3D model of Hellyer VHMS deposit
Monash University	David Giles	Tony Crawford	The northern end of the Tasman Line
Monash University	Ray Cas	David Cooke, Jocelyn McPhie, Cathryn Gifkins	Mineralisation in breccias

Primary Industries and Resources, South Australia	Paul Heithersay, M Schwarz	Garry Davidson, Ron Berry, David Cooke	Cu-Au-Fe oxide geology and geochemistry
Primary Industries and Resources, South Australia	Michael Schwartz	Jocelyn McPhie, Fernando Della Pasqua	Volcanology and source-vent locations of voluminous felsic lavas: Mesoproterozoic Gawler Range Volcanics in South Australia
PRISE ANU	M Fanning	Tony Crawford, David Cooke, Wally Herrmann, Sebastien Meffre, Rob Scott, Jocelyn McPhie	Origin and metallogenesis of Ordovician volcanic belts in central western New South Wales
Research School of Earth Sciences, ANU	Marc Norman	Jocelyn McPhie	Zircon dating of young arc volcanic units on Milos, Greece
Research School of Earth Sciences, ANU	Marc Norman	Garry Davidson, Andrew Rae, Ross Large, Peter McGoldrick	Trace element analysis of sulfides by LA-ICPMS: new applications for exploration vector geochemistry
Research School of Earth Sciences, ANU	Marc Norman	Garry Davidson, Ron Berry, David Cooke	Cu-Au-Fe oxide geology and geochemistry
University of Adelaide	K Barovich	Garry Davidson, Ron Berry, David Cooke	Cu-Au-Fe oxide geology and geochemistry
University of Melbourne	Rick Squire	David Cooke, Jocelyn McPhie, Cathryn Gifkins	Mineralisation in breccias
University of Sydney	Eleanor Bruce	Khin Zaw, Clive Burrett, Ron Berry	Tectonics and metallogenesis of South China

Visitors to CODES 2003

ACADEMIC (INTERNATIONAL)

Bhattacharya	Harendra Nath	Professor	Presidency College, Calcutta, India	Collaborative work with S Bull and P McGoldrick	December-March
Broughton	David	PhD student	Colorado School of Mines, USA	AMIRA P544 meeting	July
Coggon	Roz	PhD student	Southampton Oceanography Centre, University of Southampton, UK	Collaborative work with G Davidson	February
Garven	Grant	Professor	Johns Hopkins University, USA	Collaborative work with R Large	July
Goto	Yoshi	Lecturer	Tohoku University, Japan	Collaborative work with J McPhie	February-March
Herrington	Richard	Research Leader	The Natural History Museum, London, UK	Presentation to CODES staff	January
Hitzman	Murray	Professor	Colorado School of Mines, USA	AMIRA P544 meeting	July
James	Noel	Professor	Queen's University, Canada	Cool water carbonates	February
Kemp	Anthony	Postdoctoral Fellow	University of Bristol, UK	Collaborative work with T Crawford	January
Lui	Xianbio	Associate Professor	China University of Earth Resources	Skarn and porphyry-type ore deposits	2002 – January 2003
Maclennan	John	Postdoctoral Fellow	Institut de Physique du Globe, Paris, France	Melt inclusion studies with L Danyushevsky	October
Pelletia	Bernard	Director of Research	IRD, France (New Cal)	Collaborative work with T Crawford	January
Simmons	Stuart	Senior Lecturer	University of Auckland, New Zealand	Collaborative work with B Gemmell	December
Teagle	Damon	Lecturer	School of Ocean and Earth Science, University of Southampton, UK	Collaborative work with G Davidson	February
Yang	Jianwen	Professor	University of Windsor, Canada	Collaborative work	various

ACADEMIC (NATIONAL)

Baker	Tim	Lecturer	Economic Geology Research Unit, James Cook University	Ore Deposit Geochemistry, Hydrology & Geochronology short course	May
Colleson	Ken	Professor	University of Queensland	Meeting with CODES staff	March
Dawson	Galvin	Student	Centre for Global Metallurgy, University of Western Australia	AMIRA P544 meeting	July
Groves	David	Director, CGM	University of Western Australia	CODES Advisory Board, Science Planning Meeting and other meetings.	various
Jackson	Simon	Senior Lecturer	GEMOC, Macquarie University	Collaborative work	February
Maas	Roland	Research Fellow	University of Melbourne	Collaborative work with D Kamenetsky	various
Mustard	Roger		James Cook University	Collaborative work with D Kamenetsky	November
Norman	Marc	Senior Research Fellow	Research School of Earth Sciences, ANU	Collaborative work with G Davidson et al	December
Oliver	Nick	Professor	Economic Geology Research Unit, James Cook University	Ore Deposit Geochemistry, Hydrology & Geochronology short course	May
Reid	Jim	Dean, Faculty of Science, Engineering & Technology	University of Tasmania	CODES Advisory Board	April
Robertson	Bruce		University of Western Australia	Ore Deposit Geochemistry, Hydrology & Geochronology short course	May
Sie	Patricia	PhD student	Monash University	Collaborative work with L Danyushevsky and T Crawford	various

GOVERNMENT					
Bagas	Leon		Geological Survey of Western Australia	Ore Deposit Geochemistry, Hydrology & Geochronology short course	May
Brown	Tony	Director	Minerals Resources Tasmania	CODES Advisory Board, other meetings	April
Carr	Graham	Deputy Chief	CSIRO E&M	Ore Deposit Geochemistry, Hydrology & Geochronology short course	May
Fabris	Adrian		PIRSA - Geological Survey	Ore Deposit Geochemistry, Hydrology & Geochronology short course	May
Green	Geoff		Minerals Resources Tasmania	Collaborative work	various
Green	David		Minerals Resources Tasmania	Collaborative work	various
Heithersay	Paul		Geological Survey, PIRSA	Science Planning Panel, AMIRA P544 meeting	various
Hodgman	Will		Government of Tasmania	Familiarisation visit	March
Huston	Dave	Project Leader	Geoscience Australia	Ore Deposit Geochemistry, Hydrology & Geochronology short course, collaborative work	various
Johnston	Anthony		Geological Survey of NSW	Ore Deposit Geochemistry, Hydrology & Geochronology short course	May
Khositanont	Somboon	Senior Geologist	Department of Mineral Resources, Bangkok, Thailand	Collaborative work	November-December
McGauran	Peter	Commonwealth Minister for Science	Australian Federal Government	Familiarisation visit	August
Mernagh	Terry	Senior Research Scientist	Geoscience Australia	Collaborative work	August
Pigram	Chris	Chief of Minerals and Geohazards Division	Geoscience Australia	CODES Advisory Board	April
Rice	Peter		Mineral Resources Tasmania	Collaborative work	March
Ryan	Chris		CSIRO E&M	Collaborative work	November
Skirrow	Roger	Senior Research Scientist	Geoscience Australia	Collaborative work with G Davidson	March
Walshe	John	Senior Research Scientist	CSIRO	Collaborative work with D Cooke	various
Wyborn	Lesley	Group Leader, Geochemistry & Metallogeny	Geoscience Australia	Ore Deposit Geochemistry, Hydrology & Geochronology short course	May
INDUSTRY					
Andrews	Dave		Rio Tinto	AMIRA P544 meeting	July
Blevin	Phillip	Consultant		Ore Deposit Geochemistry, Hydrology & Geochronology short course	May
Brand	Nigel	Senior Geochemist	Anglo American	Collaborative work	various
Broadbent	Graeme	Exploration Manager	Rio Tinto	Collaborative work	March
Butlin	Brett		Barrick Gold of Australia	Ore Deposit Geochemistry, Hydrology & Geochronology short course	May
Clarke	Darryl		AngloGold	Collaborative work	December
First	David		BHP Billiton	Collaborative work	December
Goode	Alan	Research Director	AMIRA	CODES Advisory Board, Science Planning Panel, AMIRA meetings	various
Griggs	Darren		Teck Cominco	AMIRA P544 meeting	July

Hannan	Keith		Xstrata (formerly MIM Exploration)	Science Planning Panel	April
Hayward	Nicholas		WMC Resources Ltd	AMIRA P544 meeting	July
Holliday	John	Exploration Manager	Newcrest Mining	Science Planning Panel	April
Hronsky	Jon	Exploration Manager	WMC Resources	Science Planning Panel	April
Ignacio	Allan	Geologist	Anglo American	Ore Deposit Geochemistry, Hydrology & Geochronology short course	May
Macdonald	James	Global Geoscience Leader	BHP Billiton	CODES Advisory Board and Science Planning Panel, PhD review meeting	various
Masterman	Glen		Placer Dome Ltd	Collaborative work	December
McArthur	Gary	Consultant	McArthur Ore Deposit Assessments Ltd	Collaborative work	various
McLeod	Ray	General Manager Exploration - Australia	Newcrest Mining	CODES Advisory Board and Science Planning Panel	April
Mehu	Mannie	Senior Exploration Geologist	Lihir Management Company	Ore Deposit Geochemistry, Hydrology & Geochronology short course	May
Mills	Stuart		Anglo American	CODES Advisory Board and Science Planning Panel	April
Power	Dan		Newmont	Ore Deposit Geochemistry, Hydrology & Geochronology short course	May
Radford	Nigel		Newmont	Science Planning Panel, collaborative work	various
Riedell	Brock	Chief Geologist	BHP Billiton World Exploration	Potential collaborative work	August
Rutherford	Rob		Phelps Dodge Australasia	Science Planning Panel	April
Scott	Ian		WMC Resources	Science Planning Panel	April
Sewell	Donna	Exploration Manager – Indochina & southeast Asia	AngloGold	Collaborative work	December
Smith	Roric		AngloGold Exploration Australasia	Science Planning Panel	April
Sutherland	Lin		Australian Museum, Sydney	Collaborative work	July
Tedder	Ian		Newcrest Mining	Collaborative work	various
Thornett	Jim	Principal Consultant	AusQuest Limited	Ore Deposit Geochemistry, Hydrology & Geochronology short course	May
Walters	Steve	Industry geologist	Geodiscovery	Collaborative work	various
White	Noel	Consultant		CODES Advisory Board and Science Planning Panel, collaborative work with staff and students	various
Willis	Ian		Anglo American	Collaborative work	April
Wilson	Alan		Newcrest Mining	Collaborative work	December
Wood	Bryce	Industry geologist		Collaborative work with R Large	September