



Centre for Ore Deposit Research

An ARC Special Research Centre

at the University of Tasmania

• Australia •

Annual Report 2005

MISSION

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

GOALS

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

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DIRECTOR'S REPORT

It is particularly pleasing for me to write the CODES Director's Report for 2005, the final year of the prescribed nine-year funding period of the ARC Special Research Centre, secure in the knowledge that CODES will continue on into a new 5-year phase of existence, as an ARC Centre of Excellence. This optimum outcome for CODES results from very careful planning by the executive team, commenced in mid-2003. It reflects four major factors that each contributed significantly to the ultimate positive outcome. These are: (1) the strong reputation gained by CODES research staff and students from industry sponsors and the ARC over the life of the Special Research Centre, (2) the commitment and effectiveness of the CODES support staff team, (3) the strong financial commitment by the exploration and mining industry and (4) the unswerving support of CODES by the University of Tasmania senior management. We move into our new life as a Centre of Excellence with particular optimism, confident that our research portfolio (expanded, both staff- and project-wise, to include exploration geophysics, nickel-PGE research, and a major component of geometallurgy) is well matched to the interests of the booming exploration and mining industry.

In looking back over the nine-year existence of CODES SRC, there are many things to be proud of. An initial aim was to integrate more fundamental research in igneous petrology, geochemistry, tectonics and volcanology with the existing more industry-focused research of the original CODES research team. This was notably successful, with our Program 1 (Tectonics, Magmas and Fluids) and Program 2 (Volcanic Facies Architecture and Ore-forming Environments) research teams generating a large number of publications across a range of the most highly-cited Earth science journals, and winning numerous external Grants. Team leaders Tony Crawford and Jocelyn McPhie were both awarded Personal Chairs, and Program 1 researcher Dima Kamenetsky was awarded both the prestigious Bessell Award of Germany's Humboldt Foundation, and an ARC

Professorial Fellowship. Leonid Danyushevsky and Dima have set-up in CODES, what we believe to be the best equipped and most productive melt and fluids laboratory globally. Exciting and particularly novel research on the generation and nature of the precursors of mineralising hydrothermal fluids is striding ahead, and well illustrates the effectiveness of our approach linking more fundamental research and researchers with those working directly on major mineral deposits, hand in hand with industry. Leonid Danyushevsky was also instrumental in the development of the CODES LA-ICPMS laboratory that now supports a wide range of projects, including uranium-lead zircon age dating, and trace element microanalysis of sulfides and fluid- and melt inclusions.

Collaborative research with industry continued to be a major item on our agenda, and much of this was achieved via productive interaction with the AMIRA International. Research facilitated by AMIRA made up about one quarter of the CODES external income over the life of the SRC, and included some 10 major projects that saw CODES researchers working closely with industry in all continents (apart from Antarctica). These programs were driven by Program leaders Bruce Gemmell (Program 3 Ores in Volcanic Arcs), Peter McGoldrick (Program 4, Ores in Continental Rift Basins), and Dave Cooke (Hydrology and Geochemistry of Hydrothermal Systems), as well as senior researchers Stuart Bull, Garry Davidson, David Selley and Khin Zaw. On the basis of his strong reputation with industry and excellent research, David Cooke was awarded the Society of Economic Geology's Thayer Lindsay Travelling Fellowship in 2004, and post-doctoral fellow Anthony Harris was awarded the Lindgren Award for high quality research by a person less than 30 years of age.

Steve Walters joined CODES in 2005 to initiate and direct our drive into geometallurgy, and a new AMIRA project in collaboration with JKMRC on this theme, GEM^{III}, has been strongly supported by industry (12 sponsors, contributing \$1.1 million per year) and will

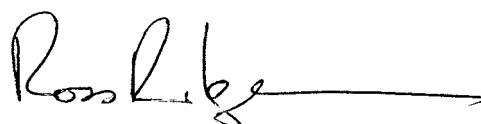
continue into the new CODES Centre of Excellence as the centerpiece of one of our new research Programs. I take this opportunity to acknowledge the strong support provided to CODES by AMIRA International, and particularly by Alan Goode, whose efforts and energy were no small part of our continued successful dealings and sponsorship from industry.

Many of the major AMIRA projects generated excellent spin-offs in the form of international workshops, each backed-up by an accompanying CODES Special Publication that have proved very popular. ARC-AMIRA Linkage projects have also led to several special issues of papers in international journals. A Special Issue of *Economic Geology*, including twelve CODES research papers on 'Alteration Associated with VHMS Deposits' was published in 2001, and has been followed recently by a second Special Issue of *Economic Geology* on 'Giant Porphyry Copper Deposits' containing seven papers by CODES researchers. Two further Special Issues to result from recent CODES ARC Linkage and AMIRA projects will appear in the *Australian Journal of Earth Sciences* and *Ore Geology Reviews* in 2006. The success of our two AMIRA-ARC Linkage projects — 'North Australian stratiform zinc-lead-silver deposits' (1996–1998) and 'Sediment-hosted copper deposits of Zambia' (1999–2003) — has been shown by invitations to the CODES researchers from Program 4 (Ores in Continental Rift Basins) to provide two review papers for the prestigious 100th Anniversary Volume of the Society of Economic Geologists, published in 2005.

CODES researchers have also produced two major research and teaching resource volumes; the first of these, Jocelyn McPhie's 'Volcanic Textures' has been exceptionally popular, with over 4000 copies sold to date, and a continuing steady demand. In 2005, another volume — 'Alteration of Volcanic Rocks' by Cathryn Gifkins, Wally Herrmann and Ross Large — was released and is selling very well. In 2002, CODES staff contributed substantially to the production of a CD that was distributed to school-leavers in Tasmania, advertising careers at UTAS in Earth sciences. Aimed to increase student numbers at a time of dwindling undergraduate enrolments, this CD was a great success, and student numbers in the School of Earth Sciences almost doubled the next year, and have remained at that high level. I note that an effective and comfortable symbiosis with a healthy School of Earth Sciences at UTAS

has been one of the important underpinnings of CODES on-going success, and I acknowledge the input and support of successive Heads of School, namely Clive Burrett, Ron Berry and Bruce Gemmell.

In summary, I am extremely satisfied with the performance of CODES SRC over the last nine years. Our success reflects a commitment to team effort, and the quality of the people that make CODES. My Deputy Director Tony Crawford, and Program Leaders (Dave Cooke, Peter McGoldrick, Bruce Gemmell, Jocelyn McPhie and Tony Crawford) have each done a sterling job in their respective areas. Our administrative and technical staff led by June Pongratz, Peter Cornish, Christine Higgins and Katrina Keep have equally made outstanding contributions to CODES success. I look forward with optimism, confidence and excitement to the next five years, in which CODES Centre of Excellence in Ore Deposits will aim to continue and build on this success. I thank all at CODES for their dedication, commitment and contribution to building a world-class team.



Ross R Large
Director

STAFF AND MANAGEMENT

Director

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

Advisory Board

The Advisory Board members represent major industry sponsors, University of Tasmania senior managers and other key national geoscience organisations. The Board meets annually to review progress of the Centre and to advise on future directions. New members who joined the board in 2005 are Graham Begg, John Hammond, Paul Heithersay and Lynton Jaques.

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

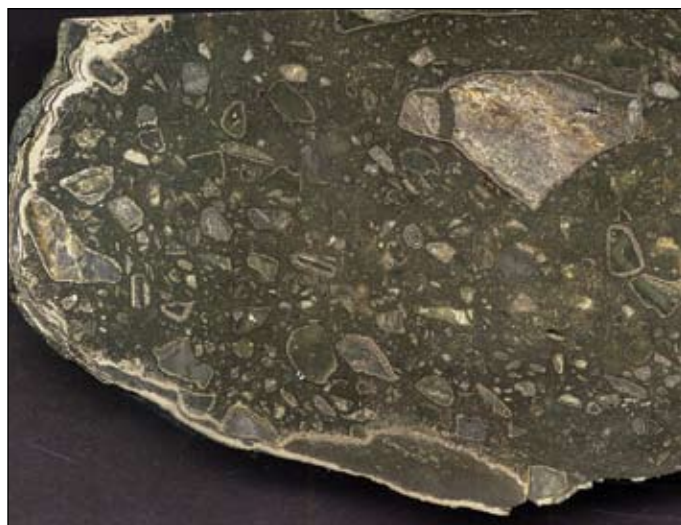
The Executive Committee works closely with the Director to develop the Centre's aims, strategies, plans and performance indicators. The Committee includes the five program leaders plus administrative managers and meets, on average, six times a year.

Staff

CODES employ twenty seven research staff and eleven administrative and technical staff that are funded by the SRC grant, industry and the university. Twenty five of the academic staff and eight of the general staff are joint appointments between CODES and the School of Earth Sciences.

ADVISORY BOARD

Chair: Andrew Glenn	Pro Vice-Chancellor (Research), UTAS
Jim Reid	Dean, Faculty of Science Engineering and Technology, UTAS
Ross Large	Director, CODES
Tony Crawford	Deputy Director, CODES SRC
Bruce Gemmell	Head of School, Earth Sciences
Tony Brown	Executive Director, Mineral Resources Tasmania
Alan Goode	Research Coordinator, AMIRA International
John Holliday	Principal Geologist- SE Australia, Newcrest Mining Limited
Jocelyn McPhie	Program 2 Leader, CODES
Noel White	Consultant
Graham Begg	WMC
John Hammond	Chief Geologist, Newmont Exploration
Paul Heithersay	PIRSA
Lynton Jaques	Geoscience Australia
James McDonald	BHP Billiton
Paul Agnew	Rio Tinto



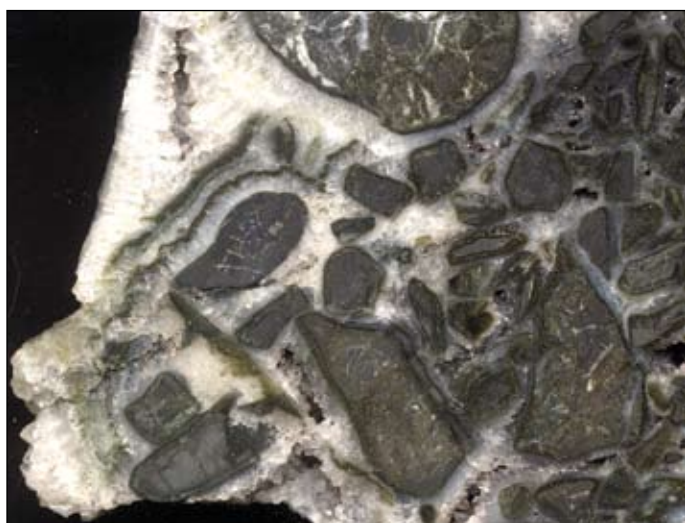
Thin bands of pyrite surrounding altered wallrock clasts in roscoelite-pyrite-quartz-altered rock flour matrix breccia, Porgera gold mine, PNG

EXECUTIVE COMMITTEE

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

SCIENCE PLANNING PANEL (includes all CODES research staff)

Chair: Ross Large	Director, CODES
Paul Agnew	Consulting Geochemist, Rio Tinto
Trevor Beardsmore	Barrick
Graham Begg	WMC
Nick Franey	Vice President Exploration Asia Pacific, Anglo American
Duncan Gibbs	AngloGold Ashanti
Alan Goode	Research Director, AMIRA International
Geoff Green	Managing Geologist, Metallic Minerals and Geochemistry, Mineral Resources Tasmania
David Groves	Director, Centre for Global Metallogeny, University of Western Australia
John Hammond	Chief Geologist, Newmont Exploration
Paul Heithersay	Director, Geological Survey, Primary Industries & Resources South Australia
John Holliday	Regional Exploration Manager, Newcrest Mining Limited
James Macdonald	Global Geoscience Leader, BHP Billiton - Minerals Exploration
Andrew McNeil	Senior Geologist, Zinifex
Kevin Tuckwell	Minerals Council of Australia
Noel White	Consultant



Rebrecciated breccia: rounded clasts of brecciated roscoelite-pyrite-altered mudstone cemented by late stage cockade textured quartz, Porgera gold mine, PNG



Brecciated calcite vein cut by quartz-roscoelite-gold vein, Porgera gold mine, Papua New Guinea

CODES Staff 2005

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

CODES achievements with respect to the ARC Special Research Centre program aims and objectives

In 2005, CODES SRC completed its ninth and final year as an ARC Special Research Centre. Here, the Centre's achievements with respect to the ARC Special Research Centre aims and objectives are reviewed. Part 2 evaluates the Centre's achievements against those aims and objectives submitted in the original SRC application.

Establish concentration of quality researchers and resources; ability to attract high quality research staff

Research Concentration

- In 2005, CODES comprised a multi-disciplinary research team of 25 research and teaching geoscientists and 53 postgraduate students (including 36 PhD, 19 Master of Economic Geology and 5 Master of Exploration Geoscience students). In terms of research staff, this represents the major concentration of researchers in the field of ore deposit and mineral district studies within the Australian university environment, and it is among the largest globally.
- Other Australian units of concentration in ore deposit research are at the University of Western Australia (Centre for Global Metallogeny, with 18 geoscientists, 26 PhD students), and James Cook University (Economic Geology Research Unit, with 8 geoscientists, 26 PhD students). In 2001, a CRC in the area of mineral exploration commenced, involving CSIRO E&M, Geoscience Australia, JCU, UWA, Melbourne U and Monash U. In 2004-5, this CRC had 22 fulltime research staff and 25 PhD students across the sponsor universities and government entities.
- Internationally, there are only around five other significant ore deposit research units. These include the Mineral Exploration Research Centre at Laurentian University (Sudbury, Canada), that has 20 staff, 8 PhD students and 32 Masters students, University of Arizona Centre for Mineral Resources (8 staff, 15 PhD

students in ore deposit research), University of British Columbia's Mineral Deposit Research Unit (10 staff, 12 PhD students), and Freiberg University of Mining and Technology Dept. of Mineral Resources (Germany; with 13 staff, 10 PhD students). A smaller active group at Colorado School of Mines has worked closely with CODES on several projects.

Resources

- Cutting-edge analytical facilities, including a LA-ICPMS system and a new electron microprobe, have been purchased using a combination of ARC and University funding to support the research programs at the Centre. In particular, SRC funds, complemented by ARC-RIEF funds, were used to set-up the LA-ICPMS laboratory. It is used by CODES researchers, and increasingly, by interstate visitors, for trace element microanalysis and U-lead geochronology.
- Video-capable, computer-controlled heating-cooling stages capable of working from room temperature to 1500°C have been installed in the Fluid and Melt inclusions Laboratory, one of the best equipped and most productive of such research units globally. This lab is starting to attract users from among staff and student researchers from interstate and overseas universities.

Attracting high-quality staff

Key staff appointments since 1997 include:

- Dr Jianwen Yang (from U Toronto), a geophysicist with extensive fluid modelling experience who has developed a new code to model fluid migration in real geological settings including sedimentary basins and thick volcanic piles. Now at WindsorU, Canada.
- Dr Sharon Allen (ARC post-doctoral fellow; PhD Monash U), a volcanologist studying the nature of submarine volcanoclastic mass flows, recently appointed to the Editorial Board of *Journal of Volcanology and Geothermal Research*.

- Dr Marc Norman (Macquarie U, PhD Rice U), a geochemist with particular expertise in analytical geochemistry and laser ablation ICP-MS. Now at RSES, ANU.
- Dr Robert Scott (from Research School of Earth Sciences at ANU), a structural geologist with experience in both academic research and industry.
- Dr Robina Sharpe (PhD UTasmania), an ARC APD-I fellow with 5 years industry experience. Now working in exploration in Africa.
- Dr Pete Hollings (PhD USaskatchewan), an igneous petrologist-geochemist funded in CODES by a Canadian NSERC post-doctoral fellowship. Now at Lakehead U, Canada.
- Dr Vadim Kamenetsky (PhD Vernadsky Institute of Geochemistry, Moscow), a geochemist with extensive experience in melt and fluid inclusions in mafic and felsic rocks. Dr Kamenetsky was awarded an ARC Professorial Fellowship in 2004.
- Dr Cari Deyell (PhD UBC), awarded a Canadian NERC post-doctoral fellowship, and chose to work at CODES on epithermal systems.
- Dr James Reid (PhD MacquarieU), an electrical methods geophysicist, James is President-Elect of the Australian Society of Exploration Geophysicists.
- Dr Sebastien Meffre (PhD USydney), responsible for the U-lead dating program using LA-ICPMS.
- Dr Anthony Harris (PhD UQld), an ore deposit geologist working mainly on porphyry copper-Au systems.
- Dr Steve Walters (PhD USheffield), a highly experienced exploration geologist who came to CODES in 2005 to coordinate and implement the new geometallurgy program.
- Dr Zhaoshan Chang (PhD Washington StateU), a skarn, porphyry and epithermal expert working in the AMIRA-funded global epithermal project.

Research advancement and excellence as measured by national and international publications, conference participation, and collaboration

CODES has had a significant impact on both the national and international research scenes. In the 1997-2005 interval, CODES produced:

- 306 refereed papers in international journals
- 500 presentations at national and international conferences
- 185 papers published in high impact journals (below)

Included among the refereed publications are papers in:

Journal	Number
<i>Economic Geology</i>	55
<i>Earth & Planetary Science Letters</i>	11
<i>Geology</i>	13
<i>Journal of Volcanology & Geothermal Research</i>	21
<i>Journal of Petrology</i>	14
<i>Nature</i>	2
<i>Science</i>	1
<i>Australian Journal of Earth Sciences</i>	29
<i>Bulletin of Volcanology</i>	7
<i>Contributions to Mineralogy & Petrology</i>	5
<i>Journal of Geochemical Exploration</i>	3
<i>Chemical Geology</i>	10
<i>Precambrian Research</i>	4
<i>Mineralium Deposita</i>	8

We note that the journals *Economic Geology*, *Journal of Petrology*, *Earth & Planetary Science Letters*, *Contributions to Mineralogy & Petrology*, *Journal of Volcanology & Geothermal Research* and *Geology*, are all the leading journals in their field, with high impact factors. Other international refereed journals publishing CODES papers in this period include *Tectonics*, *The Island Arc*, *Canadian Journal of Earth Sciences*, *Journal of the Geological Society of London*, *Lithos*, *Geochimica et Cosmochimica Acta*, *Bulletin of the Geological Society of America*, *Marine Geology*, *Sedimentology*, *Exploration Geophysics*, *Tectonophysics*, *Hydrology Journal*, *Canadian Mineralogist*, *Journal of Structural Geology*, *Ore Deposit Reviews* and *Geofluids*.

A benchmarking exercise at the completion of the sixth year of CODES as an SRC compared CODES publication output with 14 Australian and 11 similar international research groups. CODES performed exceptionally in the fields of ore deposit geology, volcanology, and petrology and geochemistry (see 2002 Annual Report).

- Major involvement in four thematic Special Issues of international journals (*Economic Geology* and *Australian Journal of Earth Sciences*), including three edited by

CODES researchers, that include a significant number of research papers from CODES staff and students.

- Fifty-four keynote and invited speaker presentations at conferences.
- In 2005, CODES researchers have significant research collaborations with 50 international research groups.
- In the period 1997-2005, 86 international researchers visited CODES for more than one week, to establish or continue research collaborations.
- CODES refereed publications over the 9-year life of the SRC included 103 with co-authorship involving international researchers.

Provision of high quality research environments for postgraduate research education and postdoctoral research training

- CODES has been successful in attracting high quality postgraduate students and postdoctoral fellows from both overseas and interstate, and has an outstanding record of PhD completions compared with the national average.
- Over the nine-year term of the SRC, CODES averaged ~35 PhD students, 22 Masters students, and 12 Post-doctoral and Research Fellows.

Our balanced spread of PhD students originated from:

Overseas	35%
Interstate	55%
Tasmania	10%

CODES maintained a healthy and stimulating research environment by having:

- a PhD Coordinator (Profs Crawford 1997-2002, and McPhie 2003-2005) responsible for induction and guidance of PhD students, and management of the PhD program
- joint supervision of all higher degree students
- weekly research seminars
- active student involvement in large multi-disciplinary research projects
- biannual PhD forum/retreat to discuss strengths and weaknesses of the program
- PhD students encouraged to give presentations at national and international conferences and publish their research during their candidature. In the period 1997-2005, CODES postgraduate students made 142 conference presentations, and were authors or coauthors of 121 refereed papers and 81 gave presentations/reports to ARC SPIRT/AMIRA research meetings)

The success of the PhD program at CODES is

indicated that only five PhD students have withdrawn from the course since 1997. All five withdrawals were due to contingent factors, four affecting international students, and one a medical problem involving an Australian student, and were beyond CODES' control. This withdrawal rate (<5%) compares with the national PhD withdrawal rate of ~30%, and attests to the nurturing environment CODES offers PhD students.

Post-doctoral fellows (which included six ARC post-doctoral fellows, Allen, Danyushevsky, Davidson, Kamenetsky, Norman, Sharpe and two NSERC fellows Deyell and Hollings) were the engine-room of CODES research, contributing to 163 of the 306 published papers (53%), 83 of these as senior author (27%). In most of the major industry-sponsored research projects, post-doctoral fellows have made important contributions, contributing close to 50% of all reports to industry.

Promotion of research which is of national benefit to Australia

Mineral resources exports contributed \$44 billion to the Australian economy in 2000, and current estimates are that in 50 years from now, the world will need five times more metal than has been mined in the last 2000 years (Prof. Brian Skinner, Yale University, 2000). Australia and Canada lead the world in mineral exploration, and should be well placed to take advantage of this.

- Our vision has been to undertake research on ore forming processes in volcanic arc and rift basin settings which will assist the discovery of new mineral deposits, thus improving Australia's position as a global leader in mineral exploration and mining.
- This vision has been achieved by conducting high quality research in consultation and collaboration with the minerals industry. To this end, over the nine-year life of the SRC we conducted 42 major research projects, at over 90 different locations within Australia and overseas, involving collaborations with 72 national and international research organisations and 75 mineral exploration companies (see lists in past Annual Reports).
- The continuing industry commitment to CODES (averaging \$1.01 million annually from 1997-2005) is testament to the perceived national benefit of CODES research.

Annual cash funding for CODES research:

1997	855869
1998	887105
1999	732548
2000	1,001,084
2001	1,150,595
2002	1,194,490
2003	766,781
2004	962,434
2005	1,570,969

**Centre's interaction with the private sector,
State and Commonwealth Governments,
including evidence of the Centre's ability to
attract financial contributions from external
sources - potential commercial applications of
research, reputation and visibility within the
institution and the wider community**

- CODES has had on-going productive collaborations with researchers from major government organisations (e.g. Geoscience Australia, CSIRO, State Government Geological Surveys) and other higher education institutions. A full list of our national collaborations is given in each of the nine Annual Reports since 1997.
- CODES has been lead player in a number of major industry collaborative AMIRA projects (P511, P552, P603; P588; P544; P765; P782) and ARC SPIRT and Linkage research programs (NSW Ordovician porphyry district; giant ore deposits; electrical properties of sulphide ores; isotope studies of Mount Read Volcanics alteration systems; trace elements in sulfides; SE Asian metallogeny). These programs have effectively brought together research expertise in CODES with researchers from Geoscience Australia, CSIRO and several University geoscience departments, in partnership with a group of Australian and overseas mining companies.
- In the nine years since 1997, CODES has been a major industry collaborator via AMIRA (the Australian Mineral Industry Research Association), and since 1997, CODES has been the major University research group undertaking collaborative exploration research with AMIRA.
- Since 1997, funding for CODES research from industry has totalled \$9.12 million, \$6.2 million has come from

ARC (excluding the SRC Block Grant), and \$886,000 has come from the Tasmanian State Government

- Although CODES produces no patent-generating research, the on-going commitment to CODES from Australian and international exploration companies amply demonstrates that CODES research is of value to explorers both here and overseas.
- CODES ran a number of very successful symposia for academic, government and industry participants, including
 - June 1998 "Basins, Fluids and Zinc-lead Ores" Symposium,
 - November 2000 "Volcanic Environments and Massive Sulfide Deposits" Symposium,
 - May 2002 "Giant Ore Deposits" Symposium
 - June 2004 "24 Carat gold" Workshop

PART 2

CODES' performance measured against its own Strategic Plan

The following are the Centre's achievements measured against the original goals and performance indicators as set out in the initial funding application, and subsequently modified in the CODES Strategic Plan.

GOAL 1 — To build upon the success of the Key Centre for Ore Deposit and Exploration Studies (CODES) by integrating the applied aspects of CODES ore deposit research with fundamental research expertise in igneous petrology, volcanology, sedimentology, tectonics and fluid processes

Five major research programs were established and their research philosophy was based on integration of fundamental, strategic and applied research across all programs. In the following pages, an evaluation of performance against plan is presented, updating information presented to the ARC Review Panel for the CODES Sixth Year Review in 2002. Performance Indicators (with targets in brackets) are listed below for each Aim.

The successful bid by CODES SRC to continue existence as a ARC Centre of Excellence for 5 years from July 2005 demonstrates that CODES SRC achieved the proposed aims, successfully addressing both fundamental and strategic research directions of government and industry.

GOAL 2 — To develop a centre that is ranked among the top international research centres specialising in ore deposit research

In terms of key indicators — such as researcher numbers (including PhD students), refereed publications and report to industry output, collaborations, and funds committed from industry — CODES is certainly within the top three international research centres in ore deposit and exploration geology. See Goal 1 on page 7 for further details.

PERFORMANCE INDICATORS (with targets in brackets)

- **Quality and impact of published papers (target >80% of papers in international journals)**

	Refereed papers	% International journals
1997	23	91
1998	33	93
1999	31	61
2000	28	89
2001	53	92
2002	30	73
2003	40	95
2004	32	100
2005*	36	100
Total	306	88%

With the exception of 1999, when CODES researchers published 12 of the year's 31 papers in volumes/books associated with major symposia, the percentage of papers in international refereed journals has been maintained around 90%, well exceeding the target. More details of the CODES publication record are given in the benchmarking exercise presented in the 2002 Annual Report.

- **Invitations to SRC staff to give keynote papers at international conferences, short courses and workshops (target > 2 per year)**

During the nine years of the SRC, CODES researchers received 45 invitations (with financial support) to present keynote papers at international meetings, far in excess of the target 2 per year. Similarly, invitations to convene or chair sessions at international conferences/symposia well exceeded the target of three per year (see Annual Reports 1997–2004 for listing).

* Data included in these tables is for the full year 2005, even though the ARC SRC funding finished at 30 June 2005.

- **Papers presented at national/international conferences (target: average 0.66 per academic staff member per year)**

	National	International	Per Staff
1997	19	19	2.2
1998	32	19	2.6
1999	11	24	1.6
2000	42	26	3.1
2001	15	21	1.4
2002	33	33	2.5
2003	12	52	2.5
2004	76	31	3.8
2005	2	33	1.1
TOTAL	242	258	10.8

Over the nine-year period of the SRC, CODES staff delivered conference papers at the average rate of 2.4 per year, well in excess of the target. Forty-eight percent of these presentations were at international conferences.

- Joint publications with international collaborators (target 20%)

1997	22%
1998	9%
1999	30%
2000	39%
2001	34%
2002	27%
2003	37%
2004	22%
2005	69%
average	32%

Joint publications with international researchers have increased from an average of 15% in the first two years of funding, to average 32% over the life of the SRC, well exceeding the target 20%.

GOAL 3 — To develop a national intellectual focus for research in metallogenesis in volcanic arcs and rift basins

- **The development of an intellectual focus in ore deposit research is indicated by the five highly successful, national/international conferences/symposia convened at the University of Tasmania by CODES research staff since 1996**

- July 1996: New Developments in Broken Hill type Deposits (Convenor – Garry Davidson)
- June 1998: Basins, Fluids and zinc-lead Ores (Convenor – Peter McGoldrick)

- November 2000: Massive Sulfide Deposits and their Volcanic Environments (Convenors – Bruce Gemmell and Jocelyn McPhie)
- June 2002: Giant Ore Deposits (Convenor – David Cooke)
- June 2004: 24 Carat Gold Workshop (Convenors –David Cooke and Cari Deyell)

An edited volume of papers presented at each of these international meetings was published by CODES, and all have sold very well.

- **Number and nature of collaborations established by SRC staff with other national institutions (30%)**

Twenty-three of CODES major projects (45% of total) involved significant collaboration with other national research institutions, one third above the target 30%. Lists and nature of collaborations are given in each of the previous eight Annual Reports.

Our most significant national collaborators were CSIRO Exploration and Mining and Geoscience Australia. We are also collaborating with eight Australian universities (ANU, Monash, Melbourne, Latrobe, Adelaide, JCU, UWA and Queensland) and four State Geological Surveys (Tasmania, NSW, Queensland and South Australia).

- **Number and nature of collaborations with industry geologists (40% of projects with industry collaborators)**

Over the nine-year life of CODES SRC, exactly half of our major research projects, and 70% of our PhD projects, have involved collaboration with industry geoscientists.

CODES has developed a reputation among industry geoscientists as the leading Australian group in mineral deposit research, particularly base metal and gold deposits in volcanic arcs and extensional basins. This accounts for the large number of projects with industry collaborators and reflects the fact that CODES receives more sponsorship via AMIRA than any other group nationally.

- **Number of national geoscience visitors to SRC (target 20 per year)**

1997	24 national visitors
1998	79
1999	66
2000	84
2001	38
2002	83
2003	61
2004	43
2005	40
Average	55

Over the nine years as an SRC, the number of national scientific visitors to CODES has averaged 55, which is well above our target of 20. Visitor numbers dropped in 2001, due to a deliberate

CODES policy that year for our staff to visit other research and industry groups at several international field locations (Chile, Zambia, New Zealand, Indonesia and Canada); i.e. we went to visit them, rather than encouraging them to visit us.

- **Joint papers between SRC staff and researchers from other Australian research organisations (target 30%)**

1997	13	57% of total output
1998	7	23%
1999	8	26%
2000	9	23%
2001	15	28%
2002	11	37%
2003	16	40%
2004	11	33%
2005	12	33%
Total	52	33%

The average number of papers co-authored by CODES researchers with geologists from other Australian research organisations is very close to the target set in 1997.

GOAL 4 — To improve collaboration and technology transfer with end-users in order to give the Australian mineral exploration industry a competitive advantage in Australia and the West Pacific region

- **Research projects with company involvement (target 40%)**

During the nine-year course of the SRC, 36 major projects (47%) involved private industry collaborators or have industry funding. This exceeds the target 40%, and is particularly encouraging given the pronounced downturn in exploration over during the mid-term of the SRC.

- **Level of research funding from industry (target \$800,000 p.a.)**

1997	\$855,569
1998	\$887,105
1999	\$732,648
2000	\$1,001,084
2001	\$1,150,595
2002	\$1,194,490
2003	\$766,781
2004	\$962,434
2005	\$1,570,969
Average	\$1,013,630

Industry funding has been above target for seven of the nine years of the SRC's operation. The drop in industry funding in both 1999 and 2003 relate to the start of the mining industry

downturn, and the completion of major AMIRA projects. However, in both instances this drop was turned around when new AMIRA/ARC Linkage projects commenced. Again, this is a very encouraging result given the poor climate for exploration in the period 1999–2003.

Details about the types and individual projects/amounts of industry funding to CODES are provided in the past Annual Reports.

- **Level of ARC SPIRT/Linkage funding (target \$400,000 p.a.)**

1997	\$518,518
1998	\$392,307
1999	\$274,113
2000	\$394,91
2001	\$405,697
2002	\$332,092
2003	\$246,607
2004	\$319,098
2005	\$258,389
Average	\$349,080

ARC SPIRT/Linkage funding includes several major collaborative projects with AMIRA and industry, in addition to one-on-one APA-I postgraduate research projects. In 2005, CODES won a \$500,000 p.a. Linkage grant for our geometallurgy project. This funding was immediately relinquished into the new Centre of Excellence grant and therefore does not appear in the above figures.

- **Number of mining and exploration companies collaborating with SRC (target 25)**

1998	44 companies
1999	53
2000	71
2001	60
2002	46
2003	45
2004	42
2005	50
Average	46

The average of 46 companies supporting and collaborating with the SRC is well above our target of 25. The list of companies for 2005 is provided in the Industry Links section of this Annual Report. The decline in companies involved with CODES from 71 to 50 post-2001 is due to both the large number of recent mergers and takeovers in the mining industry, and the slow down over that time in exploration and research activities in the minerals sector.

Goal 5 — To undertake collaborative research with industry and Mineral Resources Tasmania aimed to increase the discovery rate of major mineral deposits in Tasmania

• Level of funding from State Government (target \$200,000 p.a.)

1997	\$115,000
1998	\$ 72,505
1997	\$68,000
1998	\$68,000
1999	\$76,600
2000	\$68,000
2001	\$76,600
2002	\$102,240
2003	\$138,102
2004	\$77,769
2005	\$68,000
Average	\$90,659

Although we are well below the target of \$200,000 p.a., the State Government has continued to fund the PhD and Honours scholarship program at the level of \$68,000 pa. This is a critical program that has enabled CODES to continue a series of Honour and PhD projects in collaboration with the mineral industry on problems relevant to the Tasmanian mining and exploration industry.

• Research results of relevance to Tasmanian mineral exploration

AMIRA/ARC SPIRT Project P439 developed a series of alteration models and exploration vectors directly relevant to the discovery of deeply buried massive sulfide deposits in the Mount Read Volcanics, western Tasmania. This research was published in a series of papers in a Special Issue of *Economic Geology* in November 2001.

A collaborative ARC SPIRT project involving CODES, MRT and two major mining companies in Tasmania developed an innovative isotopic approach to distinguish targets that relate to major mineralised systems.

PhD research by Bill Wyman (completed 2000) defined the nature and source of copper-gold mineralisation in the Jukes–Darwin area south of Mount Lyell.

PhD research by Catherine Gifkins (completed 2001) redefined the volcanic stratigraphy and facies relationships in the Mount Black Volcanics to the north of Rosebery. This work, undertaken in collaboration with Dr Rod Allen, has revealed potential areas for mineralisation in the region from Hercules to the Stirling Valley.

PhD research by Oliver Holm (completed 2002) refined the structural and stratigraphic interpretation of the Arthur Mobile Belt, and proposed models for the control of gold mineralisation in the belt. Two papers deriving from this study have been published in Australian Journal of Earth Sciences.

PhD by Neil Martin (completed 2004) on the origin of the volcanic-hosted mineralisation at the Rosebery mine

On-going Tasmania-focussed PhD projects include:

- Kim Denwer's synthesis of the styles and origin of mineralisation and alteration in the giant Mount Lyell field
- Darren Andrew's time-lapse geophysical modelling of acid mine drainage at Savage River
- Greg Ebsworth's regional volcanic facies analysis of the Tyndall Group in the Cambrian Mount Read Volcanics
- Lee Evans' study of acid mine drainage at Rosebery
- Steve Lewis' study of hydrothermal alteration of oceanic crust exposed on Macquarie Island
- Lee Robson's application of remote sensing to geological mapping and exploration in western Tasmania.

In addition, 105 honours field projects have been completed on Tasmanian geological problems, mainly in the west and northeast of the state. About half of these projects involved industry support, with results of direct relevance to the Tasmanian minerals industry.

• Numbers of Honours, MSc and PhD research projects on Tasmanian mineral developments (target 35)

	Honours	MSc	PhD	Total
1997	15	8	2	25
1998	13	8	3	24
1999	15	7	6	28
2000	14	4	6	24
2001	18	3	8	29
2002	18	0	7	25
2003	19	0	8	27
2004	15	0	8	23
2005	6	0	9	6
Average	15	3	6	24

We have not achieved the target of 35 Tasmanian projects per year. This is largely due to the limited industry funding for research in Tasmania compared with mainland and overseas research projects. However, we have averaged 24 student research projects on Tasmanian mineral development with a gradual increase in PhD projects to average over eight in the last three years.

• National conferences and workshops concentrating on Tasmanian minerals issues (target 1 per 2 years)

- 1999/2000/2001: CODES was a supporter of the annual Australian Journal of Mining Tasmanian Minerals Conference. Six papers were presented at the three conferences.
- August 1999: A two-day international workshop in London

attached to the SGA/IAGOD meeting was run by CODES researchers. This workshop emphasised research advances in the western Tasmanian Mount Read Volcanics relevant to mineral exploration.

- June 1998, 2000, 2002: Every two years, a one day short course on the mineral deposits of the Mount Read Volcanics, Tasmania, is run by CODES staff as part of our Masters program
- November 2000: CODES organised an international conference on VHMS deposits and their volcanic environments. This conference, which attracted 130 national and international geoscientists, concentrated on the Mount Read Volcanics in Tasmania.
- June 2002: CODES organised an international workshop on giant ore deposits. The workshop involved a visit to the west coast of Tasmania to discuss research and exploration developments related to Tasmanian mineral deposits.
- February 2004: A western Tasmania field trip focussing mainly on the mineralised Mount Read Volcanics was run as part of the 17 Australian Geological Convention held in Hobart.

Funding for Tasmania-specific research has dropped significantly due to a decline in mineral exploration activity in the state, compared with activity elsewhere in Australia and overseas. However, even under these difficult circumstances, CODES has managed to maintain the number of postgraduate students studying Tasmanian projects and also maintained research output relevant to Tasmanian exploration in both refereed journals and conference presentations.

Goal 6 — To increase our research focus on mineral deposit studies in the western Pacific and SE Asia

- **Number of research projects in Western Pacific and SE ASIA (target 12)**

	Major Projects	PhD Projects	Total
1997	11	4	15
1998	12	5	17
1999	17	8	25
2000	18	8	26
2001	20	10	30
2002	12	9	21
2003	12	11	23
2004	10	8	18
2005	7	10	17
Average	16	7	23

There has been a healthy number of SE Asia and Western Pacific projects varying from from 15 to 30, despite the exploration downturn and political instability of the region. We are well exceeding the 1997-set target.

- **Expenditure level on projects with a major western Pacific & SE Asian component (target 15% of budget)**

1997	\$292,000 (12%)
1998	\$295,000 (12%)
1999	\$408,800 (13%)
2000	\$624,194 (17%)
2001	\$705,300 (17%)
2002	\$544,017 (13%)
2003	\$292,920 (7.5%)
2004	\$702,507 (17%)
2005	\$558,000 (11%)
Average	\$491,415 (13%)

Expenditure in the western Pacific was maintained close to the target despite political uncertainties and instability in a number of the target countries, particularly Indonesia, which forced us rethink our priorities related to SE Asia.

- **Publications on western Pacific topics (target 7)**

1997	5 papers (22%)
1998	4 papers (12%)
1999	5 papers (16%)
2000	5 papers (18%)
2001	7 papers (13%)
2002	9 papers (30%)
2003	16 papers (25%)
2004	10 papers (31%)
2005	8 papers (22%)
Average	8 papers

With the maturing of AMIRA porphyry and epithermal projects and the completion of ARC Discovery Grant-funded western Pacific petrology-geochemistry-tectonics projects, there has been a gradual increase in papers relating to the western Pacific and SE Asian regions.

GOAL 7 — To expand our international linkages with other specialist centres in the field

- **Effectiveness of international visiting fellow program**

A good example of success of this program has been the 12-month visit in 1998 by Professor Grant Garven, John Hopkins University, who came to work with the Programs 4 and 5 researchers on numerical modelling of fluid flow related to formation of stratiform zinc deposits in sedimentary basins. He subsequently visited for several weeks each year, to continue the highly successful research collaboration, which has positioned CODES at the cutting edge of basin-scale modelling research. Visits by other researchers (see below), although not as demonstrably successful, have been very fruitful in developing key collaborative links with other world class research groups.

- **Number of international visitors to SRC (target 1 long term and 5 short term per year)**

Long-term international visitors have been:

Prof. Grant Garven, Johns Hopkins University (Program 4 & 5)
 Dr Carlos Inverno, University of Lisbon (Program 3)
 Dr Carsten Munker, Gottingen University (Program 1)
 Dr Peter Hollings, University of Saskatchewan (Program 1 & 5)
 Dr Yoshi Goto, Sendai University, Japan (Program 2)
 Prof. Nancy Riggs, University of Arizona (Program 2)
 Prof. Valeri Maslennikov, Institute of Mineralogy, Russian Academy of Sciences (Program 3)
 Prof. Harendra Bhattacharya, Presidency College, Kolkata (Program 4)

Seventy international geoscientists visited CODES for periods of one to eight weeks in the nine years of the SRC's existence, and a similar number of international geoscientists visited for a period of less than one week.

Although on target, it has been difficult to attract international researchers to spend a full year at CODES.

- **Joint publications with international researchers (target ~20% of publications)**

See Goal 2

GOAL 8 — To develop an international quality postgraduate and post doctoral program to produce graduates and researchers able to (i) identify and pursue new fundamental research initiatives and/or (ii) lead industry in the exploration for new mineral resources

- **Origin of postgraduate (PhD) students**

	Tasmania	Interstate	International
1998	24%	38%	38%
2000	16%	51%	33%
2002	25%	43%	32%
2004	27%	43%	30%
Average	23%	44%	33%

The current balance is considered to be a healthy mix of students from a variety of backgrounds. CODES current (2005) class of PhD students come from TasmaniaU (10), MonashU (5), ANU (2), Melbourne U (2), Latrobe U (1), SydneyU (1), JCU (2), Adelaide U (1), Queensland U (1), UTS (1), UWA (1), Canada (3), New Zealand (3), Portugal (1), USA (2), Russia (3), Zambia (1), South Africa (1), Germany (1), UK (1), China (1).

It is also noteworthy that 64% of our current PhD students have worked as geoscientists in the minerals industry, for more than a year, between finishing their Honours or MSc degree and starting their PhD.

- **Numbers of research higher degree students (target 32)**

	PhD	MSc (research)	Total
1997	24	6	30
1998	29	9	38
1999	36	12	48
2000	37	10	47
2001	37	7	44
2002	38	7	45
2003	40	6	46
2004	37	6	43
2005	38	5	43
Average	35	8	43

Our numbers of research higher degree students have been more than five above target for the last 6 years. This trend is driven in part by the current University research funding model, which has a heavy weighting on PhD numbers.

- **Level of funding attracted from Industry, ARC, UTAS and State Government for postgraduate student research (target \$350,000 p.a.)**

1997	\$327,000
1998	\$360,000
1999	\$347,000
2000	\$278,000
2001	\$303,000
2002	\$353,463
2003	\$331,180
2004	\$238,931
2005	\$268,846
Average	\$312,000

This number includes cash support for scholarships, research expenses and travel (not including APA scholarships). The general situation of this funding being below the target, particularly for the last two years, reflects two things: (1) that the original target was too ambitious, and (2) that the diminishing expenditure on exploration globally is reflected in funding available for PhD student support.

- **Research Fellows attracted to SRC with own funding (target 3 Fellowships)**

1997 - Leonid Danyushevsky ARC Fellowship (QEII)
 1998 - Vadim Kamenetsky ARC ARF Fellowship
 1998 - Garry Davidson ARC ARF Fellowship
 1999 - Peter Hollings NSERC Post-doctoral Fellowship
 2000 - Marc Norman ARC Fellowship transfer from MacquarieU
 2000 - Sharon Allen ARC APD Fellowship
 2000 - Robina Sharpe ARC APD-I Fellowship
 2002 - Cari Deyell NSERC Post-doctoral Fellowship
 2004 - Sharon Allen ARC ARF Fellowship
 2005 - Vadim Kamenetsky ARC Professorial Fellowship

- **Nature and effectiveness of student supervision**

The best indicator of the effectiveness of PhD supervision is the drop-out rate (or conversely, the completion rate). Over the nine years of the SRC life to date, five students have dropped out from a total of 85 PhD students enrolled over that time (6%). In each case, the non-completions were to do with matters beyond the control of CODES and involved international students in four cases, and a medical problem in the fifth. This compares with the Australian national PhD drop-out rate of 30%, and points to substantial success in nurturing the PhD students in CODES. Joint-supervision, and annual one-on-one confidential discussions with the PhD co-ordinators Tony Crawford (1997-2002) and Jocelyn McPhie (2002–2005), were successful in ensuring that potential problems are dealt with before they become too serious.

- **Research output by postgraduate students**
(target 10 papers p.a.)

	Refereed Papers	Conference Presentations
1997	6	22
1998	15	19
1999	14	9
2000	8	30
2001	19	10
2002	12	26
2003	14	10
2004	13	35
2005	14	4
Average	13	18

Although we have exceeded the target of 10 papers per year, we consider this figure to be low for a class of 35 or so PhD students. This means, that on average, each student has produced one published paper over the period of their PhD. For the new CODES Centre of Excellence, we plan to increase this to 1.5 to 2 papers per PhD student.

AMIRA P843 GeM^{III} – a major new collaborative research project

The AMIRA P843 GeM^{III} project (Geometallurgical Mapping and Mine Modelling) is a major new CODES research initiative addressing the cross-discipline interface between ore deposit characterisation, mining and mineral extraction. The initiative was developed in direct response to an industry identified need for coordinated cross-discipline geometallurgical research, and is an important strategic component in support of the Centre of Excellence bid. A key aspect of the project is formal collaboration between CODES and the Julius Kruttschnitt Mineral Research Centre (JKMRC) at the University of Queensland, widely regarded as a world leader in mining and mineral processing research; and the WH Bryan Mining Geology Research Centre (BRC) at the University of Queensland, a world leader in mining geostatistics and optimisation in mine design and planning. This is the first time the three high profile groups have worked together.

As reported in the previous Annual Report, a detailed phase of project development during 2004 coordinated by Associate Professor Steve Walters of CODES resulted in submission of the AMIRA P843 proposal to industry in late 2004 with rapid support from an initial eight companies ensuring project viability. Following this strong support the project formally commenced on 1 January 2005 for a period of 4.5 years. Associate Professor Steve Walters has been appointed Project Manager.

The first six months involved a ramped start-up phase pending the outcomes of funding submissions to the ARC. During this period BHP Billiton and Inco joined the project – bringing the total number of sponsors to eleven with an industry cash funding commitment of \$3.7 million over life of project.

Principal aims of the ramp-up phase were:

- Promotion of cross-discipline technical awareness and collaboration among the participating research institutions.
- Provision of a detailed research plan backed by scoping studies for sponsor consideration and sign-off in mid 2005.
- Building an effective integrated project team and management structure ready for full project following finalisation of ARC funding submissions.

Outcomes were presented to sponsors in July 2005

including a detailed four-year research plan with defined activities, deliverables and milestones.

The project is based on a modular structure that covers the range of techniques and disciplines required for more effective and systematic automated core logging and process domaining; automated textural measurement, classification and categorisation; correlation of textural domains with small-scale physical testing for processing performance; statistical distribution of new and more effective processing indices; and the need for integrated training and education. Although organised around discrete modules, a key aspect of the AMIRA P843 GeM^{III} is integration of outcomes that will help overcome the 'silo effect' often evident in cross-discipline geometallurgical studies.

The AMIRA P843 GeM^{III} initiative is the largest industry-supported research project that CODES has been involved with. It represents a significant new strategic direction and forms the core of Program 4 'Recovery' in the CODES Centre of Excellence bid.

For more details contact Associate Professor Steve Walters <steve.walters@utas.edu.au>, ph +61 4 1231 9233.



The GEM^{III} team

PROGRAM I: 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; and (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 copper-gold, and high-sulphidation epithermal gold/silver mineralising systems.
- To build on our existing program of fundamental research in igneous petrology and geochemistry of magmatism in arc, backarc and ocean floor settings, in order to better understand the genesis of ore deposits in the entire context of the evolution of arc systems and rift basins.
- To document the geochemical and petrological signatures of ancient (Tertiary to 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 South East Asian terrains.

Highlights

Dima Kamenetsky awarded an ARC five-year Australian Professorial Fellowship

Program I researchers and their collaborators authored 12 publications in the following peer-reviewed international journals in 2005: *Journal of Petrology* (2), *Earth and Planetary Science Letters*, *Geology*, *Meteoritics and Planetary Science*, *Australian Journal of Earth Sciences*, *Terra Nova*, *Economic Geology*, *International Geology Review* and *Geochimica et Cosmochimica Acta*

Tony Crawford awarded Geological Society of Australia (Victoria Division) Selwyn Medal for contributions to understanding the geological evolution of Victoria

Two new students commenced PhD studies — Weerapan Srichan ‘Geological evolution of the Chiang Khong–Lampang Belt, northern Thailand’, and Dinh Quang Sang ‘Geology and geochronology of the northern margin of the Precambrian Kontum Massif in the Kham Duc region, Vietnam’

PhD awarded to Maya Kamenetsky ‘New identity of the kimberlite melt: constraints from unaltered diamondiferous Udachnaya-East pipe kimberlite, Siberia, Russia’ and Roman Leslie ‘Petrogenesis of SW Pacific shoshonites as revealed by melt inclusion studies’



Dima Kamenetsky on Vulcano Island (Aeolian Islands, Italy) during a post-ACROFI 2005 field excursion

Team Leader

Tony Crawford

Team Members

Ron Berry, Leonid Danyushevsky, Vadim Kamenetsky, Khin Zaw, Sebastien Meffre, Phil Robinson

PhD Students

Michael Baker, Ding Quang Sang, Patricia Durance (part-MonashU), Ben Jones, Weerapan Srichan, Sofia Tetroeva

Collaborators

CSL (UTAS), Geoscience Australia (Terry Mernagh, Neville Exon, George Bernardel), CSIRO E&M (Chris Ryan, Esme Van Achterbergh), Geological Survey of New South Wales (Barney Stevens, Dick Glen), Australian Crustal Research Centre and School of Earth Sciences MonashU (David Giles), UAdelaide (Nick Direen), University of Melbourne (Roland Maas), Research School of Earth Sciences ANU (Marc Norman), Vernadsky Institute of Geochemistry

and Cosmochemistry, Russia (Alex Sobolev, Alexei Ariskin and Valentina Batanova), University of Pisa, Italy (Paolo Fulignati, Alessandro Sbrana and Paolo Marianelli)

Core Projects in Program I

- 1.1 Volatiles and chalcophile elements in porphyry copper-gold-hosting magmas
- 1.2 Volatile elements and chalcophile metals in magmas from different supra-subduction zone tectonic settings
- 1.1 Development of analytical techniques

Project 1.1 CORE*

Volatile and chalcophile elements in porphyry-gold/copper-hosting magmas

V Kamenetsky, P Davidson, A. Crawford, T Mernagh (GA), L Danyushevsky, C Ryan and E van Achterberg (CSIRO E&M), S Garwin (Geoinformatics); PhD student B Jones

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

Much of the activity in this project during 2005 was driven by Paul Davidson and Dima Kamenetsky, underpinned by excellent microanalytical data provided via laser ablation ICP-MS (Leonid Danyushevsky), laser Raman spectrometry (Terry Mernagh at GA) and PIXE probe (Chris Ryan, Esme Van Achterbergh at CSIRO). Major outcomes were:

- a paper by Davidson et al. in the 100th Anniversary volume of *Economic Geology* documenting the magmatic precursors of hydrothermal fluids at the immense Río Blanco copper-molybdenum deposit, Chile.

* Even though the ARC SRC funding ceased on 30 June 2005, for completeness these reports on research activities in each SRC project cover the full year's activities.

- a research grant from Newmont Ltd to Paul Davidson and Tony Crawford to apply melt inclusion techniques to better understand the origin of the fluids involved in the Batu Hijau porphyry copper/gold deposit.
- a paper in *American Mineralogist* by Dima Kamenetsky and Leonid Danyushevsky demonstrating exceptional volatility of copper and silver during heating of melt inclusions trapped in quartz.
- a study by Dima Kamenetsky and Italian colleagues focused on documenting the nature and origin of fluids involved in generation of endoskarn during the 79 AD eruption of Vesuvius

The Batu Hijau study revealed some exciting results. In this study melt and fluid inclusions in both pre- and syn-mineralisation samples from the Batu Hijau porphyry copper-gold deposit in Sumbawa, Indonesia, conclusively demonstrated the co-existence of a silicate melt and a hypersaline aqueous fluid in the parental magma. Primary magmatic fluid inclusions trapping the hypersaline aqueous fluid exsolved from the pre-mineralisation and syn-mineralisation sample showed significant compositional differences, particularly of copper. In contrast to the primary magmatic fluid inclusions, melt inclusions in quartz phenocrysts differed little between the pre- and syn-mineralisation samples. From these observations, it was concluded that microanalysis of primary magmatic fluid inclusions may provide strong evidence of whether or not an intrusion may have sourced metal-rich hydrothermal fluids.

The experimental study by Kamenetsky and Danyushevsky published in *American Mineralogist* investigated the possibility that quartz-hosted rhyolitic melt inclusions may change their composition during laboratory heating under different conditions. Exceptional volatility of copper and silver and inert behavior of other metals (zinc, lead, molybdenum, tin, tungsten) and lithophile trace elements at high temperature (850°C) was demonstrated. Heating experiments with melt inclusions require specific conditions that should take the high volatility of copper and silver into account. It was shown that open system behavior of copper and silver can also affect the composition of melt inclusions within the time frame between trapping and eruption.

Dima Kamenetsky and colleagues from the University of Pisa published a study in *Periodico di Mineralogia* on multiphase fluid/melt inclusions in the 79 AD Mount Vesuvius endoskarn xenoliths. The exsolution of a magmatic chloride-carbonate liquid phase from the peripheral parts of the silicate magma chamber was demonstrated, together with multiple immiscibility events of magmatic fluids during cooling.

PhD student Ben Jones, in the last year of his study of the Antapaccay skarn-porphyry deposit in Peru, has amassed an immense amount of data for magmatic units in the region. One final aspect of this project, currently underway, is to use melt inclusions in quartz in pre-, syn- and post-mineralisation intrusions and veins to clarify the origin of the mineralising fluids.

Project 1.2 CORE

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

A Crawford, L Danyushevsky, V Kamenetsky; PhD students M Kamenetsky, R Leslie, S Tetroeva, P Durancie-Sie

As noted in the Annual Report for 2004, our detailed studies of melt inclusions trapped in primitive olivine phenocrysts in lavas from diverse SW Pacific tectonic settings have shown that many are not, in fact, representative of the main magma that transported the host olivines to the surface. Rather, many melt inclusions are trapped in olivines growing during interactions between magmas and their wallrock (either in the upper mantle or lower crust), so that in these cases the melt inclusions are ephemeral, small volume, reaction-zone melts not representative of typical mantle-derived magmas. Criteria for the identification of 'useful' melt inclusions have been developed and are being applied to olivine-hosted melt inclusions from magmas from a variety of tectonic settings.

Following acceptance of his PhD thesis on the petrogenesis of the shoshonitic magmatic suite that hosts the Emperor gold deposit in Tavua caldera, Viti Levu (Fiji), Roman Leslie returned to CODES to write up two papers on the petrogenesis of these magmas, presenting among other things new data for magmatic budgets of sulfur, chlorine and chalcophile elements during the fractionation of this typical SW Pacific shoshonite suite.

We commenced a new research direction focusing on sulfide melt inclusions in olivine phenocrysts in diverse magma types, including komatiites, mid-ocean ridge basalts, backarc basin basalts, arc basalts, boninites, flood basalts and ocean island intraplate basalts. Initial studies of sulfide melt inclusions in mid-ocean ridge basalt olivines showed that the sulfide melts have unmixed to complex and non-stoichiometric iron-nickel-copper sulfides, and that detailed microanalytical studies require high-temperature homogenisation of these melts using a vertical quench furnace or heating stage microscope. Such studies have the potential to provide new information about the behaviour and composition of sulfide melts during fractionation, and the sulfur content of mantle peridotites in different tectonic settings.

Magnificent suites of arc tholeiites, boninites and adakitic magmas were dredged from the southern section of the Hunter Ridge, between Vanuatu and Fiji, during a late 2004 R/V *Southern Surveyor* cruise that swath-mapped part of the ridge and the adjacent backarc basin spreading centre in the North Fiji Basin. Detailed studies of melt inclusions in several of these suites constitute major parts of the PhD projects of Sofia Tetroeva and Patti Durance-Sie.

Patti's major output during 2005 was a bouncing baby boy, but she was able to return to work late in the year to press on with her investigation of the petrogenesis of arc tholeiites from the Hunter Ridge. Sofia's major research effort involves elucidating the processes and products involved during partial melting of subducting oceanic crust, and subsequent reaction of these melts with the oceanic crust and upper mantle. Recent studies have suggested that adakitic magmas believed to have been generated in this way are abnormally frequently associated with either copper/gold porphyry mineralisation, or VHMS-style mineralisation. Data from melt inclusions can be used to evaluate this hypothesis, since they provide direct information about the volatile and chalcophile element compositions of such melts.

Work completed several years ago by BSc(Hons) student Daniel Bombardieri on the sulfur contents of lunar basalts from Apollo 12 was published in 2005 in *Meteoritics and Planetary Science*. Using melt inclusions in olivines, Daniel and co-authors Marc Norman, Dima Kamenetsky and Leonid Danyushevsky showed that picritic parental magmas apparently experienced outgassing and loss of S during transport and eruption on the lunar surface. Even with the higher estimates of primary magmatic sulfur concentrations provided by the melt inclusions, the magmas would have been undersaturated in sulfide in their mantle source regions and capable of transporting chalcophile elements from the lunar mantle to the surface. The measured low concentration of chalcophile elements (e.g., copper, gold, PGEs) in these lavas must be a primary feature of the lunar mantle and is not related to residual sulfide remaining in the mantle during melting. We estimated the sulfur concentration of the source regions to be ~75 ppm, which is significantly lower than that of the terrestrial mantle.

Maya Kamenetsky completed her PhD on melt inclusions in olivines from an ultra-fresh kimberlite from Udachnaya (Russia), and showed that the kimberlite melt is remarkably enriched in chlorine and alkalis (2.3–3.2 wt% Cl, 2.6–3.7 wt% Na, and 1.6–2.0 wt% K). Enrichment in CO₂, chlorine and alkalis is expressed in the essentially alkali-carbonate (shortite, zemkorite) and alkali-chloride (halite, sylvite) composition of the kimberlite groundmass. These minerals cement olivine phenocrysts and form



Leonid Danyushevsky (right) and the scientific party of the RV *Southern Surveyor* sorting volcanic rocks dredged from the sea floor in the SW Pacific during research voyage SS10/04

round segregations ('nodules'). Radiogenic (neodymium, strontium, and lead) and stable (oxygen, carbon and sulfur) isotope compositions of the chloride, chloride-alkali carbonate, carbonate and oxide-silicate constituents in the groundmass of the Udachnaya-East kimberlite effectively showed the coexistence of these phases in the closed system since kimberlite emplacement ~347 Ma.

This study also reported the discovery of previously unknown inclusions of high-Ca pyroxene in the cores of microphenocrystal olivine. These formed in the diamond stability field (45–50 kb) at temperatures of 900–1100°C, from a melt with a trace element composition resembling that of the kimberlite groundmass. The inferred P-T conditions correspond to the lower part of lithosphere beneath the Siberian craton. Maya's work demonstrated that prolonged evolution of the kimberlite magma by olivine crystallisation was responsible for a build-up of abundances of alkalis, chloride, carbonate and sulfate components. As a result, the residual kimberlite magma acquired an essentially non-silicate composition, but was high in CO₂, Cl, and alkalis. This magma crystallised at low temperatures (<650–750°C), and underwent chloride-carbonate liquid immiscibility at ~600°C.

Project 1.3 CORE

Development of analytical techniques

L Danyushevsky, S Meffre, P Robinson, R Berry, S Gilbert, V Kamenetsky, A Harris, A Rae, G Davidson; PhD student M Kamenetsky

Continued analytical developments in the LA-ICPMS microanalytical facility were aimed at improving accuracy



Sarah Gilbert operating the UP213 laser probe in the CODES LA-ICPMS facility

of analysis of fluid inclusions and silicate glasses; expanding the range of accessory minerals used for uranium-thorium-lead dating; testing techniques for lead isotopic analysis on fluid inclusions; further developing data reduction procedures; and assessing applications of a newly acquired microdrill.

The suitability of the NIST612 international glass standard for quantification of fluid inclusion analysis has been assessed by ablating glass capillaries filled with saline solutions of known compositions. It has been demonstrated that NIST612 glass can be used for quantification of concentrations of a large range of metals and lithophile elements in fluid inclusions with an accuracy of <20% when using sodium as the internal standard. A paper describing these results is now in preparation.

A possibility of analysing lead isotopic composition in fluid inclusions has been investigated by analysing high-density, high-lead-content fluid inclusions in quartz from the Gawler Range complex in South Australia. The analyses have produced promising results and the technique is under continuing development.

The effect of laser beam diameter on element fractionation during ablation of silicate glasses has been tested by analysing an international glass standard BCR-2. It has been shown that spot-size related fractionation can be significant (up to 20%) for some elements and is particularly important for spot sizes <40 microns. A paper describing these results is now in preparation for publication.

The suitability of monazites for uranium-thorium-lead dating has been assessed. The high concentration of thorium common in monazites requires small beam sizes (<8 microns), and it has been shown that the technique can produce relevant geological information.

Data reduction procedures for analyses of sulfides have been further advanced. The new additions aim at developing statistical tools for distinguishing and identifying mineral inclusions and intra-lattice variations within sulfide grains.

The New Wave microdrill has been set up and tested. Application of microdrilling to solution ICPMS analysis of fine beds in shales has been successfully demonstrated.

Project 1.5

Modern and ancient fold belt volcanics

A Crawford, S Meffre, L Danyushevsky, D Kamenetsky; D Giles (Austr. Crustal Research Centre, MonashU), I Withnall (GS-Queensland), B Stevens and R Glen (GS-NSW), P Vasconcelos (UQld), I Duddy (Geotrack International); PhD students M Baker, P Durance-Sie, S Tetroeva, W Srichan, Dinh Sang

Modern Settings

Since a large part of the continental crust of eastern Australia (Tasman Fold Belt System) was produced in subduction-related arc-backarc basin systems such as in the current SW Pacific, 'unravelling' these fold belts will be facilitated by a broad-ranging understanding of the spatial, temporal and compositional evolution of the SW Pacific region. To this end, several projects in the SW Pacific are underway, the main one being 'Tectonic Paradox of the E Margin of the Australian Plate, 120–0 Ma', that commenced in 2003 supported by an ARC Discovery Grant to Tony Crawford. This project is based around rocks dredged from a cruise of the R/V *Southern Surveyor* to the Norfolk Ridge–Norfolk Basin region between New Zealand and New Caledonia. A major outcome of the year's work has been the assembly of geochronological data for the major rock suites dredged, including argon/argon dates done in association with Paulo Vasconcelos (UQld), and LA-ICPMS zircon and titanite dates obtained in the CODES ICPMS laboratory. Pillow basalts from the southern Norfolk Basin, perhaps the least studied backarc basin on Earth, were shown to be Miocene in age, precluding the suggestion that this abnormally deep basin is trapped Cretaceous oceanic crust.

Detrital blue amphiboles in sandstones from a dredge on the western side of the Three Kings Ridge yielded an argon/argon age of 36 Ma, believed to record the overthrusting of the southern continuation of the New Caledonian ophiolite. Alkaline basaltic lavas dredged from the northern end of the Norfolk Ridge were shown by both Ar/Ar and zircon U-lead to have erupted ~30 Ma, and are thus significantly older than the hotspot trace of seamounts

that include Norfolk Island 100 km further south. This data, coupled with wholerock major and trace element compositions and strontium-neodymium-lead isotopic data, is being used to develop a new tectono-magmatic model for this part of the SW Pacific. In addition, all the cruise information and data has been assembled for publication in 2006 as a *Record* of Geoscience Australia.

Work has commenced on the diverse suites of magmas recovered from the Hunter Ridge–N Fiji Basin intersection during the late 2004 cruise of the R/V *Southern Surveyor* (Leonid Danyushevsky, Chief Scientist). An oxygen isotope study of adakitic lavas, including samples from Fiji and the Hunter Ridge, was published by Bindeman, Danyushevsky et al. in *Earth and Planetary Science Letters*.

In a collaborative project with Dominique Cluzel (UMontpellier, France), Sebastien Meffre and Tony Crawford commenced a project aimed at dating mainly felsic dykes that transect the immense but undated New Caledonian ophiolite. Emplacement of this ophiolite and locking of the plate boundary was one of the major events in the complex and still poorly understood geodynamic evolution of the SW Pacific region. Thus any information that can constrain the timing of magmatism that formed the ophiolite will be another piece of evidence to add to the jigsaw. A paper describing the results of this study is in preparation for submission to *Terra Nova*.

Basalts dredged from the Rowley Terrace–Scott Terrace–Exmouth Plateau margin of Western Australia, and previously reported on in several papers by Tony Crawford, were among a set of Cretaceous and Early Tertiary basalts from the Indian Ocean for which strontium-neodymium-lead isotopes were analysed to investigate the distribution and longevity of the anomalous Indian Ocean asthenospheric mantle. A paper documenting this study (Zhang, Mahoney, Crawford et al.) was published in *Journal of Petrology*.

Fold Belt Studies

PhD student Michael Baker obtained U-lead zircon ages and wholerock major and trace element compositions for Palaeoproterozoic mafic igneous units in the Georgetown Block, North Queensland, and reported these new findings at the Port Macquarie conference of the Geological Society of Australia's Specialist Group in Geochemistry, Mineralogy and Petrology. In terms of both age and composition, these basalts/dolerites show some striking similarities to mafic rocks in the Broken Hill Block and to basalts in the Soldiers Cap Group on the eastern side of the Mount Isa Block. On-going studies of these rocks include thermo-barometry and monazite dating to constrain the post-magmatic history of the western part of the Georgetown Block.

Also in north Queensland, geochemical and geochronological studies of diverse volcanic and intrusive units in the Greenvale region are underway in collaboration with David Giles (Australian Crustal Research Centre, MonashU) and Ian Withnall (GS-Queensland). This work, building on Withnall's regional mapping, aims to define the tectono-magmatic development of the northern end of the Tasman Line, to compare it with better defined areas along the western margin of the Tasman Fold Belt System in southeastern Australia. Our zircon dating shows that magmatic units in this area formed between Early Ordovician and at least Middle Silurian times, and geochemical data indicate that magmas had geochemical affinities best matched by lavas in modern supra-subduction zone regions involving extension of continental crust in the over-riding plate (e.g., Okinawa Trough).

Tony Crawford continued studies of the amphibolitic to granulitic mafic sills in the Broken Hill Block, in collaboration with Barney Stevens (GS-NSW). One outcome of this work has been the demonstration that geochemical transects through conformable sills >~50 m thick can effectively indicate 'way up', and thus they have immense potential to elucidate the structure of this complex region. A related study is examining relationships between the Potosi Gneiss and iron-rich basaltic magmas that form most sills in the Broken Hill Block.

Ron Berry and (former PhD student) Ollie Holm published a paper in *Australian Journal of Earth Sciences* reporting new monazite dating of rocks from King Island demonstrating a major deformation event in the region at ~1290 Ma, synchronous with Grenville-aged orogenic events in central and western Australia. This work provides the first evidence of Mesoproterozoic basement in southeastern Australia, and has significant implications for Rodinia reconstructions.

Two new PhD projects in SE Asia commenced in early 2005. Both projects use geochronological, structural and petrological-geochemical studies to clarify the geodynamic evolution of key areas in the SE Asian crustal collage. CODES first Vietnamese PhD student, Dinh Quang Sang began a project in the Central Highlands of Vietnam along the northern margin of the Khontum crustal block, and Srichan Weerapan is focusing on a key region in northern Thailand, the Chiang Khong–Lampang Belt, that crosses through Laos into southwestern China.



Tony Crawford and Dinh Quang Sang in the Dak Ni River valley near Kham Doc, in the central highlands of Vietnam

Project 1.8

Geochronology, metallogenesis and deposit styles in the Loei Fold Belt of Thailand and Lao PDR (2004-1006)

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

This project is sponsored by Oxiana Limited, Kingsgate Consolidated Limited, and Pan Australian Resources NL. The project has the following aims:

- To undertake a regional tectonic and metallogenic analysis of the Loei belt, focussing on geological features and regional metal zonation based on field observation, mineral deposit distribution, igneous and isotope geochemistry and potassium-argon, argon-argon and Sensitive High Resolution Ion Microprobe geochronological data,
- To undertake deposit-scale studies characterising the local geology, alteration patterns, mineral paragenesis, age, style and origin of mineralisation, based on field mapping, core logging, sampling and laboratory analysis, and
- To develop a geotectonic and metallogenic model for the evolution and origin of the Loei belt and the overall timing and history of terrane collision in mainland SE Asia.

The Loei Fold Belt occurs between the Shan-Thai and Indochina terranes in mainland SE Asia, extending from central Thailand to Lao PDR. It hosts a diverse array of deposit types such as skarn, porphyry and epithermal mineralisation containing significant copper and, more importantly, gold. Individual deposits can contain over a million ounces of gold; however, the timing of magmatism and mineralisation with respect to the tectonic evolution of the Loei belt is poorly understood.

Using geochronological techniques, including the newly developed the CODES LA-ICPMS zircon uranium-lead technique, with additional studies in collaboration with the universities of Queensland and Western Australia, this project is defining new key exploration criteria vital for future discoveries of world-class copper-gold resources in the region.

PhD Projects in Program 1

PhD student projects associated with Program 1 are listed below.

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

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

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

Maya Kamenetsky: Melt inclusion studies of kimberlites and flood basalts (completed 2005).

Roman Leslie: Petrogenesis and volatile evolution of shoshonitic magmas (completed 2005).

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

Sofia Tetroeva: Petrogenesis of adakitic magmas.

PROGRAM 2: Volcanic facies architecture and ore-forming environments

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

Objectives

- To develop a better understanding of the facies architecture and evolution of volcanoes in modern and ancient arc settings.
- To provide an accurate volcanological framework for examining the interplay between volcanic processes and ore-forming hydrothermal systems, focussing in particular on volcanic successions associated with massive sulfide, porphyry copper-gold and epithermal gold-silver ore deposits.
- To clarify the primary textural characteristics and textural evolution of fresh, glassy volcanic facies through syn-depositional, diagenetic and hydrothermal alteration stages.

Team Leader

Jocelyn McPhie

Team Members

Sharon Allen, Stuart Bull, Vadim Kamenetsky, Fernando Della Pasqua, Cathryn Gifkins, Wally Herrmann; Rod Allen (Volcanic Resources)

PhD Students

Susan Belford, Katharine Bull, Gregory Ebsworth, Joe Moye, Carlos Rosa

Honours Students

Adam Bath (jointly with Program 1), Joel Kitto (jointly with Program 4), Corey Jago

Highlights

Volcanological research commenced in the Archaean host volcanic succession to the Jaguar VHMS deposit, Western Australia, and the Neoproterozoic-Cambrian volcanosedimentary Carolina Terrane, South Carolina, USA

A new view emerged of Early Devonian volcanism in the Lachlan Orogen, with major implications for tectonic interpretations

A new book by Cathryn Gifkins, Wally Herrmann and Ross Large on altered and mineralised volcanic successions was published

New melt inclusion data from extensive felsic lavas in the Gawler Range Volcanics has revealed a complex magmatic history involving exsolution of CO₂ and fluorine-rich fluid phases

Collaborators

Macquarie University, Geomarine Research (New Zealand), University of Lisbon (Portugal), University of Oregon (USA), Smithsonian Institution (USA), Institute for Frontier Research on Earth Evolution (IFREEE, Japan), GEOMAR (German), Institute of Geology and Mineral Exploration (Athens, Greece), National Institute for Engineering, Technology and Innovation (INETI, Lisbon, Portugal), Geological Survey of New South Wales, Mineral Resources Tasmania, Primary Industries and Resources South Australia, Silver and Baryte SA (Greece), SOMINCOR (Portugal), Kennecott Minerals (USA), Newcrest Mining Limited, Zinifex Limited

Core Projects in Program 2

- 2.1 Facies architecture models for submarine volcanic successions that host base- and precious-metal ore deposits in arc environments.
- 2.2 Facies characteristics and textural evolution of submarine-emplaced rhyolitic pumice breccias.
- 2.7 Experimental simulations and textural analysis of submarine volcanoclastic mass-flow deposits that result from large-scale eruption and failure events.

Project 2.1 CORE

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

J McPhie, S Allen, C Gifkins, W Herrmann; R Allen (Volcanic Resources), S Meakin (GS-NSW), J Relvas (ULisbon), A McNeill (Zinifex Ltd); PhD students S Belford, K Bull, G Ebsworth, J Moye, C Rosa; Honours student C Jago

Research for this project involves a combination of volcanic facies analysis and textural studies both in ancient, deformed and young, well preserved arc successions. In 2005, this project included contributions from five PhD students and two Honours students (summarised below), and collaboration with Program 1 (magma geochemistry and tectonics) and Program 3 (textural and compositional effects of hydrothermal alteration). Study areas included Ural Volcanics (New South Wales), Mount Read Volcanics (western Tasmania), Eastern Yilgarn Craton (Western Australia), Carolina Terrane (South Carolina, USA), Iberian Pyrite Belt (Portugal), and Milos (Greece).

Kate Bull completed her PhD research on the Early Devonian submarine volcanic successions in central western New South Wales, particularly the Ural Volcanics and the Mount Hope Volcanics. Kate's project is conducted in collaboration with the Geological Survey of New South Wales. She submitted her thesis in November and has taken a position as Volcanologist with the Alaska Volcano Observatory in Fairbanks. Major results of Kate's research in the Ural Volcanics, including a new 1:10,000 scale geological map, are in press in the *Australian Journal of Earth Sciences* and she has two more manuscripts in the final stages of preparation. Kate has shown that the Early Devonian volcanic activity was dominated by submarine rhyolitic and dacitic domes, lavas and shallow intrusions which were active in a deep-water intra-continental sedimentary basin. She was also responsible for a rare

achievement -defining the source of pumice-rich facies generated by submarine explosive eruptions.

Greg Ebsworth has been studying part-time, producing new data on regional variations in the internal stratigraphy of the Tyndall Group in western Tasmania, and a re-assessment of stratigraphic correlations of major importance in exploration in the Mount Read Volcanics. Greg concentrated on writing his thesis in 2005 in preparation for submission in early 2007. One Honours project was also conducted on the Mount Read Volcanics. Corey Jago completed a study of the stratigraphy and facies architecture of the Central Volcanic Complex and White Spur Formation in the White Spur area. Corey's research was supported by Zinifex Limited. Corey logged five diamond drill holes and mapped three areas in detail. He established stratigraphic correlations for the area south of South Hercules and clarified the volcanic facies above and below the highly prospective "host rock unit". Corey's results have contributed to on-going efforts to refine the stratigraphic framework that guides VHMS exploration in the Mount Read Volcanics.

Susan Belford began a new PhD project in 2005, supported by an ARC Linkage Grant to Garry Davidson and Jabiru Metals Ltd. Susan's research is focusing on the volcanic architecture of the succession that hosts the recently discovered Jaguar VHMS deposit. The succession is Archaean in age but very well preserved and includes a variety of pillow basalts and related volcanoclastic facies, as well as more felsic volcanoclastic and coherent units. Susan will also provide the first review of the alteration facies and new information on the ore mineralogy and textures.

A new research PhD project examining the setting and origin of the Ridgeway gold and silver deposit, South Carolina, began at the end of 2005. Joe Moye completed a first field season of drill core logging, mapping and sampling the Persimmon Fork Formation, host to the world-class Ridgeway ore bodies. The style of mineralisation and its setting have been contentious since discovery of the deposit, in part because exposure is poor and locally the effects of alteration are intense. In addition, some aspects of the host rocks and their relationship to the ore bodies have been misunderstood. Joe will initially work on developing an accurate geological framework, before embarking on detailed mineralogical and compositional studies. This project is generously supported by Kennecott Minerals.

Carlos Rosa is undertaking PhD research on the volcanic successions in the Iberian Pyrite Belt, Portugal. These successions host one of the richest massive sulfide districts in the world, and one of the largest single massive sulfide deposits (Neves Corvo). This research is jointly supervised by Dr Jorge Relvas at the University of Lisbon and receives

support from the Portuguese Science and Technology Fund, INETI and SOMINCOR mining company. Carlos has mapped sections in Portugal, including the host succession to the giant Neves Corvo massive sulfide deposit, and Spain. He has concluded that two major felsic volcanic associations are present throughout the belt, repeated in different proportions and different order: one association is dominated by submarine felsic lavas and the other is mainly composed of felsic pumice breccia generated by explosive eruptions. Other important conclusions are that most sections are dominated by extrusive (rather than intrusive) units, and that peperite is a very minor component of the volcanic succession. Carlos' efforts in 2005 were devoted mainly to writing his thesis, due for submission early in 2006.

Members of the Volcanology Program (Stuart Bull and Jocelyn McPhie) participated in fieldwork examining the style and setting of banded chalcedony and barite veins in the Early Archaean Dresser Formation, Western Australia, a project supported by an ARC Internal Research Grant to Anthony Harris and by Haoma Mining NL. The team also included Noel White and Bob Skrzeczynski (Haoma Mining NL). The Dresser Formation is a well-preserved pillow basalt succession and famous as the host to thin sedimentary units that contain structures thought to be stromatolites. These probable stromatolites are amongst the oldest known and appear to be closely associated with the banded chalcedony and barite veins. The pillow basalt succession includes many fine examples of formerly hollow pillows that had been filled by banded chalcedony prior to any compaction, implying a close temporal relationship between volcanism and hydrothermal activity.

Andrew Stewart's PhD thesis on the volcanic facies architecture of Milos, Greece, was passed and he graduated in August, 2004. This research was conducted in collaboration with Dr Georges Vougioukalakis of the Institute of Geology and Mineral Exploration, Athens, and with Silver and Baryte SA, an exploration company active on the island. Andrew has published two papers and a third was accepted in 2005: Facies architecture and evolution of an Upper Pliocene-Pleistocene felsic submarine-to-subaerial volcanic island, Milos, Greece (Stewart and McPhie, *Bulletin of Volcanology*).

The new book by Cathryn Gifkins, Wally Herrmann and Ross Large — *Altered Volcanic Rocks* — was published early in 2005 and has been very well received. The book deals with the textural, mineralogical and compositional changes that accompany alteration of volcanic successions, especially hydrothermal alteration associated with volcanic-hosted massive sulfide deposits. The effects of diagenetic alteration and regional metamorphism are also reviewed. Summaries



Spectacular scenery featuring resistant "chert" ridges in the pillow basalt-dominated Dresser Formation, Pilbara region, Western Australia



Bob Skrzeczynski, Stuart Bull, Noel White and Anthony Harris, sampling banded chalcedony veins in the Early Archaean Dresser Formation, Western Australia



Pseudomorph textures in banded chalcedony, Dresser Formation, Western Australia

of alteration processes and products are complemented by a series of case studies based on deposits in Australia and overseas, incorporating many of the outcomes of AMIRA project P439 ('Studies of VHMS-related alteration: geochemical and mineralogical vectors to ore').

Project 2.2 CORE

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

S Allen, J McPhie, V Kamenetsky; K Cashman, P Wallace (UOregon), R Fiske (Smithsonian Institution), Y Tamura (IFREE); PhD student K Bull

Rhyolitic pumice breccia is a characteristic facies in submarine volcanic successions and common in the host successions to massive sulfide deposits. In most cases, the pumice is thought to have been produced by explosive eruptions from submarine vents and yet very little is known about the behaviour of subaqueously-erupted pumice and subaqueous explosive eruption plumes. Moreover, there are currently no criteria for distinguishing pyroclastic pumice clasts from pumiceous lava clasts. A better understanding of the origins and characteristics of submarine rhyolitic pumice breccias also underpins correct facies identification and interpretation. Major textural and compositional changes occur in glassy, porous pumice breccias during compaction, diagenesis, hydrothermal alteration and metamorphism. This project involves studies of modern (Izu-Bonin Arc, Japan), Pliocene (Milos, Greece), Pleistocene (Yali, Greece) and Palaeozoic (Cambrian, western Tasmania; Early Devonian, New South Wales) pumice breccias.

In 2005, Sharon Allen obtained new analytical data on seafloor pumice clasts collected while Research Scientist on board the *Natsushima* in collaboration with Dr Yoshihiko Tamura (Group Leader, Institute for Frontier Research on Earth Evolution, IFREE). The pumice was generated by submarine eruptions of volcanoes of the Izu-Bonin Arc south of Japan. Permeability measurements on the samples produced surprising results: the permeability of subaqueously erupted pumice is not significantly different from subaerially erupted pumice, and the porosity is dominated by interconnected vesicles that allow rapid water-logging. Magmatic water content is one of the most important controls on vesicularity and best determined by FTIR analyses on glass but this technique does not work well on submarine pumice clasts (the glass is too thin and vesicular, and has typically been hydrated). Instead, water contents of tiny glass inclusions trapped within quartz phenocrysts were determined, in collaboration with Vadim Kamenetsky (University of Tasmania) and Paul Wallace



Submarine pumice breccia on Milos, Greece

(University of Oregon). The data suggest that the magmas had high water contents (~5 wt%), sufficient to counteract the effects of the extra confining pressure on exsolution.

Sharon and Richard Fiske (Smithsonian Institution) have also used the modern seafloor samples in a series of experiments exploring rates of saturation and settling behaviour of submarine-erupted pumice. They have demonstrated that submarine erupted pumice is initially buoyant but, on cooling, the magmatic steam in vesicles condenses, causing the pumice to sink. They have prepared a manuscript showing how the physical properties of magmatic steam affect the density of freshly erupted submarine pumice.

Three now-uplifted but originally submarine pumice deposits in Greece were sampled to further clarify the character and origins of submarine rhyolitic pumice breccias. These deposits (Yali, Filakopi, Bombarda) are amongst the best exposed and preserved submarine pumice deposits in the world, and were generated by contrasting mechanisms: Filakopi involved an eruption driven by decompression of the magma, Bombarda was a dome-related explosive event, and Yali involved deep-

seated eruptions through a magmatic foam. Vesicularity studies commenced in October in collaboration with Kathy Cashman, University of Oregon, and the data will be compared with similar data from the modern seafloor samples.

Ancient pumice breccias commonly display a bedding-parallel foliation defined by altered and compacted pumice clasts (fiamme). The texture strongly resembles eutaxitic texture produced by compaction of hot pumice in welded pyroclastic deposits. However, the texture can also result from early diagenetic compaction and alteration of glassy pumice in a wide variety of non-welded pumice-rich facies. Many examples occur in the Early Devonian Ural Volcanics, New South Wales. Kate Bull and Jocelyn McPhie have completed a manuscript on fiamme in volcanic successions, including a new definition that caters for fiamme textures of unknown origin that are so common in strongly altered volcanic rocks.

Project 2.3 CORE

Facies architecture of volcanic successions that host porphyry copper-gold ore deposits in arc settings

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

Further research was conducted on the Forest Reefs Volcanics in New South Wales, in collaboration with Program 3. Joel Kitto studied the volcanic facies, stratigraphy, alteration and mineralisation of the Cadia East porphyry copper-gold deposit, one of five such deposits in the Cadia district. The project was supported by Newcrest Mining Limited and based on data from detailed drill core logging integrated with textural and geochemical analyses. Joel clarified the structure of the Cadia East succession and refined current ideas on the style and setting of the Ordovician volcanic activity. He also determined the order, products and distribution of the hydrothermal alteration and ore-forming events.

This project built on an earlier major research project that involved collaboration with Program 1 (Project 1.4) on the Ordovician volcanic successions of central western New South Wales. The final report was presented in 2002. A Thematic Issue of the *Australian Journal of Earth Sciences* devoted to the results of the project is due for publication in 2006 and includes papers by Rick Squire, Jocelyn McPhie, Carol Simpson and Wally Herrmann.

Project 2.7 CORE

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

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

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 both massive sulfide and precious metal ore deposits, and yet presently there are no physical constraints linking deposit characteristics with origin. These physical constraints are being studied by Sharon Allen, using both experimental and field-based approaches.

The experimental phase of the research was completed in collaboration with Armin Freundt at the Experimental Volcanology Laboratory, GEOMAR, Germany. The experiments involved hot-dry, cold-dry and cold-wet pyroclastic samples being resedimented into a water-filled flume. Each experiment produced a gravity current from which a volcanoclastic deposit formed on the base of the flume. Textural, grain size and componentry data were then measured for a series of samples taken along the flume. The important outcomes of these experiments are that (1) pumiceous deposits are inherently unstable on slopes greater than a few degrees and will be easily remobilised, (2) different resedimentation processes can generate texturally similar facies, and (3) distance from source is one of the main controls on facies characteristics. Sharon and Armin have submitted a manuscript to *Sedimentology* summarising the results of the experiments.

The field-based research on the Miocene Manukau volcanic complex, Northland, New Zealand, was completed in 2005. Sharon and co-author Bruce Hayward (Geomarine Research) have presented their results in a manuscript submitted to the *Bulletin of the Geological Society of America*. The Manukau succession provided data for a facies model of a submarine volcanoclastic fan that accumulated on the slopes of a basaltic to andesitic volcanic island. Dramatic changes in lithofacies character occur laterally, primarily in response to changes in eruption style (explosive versus effusive), eruption frequency and distance from source vents, and subaerial emergence of the source volcano.

Project 2.9

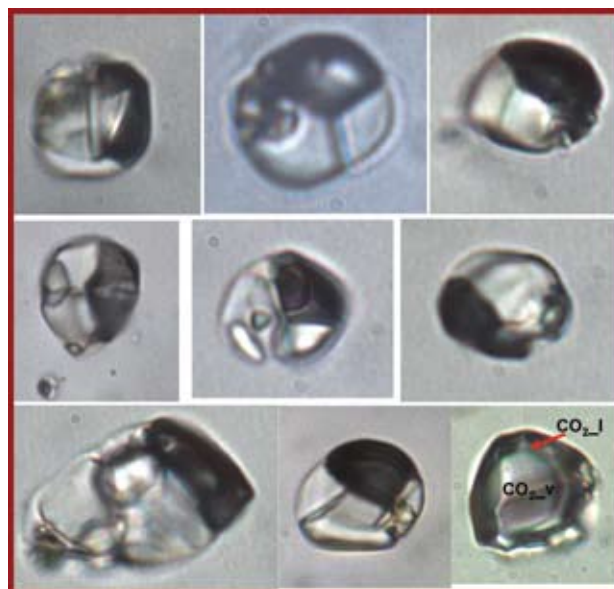
Volatile budget, volcanology and source-vent locations of voluminous felsic lavas: Mesoproterozoic Gawler Range Volcanics in South Australia

S Allen, F Della Pasqua, V Kamenetsky, J McPhie; M Lackie (Macquarie U), C Simpson (UNewcastle); G Ferris, M Schwartz (PIRSA); Honours student A Bath

This project builds on the results of a field-based study of the volcanology and facies architecture of the Mesoproterozoic Gawler Range Volcanics in South Australia (Project 2.4). The Gawler Range Volcanics is a continental intraplate volcanic province that includes voluminous ($>10^2 \text{ km}^3$) felsic lavas. Information on the location and nature of the source vents for the lavas is critical for calculations of outflow distances and eruption rates, and for inferences regarding magma rheology. Magma rheology also depended on the pre-eruption volatile content which can be determined using a range of microanalytical techniques applied to melt inclusions in quartz phenocrysts. The project was funded by a Discovery Grant from the Australian Research Council and also generously supported by Primary Industries and Resources South Australia. The results are of interest to mineral exploration as the volcanic succession and related granitoids host the giant Olympic Dam copper-gold-uranium deposit.

The Eucarro Rhyolite ($>500 \text{ km}^3$) was selected for palaeoflow study as its extent and characteristics have been carefully documented in our previous work. Two palaeoflow techniques have been attempted. One technique (petrofabric analysis) involves statistical analysis of the lineations defined by the long axes of elongate phenocrysts (principally plagioclase) on oriented slabs. Fernando Della Pasqua carried out petrofabric analyses on samples from a series of base-to-top sections through the Eucarro Rhyolite. The other technique is anisotropy of magnetic susceptibility (AMS), and involves measurement of the magnetic properties of cores drilled from oriented samples. The AMS measurements were performed by Dr Mark Lackie at Macquarie University.

Results from the AMS analyses confirm that the Eucarro Rhyolite has a well-preserved magnetic fabric. There are no published data on the AMS foliation patterns in extensive felsic lavas but the Eucarro Rhyolite AMS data match the patterns shown by mafic lavas. The AMS data suggest that much of the lava followed northerly and easterly directed outflow paths from a source(s) located to the southwest of present outcrops. Directions defined by the long axes of elongate phenocrysts are harder to interpret and show greater variability than the AMS foliation data. The results have been presented in a manuscript submitted to the



Complex multiphase melt and fluid inclusions in quartz rhyolites in the Mesoproterozoic Galwer Range, South Australia

Journal of Volcanology and Geothermal Research.

The Eucarro Rhyolite is one of three exceptionally large-volume ($>500 \text{ km}^3$), high-silica units in the upper part of the Gawler Range Volcanics that contrast in dimensions, composition, texture and geometry with the units in the lower Gawler Range Volcanics. New work on the facies architecture of the succession by Sharon Allen and co-authors (McPhie, Ferris and Simpson) has been presented in a paper accepted in 2005 by the *Journal of Volcanology and Geothermal Research*. A second manuscript focussing on the youngest of the extensive felsic lavas, the Yardea Dacite, is in the final stages of preparation.

Another direction in this project involves a detailed examination of melt inclusions in quartz phenocrysts in a number of units in the Gawler Range Volcanics. Perfectly preserved melt inclusions were originally discovered by Vadim Kamenetsky and Nicole Morrow (Honours student 1997) in the course of the previous project on the Gawler Range Volcanics (project 2.4) (Morrow et al. 2000). Vadim has extended this research, in part through the Honours project undertaken by Adam Bath (2004-2005). Most of the data are from quartz in the Eucarro Rhyolite and in granitoid lithic clasts that are locally abundant and coarse. There are three quartz populations: (1) Conventional quartz phenocrysts that contain “normal” silicate melt inclusions representative of crystallising felsic melt. The major element compositions of the melt inclusions are similar to the host rock, but are less fractionated than the groundmass compositions. There is also an overall similarity in the rare-earth element abundances. However, the abundances of some elements (e.g., fluorine, molybdenum, tungsten,

uranium, thorium, tin and lead) are significantly higher (up to 1–2 orders of magnitude) in the melt inclusions compared to whole-rock and groundmass compositions. Enrichment of melt inclusions in fluorine (up to 1.25 wt%) can be important in understanding the predominantly effusive eruption style of magmas that had high silica contents, as fluorine is known as an effective melt depolymeriser. (2) Anhedral quartz grains that are a major constituent of the granitoid lithic clasts contain diverse melt and fluid inclusions. The inclusions contain coexisting silicate melt (glass), alkali- and iron-bearing chloride melt/fluid and CO₂ fluid, indicating unmixing into at least three immiscible phases. (3) Fine quartz crystals occur in micro-miarolitic cavities and veinlets in some rhyolitic lavas. These quartz crystals are associated with apatite, zircon and fluorite and represents the latest crystallisation event of the magma, during and after emplacement, and largely unrelated to magma chamber processes.

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.

Joe Moya: Origin and setting of the Ridgeway gold-silver ore deposit, Carolina Terrane, USA.

Carlos Rosa: Character and setting of volcanic successions that host massive sulfide ore deposits in the Iberian Pyrite Belt, Portugal.

Other achievements and activities

- Jocelyn McPhie and Bruce Gemmell presented a short course on ‘Volcanology and VHMS deposits’ to Oxiana Limited exploration geologists.
- Kelsie Dadd (Macquarie U) visited CODES as part of her study leave research, collaborating with Jocelyn McPhie and other members of the Volcanology Program.
- Sharon Allen is on the Editorial Boards of both the *Australian Journal of Earth Sciences* and the *Journal of Volcanology and Geothermal Research*, and Leader of the IAVCEI Commission of Explosive Volcanism. Sharon is also on the Executive Committee of LAVA, the Geological Society of Australia Special Interest Group in volcanology.
- Jocelyn McPhie is an Associate Editor for the *Bulletin of Volcanology* and Vice President of the International Association for Volcanology and Chemistry of the Earth's Interior. Jocelyn is also a member of the Executive Committee of the Geological Society of Australia.

PhD projects in Program 2

Susan Belford: Volcanic architecture of the Jaguar VHMS host succession, Western Australia.

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

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 copper-lead-zinc and epithermal gold-silver in modern and ancient, subaerial and subaqueous environments in Australia and the Pacific Rim.

Team Leader

Bruce Gemmell

Team Members

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

PhD Students

Singoyi Blackwell, Kim Denwer, Russell Fulton, Tim Ireland, Steve Lewis, Claire McMahon

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 Ottawa, 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, Instituto Geológico e Mineiro (Portugal), Istanbul Technical University

Highlights

Publication of the book *Altered Volcanic Rocks* by Gifkins, Herrmann and Large

Graduation of a Master of Exploration Geoscience student (Albert Chong) and submission of Steve Lewis' PhD thesis

Invited talks by Program 3 researchers at international meetings — Geological Association of Canada, New Zealand Minerals Conference, and Western Canadian Cordilleran Roundup

Completion of the Industry-ARC Linkage project on trace element analysis of sulfide by LA-ICPMS: new applications for exploration vector geochemistry

Participation by Program 3 researchers in the IGCP project Bathurst VHMS district field meeting

Core Projects

- 3.1 Magmatic-volcanic evolution and generation of hydrothermal fluids in the backarc environment.
- 3.3 Active base and precious metal-rich massive sulfide deposition associated with submarine volcanism.
- 3.5 The nature, diversity and genesis of ancient massive sulfide copper-lead-zinc-silver-gold deposits in volcanic arc settings.
- 3.8 Subaqueous epithermal mineralisation, Conical Seamount, Tabar-Feni island chain (Papua New Guinea).

Project 3.1 CORE

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

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

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

This project was completed in 2004. Ross Large presented an invited keynote address to the Geological Association of Canada annual meeting in May 2005 in Halifax summarising the results from our research with the title 'Magmas to massive sulfides: the Tasmanian perspective'.

Project 3.3 CORE

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

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

Manus Basin, Papua New Guinea: The actively forming hydrothermal deposits at the felsic-hosted PACMANUS field 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). A paper by Petersen et al. was published in *Marine Georesources and Geotechnology* outlining the shallow drilling of seafloor hydrothermal systems using the BGS Rockdrill. This paper is based on the first use of the BGS Rockdrill on modern seafloor hydrothermal mineralisation at PACMANUS (Eastern Manus basin) and Conical Seamount (New Ireland Fore-Arc) and Papua New Guinea. At Roman Ruins site within the PACMANUS field, drilling revealed high base- and precious metal contents at depth, similar to those in chimneys collected from the surface. The mineralogy observed in drill core samples from Roman Ruins is also

similar to those of surface samples, however, the amount of As-Sb-sulfosalts and galena seems to be lower at depth. The nodular texture observed in some cores strongly resembles cores from the central part of the TAG hydrothermal field that were recovered during Ocean Drilling Program Leg 158. These textures were interpreted to be the result of multiple episodes of hydrothermal activity and associated zone refining of elements. Although at a smaller scale, a similar decrease in the concentration of several elements down core is evident in the breccia sections at the Roman Ruins site, with enrichment of the precious metals gold and silver, as well as zinc, copper, and lead at the seafloor. The abundance of anhydrite, the occurrence of reworked sulfides, and the complex intergrowths observed throughout the core sections at PACMANUS imply that seawater penetration, reworking of primary sulfide material and possibly multistaged hydrothermal activity are important processes during the near-seafloor evolution of the deposit.

Okinawa Trough, Japan: Collaborative research on modern seafloor system focussing at JADE hydrothermal field, Okinawa Trough was undertaken by Khin Zaw with researchers from Chinese Academy of Geological Sciences (CAGS), Beijing and Geological Survey of Japan to understand the importance of magmatic input of ore fluids and metals. The Okinawa trough is an active, back-arc-spreading basin in which hydrothermal fluids are venting from black and white smoker chimneys along a felsic volcanic ridge. The paper from the outcome of this research (Zengqian et al) using the fluid inclusions and isotope geochemistry has been published in the *International Geology Review*.

Project 3.5 CORE

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

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

There are many styles of ancient VHMS deposits. These include mounds, pipes, sheets, layered, stacked, stockwork, disseminated, distal re-worked and cyclic layered deposits. Our research suggests that a spectrum of massive sulfide

deposit types develop in submarine volcanic environments. These types range from typical seafloor VHMS (zinc-lead-copper-silver-gold) deposits, through sub-seafloor shallow-water, replacement gold-rich epithermal styles, to deep sub-volcanic intrusion-related copper-gold-rich styles. To improve our understanding of the formation of VHMS deposits, a variety of ancient and modern deposits has been selected for detailed studies. These studies concentrate on the geological and geochemical attributes of the deposits, and aim to characterise the spectrum of VHMS deposits and their origins in submarine volcanic environments.

During 2005, research was undertaken on the following VHMS deposits: Mount Lyell (Tasmania), Jaguar, (Western Australia), Lewis Ponds (NSW), Myra Falls (Canada), Greens Creek (Alaska), and Feitais (Aljustrel, Portugal), Neves Corvo (Portugal), Tharsis (Spain), and Hongtoushan and Baiyinchang (China). Brief reports on the individual sub-projects within this overall study of VHMS and related deposits are given below.

Australia

Kim Denwer continued his PhD project research at Mount Lyell into how the giant Mount Lyell copper-gold orebody formed. Several months of fieldwork was followed by detailed SWIR (PIMA) analyses of alteration which outlined the alteration zonation surrounding the Prince Lyell orebody. This alteration study was coupled with a magnetic susceptibility study, to understand the 3-D relationships between magnetite, pyrite and copper-gold mineralisation.

Michael Agnew published a paper from his 2003 PhD thesis entitled 'Lewis Ponds, a hybrid carbonate and volcanic-hosted polymetallic massive sulfide deposit, New South Wales, Australia' in *Mineralium Deposita*, Agnew et al. utilise textural, composition and isotopic studies to propose that low temperature dolomitisation of limestone-bearing facies in the main zone host sequence created secondary porosity and provided a reactive host rock for fluid-rock interactions. The main zone ore body was interpreted to form by lateral fluid flow and sub-seafloor replacement of the poorly sorted breccia and sandstone beds. Base-metal sulfide disposition probably resulted from dissolution of dolomite, fluid mixing and increased fluid pH. In contrast the Toms zone ore body was emplaced on the sea floor above a zone of focused up-flowing hydrothermal fluids.

Susan Belford commenced work on her PhD project investigating the genetic and chemical characterisation of the pristine Archean Jaguar base-metal deposit and made three field visits to the Jaguar prospect site. Her work to date has centred on logging three geological sections



Ross Large, chief geologist Katherine Evdokimova and Valeriy Maslennikov at Sukhoi Log, Russia



Jandam epithermal vein, Pajingo district, Queensland, Australia

through the deposit, including the additional step of incorporating the information into graphic sections. During this phase of study it has become evident that more detailed facies analysis of some drill holes between sections will be necessary, especially around areas that display rapid variation between sections. Susan's other activities to date have included a first round of immobile element geochemistry, which is aimed at defining robust chemical parameters for subdividing the volcanic stratigraphy, petrography of fresh and altered volcanic rocks, and a first phase of on-site and laboratory based acquisition of long wave PIMA spectra, which is aimed at assisting the identification of alteration zoning.

International

Albert Chong completed and graduated with his Master of Exploration Geoscience degree. His project study focused on the geology, mineralisation, hydrothermal alteration, metal zonation and genesis of the Jurassic Ridge Zone



Ross Large, Jan Peter (GSC), Fernando Tornos, and Wayne Goodfellow (GSC) examining drill core, Bathurst #12 VHMS deposit, New Brunswick, Canada

West orebody, Myra Falls, British Columbia, Canada. The Ridge Zone West is a zinc-lead-copper-gold-silver-barium-rich VHMS deposit composed of stacked lenses of disseminated to massive mineralisation associated with fine and coarse-grained volcano-sedimentary rocks. Four phases of mineralisation are identified in the Ridge Zone West deposit: (1) Lower lens mineralisation formed on the palaeo-seafloor with fine-grained facies sediments during a period of quiescence and consist of disseminated and banded mineralisation with pyrite framboids; (2) Main lens mineralisation is the most economically significant mineralisation observed, consists of sphalerite, pyrite, chalcopyrite, galena, tetrahedrite-tennantite, and barite, and is formed by infiltration and replacement of dominantly permeable, coarse volcanoclastic deposits in a shallow sub-seafloor environment. Sulfide textures include anastomosing veins progressing up to massive sulfide with relic lithic clasts; (3) Upper lens mineralisation deposited on the paleo-seafloor during a secondary period of quiescence is composed of sulfide bands with graded grains and soft-sediment deformation textures, and (4) Upper lens mineralisation comprising late pyrite-chalcopyrite \pm sphalerite veins crosscutting siliceous mudstone breccias. Albert's geologic and genetic model will be an important aid to exploration in the Myra Falls district.

Based on research from her PhD thesis, Sarah Jones published a paper in *Economic Geology* (Jones, Herrmann and Gemmell) on the shortwave infrared spectral characteristics of the HW horizon and their implications for exploration in the Myra Falls volcanic-hosted massive sulfide camp (Vancouver Island, Canada). This study showed that SWIR analysis is an effective field-based exploration tool for quantifying the intensity of alteration

associated with VHMS orebodies, and that trends in mineral compositions, even in very fine-grained rocks, can be used as mine-scale vectors to ore. Another paper from her thesis (Jones, Gemmell and Davidson) on the origin of the caprocks above VHMS deposits using evidence from petrology and fluid inclusions at the Myra falls VHMS camp, was submitted to *Economic Geology* for review. This paper has been accepted with minor revisions and will be published in 2006.

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 zinc-lead-silver-gold deposit on Admiralty Island in southeastern Alaska. Limited work was undertaken due to a suspension of candidature due to personal reasons but included whole rock chemistry, whole rock stable isotope chemistry, mineral chemistry, petrographic studies, and data analysis.

A new industry-funded (Kennecott Greens Creek Mining) PhD study of the footwall stratigraphy at the Greens Creek deposit was initiated in 2005 by Patrick Sack. This study will characterise the geologic and structural setting of the footwall phyllite and associated footwall lithologies with the aims of determine the depositional environment and architecture of the footwall phyllite and its relationship to massive sulfide formation. U/lead dating of zircons will be a focus in order to accurately determine the ages of the footwall stratigraphy.

Mike Solomon, in conjunction with Carlos Inverno (Instituto Geológico e Mineiro, Lisbon), Fernando Tornos (Instituto Geológico y Minero de España, Salamanca), Orlando Gaspar (Consultant, Porto), and the senior mine geologists of Somincor Ltd at Neves Corvo, is studying the genesis of massive sulfide deposits in the IPB of Spain and Portugal. This year saw completion of two papers for the *Economic Geology* Special Issue on massive sulfide deposits, one on the Tharsis deposit, now finally accepted, by Tornos, Solomon and Conde (CODES and IGM, Salamanca), and one on the Feitais (Aljustrel) deposit, still awaiting final acceptance, by Inverno, Solomon, Barton and Foden (IGM Lisbon, CODES, Universities of Arizona and Adelaide). In each case, though with different types of data, a case has been made for deposition in a brine pool. This brings the total of proposed brine pools in the IPB to 10, all but one having fluid inclusion data from stockwork vein quartz. In the Feitais paper we have outlined evidence that allows us to follow Nehlig et al. (1998) at Rio Tinto in suggesting that the ore-forming fluids were overpressured relative to convective fluids.

Mike Solomon has continued his collaborative at Neves Corvo. One project is investigating the formation of the

Lombador and Neves Norte ore lenses, Neves Corvo, in collaboration with Carlos Inverno (Instituto Geológico e Mineiro) and Alfredo Ferreira, Paulo Caetano, and Nelson Pacheco (Somincor Ltd). Limited work has been carried out on core samples from the Lombador orebody at Neves Corvo. Some of the samples show clear evidence of pyrite sedimentation (layering, cross bedding), presumably the result of reworking of sulfide bodies on the sea floor, thus adding to the otherwise rather limited evidence of sulfide deposition on the seafloor.

Mike Solomon was also busy with a protracted review of the geology of the Bathurst, Canada mining camp, made possible by a recent *Economic Geology* monograph, that has resulted in preparation of two manuscripts. One compares the Iberian Pyrite Belt and Bathurst ores, and their host rocks and histories, concluding that similar processes were responsible for ore deposition in each area. It also discusses the anoxic water column model proposed in the literature and finds it not viable. This paper is close to submission to *Mineralium Deposita*. The other paper compares the geological histories of the two areas.

Collaborative research on VHMS deposits in China by Khin Zaw with Chinese colleagues from CAGS and Nanjing University has continued. A paper on the Hongtoushan copper-zinc-gold-silver deposit, the only Archaean VHMS deposit in China, by Lianxing et al. has been submitted and accepted by *Ore Geology Reviews*. In a second project, a fluid inclusion and stable isotope study as evidence for sub-seafloor replacement and fluid mixing at the Baiyinchang massive sulfide deposit, China has been submitted by Zengqian et al. to *Economic Geology*. The Baiyinchang VHMS deposit is the largest VHMS copper deposit in China and hosted in an Early Cambrian, submarine, felsic volcanic succession associated with an overlying basaltic lava in north Qilian Orogen, northwestern China. The deposit forms as a pyrite-chalcopyrite pipe comparable with deposits, such as the Mount Lyell deposit in the Cambrian Mount Read Volcanic belt of Western Tasmania, Ordovician Highway and Reward deposits, Mount Windsor subprovince, Queensland and the Cambrian Bawdwin deposit in NE Myanmar.

Project 3.6

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

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



Patrick Sack, Erika Greiner, Christian Schraeder and Ron Berry on traverse at Greens Creek VHMS deposit, Alaska

Cathryn Gifkins, Wally Herrmann and Ross Large published the highly anticipated book *Altered Volcanic Rocks*, which is based largely on the results from AMIRA project P439. This 275-page book which contains 105 figures and over 50 comprehensive ore-deposit data sheets, brings together results of CODES research on the textures, alteration, geochemistry and formation of altered volcanic rocks amassed over the past 15 years. Over 400 copies of the book had been sold to June 2005, equally divided between Australian and international readers.

Based on Thomas Monecke's 2003 PhD research which investigated how volcanic facies architecture of the host succession helped to unravel the temporal and spatial relationships between volcanism and massive sulfide formation at the Waterloo VHMS prospect in the Mount Windsor Subprovince, Queensland, a paper detailing the results (Monecke, Gemmell and Herzig) has been accepted by *Economic Geology*. In addition, Thomas published a paper proposing a dynamic model for the metasomatic enrichment of base and precious metals in VHMS deposits (Monecke et al.) in *Earth and Planetary Science Letters*.

Project 3.7

Sulfur geochemistry of hydrothermally altered volcanic terrains

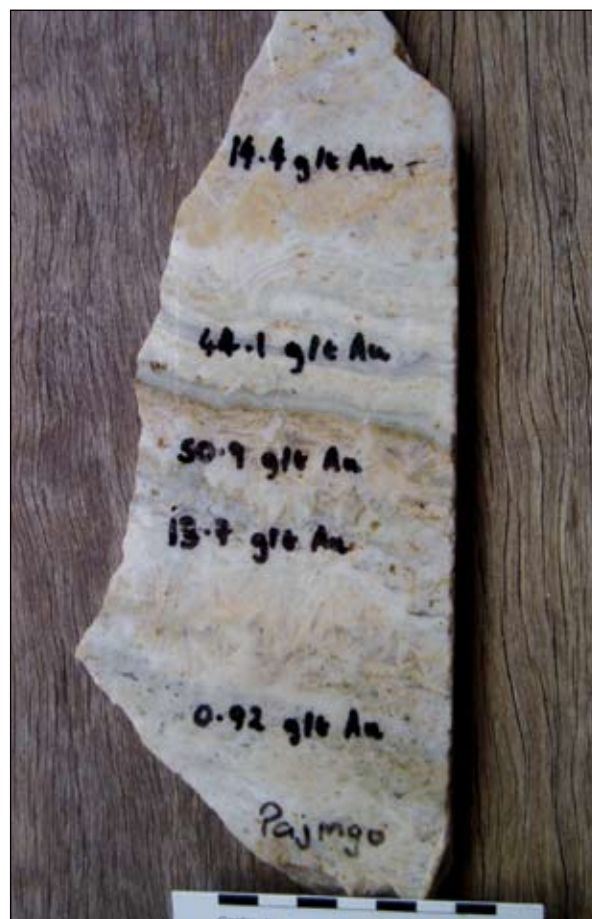
G.J. Davidson, M Roach, R Berry, PhD student S Lewis, volunteers A Wakefield and B Kimber; J Alt (U Michigan); J Karson (Duke U); C Finn (USGS); A Brown (MRT, Tasmania), D. Teagle and PhD student R Coggan (U Southampton)

Based exclusively on Macquarie Island oceanic crust (~10 Ma old), and fully logistically supported by the Australian

Antarctic Division (AAD), this program is employing the sulfur geochemistry of altered seafloor rocks to understand the nature of seafloor hydrothermal activity. The application to land-based mineral exploration is an increase in our comprehension of the nature and distribution of hydrothermal activity in a rifted area which had extension rates comparable to those of continental rifts (1–2 cm/yr). After detailed documentation of dyke-basalt sections in a previous phase, the program is currently using a range of regional methods to identify fluid flow pathways in the crust. The 2006 plan is to undertake detailed studies to evaluate the nature of alteration along these identified fluid pathways, including evaluation of S isotope chemistry.

In 2004 we began a major detailed magnetic mapping of the island, involving an amazing 3500 line kilometres of ground-based data acquisition by volunteers Bronwyn and Andy. They continued this program through to mid-March 2005, including approximately four complete circumnavigations of the island to obtain shallow water marine magnetic data. Our volunteers wintered on the island to obtain the data, because some critical areas are off-limits in the warmer months due to Sub-Antarctic wildlife breeding. Twenty 3–5 kg samples were also obtained by the volunteers, and these began to be processed in 2005 for paleomagnetic orientations under the supervision of Dr Bob Varga and Jeff Karson. In 2006, the onshore magnetics will be supplemented by a heli-mag survey, in collaboration with AAD and the USGS. The aim of this two day survey is to determine the extent of hydrothermally altered crust, and crustal features such as massifs of serpentinised ultramafics. The USGS are also interested in the internal structure of the strike-slip formed submarine mountain chain.

In other ongoing Macquarie Island work, PhD student Steven Lewis (Ron Berry additional supervisor), completed his study of the processes and history of several major hydrothermally altered seafloor fault zones. The final laboratory-based phase included (1) quartz-based oxygen isotopes in collaboration with U Michigan which constrained fluid temperatures at four different sites; (2) LA-ICPMS analysis of pyrite trace elements in fault complexes that transgress the sheeted dyke-basalt boundary; (3) S-isotope determinations from pyrite in the fault zones; and (4) mineral chemistry of chlorite to further constrain temperature. The thesis entered examination at the end of 2005. Collaborative research on the hydrothermal geochemistry of oceanic crust continued with the Michigan and UK groups. This included the submission of a second PhD thesis for the year, in this case dealing with Sr isotope systematics of Macquarie Island and other ocean floor sections by Roz Coggan, U Southampton.



Multi-textured epithermal vein with associated gold grades, Pajingo district, Queensland, Australia

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)

Conical seamount is a submarine alkali basalt volcano situated 10 km south of Lihir Island in the Tabar-Feni island chain, Papua New Guinea. Polymetallic (zinc-lead-silver-gold-arsenic-antimony) veins, pyritic stockwork, and hydrothermally altered rocks discovered on the summit of Conical seamount represent an unique example of submarine gold mineralisation with mineralogical, chemical, and textural characteristics common to some subaerial epithermal systems. A paper by Petersen et al. was published in *Marine Georesources and Geotechnology* outlining the shallow drilling of seafloor hydrothermal systems using the BGS Rockdrill. This paper is based on the first use of the BGS Rockdrill on modern seafloor hydrothermal mineralisation at Conical Seamount (New Ireland Fore-Arc) and PACMANUS (Eastern Manus basin),



Native gold in epithermal vein, Pajingo district, Queensland, Australia

Papua New Guinea. Drilling the upper five meters at the top of Conical Seamount has provided evidence for more widespread alteration and mineralisation in the subsurface. The extension of mineralisation to the western part of the summit plateau and the recovery of altered material below a carapace of least-altered volcanic rocks indicates the possibility of a larger gold-mineralised hydrothermal system at depth. At Conical Seamount deeper drilling is now required to fully assess the depth extent of the mineralisation. This paper suggests that shallow drilling is a fast and cost efficient method that bridges the gap between surface sampling and deep (ODP) drilling and will become a standard practice in the future study of seafloor hydrothermal systems and massive sulfide deposits.

Project 3.9

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

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

Bruce Gemmell was invited by the New Zealand Minerals Conference to present a keynote talk on the geology, geochemistry and exploration implications of hydrothermal alteration associated with epithermal gold-silver deposits. This paper was a summary of the key results of the AMIRA P588 project.

The results of the ARC Linkage/AMIRA P588 research project are to be included in a proposed Special Issue of *Economic Geology* tentatively titled 'Setting, geochemistry and exploration significance of alteration associated with epithermal gold-silver deposits'. It is anticipated that this issue will contain 12 papers (P588 research plus invited

contributions) on epithermal deposits and districts from New Zealand, Indonesia, Philippines, Argentina and Australia. Bruce Gemmell and Stuart Simmons are guest editors and in 2005 the papers were written and have been through one round of reviews. It is anticipated that the Special Issue will be published in late 2006 or early 2007.

Project 3.10

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

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

This project, led by Rod Allen, Fernando Tornos, Jon Peter and N Cagatay, aims to compare a number of the world's important VHMS districts in order to define the key geological events that control the distribution and timing of high-value VHMS deposits; and thereby develop new criteria for locating these ore deposits. Present knowledge suggests that VHMS deposits form at specific times (in specific stratigraphic intervals) in marine, volcanically active, extensional basins. We propose that the key global issue to be addressed is to document the connection between VHMS ore formation, magmatism and extensional tectonics. In this IGCP project we will focus on the following critical steps: (1) define the main different styles of VHMS ore deposit, (2) define the character and stratigraphic position of the ore horizons that host these VHMS deposits in about ten VHMS districts, (3) assess how far these horizons can be followed and in what way they change with distance from ore, (4) where possible, define the volcanic, tectonic or volcano-tectonic structure(s) that appear to localise VHMS deposits, (5) assess whether the VHMS horizons in each district are part of one or two specific basin-wide favourable stratigraphic intervals, (6) interpret the significance of these favourable stratigraphic intervals in terms of basin evolution, and (7) test the results and hypotheses on the other less well known VHMS districts.

This project is an integrated multi-disciplinary project with field and laboratory components. The work includes syntheses and new studies of volcanic architecture, regional tectonic evolution, regional magmatic evolution, radiometric dating of ore horizons, and studies of the various different styles of VHMS deposits. A network of over 50 of the world's leading scientists (from 22 nations)

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

In 2004, Ross Large and Bruce Gemmell attended a field workshop in the Bathurst mining camp, New Brunswick, Canada, held in conjunction with the GAC-MAC annual meeting in Halifax. Ross Large has been invited to make a keynote presentation on CODES research on VHMS deposits at the Halifax meeting.

Project 3.1.1

Epithermal deposits of the Pacific Rim

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

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.

Bronto Sutopo continued his thesis research at the Martabe high-sulfidation copper-gold deposit, Sumatra, Indonesia. The Martabe gold district is situated within and adjacent to a Late Tertiary porphyritic dacite-andesite dome and diatreme complex that was emplaced into a volcano-sedimentary sequence comprising interlayered sandstone, siltstone, carbonaceous mudstone and andesite lava flows. The Martabe district is located near a series of fault splays that form part of the Sumatra Fault System. This structural framework has played an important role for the multi-phase magmatic, phreatomagmatic-phreatic and hydrothermal events at Martabe. All identified economic and sub-economic gold-silver mineralisation and related alteration is of high-sulfidation epithermal style. Alteration is typically zoned from a core of brecciated, massive and vuggy, residual quartz that grades outwards through advanced argillic comprising quartz-alunite or quartz-dickite and quartz-kaolinite+dickite. Advanced argillic alteration passes out to quartz-illite and argillic (illite-smectite) zones that are surrounded by a peripheral zone of pervasive propylitic (chlorite-smectite) alteration. The best



Pillow basalt, Ordovician Fournier Group, Bathurst VHMS district, New Brunswick, Canada

economic gold mineralisation is hosted within the vuggy quartz and advanced argillic alteration zones. Alteration and mineralisation is dated at 2.0 to 3.3 Ma based on argon-argon dating of hypogene vein alunite. Bronto's project is a comparative mineralogy, mineral chemistry and metal zonation study of the various ore bodies in the Martabe district. Bronto will be presenting a poster on his research at Martabe at the Society of Economic Geologists conference in Keystone (USA) in May 2006.

Project 3.1.3

Trace element analysis of sulfide by LA-ICPMS: new applications for exploration vector geochemistry (ARC-Industry Linkage project; also internally designated as CODES C201)

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

Commenced in 2003, this project presented its findings in March 2005 to its sponsor group, Newmont Mining, BHP-Billiton, Anglo American, AngloGold, Placer Mining and Newcrest Mining. 2005 also included the first full year of an APAI-supported PhD project, (Claire McMahon), focussing on pyrite trace element behaviour at the Hercules VHMS deposit, the Indonesian Batu Hijau porphyry copper-gold deposit, and the Nico IOCG (iron oxide-copper-gold) deposit in eastern Canada. Claire's research is the only aspect of this project expected to continue into 2006. The industry component evaluated pyrite trace element haloes in the distal fringes of a range of ore deposit types (VHMS, porphyry copper-gold, lode gold, high

sulfidation epithermal). The Linkage component of the project aimed to test hypotheses of the source of metals in sulfides in the distal haloes of ore alteration systems, mainly through radiogenic isotope analysis at RSES with Marc Norman. In a sponsor-driven variation to the project, PhD student Singoyi Blackwell also evaluated magnetite compositional variations at the Cannington BHT lead-zinc-silver deposit. Pyrite-based study sites included Yannacoccha, Batu Hijau, Cadia Far East, Calinan-777, Hercules, Hellyer, Sunrise Dam, and Kanowna Belle.

The main project was written up as unpublished reports, and presented to the industry partners at a two day meeting in Hobart. This final 355-page volume ambitiously brought together all the work from the entire C201 project. Thus, the 16 written reports not only addressed the work of the last year, but integrated it with studies completed in the first two years of the project. This was a great effort for such a small research group. Only the 2004 research work was reported in the accompanying oral presentations (together with a printed volume of Powerpoint handouts), although for completeness there was some revision of topics, such as the current mode of the LA-ICPMS method at the University of Tasmania, sample population statistics, and comparisons between different systems. The raw and processed LA-ICPMS, microprobe, major element and petrographic data was supplied as digital appendices on a CD at the back of the volume.

Due to the confidential nature of the research, no refereed publications were produced during the year. However, a special issue of *Geochemistry: Exploration, Environment, Analysis* has been organised, with first submission of papers scheduled for end of April 2006. Sadly, Andrew Rae left CODES in 2005, but will complete his components of the write up from his new geothermal research position in New Zealand. A proposal for a project extension is being circulated amongst potential sponsors in 2006.

Project 3.14

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

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

Porphyry-related mineral districts host many major ore deposits of diverse styles and metal associations. These include the porphyry (copper-molybdenum-gold) deposits themselves, but also epithermal gold-silver deposits, skarn

copper-gold deposits, carbonate replacement zinc-lead-silver, and sediment-hosted gold. These districts continue to be major targets for both copper and gold explorers.

The purpose of this project (AMIRA P765), a collaboration between CODES Programs 3 and 5, is to determine the links between the diverse deposit styles within porphyry-related mineral districts, and identify where the highest grade copper and gold accumulations are expected to occur. We aim to improve exploration success in porphyry-epithermal districts by providing geological, geochemical, and geophysical vectors towards major metal accumulations, and indicate the likely distance. Study areas include Lepanto, and Baguio (Mankayan, Philippines), Batu Hijau (Indonesia), Collahuasi (Chile), Pueblo Viejo (Dominican Republic), Colquijirca (Peru) and Cadia (Australia). This project has ARC-Linkage funding and industry funding through AMIRA (AngloGold Australia Limited, Placer Dome Inc, Teck-Cominco, Gold Fields Ltd, Newcrest Mining Ltd, Anglo American (Philippines) and Newmont.

For further detail see project 5.18.

PhD Projects in Program 3

Susan Belford: Genetic and chemical characterisation of the pristine Archean Jaguar base-metal deposit (WA), to improve local and global prospectivity.

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

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

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

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

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

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

Patrick Sack: Geology and geochemistry of the footwall lithologies, Greens Creek VHMS deposit, Alaska: implications for ore genesis and exploration.

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.

Team Leader

Peter McGoldrick

Team Members

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

PhD Students

Bryan Bowden, Mawson Croaker, Wallace Mackay, Rod Maier, Nicky Pollington

Collaborators

Colorado School of Mines, Johns Hopkins University, Geoscience Australia, University of Adelaide, PIRSA, RSES-PRISE, Simon Fraser University, James Cook University, University of California-Riverside, Russian Academy of Science

Highlights

Excellent progress in ARC/AMIRA Project P872 studying sedimentary copper deposits in the African Copperbelt and the Centralian Basin. This work continues our previous successful collaboration with researchers from Colorado School of Mines

Peter McGoldrick presented an invited paper entitled 'SEDEX deposits, siderite and sulfur-poor seas' at the Geological Society of America Annual Meeting in Denver (USA)

Two invited papers were published by CODES researchers in the 100th Anniversary Volume of *Economic Geology*: 'Sedimentary copper deposits of Zambia' by Selley et al., and 'Stratiform zinc-lead-silver deposits of northern Australia' by Large et al.

Core Projects in Program 4

- 4.1 Geological environment of stratiform zinc-lead 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 zinc-lead-silver ore formation.
- 4.5 Textural and isotopic studies of sediment-hosted zinc-lead-silver 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, Proterozoic ocean evolution and the origin of Proterozoic Sedex zinc-lead-silver deposits.

Project 4.1 CORE

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

S Bull, P McGoldrick, R Large

Although field work and laboratory studies for this project have now ceased, a major review paper entitled 'Stratiform and stratabound zinc-lead-silver deposits of the Proterozoic sedimentary basins of northern Australia', with CODES-based authors Ross Large, Stuart Bull, Peter McGoldrick and Steve Walters, was published in the 100th Anniversary volume of *Economic Geology*.

Project 4.2 CORE

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

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

This is a core project for Program 4 and is a joint project with Program 5 (see Project 5.1). The results from this project are described under Program 5 Project 5.1.

Project 4.5 CORE

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

R Large, P McGoldrick; PhD student: R Maier

The main efforts in this project have been through Rod Maier's PhD studies supervised by Peter McGoldrick and Ross Large. Rod has completed a substantial part of the pyrite trace element halo work for McArthur River deposit. was completed. This involved LA-ICPMS analysis of primary textured pyrites in a series of drill holes, distal from the HYC deposit. Encouraging preliminary results suggest that elements including cobalt, nickel, copper, zinc, arsenic, antimony, barium, thallium, lead, molybdenum, silver and tin occur at anomalous levels in the pyrite. The exact controls on these anomalies is uncertain, however, some appear at the ore-body equivalent stratigraphic level. Textural, petrographic and S-isotopic studies of the Bluebush deposit are progressing.

Project 4.6

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

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

This is a major non-core CODES project that commenced in the second half of the 2004. It has support from both the ARC and AMIRA (Project P872 'Copper-cobalt mineralisation in the Congolese, Zambian and Central Australian Basin systems') with 10 sponsoring companies:

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

Project activities undertaken in the first half of 2005 revolved around a sponsors meeting held at AMIRAs offices in Melbourne in April. As this was the first sponsors meeting of the project, the first part was devoted to overview presentations. The second part of the meeting focused on provisional analysis of the regional and deposit scale data collected in the field visit to the DRC carried out in October-November 2004. This was the first field visit since the project commenced, and we would like to take this opportunity to acknowledge the support while in Africa



Examining the Congolese "Mines Series" below the flame trees at Gecamines' geological head quarters, Likasi



KOV pit, Kolwezi, Peoples Republic of the Congo

of the local staff at Anvil Mining, Gecamines, Entreprise Generale Malta Forrest and Equinox Minerals Limited, without which research in African Copperbelt would be impossible.

The review section of the sponsors meeting opened with a review of Cu in sedimentary basins by Murray Hitzman. This was followed by a series of presentations by David Selly, Stuart Bull and David Broughton on the outcomes of the previous Zambian focused CODES/CSM research (ARC/AMIRA Project P544) that are relevant for ongoing work in the DRC. These included; a review of the sequence- and chemo-stratigraphic analytical techniques that the Zambian work suggest will help resolve the contradictions inherent in the currently proposed litho-stratigraphic correlations between Zambia and the DRC; and a summary of the implications of the relationship between basin architecture and mineralization in Zambian system.

The results-based part of the meeting commenced on a regional scale, with David Selley presenting an analysis of the relationship between regional fold and fault patterns and mineral deposits across the entire Congolese Copperbelt. On a deposit scale, Stuart Bull presented a provisional sequence stratigraphic analysis of the Congolese Mines Group based on detailed logging and sampling of the “classical” Congolese type deposits of Kambove/Kamoya located in the Likasi area in the central portion of the belt. Robert Scott presented the initial results from his microstructural and lithogeochemical studies of Equinox’s basement-hosted Lumwana Cu deposit in northern Zambia focusing on timing of ore deposition and identification of subtle alteration patterns within the ore zones.

Following the sponsors meeting, work on the project focused on interpretation of the lithogeochemical data from the closely spaced Kambove/Kamoya dataset, with aim of characterising the alteration patterns associated with the “classical” Congolese Mines Group-hosted systems.

A highlight of Program 4 research into the African sedimentary copper deposits was the acceptance of a review paper for the 100th Anniversary Volume of *Economic Geology* covering the Zambian Copperbelt. The paper (with David Selley as lead author) represents a synthesis of work carried out on ARC AMIRA Project 544 between 2000 and 2003. The 100th Anniversary volume was published in late 2005.

Project 4.8

Copper-gold-iron oxide geology and geochemistry

G Davidson, S Meffre, R Berry, PhD student B. Bowden; R. Skirrow (GA), G Fraser (GA), K Barovich (U Adelaide), T Baker (JCU), D Thorkelson (Simon Fraser U))

Active collection of data on this sub-project is only occurring at Prominent Hill, South Australia, through the agency of Brian Bowden’s PhD work. The Prominent Hill research is a collaboration with Geoscience Australia, PIRSA, Minotaur, Oxiana, and Goldstream NL. The first half of 2005 focussed on several areas of deposit characterisation, namely, alteration mineralogy (including PIMA-based zonation assessment), fluid inclusion petrology, geochemistry of identified magmatic rocks, geochemistry of altered rocks, and stable isotopes (sulfur,



carbon-oxygen) of the ores and some fault zones. The latter intriguingly contain graphite, which is largely out of equilibrium with the hematite-stable breccias seen in most of the ore complex. A large suite of dykes of different generations were submitted to collaborator Geoff Fraser at GA for zircon separation.

In other directions, the production of a Special Issue of *Economic Geology* on the IOCG deposits of the Gawler Craton, co-edited with Roger Skirrow of GA, moved to the point of submission of all papers, and appears likely to hit the presses in first half of 2007. This Special Issue includes co-authored papers on IOCG fluid neodymium isotope and stable-isotope characteristics, with Roger Skirrow, Karin Barovich and Evgeniy Bastrakov.

In terms of other collaborations, JCU student Julie Hunt completed her PhD thesis studies of the Wernecke Mountain breccias, and the joint research with Garry Davidson into stable isotopic characteristics, is due for refereed journal submission in first half 2006. A collaboration with Lucas Marshall and Nick Oliver on the carbon-oxygen isotope constraints on fluid evolution in the Mount Isa Eastern Succession was in review through 2005.

Project 4.9 CORE

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

P McGoldrick, M Norman (RSES), L Danyushevsky, K Harris, S Gilbert

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 Programs 1, 3 and 4. Project 4.9 is a joint project with Program 1 and recent work is described in Program 1 Project 1.3.

Project 4.10 CORE

Microbes, Proterozoic ocean evolution and the origin of Proterozoic SEDEX zinc-lead-silver deposits

P McGoldrick, S Bull, 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 (carbon and sulfur) evidence for microbial activity associated with the northern Australian Proterozoic Sedex zinc-lead deposits. The work aims to determine if microbes played an active or passive role in the origin of these important deposits, and the role of microbial processes in causing sulfidation and oxygenation of the world oceans during the Proterozoic.

Peter McGoldrick, Tim Lyons and Poul Emsbo undertook field work in northwestern Queensland and visited Century, Lady Loretta and Mount Isa mines in May.

Peter McGoldrick presented an invited paper, 'SEDEX zinc deposits, siderite and sulfur-poor seas', at a symposium called 'The Evolving Earth: Implications for Ore Deposit Formation, Evolution, and Benefaction' held at the annual Geological Society of America meeting in Denver (USA).

Project 4.13

Controls on the formation and Sulfide trace element signatures of sediment-hosted gold deposits (AMIRA P923)

R Large, R Scott, A Rae, W Herrmann, L Danyushevsky, S Gilbert, S Bull, Valeriy Maslennikov (Russian Academy of Sciences), P Emsbo (USGS)

The non-core CODES project AMIRA P923 'Controls on the formation and sulfide trace element signatures of sediment-hosted gold deposits' commenced in January 2005 and will run for three years. This project aims to characterise variations in the trace element and isotopic composition of sulfides around and throughout the host stratigraphy to sediment-hosted gold deposits. Data will be used to develop new approaches for terrane selection and deposit characterisation, as well as longer-range, more robust deposit proximity indicators. The research capitalises on recent developments enabling low-level quantitative analysis of over 40 trace elements in sulfides by LA-ICPMS with a spatial resolution down to 8 microns.

Major impetus for the project was provided by the results of a pilot study investigating the trace-element compositions of sparsely disseminated pyrite, interpreted to be diagenetic in origin, in the Ordovician host rocks to the Central Victorian gold deposits. LA-ICPMS analyses indicated much of the pyrite contained elevated levels of gold (up to 2.7 ppm gold) as well as arsenic, lead, Bi, Sb, Te and Se. Gold-enriched pyrite of syn-sedimentary or early diagenetic origin has also been reported from the Devonian host rocks in and adjacent to several of the largest and highest grade gold deposits of the Northern Carlin Trend (Poul Emsbo and co-workers). The presence of anomalously gold-enriched syn-sedimentary or diagenetic pyrite within the host successions of two major epigenetic gold districts raises the intriguing possibility that either the host-rocks themselves were a source of metals for the epigenetic deposits, or that multiple episodes of gold enrichment within the basins record episodic tapping of a major, long-lived metal sources at depth. Alternately, the gold enrichment may be entirely epigenetic in origin with the early formed sulfides simply forming a sink or nucleation site for the precipitation of gold and other metals introduced in later hydrothermal fluids.

The current research addresses three themes:

- Theme 1 is concerned with terrane prospectivity evaluation and regional targeting. The researchers aim to determine the extent of pre-concentration of gold and other metals in sedimentary host rocks to major epigenetic gold deposits, which types of sediments

preferentially concentrate gold in pyrite, and whether there is any relationship between the distribution of gold enriched strata and the location of the major gold deposits.

- Theme 2 will examine spatial zonations in sulfide trace element composition around individual deposits with the aim of developing more robust, longer-range deposit-proximity indicators.
- Theme 3 will assist with prospect evaluation and the development of targeted exploration strategies, and aims to characterise variations in sulfide trace element and isotopic composition that reflect deposit size, age or type.

P923 is sponsored by five companies (Barrick, Newcrest, Newmont, Perseverance and Placer-Dome). The research is being undertaken in three world-class sediment-hosted gold districts: the Carlin District of northeastern Nevada, Central Victoria and the Lena Goldfields (including the giant Sukhoi Log deposit) in Siberia. Initial sampling trips to each of these districts were undertaken in the first half of 2005. Work in the Lena Goldfields is being conducted in collaboration with Valeriy Masslenikov from the Institute of Mineralogy, Miass (Russian Academy of Science), while that in the Carlin District is conducted in collaboration with Poul Emsbo from the USGS.

PhD Students in Program 4

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

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

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

Rod Maier: Pyrite and base metal trace element haloes in the northern Australian zinc-lead-silver deposits.

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

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.

Team Leader

David Cooke

Team Members

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

PhD Students

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

Collaborators

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

Highlights

Publication of a Special Issue of *Economic Geology* on the giant porphyry-related mineral deposits of the Chilean and PNG–Irian Jaya foldbelts from AMIRA Project P511 (Project 5.7)

Cari Deyell published a series of papers dealing with alunite chemistry and ore genesis in high sulfidation epithermal deposits (Project 5.5)

AMIRA P765 sponsored a field meeting to the Baguio and Mankayan mineral districts, Philippines, to review the +70 Moz accumulation of gold resources in porphyry and epithermal deposits (Project 5.18)

Anthony Harris gave a keynote address at SGA meeting in Beijing, and received the 2004 Lindgren Award from SEG at Salt Lake City, USA (Project 5.1)

New insights into fluid flow in sedimentary basins through application of numerical modelling by Lyudmyla Koziy (Project 5.3)

Core Projects

- 5.1 Nature, timing and significance of fluid flow and fluid chemistry in Proterozoic sedimentary basins, and relationship to stratiform zinc-lead-silver ore formation
- 5.2 Fluid flow in the Mount Isa Basin (AMIRA P552)
- 5.3 Software development

- 5.5 Fluid flow and fluid chemistry of high- and low-sulfidation epithermal and subaerial geothermal systems
- 5.7 Giant porphyry copper 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)

Project 5.1 CORE

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

S Bull, R Large, D Cooke, P McGoldrick, R Scott, S Walters; G Garven (Johns HopkinsU)

Ross Large Stuart Bull, Peter McGoldrick, Geoff Derrick, Graham Carr and Steve Walters published a manuscript in the 100th Anniversary volume of *Economic Geology* that described the stratiform and stratabound zinc-lead-silver+copper deposits of the Proterozoic sedimentary basins of northern Australia, and which included reviews of hydrological and chemical models of fluid flow and mineralisation. Ross Large and Steve Walters also contributed to a second manuscript in the same volume entitled 'Sediment hosted lead-zinc deposits; a global perspective', which reviews the global characteristics and genetic models for SEDEX and MVT deposits. David Cooke gave talks on the giant stratiform sediment hosted lead-zinc deposits of Northern Australia in Denver and Melbourne as part of his Thayer Lindsley lecture tour. One of these talks was published as part of the Society of Economic Geologists lecture series (Video #17). Ross Large gave a presentation on the 100th Anniversary volume paper on stratiform sediment-hosted zinc-lead deposits at the annual GSA meeting in Salt Lake City, USA, October 2005.

Project 5.2

Fluid flow in the Mount Isa Basin (AMIRA P552)

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

Research on this collaborative project has been completed. A manuscript on fluid modelling in the northern Mount Isa Basin by Jianwen Yang, Ross Large and Stuart Bull has been accepted for publication in *Economic Geology*.

Stuart Bull gave a presentation on 'Basin-scale numerical modelling of buoyancy-driven hydrothermal fluid flow associated with the formation of stratiform zinc-lead-silver deposits in the Mount Isa Basin, northern Australia' at the Central Australian Basins Symposium in Alice Springs. His co-authors were Jianwen Yang, Ross Large and Deb Scott.

Project 5.3 CORE

Software development

R Large, S Bull, D Selley; PhD student L Koziy

Lyudmyla Koziy has developed a numerical model simulating 2-D migration of ore-forming fluids in complex sedimentary structures. Extensive work on code validation was carried out in 2005. First, the numerical results were compared with the analytical solutions obtained under restrictive simplifying assumptions. Second, the model was applied to several problems of free convection in a porous media. The model output was compared both with the published results of several numerical studies and experimental data. The model output was found to be physically correct and quantitatively consistent with the reported data. A set of tests were then performed for a more complex structure, a faulted sedimentary section of the McArthur Basin, Northern Territory, Australia. The final stage of model validation involved the results of the coupled heat-mass transport simulation being compared with the published data on numerical study of the thermohaline convection. The developed model showed the ability to reproduce the results obtained by an independent algorithm for a broad range of boundary and initial conditions and model parameters.

The numerical model has now been applied to a 2-D vertical profile representing a section of the Zambian Copperbelt. Over 60 numerical simulations on different scenarios were conducted. As a result, a set of 12 basic case studies was selected, which represent different stages of the basin development and test various possible hydrogeological settings. The simulations implied coupled fluid flow, heat and mass transport with the parametrisation of the salt sheet



Thayer Lindsley Visiting Lecture – Peking University, Beijing, China. David Cooke and Zhaoshan Chang visiting Professor Zhue and his students

dissolution. The effect of different factors, such as salt layer characteristics (permeability, degree of anisotropy), fault network configuration, piercement structures, salt layer geometry, have been tested numerically.

Project 5.5 CORE

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

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

Cari Deyell published three papers that dealt with aspects of high sulfidation style epithermal mineralisation in 2005. Together with co-authors Robert Leonardson, Bob Rye, John Thompson, Thomas Bissig, and David Cooke, Cari reported in *Economic Geology* on alunite in the Pascua-Lama high-sulfidation deposit: Constraints on alteration and ore deposition using stable isotope geochemistry. This manuscript demonstrated that the hydrothermal system at Pascua-Lama was dominated by magmatic fluids. The limited availability of meteoric water is attributed to the arid climatic conditions which produced a dessicated pediment landscape.

Cari Deyell contributed two manuscripts on alunite chemistry to a Special Issue of *Chemical Geology* in 2005. Together with Greg Dipple, Cari published a paper on equilibrium mineral-fluid calculations and their application to the solid solution between alunite and natroalunite in the El Indio-Pascua belt of Chile and Argentina. This study showed that increased Na substitution into the alunite mineral structure is favoured at higher temperatures,

and that a wide range in fluid K/Na ratios is required to precipitate both potassium- and sodium-rich alunite under these conditions. A second paper in the same special issue dealt with alunite and the role of magmatic fluids in the Tambo high-sulfidation deposit, El Indio-Pascua belt, Chile, and was co-authored by Bob Rye, Greg Landis and Thomas Bissig. This study demonstrated that some alunite at Tambo formed due to condensation from magmatic steam, in addition to the three more widely recognised methods of deposition (magmatic-hydrothermal, steam-heated and supergene origins).

Project 5.7

Giant porphyry copper deposits (AMIRA P511)

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

AMIRA Project P511 (Giant Ore Deposit Systems) was an industry-funded project involving collaborative research between CODES, the CSIRO Division of Exploration and Mining and the Centre for Global Metallogeny (CGM, University of Western Australia). The project consisted of three modules, which focussed on Archaean lode gold (CGM/CSIRO), PNG gold-copper (CSIRO) and Chilean porphyry copper-molybdenum deposits (CODES/CSIRO). The final AMIRA sponsors meetings were held in 2003, although research continued into 2005 due to delays in the completion of the final CODES PhD thesis by James Cannell.

A Special Issue of *Economic Geology* summarising the results of AMIRA project P511 was published in August 2005. The Special Issue contains senior author papers by David Cooke, Glen Masterman, Anthony Harris, Peter Hollings, Peter Frikken, Paul Davidson and James Cannell, and also by collaborators from CSIRO (Gow and Walshe), and several external contributions (Deckart et al., Pollard et al., Prendegast et al.). This issue reported on the results of new research into the characteristics and origins of porphyry copper-molybdenum and copper-gold deposits of Chile, Argentina and PNG-Irian Jaya. The Andean and PNG-Irian Jaya foldbelts host some of the world's largest and highest-grade porphyry deposits and have been subjected to several cycles of mineral endowment during episodes of convergent margin tectonism. The production of major deposits in a terrane is commonly limited to discrete epochs (e.g., Hollings et al., Deckart et al., Pollard et al.), implying that fluid production and/or release is episodic and linked to the geodynamic evolution of the terrane. The structural architecture of the province is also critical

(e.g., Gow et al.), with reactivation of basement faults a recurring theme in the evolution of porphyry mineral districts. The productivity of the Andean and PNG-Irian Jaya foldbelts, in terms of porphyry ore formation, has been a consequence of factors that operated effectively at crustal to mantle and district- and deposit-scales. Large-scale factors (e.g., geodynamics, lithological and structural architecture) have constrained total metal endowments by providing effective fluid pathways and controlling the generation, location, nature and size of fluid reservoirs as well as the timing and manner of release of stored fluids. Hypogene ore grades, in contrast, appear to be controlled mostly by factors that operated at the district- and deposit-scales. The processes that generated and maintained the physicochemical gradients (temperature, pressure, salinity, acidity, redox and reduced sulfur) required to form elevated hypogene ore grades remain poorly understood and continue to be debated. Some papers in this special issue investigate processes of mineralisation and alteration within individual ore systems (e.g., Masterman et al., Harris et al., Davidson et al., Frikken et al., Cannell et al., Prendergast et al.). While most of the available isotopic, fluid and melt inclusion evidence points towards for a preponderance of magmatic-derived fluids in porphyry systems (e.g., Davidson et al., Harris et al.), there are data from individual deposits that are not readily explained by a purely orthomagmatic model for ore formation and probably require input of external fluids during the mineralizing processes (e.g., Frikken et al.). Other ongoing controversies regarding porphyry systems that are discussed in this volume include the relative importance of cooling (e.g., Redmond et al.), hydrothermal alteration (e.g., Harris et al.) and fluid mixing (e.g., Frikken et al.) for deposition of high grade ore in porphyry systems, the relative importance of ridge subduction and flat subduction in the formation of giant porphyry deposits (e.g., Hollings et al., Deckart et al.), the nature and origin of copper mineralisation at the largest of the Andean deposits, El Teniente (e.g., Skewes et al., Cannell et al.), the duration and timing of magmatic-hydrothermal activity (e.g., Río Blanco-Los Bronces — Deckart et al., Frikken et al.; El Teniente — Maksiyev et al., Cannell et al.) and the relative importance of strike-slip, compressional and extensional tectonism during the formation of the Eocene-Oligocene porphyry belt of northern Chile (Masterman et al.). Overall, the aim of the special issue was to help explorers and researchers better understand how and where processes of ore formation have combined effectively to produce some of the world's largest high grade hypogene porphyry copper and gold resources.

The results of P511 were disseminated at several conferences and invited presentations in 2005. Peter

Hollings and David Cooke presented a review of the metallogenic evolution of the Andean margin at the annual Geological Society of America meeting in Salt Lake City, October 2005. David Cooke, in collaboration with his coauthors James Cannell, John Walshe and Holly Stein, gave talks on El Teniente at Vancouver, Denver, Beijing, Townsville, Canberra and Melbourne as part of his Thayer Lindsley lecture tour. In collaboration with Glen Masterman, Ron Berry and John Walshe, David also gave keynote addresses on the Collahuasi system at the STOMP conference in Townsville, and the New Zealand minerals conference in Auckland. Talks on Collahuasi were also presented at the Vancouver Roundup meeting and the SGA meeting in Beijing.

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, Jianwen Yang and Ross Large published a paper in *Economic Geology* entitled 'Numerical heat and fluid-flow modeling of the Panorama volcanic-hosted massive sulfide district, Western Australia'. This manuscript summarises the major research findings of Project 5.8, providing insights into the evolution of the Panorama system. The lifespan of the hydrothermal system is predicted to have potentially been as short as a few thousand years under optimum fluid flow conditions. However, the overall time period for the formation of massive sulfide mineralisation could have been anywhere between 30,000 and 200,000 years depending on variations in rock properties and fault permeability with time.

Project 5.14

Proterozoic sediment-hosted copper deposits (AMIRA P544a)

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 project is a collaboration between Programs 4 and 5. Research on AMIRA Project P544a continued throughout 2005 in the form of the on-going PhD study of Lyudmyla Koziy (see Project 5.3). No new chemical modelling was undertaken for P544a in 2005. David Selley and

several team members of P544 published a manuscript in the 100th Anniversary volume of *Economic Geology* that described the geology of the Zambian copperbelt, and which included reviews of genetic models for mineralisation.

Project 5.15

Fluid chemistry in porphyry copper-gold-molybdenum deposits

D Cooke, C Deyell, A Harris, L Danyushevsky, S Gilbert, N White, C Ryan (CSIRO E&M), A Berry, J Mavrogenes, M Norman, J Dunlap (ANU); P Reiners (Yale U), E Seedorf (University of Arizona), J Cline (University of Las Vegas). PhD students D Braxton, B Jones, A Wilson, F Urzua; MEconGeol. student A Ignacio

Anthony Harris, Leonid Danyushevsky and Sarah Gilbert have continued utilising the 213 nm laser system at CODES to help quantify primitive ore-forming fluids in porphyry ore deposits. Physicochemical characteristics were determined for fluid inclusions found in early-formed magmatic-hydrothermal quartz in porphyritic rocks from several ore deposits, providing new insights into the physical processes that operate in crystallizing volatile-rich silicic magma. This work is a collaborative effort with Eric Seedorf (University of Arizona) and Jean Cline (University of Las Vegas). Other continuing collaborative fluid inclusion research devoted to better understanding porphyry copper deposits includes the application of the synchrotron to fluid inclusion microanalysis. Anthony Harris together with Andrew Berry (Imperial College) is developing a major research project to investigate the speciation of copper in primitive ore fluids in porphyry copper deposits. This has included the submission of a major Natural Environment Research Council (NERC) grant application that links researchers from Imperial College, The Natural History Museum, ETH, The Advance Photon Source and CODES. New insights into fundamental processes operating in the source magma to porphyry ore deposits has come from the application of several dating strategies (including uranium-lead, $^{40}\text{Ar}/^{39}\text{Ar}$ and (U-Th)/He) to a single deposit. On-going collaborative research between CODES (Anthony Harris), ANU (Jim Dunlap) and Yale (Peter Reiners) has been focused on establishing the low temperature (<200°C) thermal history of Bajo de la Alumbrera. This novel application of low temperature chronometers suggest that heat and/or volatiles must have been sourced from deeper-seated magma bodies or blind intrusions beneath Bajo de la Alumbrera for several millions of years. Anthony gave a keynote address on this topic at the SGA meeting in



Late amethyst vein, El Penon silver-gold epithermal deposit, Chile

Beijing (PRC) in August 2005. Anthony was presented with the 2004 Lindgren Award from the Society of Economic Geologists at the Geological Society of America annual general meeting at Salt Lake City (USA) in October 2005.

Cari Deyell presented a paper at the SGA meeting in Beijing, summarising the results of her sulfur isotopic study of the Mount Polley porphyry copper-gold deposit in British Columbia (Canada), demonstrating that isotopic zonation patterns broadly mimicked the sulfide zonation. Alan Wilson, David Cooke and Ben Harper published a reply to a discussion of their paper on the Ridgeway porphyry gold-copper system in *Economic Geology*. They clarified that although the alteration assemblages they had described were similar in terms of their mineralogy to the regional alteration assemblages described by Smith (1965), they differed significantly in their symmetrical and narrow zonation patterns around the Ridgeway intrusive complex.

David Braxton continued his PhD study of the Boyongan porphyry copper-gold deposit, Philippines. Research in 2005 focussed on constraining the absolute timing and duration of magmatism, hydrothermal activity, and low-temperature cooling history of the Boyongan porphyry copper-gold deposit (Mindanao, Philippines), by employing various radioisotopic age determinations. In collaboration with Marc Norman (ANU), SHRIMP-2 U-lead dating of magmatic zircons from the earliest and latest intrusions in the deposit constrained the timing of magmatism. Re-Os age determinations of molybdenite (in collaboration with Holly Stein at Colorado State University) from late-stage porphyry veining enabled precise time constraints on the end of porphyry-style hydrothermal activity. Potassium-argon dating of illite and alunite (in collaboration with Jim Dunlap, ANU) placed constraints on the timing of onset of phyllic and advanced argillic alteration overprinting porphyry-veining events. Dating

of apatite by the U-Th/He method (in collaboration with Pete Reiners, Yale University), documents the timing and duration of the low-temperature cooling history of the porphyry system and environs. In late 2005, David focused on characterizing the evolution of magmatic-hydrothermal fluid chemistry in support of a physiochemical model describing the deposit formation. Fluid and melt inclusion studies formed the basis of this ongoing research, with petrography, cathodoluminescence, and microthermometry conducted at the University of Tasmania. Direct chemical analysis of fluid inclusion composition, using LA- ICPMS technology, enabled tracking of the metal budget in the fluids through time, and comparison of fluid metal endowment between barren and mineralised portions of the hydrothermal system.

Allan Ignacio completed his Masters dissertation on the supergene profile at the Boyongan porphyry copper-gold deposit, Philippines. Ben Jones continued his BHP Billiton-supported PhD study of the Antapaccay porphyry copper-gold deposit. Felipe Urzua upgraded his candidature to PhD, and finished first drafts of several chapters of his thesis, which deals with the regional geology of La Escondida, Chile.

Project 5.16

Fluid mixing in hydrothermal systems

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

This Project is a collaboration between James Cook University, the University of Leeds and CODES. It aims primarily to determine the key processes that lead to fluid mixing in certain geological environments, and to determine the relative importance of fluid mixing as an ore forming process with respect to other mineral depositional mechanisms. Key results that emerged from this research were a recognition that both fluid mixing and unmixing may operate simultaneously in ore deposition, that parameters to distinguish wallrock interaction from fluid mixing as a primary ore forming mechanism can be relatively easily defined, and that the evolution of fluid inclusions across the paragenetic lifetime of many ore deposits provides the essential clues to the mixing mechanisms and proportions. Fluid mixing appears to be responsible for the huge size and grade of giant iron ores of the Hamersley Province, with deep seated basinal fluids initiating a phase of carbonate dissolution prior to mixing with heated surface fluids, the latter providing the conditions for voluminous silica loss. Fluid mixing appears

to be crucial in shale-hosted lead-zinc systems — the manganiferous carbonate halo observed around Century, and zincian siderite within the deposit, represents the signal of the metal-bearing brine prior to its interaction with sulfur, the latter being provided by organic seawater sulfate reduction and mixing with the metal-bearing brine around fault zones. A defining hallmark of IOCG deposits of substantial grade would appear to be fluid mixing, as lower tonnage, more reduced IOCGs (e.g., Eloise) may not have reached full depositional efficiency due to insufficient supply of oxidised fluid which otherwise triggered widespread mixing at Ernest Henry. Furthermore, the violent brecciation accompanying Ernest Henry was caused by CO₂-rich fluids mixing with metal-bearing brines in a structural fluid conduit, and this physical brecciation process was apparently instrumental in ensuring mixing (overcoming potential problems of initial immiscibility. Indeed the concept of progressive mineralisation along a temperature gradient, without fluid mixing, appears now only to be important for some porphyry systems (Heinrich papers) whereas our observations of one of the world's biggest porphyry system appears to require fluid mixing (with surface waters) to explain the reduced/oxidised co-associated sulfides and sulfates, in particular within zones of intense brecciation where mixing was favoured. The research contributed directly or indirectly to 22 refereed journal articles, one book chapter, and several conference proceedings and abstracts.

Project 5.17

Hydrology and chemistry of mine drainage waters

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

Lee Evans is undertaking a PhD study of 'Groundwaters in wet, temperate, sulfide mining districts: delineation of modern fluid flow and predictive modelling to improve management after mine closure (Rosebery, Tasmania)'. Lee took an 18-month leave of absence, commencing in December 2004.

David Cooke co-authored a manuscript with Andy Gault (LeedsU), Ashley Townsend (Central Science Laboratory, UTAS), John Charnock, and Dave Polya (LeedsU) entitled 'Mechanisms of arsenic attenuation in acid mine drainage from Mount Bischoff western Tasmania'. This manuscript was published in *Science of the Total Environment* in 2005, and showed how arsenic had substituted into the jarosite mineral structure in the iron bogs associated with acid drainage at Mount Bischoff.



AMIRA P765 sponsors field meeting, April 2005, Acupan gold mine, Baguio, Philippines

Project 5.18

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

D Cooke, B Gemmell, C Deyell, Z. Chang, N White, J Reid, M Roach, J McPhie; J Hedenquist (CSM), P Hollings (Lakehead U); PhD student T Ireland; M Econ Geol students G Midgley, J Polanco

Porphyry-related mineral districts host many major ore deposits of diverse styles and metal associations. These include the porphyry (copper-molybdenum-gold) deposits themselves, but also epithermal gold-silver deposits, skarn copper-gold deposits, carbonate replacement zinc-lead-silver, and sediment-hosted gold. These districts continue to be major targets for both copper and gold explorers. 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 mineralisation 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. 2005 saw the completion of field work and the instigation of detailed geochemical studies at all major and comparative study sites. A one-week sponsors field

meeting in northern Luzon, Philippines, was the highlight of this year's research activities.

PhD Projects in Program 5

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

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

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

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 copper-molybdenum mineralisation at Rio Blanco, Chile. (completed and graduated in 2004)

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

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

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

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

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

Felipe Urzua: Geology of La Escondida region, Northern Chile

EDUCATION

Objectives

- To produce outstanding post-graduates who are able to identify and pursue new fundamental research initiatives and to lead industry exploration for new mineral resources.
- To develop a high-quality post-graduate and post-doctoral program that integrates ore deposit and mineral province studies, concentrating on geological processes, geological environments and ore formation.
- To enhance post-doctoral research career opportunities by actively involving research fellows in the planning, supervision and management of CODES research programs.

Post-Doctoral Fellows

- Sharon Allen completed the second year of her five-year ARC Research Fellowship. Her research focuses on the products of explosive eruptions from felsic submarine volcanoes using data from the modern seafloor, numerical models and experimental simulations (Project 2.2).
- Zhaoshan Chang continued to work on epithermal-porphyry transitions, and AMIRA project led by David Cooke and Bruce Gemmell (Project 5.18). Zhaoshan undertook field work for the project in Indonesia and the Philippines.
- Cari Deyell has played a major part in the AMIRA project on epithermal-porphyry transitions led by David Cooke and Bruce Gemmell (Project 5.18). She undertook fieldwork for deposit studies in Chile, Peru, the Dominican Republic and Canada.
- Cathryn Gifkins completed CODES' new book, 'Altered Volcanic Rocks', with co-authors Wally Herrmann and Ross Large (Project 2.1). The book was published early in 2005 and has already proven to be in demand from industry and graduate students worldwide.
- Andrew Rae has been engaged in analysis of sulfides for trace elements using LA-ICPMS (Project 3.13) using samples from a variety of ore deposits. Andrew took a

research position in hydrothermal geochemistry with Geological and Nuclear Sciences, New Zealand, and is now based at the Wairakei Research Centre.

PhD Program

There were two PhD graduations in 2005 (James Cannell and Roman Leslie), and two theses were submitted late in 2005 (by Kate Bull and Maya Kamenetsky). Kate Bull has taken a position as Volcanologist with the Alaska Volcano Observatory in Fairbanks, USA. Maya Kamenetsky has joined the Centre of Excellence, contributing primarily to the Location and Recovery research programs.

CODES had 34 PhD candidates at the end of 2005, which is approaching the all-time high of 37 in 2000. Recruitment of new PhD students within Australia has been challenging in the continuing extremely buoyant employment market for geologists, a situation that shows no sign of changing in the near future. As a result, CODES has been investing additional effort in recruiting international candidates. Eleven new PhD students enrolled in 2005, all but two of whom are international. The new students and their project titles are:

- Susan Belford – Genetic and chemical characterisation of the Archaean Jaguar base-metal deposit, Western Australia
- Reia Chmielowski – Metamorphic history of Tasmania
- Teera Kamvong – Geology and genesis of porphyry-skarn copper-gold deposits in the northern Loei Fold Belt, northeastern Thailand and Laos
- Joe Moye – Character, setting and genesis of the Ridgeway gold deposit, South Carolina, USA
- Heidi Pass - Zonation and carbonate geochemistry of alkalic porphyry systems
- Patrick Sack – Geology and geochemistry of the Footwall Phyllie, Greens Creek VHMS deposit, Alaska, USA: Implications for ore genesis and exploration
- Dinh Quang Sang – Geological evolution of the northern suture of the Khontum Massif, central Vietnam
- Ralf Schaa – Rapid approximate imaging of electromagnetic data acquired using distributed multichannel data acquisition systems

Weerapan Srichan – Petrological, geochemical and tectonic studies of the Lampang volcanic belt, Thailand
Xavier Webb – Mineralogical, geochemical and textural changes related to the metamorphism of stratiform zinc-lead-silver deposits
Wojciech Zukowski – Geology and gold mineralisation of the Cowal district, NSW

CODES current PhD students authored or co-authored 14 of the total of 36 papers during 2005.

Master of Economic Geology Program

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

During the year, two Masters short-course modules were held, 'Ore Deposit Geochemistry, Hydrology and Geochronology' and 'Ore Deposits of South America'. Fifteen attendees took the geochemistry course that was taught by a team of national and international experts, Phil Blevin (consultant), Ron Berry (CODES), David Cooke (CODES), Tony Crawford (CODES), Garry Davidson (CODES), Cari Deyell (CODES), Bruce Gemmell (CODES), Anthony Harris (CODES), Khin Zaw (CODES), Ross Large (CODES), Nick Oliver (JCU), John Walshe (CSIRO) and Lesley Wyborn (Geoscience Australia). Thirteen of the participants undertook the course as part of the Master in Economic Geology degree, including three students from UWA doing the course under the National Masters umbrella.

In addition CODES ran the popular 'Ore deposits of South America' course, to a full compliment of 27 attendees. This course, led by David Cooke and Peter McGoldrick, was a two-week odyssey to the Candelaria, Mantoverde, Mantos Blancos, Chuquicamata, El Teniente, Los Bronces, Escondida, El Pennon, La Copia and Spence deposits of Chile. Eight of the participants taking the course as part of the Master in Economic Geology degree, including two students from JCU doing the course under the National Masters umbrella.

Along with the boom in the minerals industry the Masters program has experienced something of a recruitment boom with 10 new students joining the program. Continued strong interest from across the minerals industry indicates that 2006 should also be a good year for student recruitment.

Finally, in September Andrew Tunks, the MTEC lecturer and the coordinator of the CODES Masters program, left to take up employment in Africa. We wish him well and thank him for his dedication to the program. A new

MTEC lecturer and Master coordinator will be appointed in 2006.

Minerals Tertiary Education Consortium

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

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

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

Honours

The program was administered by Garry Davidson and Peter McGoldrick in 2005. Fifteen CODES staff members, and two School of Earth Science staff, were involved in supervision. The honours student population (12) shrank by three compared to 2004, reflecting a trend of decreasing undergraduate numbers from 2001–2003 in the SES. In another possible trend, four of the 12 had all taken one or more years off before returning to complete the honours year. One mainland student joined the group from NSW, and we also had our first student from the USA (Nate Allen) working in the fresh sea air of Tasmania's Elliott Bay. The move back into economic geology seen in 2004 was sustained in 2005 (10 of 12 students), although one of these projects was pure palaeontology, focussing on the dating of sediments around the Sepon Cu-Au deposit in Laos (our only overseas project in 2005). Five Tasmanian projects were undertaken. Mainland Australia projects occurred in the Yilgarn and Gawler cratons, and in the Cadia district of NSW. For results known to the end of 2005, six of 11 students secured first class results, with the rest securing 2A status, and one withdrawn (deemed failed). This is an excellent group result compared to the university average.

CODES PhD GRADUATES 1997–2005

Anthea Peta Hill
Structure, Volcanic Setting, Hydrothermal
Alteration and Genesis of the Thalanga
Massive Sulphide Deposit
Date of graduation: 17 May 1997

Marcel Kamperman
An Experimental Study into the Behaviour
of Titanium-Rich and Chromium-Rich
Oxide Mineral Phases at High Pressures
and Temperatures
17 May 1997

Gary John McArthur
Textural Evolution of the Hellyer Massive
Sulphide Deposit
17 May 1997

Jamie Ray Rogers
Geology and Tectonic Setting of the
Tawallah Group, Southern McArthur
Basin, Northern Territory
17 May 1997

David Selley
Structure and Sedimentology of the
Dundas Group, Western Tasmania
17 May 1997

Stuart Gregory Smith
Geology and Geochemistry of the
Warrabarty Carbonate-Hosted Zn-Pb
Prospect, Paterson Orogen, Western
Australia
17 May 1997

Andrew James Tunks
Geology of the Tanami Gold Mine,
Northern Territory
17 May 1997

Matthew John White
Stratigraphy, Volcanology and
Sedimentology of the Cambrian Tyndall
Group, Mount Read Volcanics, Western
Tasmania
17 May 1997

John Noel Dunster
The Lady Loretta Formation:
Sedimentology and Stratiform Sediment-
hosted Base Metal Mineralisation
17 December 1997

Mark Geoffrey Doyle
A Cambro-Ordovician Submarine
Volcanic Succession Hosting Massive
Sulfide Mineralisation: Mount
Windsor Subprovince, Queensland
16 May 1998

Michael William Roache
The Geology, Timing of
Mineralisation, and Genesis of the
Menninnie Dam Zn- Pb-Ag Deposit,
Eyre Peninsula, South Australia
16 May 1998

Nicholas Gerard Direen
Geology and Geophysics of the
Koonenberry Belt, Far Western New
South Wales, and Eastern Australian
Correlates: Part II Delamerian Fold-
Thrust Belts in Eastern Australia
14 December 1999

Robina Sharpe
The Archean Cu-Zn Magnetite-
rich Gossan Hill VHMS Deposit,
Western Australia: Evidence of a
Structurally-focussed, Exhalative
and Sub-seafloor Replacement
Mineralising System
14 December 1999

Peter Richard Winefield
Sedimentology and Diagenesis of
Late Palaeoproterozoic Carbonates,
Southern McArthur Basin, Northern
Australia
14 December 1999

Bruce Ronald Anderson
Structure, Alteration and
Mineralisation of the Nifty Copper
Deposit, Western Australia:
Implications for Ore Genesis
12 August 2000

Holger Paulick
The Thalanga Sequence — Facies
Architecture, Geochemistry,
Alteration and Metamorphism
of Felsic Volcanics Hosting the
Thalanga Massive Sulphide Deposit

(Early Ordovician, Northern Queensland,
Australia)
12 August 2000

Mark Leslie Duffett
Geophysical and GIS Applications to
Exploration for Proterozoic Sediment-
hosted Zn-Pb Mineralisation, Northern
Australia
12 December 2000

Briony Jean Sinclair
Geology and Genesis of the Battle Zone
VHMS Deposits, Myra Falls District,
British Columbia, Canada
11 August 2001

Cathryn Clare Gifkins
Submarine Volcanism and Alteration in
the Cambrian, Northern Central Volcanic
Complex, Western Tasmania
11 August 2001

William Fenton Wyman
Cambrian Granite-related Hydrothermal
Alteration and Cu-Au Mineralisation
in the Southern Mount Read Volcanics,
Western Tasmania, Australia
18 May 2001

Zongshou Yu
Development and Application of
Inductively Coupled Plasma-Mass
Spectrometric Techniques for the Precise
Measurement of Trace Elements and Lead
Isotopic Compositions in Geological
Materials
11 August 2001

Steven Robert Hunns
Style and Setting of Volcanic-hosted
Massive Sulphide Mineralisation in the
Early Permian Berserker Beds, Mount
Chalmers, Queensland
18 December 2001

Alison Mary Raos
The Volcanic and Geochemical Evolution
of a Trachydacite-dominated Island Arc
Centre: Efaté Island Group, Vanuatu Arc,
SW Pacific
18 December 2001

- Kirsten Anne Simpson
Volcanic Facies Architecture of the
Cambro-ordovician Seventy Mile Range
Group, Northern Queensland Australia
18 December 2001
- Richard James Squire
Volcanological and Tectono-magmatic
Evolution of the Cadia-Neville Region,
Southern Molong Volcanic Belt, Australia
18 December 2001
- Andrew John Rae
Alteration Systematics and Mineralising
Potential of the Palinpinon Geothermal
Field, Negros Island, Philippines
10 August 2002
- David John Rawlings
Sedimentology, Volcanology and
Geodynamics of the Redbank Package,
McArthur Basin, Northern Australia
10 August 2002
- Sarah Anne Jones
Geology and Geochemistry of the
'Caprocks' above VHMS Deposits at Myra
Falls, Vancouver Island, British Columbia
10 August 2002
- Rohan Wolfe
The Dinkidi Cu–Au Porphyry: Geology of
the Didipio Region and Paragenesis of the
Dinkidi Cu–Au Porphyry Deposit
10 August 2002
- Stephen Bruce Bodon
Geodynamic Evolution and Genesis of the
Cannington Broken Hill-type Ag–Pb–Zn
Deposit, Mount Isa Inlier, Queensland
17 December 2002
- Oliver Håkan Holm
Structural and Metamorphic Evolution
of the Arthur Lineament, Northwestern
Tasmania, Australia
17 December 2002
- Vanessa Lickfold
Intrusive History and Volatile Evolution of
the Endeavour Porphyry Cu–Au Deposits,
Goonumbla District, NSW, Australia
17 December 2002
- Phisit Limtrakun
Origin and Distribution of Corundum
from an Intraplate Alkali Basaltic Province
in Thailand: Evidence from Field and
Inclusion Studies
9 August 2003
- Karin Orth
Setting of the Palaeoproterozoic Koongie
Park Formation and Carbonate-associated
Base Metal Mineralisation, at Koongie
Park, Northwestern Australia
9 August 2003
- Glenton John Masterman
Structural and Geochemical Evolution of
the Rosario Cu–Mo Porphyry Deposit and
Related Copper–Silver Veins, Collahuasi
District, Northern Chile
16 December 2003
- Michael William Agnew
Geology and Genesis of the Lewis Ponds
Carbonate and Volcanic-hosted Massive
Sulfide Deposits, New South Wales,
Australia
16 December 2003
- Darryl James Clark
Geology and Genesis of the Mammoth Cu
Deposit, Mount Isa Inlier, Australia
16 December 2003
- Andrew George Stephen Davies
Geology and Genesis of the Kelian Gold
Deposit, East Kalimantan, Indonesia
16 December 2003
- Alan James Wilson
The Geology, Genesis and Exploration
Context of the Cadia Gold–Copper
Porphyry Deposits, New South Wales,
Australia
16 December 2003
- Paul Davidson
A New Methodology for the Study of the
Magmatic–Hydrothermal Transition in
Felsic Magmas: Applications to Barren and
Mineralised Systems
7 August 2004
- Owen James Hatton
Sedimentology, Geochemistry,
Volcanology and Basin Evolution of the
Soldiers Cap Group, Eastern Succession,
Mount Isa Inlier, Northwest Queensland,
Australia
7 August 2004
- Christian Schardt
Heat and Fluid Flow Simulations
in Submarine Volcanic Terrains and
Implications for the Formation of Massive
Sulfide Deposits
7 August 2004
- Andrew Lachlan Stewart
Volcanic Facies Architecture and Evolution
of Milos, Greece
7 August 2004
- Peter Harmen Frikken
Breccia-hosted Cu–Mo Mineralisation at
Rio Blanco, Chile
14 December 2004
- Neil Karl Martin
Genesis of the Rosebery Massive Sulphide
Deposit, Western Tasmania, Australia
14 December 2004
- Anthony Edward Webster
The Structural Evolution of the Broken
Hill Pb–Zn–Ag Deposit, New South Wales,
Australia
14 December 2004
- Andrew Trevor Wurst
Geology and Genesis of the Permata-Batu
Badinding–Hulubai and Kerikil Au–Ag
Low Sulfidation Epithermal Deposits,
Mount Muro, Kalimantan, Indonesia
14 December 2004
- James Beresford Cannell
El Teniente Porphyry Copper–
Molybdenum Deposit, Central Chile
13 December 2005

INDUSTRY LINKS

CODES has developed an international reputation for undertaking research which is relevant to, and closely linked with, the minerals industry. In 2005, we were supported by 12 major corporate sponsors and were involved in research collaborations with over 50 national and international mining/exploration companies. A list of all companies involved with CODES is given on the following pages.

Strategy

There are five elements in our industry links strategy:

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

CODES Corporate Sponsors in 2005

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

Benefits of being a CODES Sponsor

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

Corporate Sponsors Program

Sponsorships are vitally important in maintaining critical mass at CODES and to ensure the development, and nurturing, of strategic and applied research programs relevant to the exploration industry. We are grateful for the continuing support of the above sponsors, and look forward to signing up further corporate sponsors as the exploration climate continues to improve.

AMIRA Interantional Research Projects

CODES is currently operating four projects under the AMIRA umbrella.

1. Project P765 ‘Transitions and zoning in porphyry-epithermal districts: indicators, discriminators and vectors’ is funded by seven sponsors and an ARC Linkage grant, and has work programs in Chile, Peru, Dominican Republic, Indonesia and the Philippines. Further details are listed under the Research section (Project 3.14 and 5.18).
2. Project P843 ‘Geometallurgical Mapping and Mine Modelling – GEM^{III}’ is funded by ten sponsors. This is a truly international project, involving a major collaboration with JKMRRC at the University of Queensland, with study sites at Red Dog (Alaska), Sudbury Basin (Quebec), Bingham Canyon (Utah), Cadia East (NSW), Ernest Henry (Queensland) and Boddington (WA). This project was successful in gaining ARC Linkage funding in 2005, of \$500,000, which will be rolled-in to Program 4 of the new Centre of Excellence in Ore Deposits. See special report on p.xx.
3. Project P872 ‘Copper-cobalt mineralisation in the Congolese, Zambian and Central Australian Basin systems’ has attracted nine sponsors and an ARC Linkage grant. Further details are listed under the Research section (Project 4.6).
4. Project P923 ‘Controls on the formation and sulfide trace element signatures of sediment-hosted gold deposits’ has attracted four sponsors. This project is focused on the Carlin district (Nevada), the Victorian goldfield

(Australia) and the Sukhoi Log deposit (Siberia). Further details are listed under the Research section (Project 4.13).

ARC Linkage Projects

During 2005, CODES researchers held six ARC-Linkage grants. Major Linkage projects include David Cooke and Bruce Gemmell's transitions and zonation in porphyry-epithermal mineral districts (Project 3.14), Khin Zaw's SE Asian-based project on the development and mineralisation potential of the Loei Fold Belt in Thailand (Project 1.8), and Stephen Walters project on geometallurgy, mineral mapping and mine planning. APAI-Linkage PhD projects include the Jaguar VHMS deposit, Western Australia, the Mount Bischoff tin deposit, Tasmania and a tailings pile groundwater study at the Rosebery deposit Tasmania.

Industry Linked Student Projects

Some 67% of 2005 post-graduate research 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 2005, three PhD students (Kim Denwer studying Mount Lyell, Singoyi Blackwell studying magnetite geochemistry, and Lee Robson studying remote sensing applications to exploration) and four Honours students were funded by this scheme.

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 courses listed below were held in 2005 and involved the participation of CODES staff and invited national and international speakers.

SHORT COURSES 2005

Course	Presenters (CODES presenters are in bold)	Number of participants	Location	Date
Ore Deposit Models	Ross Large, Bruce Gemmell, David Cooke, Garry Davidson, Anthony Harris, Peter McGoldrick	20	Melbourne	9-13 May 2005
Ore Deposit Geochemistry, Hydrology and Geochronology	Tony Crawford, Dima Kamenetsky, Anthony Harris, Phil Blevin, Lesley Wyborn, Ron Berry, Ross Large, Garry Davidson, Andrew Rae, Cari Deyell, Peter McGoldrick, Wally Herrmann, Nick Oliver, Khin Zaw, David Cooke, John Walshe, Scott Halley	20	UTAS, Hobart	13-24 June 2005
Copper Deposits: Genesis and Giants	David Cooke, Mark Barton, David Broughton, Alex Brown, William Chavez, Greg Dipple, Jim Franklin, Patrick, Redmond, Eric Seedorff, Richard Tosdal	200	Vancouver, Canada	22-23 January 2005
Environmental Geology Field Techniques	David Cooke, Garry Davidson, James Reid	12	Strahan, Tasmania	7-11 September 2005
Structural Data from Drill Core (for Newcrest)	Robert Scott, David Selley	40	UTAS, Hobart	19-20 November 2005
Porphyry and Epithermal Deposits (for Newcrest)	Bruce Gemmell, David Cooke	50	UTAS, Hobart	19-20 November 2005
Ore Deposits of South America	David Cooke	27	Chile	30 October-12 November 2005
Mineral Exploration Field Mapping Camp	Rob Scott, Andrew Tunks	15	Western Tasmania	January 2005
GeoPIXE: Applications and Analysis with CSIRO Nuclear Microprobe	Chris Ryan and David Belton	12	UTAS, Hobart	29-30 November 2005

**MINING AND EXPLORATION COMPANIES
PROVIDING SUPPORT AND/OR
COLLABORATING ON CODES RESEARCH
PROJECTS IN 2005**

Company	Sector
Africa Rainbow Minerals	Africa
Amarc Resouces	Canada
Anglo American	Global
Anglo Gold Ashanti	Global
Anglo Plats	Africa
Anglo Vaal	Africa
Anvil Mining	Australia, Africa
Aur Resources	Canada
Barrick Gold	Global
BHP Billiton	Global
Boliden	Sweden
Buenaventura	Peru
CVRD	South America
Enterprise Generale Malta Forrest	Africa
Falconbridge	Global
First Quantum	Africa
Fortune Minerals	Canada
Goldstream Mining	Australia
Goldfields	Global
Imperial Metals	Canada
Inco	Global
Jabiru Minerals	Australia
Jubilee Ni	Australia
Kennecott Greens Creek	North America
Kingsgate	Asia
Lefroy	Australia
Lepanto Mining	Phillipines
Minotaur	Australia
Mopani	Africa
Newcrest	Australia, SW Pacific
Newmont	Global
Nova Gold	Canada
Outokumpu	Global
Oxiana	Asia, Australia
Pan Australia	Asia
Perserverence	Victoria
Phelps Dodges	Global
Placer	Global
Rio Tinto	Global
Savage River Mines	Tasmania
Somnicor Ltd.	Portugal
Equinox	Australia, Africa
Sterlite	Australia, India
Tas Gold	Tasmania
Teck Cominco	Global
Van Diemens Mines	Tasmania
WMC	Global
Xstrata	Global
Zinifex	Australia

FINANCES

The financial statements presented here contain half-year income and expenditure figures only. They reflect the final six months of the SRC (January to June 2005).

Total half year income of the SRC was \$2.4 million — very similar to the same period in 2004. University financial support increased \$70,000, mostly due to increased salary support. Industry funding was down considerably due to some new industry projects not starting until the Centre of Excellence began, and late invoicing of CODES sponsors (caused by delays in finalising the new Centre of Excellence agreement). All other income streams remained stable.

The half-year expenditure report contains an unspent balance of \$483,989.50. The reason for this is that 50% of the SRC 2005 income was required to be returned to the ARC after CODES was awarded Centre of Excellence status which began its new funding in mid-2005.

Notes to and forming part of the Financial Statements for the half year ended 30 June 2005 (the final half year of the Special Research Centre)

CODES financial data and reports for the first half of 2005 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 Income and Expenditure statements in these two finance pages reflect only CODES finance data for January to June 2005. Financial statements for the second half of 2005 are contained in a separate Annual Report that has been produced for the first six months of the new Centre of Excellence (July to December 2005).

The majority of income figures shown here represent actual income deposited into the University's Finance system in the first six months of 2005, apart from the following three exceptions:

- All ARC research grants were split in half and 50% was counted in each half year report.
- GEM AMIRA International project (P843) income of \$131,250 which was received in the first half year is not counted here. Instead it has been counted in the period that it was due (second half year report) rather than

the period that it was deposited (first half year report).

Although AMIRA made their initial payment in the first half year, the GEM project did not actually start until the second half year — it is a Centre of Excellence project.

- Newcrest/Cadia project income of \$192,225 which was received in the first half year is not counted here. The reason for this is the same as given above for the GEM project.

In the Income statement, ARC SRC Grant income is shown as the full year amount received (\$967,979).

However, half of this (\$483,989.50) will be returned to the ARC, because the SRC finished on 30 June 2005, and the new CoE funding began on 1 July 2005.

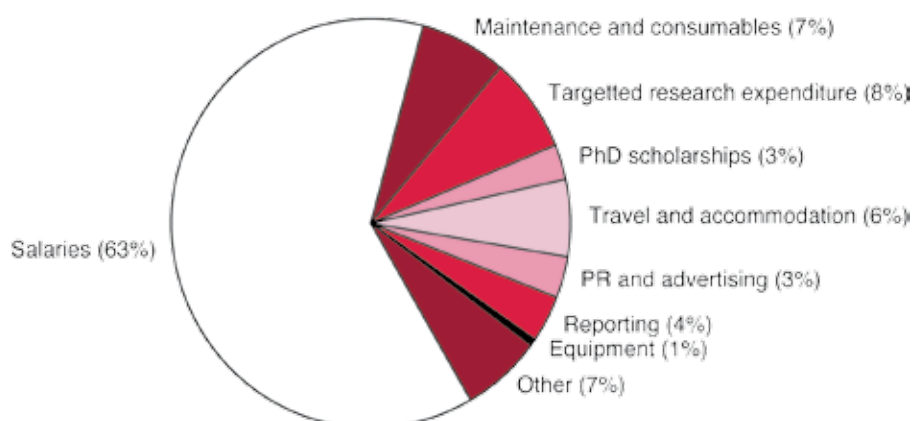
Expenditure figures shown represent 'actual' expenditure in the first half of 2005.

All income and expenditure categories are consistent with previous years — with the exception of the following two minor changes:

- IRG income has been moved from the 'Other ARC Grants' category to the 'University of Tasmania' category
- a new 'Overseas Government' income category has been added under 'Other Income Sources/Interest' — this change was required by the ARC.

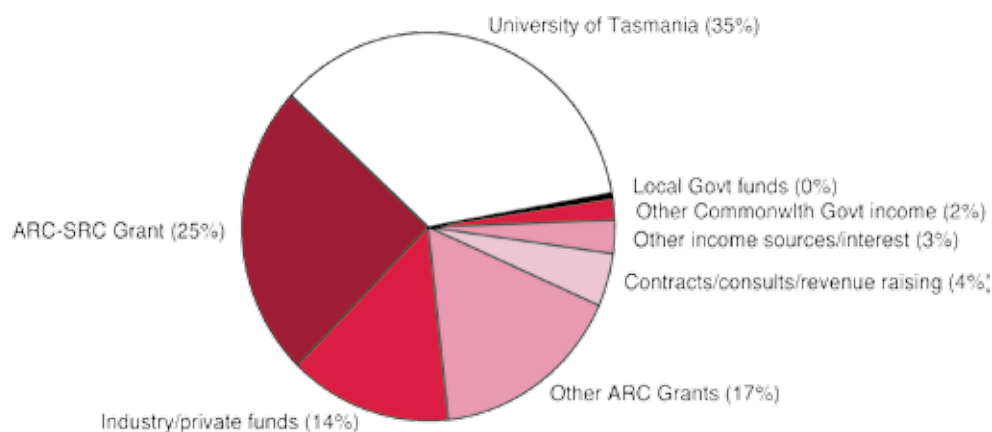
CODES SRC Grant expenditure — January to June 2005

INCOME		
SRC Grant	967,979	
Total budget		967,979
EXPENDITURE		
Salaries	(302,767)	
Equipment	(2,589)	
Travel and accommodation	(29,490)	
Maintenance/consumables	(33,982)	
Miscellaneous expenditure		
PhD scholarships	(13,341)	
Public relations and advertising	(15,864)	
Reporting	(17,942)	
Targetted research expenditure	(36,518)	
Other		
End-of-year balance brought forward from 2004	(45,409)	
Rolled-up accumulated funds from linked project a/cs	2,950	
Miscellaneous income – refund of expenses	10,962	
Total Expend		(483,990)
Account balance at 30 June 2005		483,990



CODES income — January to June 2005

ARC - SRC Grant		967,979	
Other ARC Grants			
Linkage Grants and Collaboratives	129,195		
Discovery Grants (previously called Large Grants)	199,596		
Fellowships	0		
Institutional Research Grants (previously called Small Grants)	0		
RIEF Grant	0	328,791	
Other Commonwealth Government Funds			
Scholarships	0		
Miscellaneous	36,152	36,152	
State Government Funds			
Tasmanian State Govt. - Scholarships (2004-2005)	0		
Directly funded research projects	0	0	
Local Government Funds	8,000	8,000	
Industry/Private Funds			
AMIRA International	65,880		
Industry - Other Projects	65,545		
Industry - Student Funded Projects	75,945		
CODES Industry Sponsors	0		
Minerals Council of Australia (MTEC)	62,185		
Miscellaneous	7,966	277,521	
Contracts/Consultancies/Revenue Raising			
Short Courses	14,980		
Book Sales	58,187		
Miscellaneous	14,300	87,467	
University of Tasmania - Host Institution Support			
University Support to Salaries	486,396		
General Operating Grant	29,550		
Infrastructure Grants (includes RIBG)	93,744		
Institutional Research Grants (previously called ARC Small Grants)	11,900		
University Strategic and Tasmanian Scholarships	36,104		
Student Fee Income	17,000		
Research Excellence Grant	3,750		
Study Leave	3,168		
Minor Works Grant	17,500	699,111	
Other Income Sources/Interest			
Overseas Government	43,071		
Miscellaneous	11,189	54,260	
		2,459,281	



CODES Publications in 2005

Book

- Gifkins, C.C., Herrmann, W. and Large, R.R. 2005. Altered volcanic rocks — a guide to description and interpretation. Centre for Ore Deposit Research, University of Tasmania, Hobart: 275 p.

Refereed Journal Articles

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APPENDICES

CODES POSTGRADUATE STUDENTS 2005

Name	Supervisors	Project	Industry/Govt support
Bachelor of Science (Honours)			
Nathan Allen	G Davidson, W Herrmann	Geology and genesis of the Voyager 24 Au system, Elliot Bay, MRV, Tasmania	Tasgold, NL, TGMS
Adam Bath	V Kamenetsky, A Crawford	Petrology and Geochemistry of the Mesoproterozoic Gawler Range Volcanics, South Australia	UTas
John De Little	K Zaw, A Harris	Aspects of the hydrothermal geology of the Loei Au deposit, Thailand	ARC Linkage
Sam Ekins	C Burrett, P Quilty	Stratigraphy of the Sepon Lane Xane Cu Au deposit, Sepon, Laos PDR	Oxiana
Kathryn Harris*	G Davidson, J Reid	Characteristics and causes of dryland salinity in the Hamilton district, Tasmania	TGMS, UTAS/ MRT
Benjamin Hey	M Roach, J Reid	Application of magnetics and EM to exploration of the Enterprise Au district, NE Tasmania	Tasgold, NL
Kim Hurd	W Herrmann, P McGoldrick	Characteristics of the Jubilee Cosmos gossan and discrimination of Ni sulfide gossans from false gossans in the Norseman-Wiluna Belt, Yilgarn, Craton, WA	Jubilee Nickel
Corey Jago	J McPhie	Tracking the Rosebery Host: Along-strike variation of units at the top of the CVC south of Rosebery Zn-lead VHMS mine	Zinifex Rosebery
Adam King	D Cooke, G Davidson, J Reid	Characterisation of heavy metal contamination in the subsurface of the Zinifex smelter, Hobart	TGMS, Zinifex Hobart
Joel Kitto	D Cooke, J McPhie	Lithostratigraphy, alteration and mineralisation of the Cadia East Porphyry Au-Cu Deposit, NSW.	Newcrest Mining
Brendan McGee	K Zaw, R Berry	The genesis of the Weldborough sapphires, NE Tasmania	Van Diemens Mine
Melanie Sutterby	A Tunks, R Scott	The structural history and alteration of Songvang gold deposit, EGP (NW Belt, WA)	Gold Fields
Master of Economic Geology			
Abdul Gafar Arbi	Ivanhoe Mines Ltd	Course work only	
Stephen Brown	Randgott Exploration	Course work only	
Steven Cancio-Newton	BHP Billiton	Course work only	
Alexander Eves			
Hector Galam			
Christopher Gaughan	Contractor		
Steven Groves	Newmont	Sinter at Moonlight Prospect, Pajingo, QLD	
Allan Ignacio	AngloAmerican	Supergene mineralisation of the Boyongan porphyry copper-gold deposit, Surigao Del Norte, Philippines	
Carl Jackman	Ivanhoe Mines	Course work only	
Damian Jungmann	Contractor		
Alan Ketanen	Ivanhoe Mines	Course work only	
Fiona Meaker	Triako Resources	Course work only	
Mannie Mehu	Lihir Gold	Lihir Island project	

Gem Midgley	Placer Dome	Metal Zonation at the Pueblo Viejo gold mine, Dominican Republic
Benjamin Nicolson	Kantor Gold	Project not finalised
Anna Price	IoGlobal	Course work only
Peter Pring	Newmont	Course work only
Bronto Sutopo	Newmont	Geology and genesis of Mantable deposit, Indonesia

Master of Exploration Geoscience

Albert Chong	B Gemmell, R Berry	Geology, mineralization, metal distribution and genesis of the Polymetallic Ridge and Marshall Zones, Battle Lake Camp, Vancouver Island, Canada - graduated 2005	Boliden-Westmin
Rene Gonzales	D Cooke	Geology of the Baguio mineral district, Philippines	Anglo American
Terence Hoschke	R Large, M Roach	Geophysical signatures of gold copper porphyry systems	Normandy
Kamonporn Kromkhun	K Zaw, D Cooke, A Harris	Geological setting, alteration, mineral paragenesis, & nature of ore fluids at 'H' zone, Chatree gold deposit, central Thailand	Pan Australia

Doctor of Philosophy

Darren Andrews	J Reid, M Roach	Time-lapse geophysical monitoring of acid drainage at Savage River Mine, northwestern Tasmania	Goldamere Pty Ltd, DPIWE, Aust Bulk Minerals
Michael Baker	A Crawford, R Berry	Palaeoproterozoic magmatism in the Georgetown Block, N Queensland, and comparisons with Broken Hill block.	GSNSW, GSQ
Susan Belford	R Large, G Davidson, J McPhie	Genetic and chemical characterisation of the Archaean Jaguar VHMS deposit	APA-I, Jabiru Metals
Bryan Bowden	G Davidson, R Large	Iron oxide copper-gold related alteration history of the Mount Woods Inlier, SA, with special emphasis on the Prominent Hill prospect.	PIRSA Minotaur Resources, Goldstream Mining, Geoscience Aust
David Braxton	D Cooke, A Rae	Origin of the Boyongan porphyry Cu-Au system, Philippines	Anglo American
Katharine Bull	J McPhie, A Crawford	Facies architecture of the Ural Volcanics, NSW	SEG, GSNW, ARC SRC
James Cannell	D Cooke, M Solomon	El Teniente porphyry Cu-Mo deposit, Chile: geology, geochemistry and genesis - graduated 2005	Codelco, GODS AMIRA/ ARC Linkage
Leighton Dene Carroll	A Crawford, S Meffre	Tectono-magmatic evolution of eastern Viti Levu, Fiji.	NSW ARC Linkage
Reia Chmielowski	R Berry, D Cooke	Metamorphic history of western Tasmania	Tas Govt
Mawson Croaker	D Selley, P McGoldrick	Geology and genesis of the Nkana copper deposit, Zambia	AMIRA ARC Linkage
Paul Cromie	K Zaw, D Cooke, N White	Geological setting, geochemistry and genesis of the Sepon mineral district, Laos	OXIANA
Kim Denwer	R Large, W Herrmann	Mineralogical, geochemical and isotopic investigation of the Mount Lyell Cu-Au orebody and alteration system	MRT/ TGMS, Copper Mines of Tasmania
Dinh, Quang Sang	A Crawford, R Berry	Geochronology and geological evolution of the Kham Duc region, central highlands, Vietnam	Vietnam Government
Gregory Ebsworth	J McPhie, A Crawford	Regional volcanic facies analysis of the Tyndall Group, Mount Read Volcanics, Tasmania	MRT/TGMS
Lee Evans	G Davidson, D Cooke	Groundwaters in wet, temperate sulfide mining districts: Delineation of modern fluid flow and predictive modelling to improve management after mine closure (Rosebery, Tasmania).	Zinifex, ARC Linkage
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
Tim Ireland	D Cooke, R Berry, B Gemmell	Geology and structural evolution of the Collahuasi District, Northern Chile	Codelco, AMIRA/ARC Linkage
Ben Jones	R Large, A Crawford	Genesis of the Antapaccay Cu-Au porphyry deposit, Peru	BHP World Minerals
Maya Kamenetsky	A Crawford, L Danyushevsky	Nature of primary melts in intracratonic settings: application of melt inclusions studies to kimberlites (Siberia)	ARC Discovery W. Paul project (A. von Humboldt Foundation)

Teera Kamvong	K Zaw, A Harris	Geology and genesis of porphyry-skarn Cu-Au deposits at the northern Loei Foldbelt, northeast Thailand and Laos	ARC Linkage Grant and Pan Australian Resources
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 - graduated 2005	ARC Discovery
Steven Lewis	G Davidson, R Berry	Sulfidic hydrothermal alteration in late brittle faults, Macquarie Island	Aust. Aut Division, Aus IMM , SEG
Wallace Mackay	D Selley, S Bull	Sedimentology and structure of the Curdimurka Subgroup, Willouran Range, South Australia	AMIRA/ ARC Linkage
Rodney Maier	P McGoldrick, R Large	Pyrite and base metal trace element haloes in the northern Australian Zn-lead-Ag deposits.	ARC SRC AngloAmerican
Claire McMahon	G Davidson, A Rae	Controls on the geochemistry of hydrothermal pyrite in ore systems	ARC Linkage
Robert Josephus Moye*	D Cooke, J McPhie	Origin and metallogenic significance of the Ridgeway Au-Ag-Mo Deposit in the Proterozoic Carolina Terrane, USA	CODES Scholarship
Heidi Pass*	D Cooke, C Deyell, G Davidson	Chemical and Mineralogical Zonation Patterns in Alkalic Mineral Systems – Implications for Ore Genesis and Mineral Exploration	Imperial Metals (Mount Polley), Barrick Gold Corp (Cowal)
Nicole Pollington	P McGoldrick, S Bull	Sedimentology, mineral paragenesis and geochemistry of the Konkola North Copper deposit, Zambia	AMIRA/ ARC Linkage
Quang Sang Dinh	A Crawford	Tectonic evolution of the northern margin of the Khontum massif in central western Vietnam	
Lee Robson	M Roach	Application of remote sensing for geological mapping in western Tasmania	MRT/ TGMS
Carlos Jose Rosa Paulino	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
Ralph Schaa	J Reid	Rapid approximation algorithms of TEM data	
Blackwell Singoyi	G Davidson, K Zaw, R Large	Controls on the geochemistry of magnetite in hydrothermal fluids	MRT/ TGMS, Newcrest
Weerapan Srichan	A Crawford	Petrology, geochemistry and tectonic significance of late Palaeozoic and Mesozoic mainly volcanic and volcanoclastic rocks in the Chiang Rai-Lampang belt, northern Thailand.	
Craig Stegman	R Large, R Scott	Geochemistry and structure of gold-basemetal mineralisation in the Cobar Gold Field, NSW	Rio Tinto
Sofia Tetroeva	L Danyushevsky, A Crawford	Petrology and geochemistry of adakites and related rocks from the Hunter Ridge, Southwest Pacific	ARC, SRC
Andrew Tyson	M Roach, D Cooke	Geophysical characteristics of porphyry and epithermal deposits	AMIRA/ ARC Linkage
Felipe Urzua	D Cooke	Regional geology of the Escondida district, Northern Chile	BHP Billiton

* enrolled after June 2005

MAJOR CODES AMIRA and/or ARC (Linkage) Projects 2005

Investigators	Project	Partners	Period	ARC Funding for 2005	Industry Funding for 2005
R Scott, R Large, L Danyushevsky, W Herrmann	AMIRA P923: Controls on the formation and sulfide trace element signatures of sediment-hosted gold deposits	Barrick, Placer-Dome, Newmont, Newcrest and Perseverance	2005-2007	\$30,000	\$90,000
D Cooke, JB Gemmell, C Deyell, N White	AMIRA P765. Transitions and Zoning in Porphyry-Epithermal Districts: Indicators, Discriminators, and Vectors	Anglo American, Anglo Gold Ashanti, Goldfields, Newcrest, Newmont, Placer, Teckcominco	2004-2006	\$115,012	\$131,760
D Selley, S Bull, M Hitzman, D Broughton, R Scott, R Large, P McGoldrick, M Roach	AMIRA P872 Sediment-hosted Cu-deposits of Congolese, Zambian & Central Australian basin systems	African Rainbow Minerals, Anvil Mining, CVRD, Equinox Minerals Limited, Anglo American, BHP Billiton, Enterprise Generale Malta Forrest, Phelps Dodge Exploration Corporation	2004-2007	\$130,000	\$259,120
S Walters, R Berry, M Roach, J Reid, W Herrmann, T Napier-nunn, J Franzidis	AMIRA P843 Geometallurgical mapping and mine modelling – GEM ^{III}	Newmont, Rio Tinto, BHP Billiton, Inco, Newcrest, Teckcominco, Barrick, CVRD, WNC, Xstrata, Zinifex	2005-2008	\$250,000	\$468,750
GJ Davidson, Norman M	What controls trace element levels in ore sulfides? A LA-ICPMS perspective	Anglo American, AngloGold, BHP Billiton, Newcrest, Newmont, Placer Dome	2003-2005	\$78,589	\$13,000
Khin Zaw, S Meffre, W Herrmann, SD Golding, A Harris	Geochronology, metallogenesis and deposit styles of Loei foldbelt in Thailand and Laos PDR	Kingsgate Consolidated NL, Oxiana Resources NL, Pan Australian Resources NL	2004-2006	\$90,000	\$90,000

ARC Discovery Grants 2005

Investigators	Project	Period	ARC Funding for 2005
L Danyushevsky	The role of melting of oceanic crust within the subduction factory: A melt inclusion approach	2003-2005	\$30,000
A Crawford	Tectonic paradox of the eastern margin of the Australian Plate, 120-45 Ma	2003-2005	\$78,570
S Allen	Submarine Explosive Eruptions of Silicic Magma: Constraints on Products and Processes from Modern Sea-floor Examples, Ancient Successions and Experiments	2004-2008	\$90,000
G Davidson, D Cooke, C Deyell	Cracking the sulfate isotopic composition problem in ancient hydrothermal systems: application of the carbonate-associated sulfate (CAS) method	2005-2006	\$65,000

Other Research Grants 2005

Investigators	Project	Funding Body	Period	Funding for 2005
L Danyushevsky	Trace element Analysis of fish otoliths by LA-ICPMS. Falkland Islands Government	Faulkland Island Government Fisheries Department	2005	\$45,000
D Cooke, A Rae (PhD project: D Braxton)	Boyongan Porphyry Copper-Gold Deposit, Surigao, Philippines	Anglo American Exploration	2003-2005	\$37, 896
K Zaw, D Cooke, N White, C Ryan (PhD project: P Cromie)	Geological setting, geochemistry and genesis of the Sepon mineral district, Laos	Oxiana Resources NL	2003-2005	\$14,700
JB Gemmell , R Berry	Geology and Geochemistry of the Footwall Phyllite, Greens Creek VHMS Deposit, Alaska: Implications for Ore Genesis and Exploration	Kennecott Greens Creek Mining Company	2004-2008	\$40,262
A Crawford	Broken Hill amphibolites study	NSW Geological Survey	2005	\$8,000
D Cooke	District-to Deposit-scale Structural and Geochemical Study of the Cadia Porphyry Au-Cu Deposits	Newcrest Mining Limited	2005	\$192,225
D Cooke	Shallow and deep-level alkalic mineral deposits: an integrated exploration model	Anglogold Ashanti, Newcrest Mining Ltd, Newmont Mining Corp, Barrick Gold Corp, Placer Dome Inc, Teck Cominco Ltd, Amarc Resources Ltd, Imperial Metals, Nova Gold Resources.	2005	\$65,000
R Berry, L Danyushevsky, R Large, JB Gemmell. D Cooke, J Reid	Scanning electron microscope with system for automated mineral mapping and textural analysis to support new geometallurgy research initiative	LIEF - Australian Research Council		\$512, 092
A.C. Harris, S.W. Bull, N.C. White and M.A. Line	Chemistry of magmatic gases involved in the formation of barite hosting early life structures.	IRGS	2005	\$13,000
S Meffre, S Bull, D Selley	Age of granite and quartzite from Rajasthan India	Anglo American	2005	\$8,000

Collaborations with CODES 2005

Institution	Researcher	CODES collaborators	Project
INTERNATIONAL INSTITUTIONS			
Chiang Mai University	P Limtrakun	A Crawford	Denchai sapphire host basalts
Chinese Academy of Geological Sciences	H Zhengqian	JB Gemmell, Khin Zaw	Program 3 – Ores in volcanic arcs
Colorado School of Mines	M Hitzman, D Broughton	S Bull, D Selley, R Scott, R Large	P872 Congolese Cu project
Colorado School of Mines	J Hedenquist	Z Chang, D Cooke, JB Gemmell	AMIRA/ARC P765: Transitions and Zoning in Porphyry-Epithermal. Districts: Indicators, Discriminators and Vectors
Colorado State University	H Stein	D Cooke	Re-Os dating of porphyry deposits
Consultant, Porto	O Gaspar	JB Gemmell, R Large, M Solomon, Khin Zaw, J McPhie, S Bull	Project 3.5 The nature, diversity and genesis of ancient massive sulfide copper-lead-zinc-silver-gold deposits in volcanic arc settings
Department of Mineral Resources Thailand	S Khositantont	A Harris	Mineral deposit geology of Thailand
Duke University	J Karson	G Davidson	Program 3 – Ores in volcanic arcs
Forrest Group	J Cailteux	S Bull, D Selley	P872 Congolese Cu project
Freiberg University	T Monecke	JB Gemmell, C Gifkins, W Herrmann, R Large	Program 3 – Ores in volcanic arcs
Geo Dynamics and Ore Deposit Evolution (GEODE)		B Gemmell, R Large	Program 3 – Ores in volcanic arcs
GeoForschungs Zentrum Potsdam, Germany	I Veksler R Thomas	M Kamenetsky V Kamenetsky	Immiscibility in magmas
Geological Survey of Canada	J Peter	K Zaw	Fluid composition and magmatic connection of Middle Valley system
Geological Survey of Canada	J Peter T Monecke M Hannington I Jonasson	JB Gemmell	Project 3.3 Active base and precious metal-rich massive sulfide deposition associated with submarine volcanism Project 3.5 The nature, diversity and genesis of ancient massive sulfide copper-lead-zinc-silver-gold deposits in volcanic arc settings
Geological Survey of Japan		JB Gemmell	Program 3 – Ores in volcanic arcs
Geomarine Research, Auckland, New Zealand	B Hayward	S Allen	Facies characteristics of volcanoclastic mass-flow deposits
Ghent University, Department of Geology, Belgium	M Elburg	V Kamenetsky	Origin of low-Ca olivine in SSZ magmas
Idaho Geological Survey, USA	R Lewis	Z Chang	Detrital zircons from north-central Idaho, USA
IFM-GEOMAR Leibniz-Institute for Marine Sciences, Germany	A Freundt	S Allen	Experimental simulations of submarine volcanoclastic mass-flows
Imperial College	A Berry	A Harris	Cu speciation in magmatic-hydrothermal fluids as determined by synchrotron microanalysis
Institute of Geochemistry Taiwan	TF Yui	K Zaw	Laser ablation oxygen isotope studies of sapphires and magnetites

Collaborations with CODES 2005 cont.

Instituto Geológico e Mineiro Lisbon	C Inverno	JB Gemmell, R Large, M Solomon, Khin Zaw, J McPhie, S Bull	Project 3.5 The nature, diversity and genesis of ancient massive sulfide copper-lead-zinc-silver-gold deposits in volcanic arc settings
Instituto Geológico y Minero de España Salamanca Spain	F Tornos C Quesada	M Solomon	Project 3.5 The nature, diversity and genesis of ancient massive sulfide copper-lead-zinc-silver-gold deposits in volcanic arc settings
Institute of Geology and Mineral Exploration (Athens, Greece)		J McPhie	Project 2.1 Facies architecture models for submarine volcanic successions that host base- and precious-metal ore deposits in arc environments
Institute of Mineralogy, Ural Branch of Russian Academy of Sciences	V Maslennikov	R Large, R Scott, L Danyushevsky, JB Gemmell	Study of sulphide geochemistry from active black-smokers, VHMS ore deposits and sedimentary-hosted gold ore deposits
Institute of Mineralogy and Petrography, Novosibirsk, Russia	V Sharygin A Golovin	M Kamenetsky V Kamenetsky	Identity of kimberlite magmas – study of Udachnaya-East pipe
Istituto Nazionale di Geofisica e Vulcanologia - Sezione di Pisa, Italy	M Pompilio	V Kamenetsky	Primary magmas at Mount. Etna – the ‘FS’ eruption
Instituto Geológico e Mineiro Alfragide (Lisboa) Portugal	C Inverno	M Solomon	Program 3 – Ores in volcanic arcs
Japan Marine Science and Technology Center, Japan	Y Tamura	S Allen, J McPhie, V Kamenetsky	Submarine volcanoes of the Izu-Bonin Arc
Johns Hopkins University	G Garven, C Schardt	R Large, S Bull	Fluid flows in sedimentary basins
Lakehead University	P Hollings	D Cooke	Tectonics and petrochemistry of porphyry mineral belts
Lulea University	R Allen	S Bull, B Gemmell	P872 Congolese Cu project; Program 3 – Ores in volcanic arcs
Max-Planck Institute for Geochemistry, Germany	A Sobolev	M Kamenetsky V Kamenetsky	Identity of kimberlite magmas – study of Udachnaya-East pipe
Max-Planck Institute for Geochemistry, Germany	V Batanova, A Sobolev	V Kamenetsky	Crustal evolution of island-arc ultramafic magmas: Galmoenan pyroxenite–dunite plutonic complex
MDRU	D Tosdal, C Chamberlain	D Cooke, C Deyell	Alkalic mineral deposits
Nanjing University	G Lianxing, N Pie	JB Gemmell	Project 3.5 The nature, diversity and genesis of ancient massive sulfide copper-lead-zinc-silver-gold deposits in volcanic arc settings
National Institute for Engineering, Technology and Innovation (Portugal)	L Martins	J McPhie	Character and setting of volcanic successions that host massive sulfide ore deposits in the Iberian Pyrite Belt, Portugal
Neves Corvo mine, Somincor Lisbon Portugal	N Pacheco	M Solomon	Massive Sulphide projects 3.5 and F 2.3.
New Zealand Crown Institute of Geological and Nuclear Sciences	N Mortimer, R Herzer	A Crawford	SW Pacific tectonics
Smith College, USA	L Meinert	Z Chang	Cu-Zn skarn in the Empire mine, Idaho, USA
Smithsonian Institution, USA	R Fiske	S Allen, J McPhie, V Kamenetsky	Eruption mechanisms and characteristics of submarine felsic pumice
University of Arizona	M Barton	G Davidson	Program 3 – Ores in volcanic arcs

Collaborations with CODES 2005 cont.

University of Arizona	E Seedorff	A Harris	Porphyry Ore Deposit Geology
University of Auckland	S Simmons	B Gemmell	Program 3 – Ores in volcanic arcs
University of British Columbia	D Oldenberg	M Roach	Geophysical inversion modelling
University of Chicago/ GSE-CARS	M Newville, S Sutton	A Harris	Cu speciation in magmatic hydrothermal fluids as determined by synchrotron microanalysis
Universita` degli Studi di Pisa, Italy	P Fulignati, P Marianelli	V Kamenetsky	Immiscibility in Mount Vesuvius magmas – melt/fluid inclusion study
University of Geneva, Switzerland	O Bachman	S Allen	Caldera eruptions
University of Heulva, Hielva, Spain	R Saez, M Toscano	M Solomon	Massive Sulphide projects 3.5 and F 2.3.
University of Idaho, USA	B McClelland	Z Chang	LA-ICP-MS U-lead dating of zircon
University of Lisbon (Portugal)	J Relvas	J McPhie, S Meffre	Character and setting of volcanic successions that host massive sulfide ore deposits in the Iberian Pyrite Belt, Portugal
University of Michigan	J Alt	G Davidson	Program 3 – Ores in volcanic arcs
University of Oregon, Department of Geological Sciences, USA	K Cashman, P Wallace	S Allen	Project 2.2 Facies characteristics of submarine-emplaced rhyolitic pumice breccias
University of Orleans	D Cluzel	S Meffre, A Crawford	Age of felsic dykes in ultramafic rocks from New Caledonia
University of Orleans	B Wang	S Meffre	Age of granites from the Tianshan Orogenic Belt, NW China
University of Ottawa	M Hannington	B Gemmell	Program 3 – Ores in volcanic arcs
University of Southampton	D Teagle, R Coggan	G Davidson	Program 3 – Ores in volcanic arcs
University of Toronto	S Scott	JB Gemmell, Khin Zaw, D Kamenetsky	Project 3.3 Active base and precious metal-rich massive sulfide deposition associated with submarine volcanism
University of Washington, Seattle, USA	G Bergantz	S Allen	Caldera eruptions
University of Windsor	J Yang	R Large, S Bull	Fluid flow related to SEDEX Zn-Pb-Ag deposits
US Geological Survey	C Finn	G Davidson	Program 3 – Ores in volcanic arcs
US Geological Survey	P Emsbo	R Large, R Scott	AMIRA Project 923
Waikato University	R Price	A Crawford	Vanuatu ophiolites
Washington State University, USA	J Vervoort	Z Chang	LA-ICP-MS U-lead dating of zircon; Detrital zircons from north-central Idaho, USA
Washington State University, USA	P Larson	Z Chang	Isotopes of quartz from HS environments
Yale University	P Reiners	A Harris	Thermochronologic analuese of porphyry systems to constrain their uplift and exhumation histories
Yukon Geological Survey	J Hunt	Garry Davidson	Program 4- Ores in continental rift basins

Collaborations with CODES 2005 cont.

NATIONAL INSTITUTIONS

Australian Museum	I Graham, L Sutherland	K Zaw S Meffre	Gem signatures in Pacific Rim. Age of zircon inclusions in Columbian sapphires
Australian National University, RSES	M Norman	G Davidson	Program 3 – Ores in volcanic arcs
Australian National University, RSES	G Yaxley	V Kamenetsky	Contamination of Baffin Island primitive magmas
Australian National University	C Allen, J Dunlap, I Campbell	A Harris	Geochronology and thermochronology of porphyry ore deposits
Australian National University	R Arculus, S Eggins	JB Gemmell, D Kamenetsky, Khin Zaw, M Solomon, R Large	Project 3.1 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
Consultant	N White	Z Chang, D Cooke	AMIRA/ARC P765: Transitions and Zoning in Porphyry-Epithermal Districts: Indicators, Discriminators and Vectors; Quartz from HS environments; Caijiaying Zn-Au deposit, China
CSIRO Exploration and Mining	R Binns, T McConaghy	B Gemmell	Project 3.3 Active base and precious metal-rich massive sulfide deposition associated with submarine volcanism
Department of Primary Industries and Resources SA (PIRSA)	M Schwartz	G Davidson	Program 4- Ores in continental rift basins
Geological Survey of NSW	S Meakin, G Colquhoun	J McPhie	Early Devonian volcanic successions in the western Lachlan Fold Belt
Geoscience Australia	P Southgate	S Bull, R Large	Program 5: Fluid flow related to Zn-Pb-Ag deposits
Geoscience Australia	R Skirrow	G Davidson	Program 4- Ores in continental rift basins
Geoscience Australia	D Huston	G Davidson	Program 3 – Ores in volcanic arcs
Haoma	B Skrezinski	S Bull	Project 2.1 Facies architecture models for submarine volcanic successions that host base- and precious-metal ore deposits in arc environments
James Cook University	T Baker, K Volp	G Davidson	Program 4- Ores in continental rift basins
James Cook University	N Oliver, J Cleverley	D Cooke	Fluid mixing in hydrothermal systems
Macquarie University	M Lackie	J McPhie	AMS analyses of voluminous felsic lavas in the Gawler Range Volcanics
McArthur Ore Deposit Assessments Pty	G McArthur	B Gemmell	Program 3 – Ores in volcanic arcs
Mineral Resources Tasmania	R Bottrill, R Woolley	Z Chang	Illite crystallinity
Mineral Resources Tasmania	A Brown	G Davidson	Program 3 – Ores in volcanic arcs
Mineral Resources Tasmania	J Everard	A Crawford	Tasmanian Triassic basalts
Mineral Resources Tasmania		J McPhie	Program 2
Monash University	A Morey	G Davidson	Program 4- Ores in continental rift basins

Collaborations with CODES 2005 cont.

Monash University (Australian Crustal Research Centre)	D Giles	A Crawford	N QLD tectonics
NSW Geological Survey	RA Glen	A Crawford	NSW Ordovician tectonics and mineralis
NSW Geological Survey	S Meakin	J McPhie	Project 2.1 Facies architecture models for submarine volcanic successions that host base- and precious-metal ore deposits in arc environments
NSW Geological Survey	B Stevens	A Crawford	Broken Hill amphibolites
Primary Industries and Resources South Australia	G Ferris, M Schwartz	S Allen, J McPhie	Voluminous felsic lavas in the Gawler Range Volcanics
Qld Geological Survey	I Withnall	A Crawford	Greenvale and Georgetown block magmatism and tectonics
University of Adelaide	K Barovich	G Davidson	Program 4- Ores in continental rift basins
University of Ballarat	S McKnight	Z Chang	Clay mineralogy by XRD
University of Melbourne School of Earth Sciences	R. Maas	M. Kamenetsky V Kamenetsky	Identity of kimberlite magmas – study of Udachnaya-East pipe
University of Newcastle	C Simpson	J McPhie	Project 2.3 Facies architecture of volcanic successions that host porphyry Cu-Au ore deposits in arc settings Project 2.9 Volatile budget, volcanology and source-vent locations of voluminous felsic lavas: Mesoproterozoic Gawler Range Volcanics in South Australia
University of New England	S Abbot	S Meffre	Age of detrital zircons from the Tasmania Basin
University of Queensland	S Golding	K Zaw A Harris	- Oxygen-Hydrogen isotope and ore deposits - Isotopic studies of porphyry and epithermal ore deposits
University of Queensland, JKMRC	T Napier-Nunn	S Walters, R Large	Geometallurgy
University of Western Australia	M Barley	K Zaw	SHRIMP geochronology
University of Western Australia	S Kenworthy, W Thorne, M Zucchetti, R Silva, S Hagemann, J Hodge	G Davidson	Program 4- Ores in continental rift basins
University of Western Australia, PMDCRC	F Beirlein	G Davidson	Program 4- Ores in continental rift basins

Visitors to CODES 2005

ACADEMIC AND GOVERNMENT						
Broughton	David		Colorado School of Mines	Congloese copper deposits		
Cook	Nigel		Geologisk Museum, Norway	South China ore deposits		
Emsbo	Poul	Dr	USGS	Carlin gold deposits		
Hedenquist	Jeff	Professor	Colorado School of Mines	Porphyry copper and epithermal depts		
Hitzman	Murray	Professor	Colorado School of Mines	Congloese copper deposits		
Maslennikov	Svetalana	Dr	Institute of Mineralogy, Ural Branch of Russian Academy of Sciences	Study of sulphide geochemistry from active black-smokers, VHMS ore deposits and sedimentary-hosted gold ore deposits Collaboration with R Large, R Scott, L Danyushevsky	Nov, Dec	
Maslennikov	Valery	Professor	Institute of Mineralogy, Ural Branch of Russian Academy of Sciences	Study of sulphide geochemistry from active black-smokers, VHMS ore deposits and sedimentary-hosted gold ore deposits Collaboration with R Large, R Scott, L Danyushevsky	Nov, Dec	
Plechov	Pavel	Assoc. Prof.	Moscow State University	Computer modelling of magma crystallisation processes. Collaboration with L Danyushevsky.		
Russell	Michael J	Professor	University of Glasgow, Scotland	Seminars on lead-Zn deposits of Eire, and origin of life		
Cleverley	James		James Cook University	Ore Deposit Geochemistry, Hydrology and Geochronology Short course	June	
Dadd	Kelsie		Macquarie University	Program 2 collaboration		
Glen	RA	Dr	Department of Primary Industries NSW	NSW Ordovician tectonics and mineralisation	Oct	
Heithersay	Paul	Director	PIRSA	Science Planning Panel	July	
Hergt	Janet	Dr	University of Melbourne	Collaboration with L Danyushevsky		
Hodge	Joanna	PhD student	University of Western Australia	Isotope Anlaysis – collaboration with G Davidson	Dec	
Norman	Marc	Dr	RSES, Australian National University	Program 3 – Ores in volcanic arcs – collaboration with G Davidson		
Oliver	Nick	Professor	James Cook University	Ore Deposit Geochemistry, Hydrology and Geochronology Short course	June	
Osuchowski	Monica		Geoscience Australia	Collaboration with G Davidson	June	
Silva	Rosaline	PhD student	University of Western Australia	Isotope Anlaysis – collaboration with G Davidson	Dec	
Simpson	Carol	Dr	University of Newcastle	Collaboration with A Crawford and R Scott	Aug	
Stevens	Barny		Department of Primary Industries NSW	Collaboration with A Crawford on Broken Hill	Oct	
Walshe	John	Dr	CSIRO	Ore Deposit Geochemistry, Hydrology and Geochronology Short course	June	
Woodhead	Jon	Dr	University of Melbourne	Collaboration with L Danyushevsky		
Wyborn	Lesley	Dr	Geoscience Australia	Ore Deposit Geochemistry, Hydrology and Geochronology Short course	June	
Yaxley	Greg	Dr	RSES, Australian National University	Contamination of Baffin Island primitive magmas- V Kamenetsky	Sept	

Visitors to CODES 2005 cont.

Zucchetti	Marcia	PhD student	University of Western Australia	Isotope Analysis – collaboration with G Davidson	Dec
INDUSTRY					
Allen	Andrew		Anglo American	Discussions with S Bull on exploration strategies for sediment hosted Zn-lead-Ag deposits in the Proterozoic of northern Australia	Feb
Beardsmore	Trevor		Barrick Gold	AMIRA P923 Sponsors meeting	July
Blevin	Phil		Consultant	Ore Deposit Geochemistry, Hydrology and Geochronology Short course	June
Brown	Anthony		Mineral Resources Tasmania	Program 3 – Ores in volcanic arcs – collaboration with G Davidson	
Chamberlain	Claire		MDRU	Field work with D Cooke	Nov, Dec
Chittaphai	Thongmeuan		LXML- Oxiana	Loei ARC Linkage project annual review meeting	Nov
Frederickson	Dean		Newcrest Mining	Short course - Structural data from drill core	Nov
Goode	Alan		AMIRA	AMIRA P923 meeting, Science Planning Panel and Advisory Board meeting	July
Hague	Richard		Pan Australian Resources Ltd	Loei ARC Linkage project annual review meeting	Nov
Halley	Scott		Placer Dome	Ore Deposit Geochemistry, Hydrology and Geochronology Short course	June
Hammond	John		Newmont	AMIRA P923 meeting, Science Planning Panel and Advisory Board meeting	July
Holliday	John		Newcrest Mining	Short course - Structural data from drill core	Nov
James	Ron		Kingsgate Consolidated	Loei ARC Linkage project annual review meeting	Nov
Komyshan	Peter	Gen Manager Exploration	Anglo Australian Resources NL		Sept
Langsford	Nick		Newcrest		Feb
Shelverton	Mark		Oxiana Limited	Loei ARC Linkage project annual review meeting	Nov
Smith	Stuart		Oxiana Limited	Loei ARC Linkage project annual review meeting	Nov
Song	Victor		Oxiana Limited	Loei ARC Linkage project annual review meeting	Nov
Tedder	Ian		Newcrest Mining	Short course - Structural data from drill core	Nov
Tosdal	Dick		MDRU	Collaborators Research meeting	Dec
Vorabouth	Somdee		LXML- Oxiana Limited	Loei ARC Linkage project annual review meeting	Nov
Willis	Ian		Anglo American	Meeting with D Selley, S Bull	Sept
Wilson	Alan		Newcrest	AMIRA P923 Sponsors meeting	July
White	Noel		Consultant	AMIRA P765	Dec

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Cover: Pyrite–roscoelite–gold-cemented hydrothermal breccia,
Porgera, PNG



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