



Centre for Ore Deposit Research

An ARC Special Research Centre

at the University of Tasmania

• Australia •

Annual Report 2002

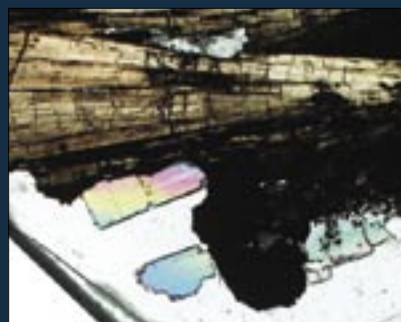
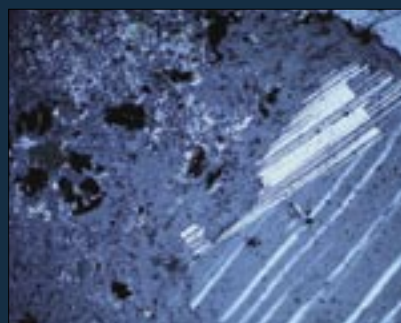
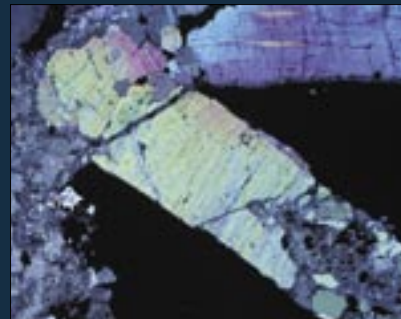
MISSION

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

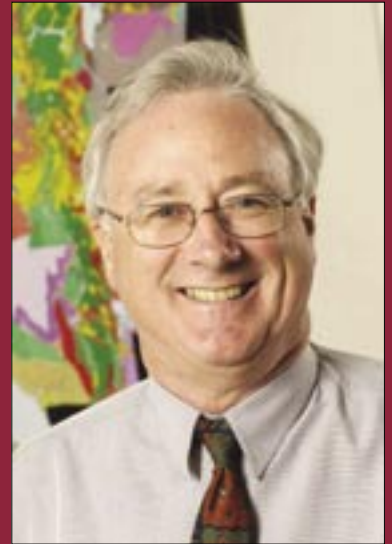
- To build upon the success of the Key Centre for Ore Deposit and Exploration Studies (CODES) by integrating the applied aspects of CODES ore deposit research with fundamental research expertise in igneous petrology, volcanology, sedimentology, tectonics and fluid processes.
- To develop a centre in 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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Ore and gangue textures from Rio Blanco Cu-Mo deposit, Chile (top to bottom): Chalcopyrite and sericite replacement of anhydrite. Dissolution of anhydrite and replacement by sericite and minor chalcopyrite. Chalcopyrite replacement of anhydrite. Tourmaline and anhydrite partially replaced by chalcopyrite. (Project 5.7)

Director's Report



ROSS LARGE, DIRECTOR OF CODES

After six years of operation as an ARC Special Research Centre, CODES has matured into a world-class research centre, with 26 geoscientists, 13 support staff and 56 postgraduate students working on more than 30 major research projects around the globe. Our primary goals are:

- to better understand the geological and geochemical controls on the location and genesis of ore deposits in magmatic arcs and extensional sedimentary basins, and
- to use this knowledge to aid the minerals industry in the discovery of new resources, thus helping to underpin Australia's economic sustainability.

The highlight of 2002 was the extremely positive ARC review of CODES operations after the first six years (1997–2002). The review panel's final assessment, outlined in their report to the Council of the ARC, stated ... *"CODES is a world leader in its field and a flagship research centre of the University of Tasmania. It is viewed within the minerals industry and research community as the premier international research centre in ore deposit geology and mineral exploration. It has a laudable reputation as an organization that balances strong fundamental research with applied outcomes. Industry values the breadth of expertise available at CODES, which facilitates a holistic, multi-disciplinary approach to projects. Staff and students are well supported by the Centre and have delivered an impressive range of research outcomes."* The panel report went on to recommend that the ARC core funding of \$903,834 per annum be continued for a further three years. This is a particularly pleasing outcome — one which places us in a strong position to plan, in collaboration with other geoscientific

organisations and the minerals industry, new research directions for the next decade.

As part of the review process, we undertook an internal publication benchmarking exercise. This assessed CODES peer-reviewed publication output over the last five years against those of 25 research centres, university departments and geoscience institutes, in Australia and overseas, which specialised in one of the three key areas of CODES research (ore deposit geology, volcanology and petrology). The results of this exercise (see page 10), demonstrate that the number of CODES publications compares very well relative to the other organisations surveyed. For example, we generated the largest number of first-authored articles in the top two international journals in ore deposit geology (*Economic Geology* and *Mineralium Deposita*), the third largest number of articles in the top two volcanology journals, and the tenth largest number of articles in the top three petrology–geochemistry journals. In addition to the 168 refereed publications by CODES staff and students during this period, we also delivered 96 research reports to industry and made 228 presentations at national and international conferences, including 29 keynote and invited speaker presentations.

The ARC review panel recognised that the excellent international profile of CODES is in part due to a strategy involving high quality communication materials. These include conference proceedings, industry reports and CDs, textbooks such as *Volcanic Textures*, academic publications and our annual report. In June 2002, we held the Giant Ore Deposits (GODs) workshop

which exemplified our commitment to quality communication. The GODs workshop was attended by 164 national and international research scientists and industry representatives. It included a series of presentations by invited international speakers and also showcased the scope and calibre of CODES research. A special publication containing papers presented at the GODs workshop was produced for the meeting and for subsequent sales. The impressive attendance and resounding success of the meeting and associated publication was due to the outstanding efforts of David Cooke, June Pongratz, Lynne Vaudrey and a devoted group of CODES staff and postgraduate students.

Over the last six years, CODES has derived approximately one-third of its research funding from industry sources, with the remaining two-thirds from the ARC and the University of Tasmania. In 2002, industry funding was \$1,200,000, which is slightly above the average of \$925,400 pa for the period 1997–2001. Forty-seven percent of our industry funding came from five major international research projects co-ordinated by AMIRA. CODES was either the principal or a leading research organisation in these projects. Four of our five AMIRA projects were successfully completed in 2002.

- P588 – 'Epithermal Au-Ag deposits: Geological, geochemical and isotopic vectors to target major deposits' had its final research meeting at Hobart in December. At the completion of the meeting, AMIRA research co-ordinator Alan Goode congratulated Bruce Gemmell (CODES) and the research team for an outstanding project.

- P511 – ‘Giant porphyry Cu deposits’, led by David Cooke (CODES) and John Walshe (CSIRO) conducted final research meetings in Hobart in June, and Santiago (Chile) in November. Sponsors were provided with a two volume final report covering aspects of the character and genesis of the giant porphyry Cu deposits of the Chilean Andes. The results are currently being written-up for a Special Issue of *Economic Geology*.
- P552 – ‘Fluid-flow modelling in the Mount Isa and McArthur Basins’, a collaboration between Peter Southgate (GA), Jianwen Yang (CODES), Kurt Kyser (QueensU), Sue Golding (UQld) and Alison Ord (CSIRO), had final research meetings in Kingston (Canada) and Canberra. This highly innovative project combined basin analysis geochronology, stable isotopes, organic maturation and numerical modelling of fluid flow to develop ideas for sedimentary Zn and U exploration.
- P603 – ‘Tectonics and metallogenesis of south China’, led by Khin Zaw (CODES) had its final meeting in Hobart in December. This project has developed a powerful GIS data framework for southern China that enables stratigraphic correlations, and a synthesis of fault histories and metallogenic/tectonic relationships. These will be invaluable for mineral explorers in the region.

The on-going AMIRA P544 led by Peter McGoldrick (CODES) and Murray Hitzman (Colorado School of Mines) is focussed on Proterozoic sediment-hosted Cu deposits in Zambia and Australia. The project held successful research meetings with sponsor companies in Adelaide (May), Denver, USA (November) and Hobart (December). This project is on track and due for completion in July 2003.

Due to the expected completion of all CODES current AMIRA-ARC-Linkage projects before mid-2003, a major effort was expended during 2002 to develop new research projects and apply for funding from AMIRA and ARC. Two major new projects, porphyry Cu and epithermal Au systems (Leaders: David Cooke and Bruce Gemmell), and BHT and SEDEX Zn-Pb-Ag systems (Leaders: Ross Large and Wayne Goodfellow, GSC), have been discussed and developed in close liaison

with potential industry partners and research collaborators. Meetings designed to get feedback were held with exploration companies in Perth, Sydney, Brisbane, London (UK), Vancouver (Canada), Denver (USA) and Santiago (Chile). Final proposals for both projects were submitted to AMIRA in December.

Exciting results continued to come from our LA-ICPMS facility during the year. The industry-funded project on sulfide geochemistry led by Garry Davidson and Andrew Rae completed the first case study on the Sunrise Dam lode Au deposit. The results were far beyond expectations, and provide exciting opportunities for the application of this technique to Au genesis studies and mineral exploration. A recent breakthrough has been the analysis of fluid inclusions by LA-ICPMS. Development work by Leonid Danyushevsky produced a specialised ablation chamber enabling quantitative analysis of fluid inclusions for a wide range of major and trace elements at low levels. This analytical advancement is set to revolutionise our research into the chemistry of hydrothermal fluids.

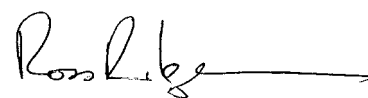
Excellent news during 2002 was the well-deserved promotion of several of CODES staff: Tony Crawford, Deputy Director of CODES, was awarded a Personal Chair in recognition of his contributions to research in petrology, geochemistry and tectonics; Bruce Gemmell, Leader of Program 3, became an Associate Professor, and Khin Zaw and Dima Kamenetsky were promoted to Senior Research Fellows.

A continuing problem, not only for CODES but for all Australian geoscience departments and centres, is the on-going decline in undergraduate and postgraduate student numbers in earth sciences. With the minerals exploration industry finally appearing to improve, there is likely to be an un-met demand for graduate geologists over the next five years. In 2002, we instigated a project in collaboration with the School of Earth Sciences (UTas) to reverse the downward trend in student numbers. This involved the development and production of a promotional CD to inform school leavers about the career opportunities in the earth sciences, and to encourage them to enrol in geology at university. We are very pleased with the CD, and early enrolment enquires for 2003 suggest the strategy may be working.

“CODES is a world leader in its field and a flagship research centre of the University of Tasmania. It is viewed within the minerals industry and research community as the premier international research centre in ore deposit geology and mineral exploration. It has a laudable reputation as an organization that balances strong fundamental research with applied outcomes. Industry values the breadth of expertise available at CODES, which facilitates a holistic, multi-disciplinary approach to projects. Staff and students are well supported by the Centre and have delivered an impressive range of research outcomes.”

Extract from the review panel's report to the Council of the ARC following the review of CODES operations 1997–2002.

In concluding, I thank our industry sponsors for their support of our research programs and student projects throughout the year, and the CODES research team, support staff and postgraduate students for their continued dedication toward achieving our goals.



Ross R Large

Management



CODES Program Leaders (left to right): Ross Large (Director), Tony Crawford, Jocelyn McPhie, Bruce Gemmell, David Cooke and Peter McGoldrick

DIRECTOR

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

ADVISORY BOARD

Advisory Board members represent major industry sponsors, University of Tasmania senior 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 2002 are James McDonald (Chief Geoscientist, BHP Billiton) and Jim Reid (Dean, Faculty of Science, Engineering & Technology, UTas).

SCIENCE PLANNING PANEL

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

EXECUTIVE COMMITTEE

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

STAFF

CODES employs 26 research staff and 13 administrative and technical staff who are funded by the SRC grant, industry and university support.

Twelve of the academic staff and seven of the general staff are joint appointments between CODES and the School of Earth Sciences.

During 2002, two new postdoctoral fellows, Cari Deyell and Anthony Harris joined CODES, to strengthen our expertise in porphyry Cu and epithermal Au systems.

Cari Deyell was working with David Cooke and Bruce Gemmell to develop a new AMIRA project on porphyry and epithermal systems. Cari graduated with a PhD from the Mineral Deposits Research Unit (UBC), in December 2001, where she worked on high-sulfidation systems in the El Indio-Pascua belt in Chile and Argentina. She has previously worked for the Geological Survey of Canada in the Canadian Arctic doing regional mapping

in Archean greenstone terrains and evaluating Au occurrences within banded iron formation.

Anthony Harris has joined CODES to work with Tony Crawford, Dima Kamenetsky and David Cooke on melt inclusions and intrusion-related mineral deposits. He obtained his PhD on the genesis of the Bajo de la Alumbrera porphyry Cu deposit in northwest Argentina from the University of Queensland.

With the departure of Marc Norman to the Australian National University in 2001, Leonid Danyushevsky has been appointed as Senior Research Fellow and manager of the LA-ICPMS laboratory at CODES. Leonid has been very active in development of analytical protocols for fluid- and melt-inclusion analysis and in further developing the LA-ICPMS facility for sulfide analyses.

We were disappointed to lose Jianwen Yang during 2002, he departed to take a faculty position at the University of Waterloo in Canada. However, our work on hydrothermal fluid-flow modelling will continue in a series of collaborative research projects with both Jianwen and Grant Garven (Johns Hopkins U).

ADVISORY BOARD

Chair: Andrew Glenn	Pro Vice Chancellor – Research University of Tasmania
Jim Reid	Dean – Faculty of Science, Engineering & Technology University of Tasmania
Ross Large	Director, CODES
Ray McLeod	Exploration Manager, Newcrest
James McDonald	Chief Geoscientist, BHP Billiton
Chris Pigram	Chief, Minerals and Geohazards Division, Geoscience Australia
Alan Goode	Research Co-ordinator, AMIRA
Tony Brown	Director, Mineral Resources Tasmania
David Groves	Director, Centre for Global Metallogeny, University of Western Australia
Andrew Gleadow	Head, School of Earth Sciences, University of Melbourne
Ian Willis	VP Exploration – Asia/Australia, Anglo American
Tony Crawford	Deputy Director, CODES
Ron Berry	Head, School of Earth Sciences, University of Tasmania
Jocelyn McPhie	Program 2 Leader, CODES

EXECUTIVE COMMITTEE

Chair: Ross Large	Director, CODES
Tony Crawford	Deputy Director, Program 1 Leader
Jocelyn McPhie	Program 2 Leader
Bruce Gemmell	Program 3 Leader
Peter McGoldrick	Program 4 Leader
David Cooke	Program 5 Leader
Christine Higgins	Finance Manager
Lynne Vaudrey	Administrative Officer
Tanzi Lewis	Public Relations Officer (until September 2002)

SCIENCE PLANNING PANEL

Geoff Green	Managing Geologist (Metallic Minerals and Geochemical Services), Mineral Resources Tasmania
David Groves	Director, Centre for Global Metallogeny, University of Western Australia
Scott Halley	Chief Geologist, AurionGold
John Hammond	Chief Geologist, Newmont
Tony Hespe	Exploration Manager, Australia, Western Metal Resources
Ian Willis	Exploration Manager, Australia, AngloAmerican
Ray McLeod	Exploration Manager, Australia and SW Pacific, Newcrest Mining Ltd
Noel White	Consultant
Tim Callaghan	Senior Geologist, AurionGold
James McDonald	Global Leader, BHP Billiton Mineral Discovery
Rob Krcmarov	General Manager Exploration, Barrick Gold of Australia
Ian Scott	Group Manager, Geoscience Technologies, WMC Resources
Mike Haederle	Chief Geophysicist, Rio Tinto
Lesley Wyborn	Geoscience Australia
David Green	Mineral Resources Tasmania
Joe Cucuzza	AMIRA

CODES STAFF 2002

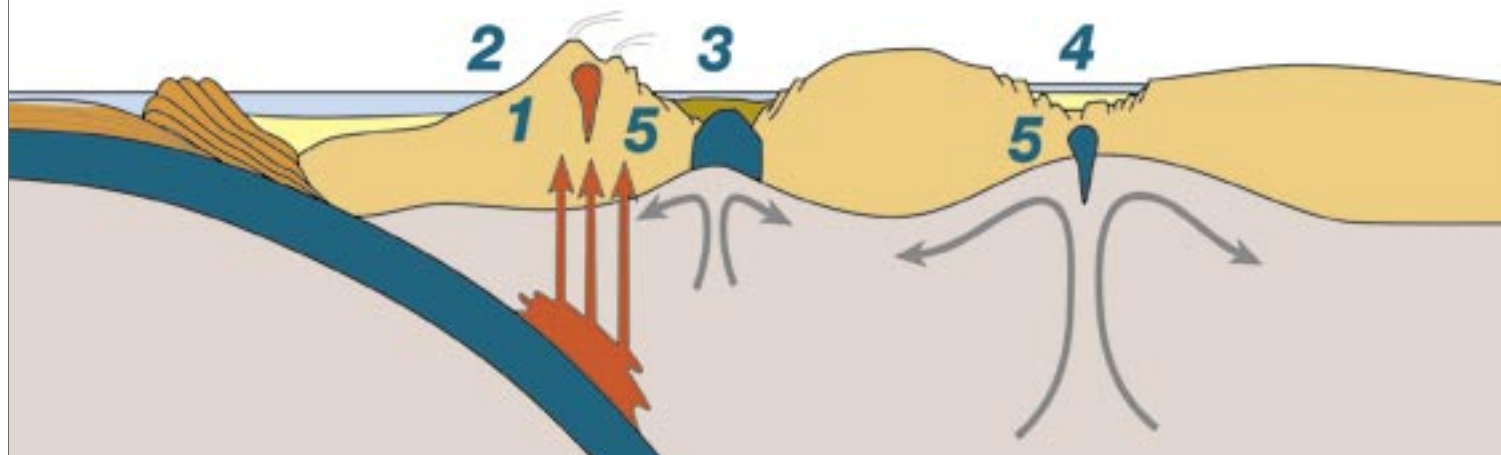
Director, Prof. Ross Large, BScHons (UTas), PhD (UNE)	Volcanic-hosted and sediment-hosted massive sulfide deposits	100*
Deputy Director, Assoc. Prof. Tony Crawford, BScHons, PhD (UMelb)	Petrology, geochemistry and tectonics of volcanic arcs	50
Academic Staff		
Dr Sharon Allen, BSc (MasseyU), MSc (UAuck), PhD (MonU)	Volcanic facies analysis	100
Dr Ron Berry, BSc, PhD (FlindersU)	Structure of mineralised provinces, CHIME dating	50
Dr Stuart Bull, BScHons, PhD (MonU)	Clastic and carbonate sedimentology and volcanology	100
Dr David Cooke, BScHons (LaTU), PhD (MonU)	Fluid-rock interaction and hydrothermal geochemistry	50
Dr Leonid Danyushevsky, PhD (Vernadsky Inst.)	Petrology, geochemistry and application of melt inclusions	100
Dr Garry Davidson, BScHons (ANU), PhD (UTas)	Sulfur isotope geochemistry and Cu-Au ores	50
Dr Cari Deyell, BSc (QueensU), PhD (UBC)	Geochemistry and mineralogy of hydrothermal systems	100
Associate Professor Bruce Gemmell, BSc (UBC), MA, PhD (Dart.Coll.)	VHMS deposits and epithermal Au-Ag deposits	50
Dr Cathryn Gifkins, BScHons (MonU), PhD (UTas)	Volcanology and alteration	100
Dr Anthony Harris, BScHons, PhD (UQld)	Ore deposit geology and geochemistry	100
Mr Wally Herrmann, BScHons (MonU), M.Econ.Geol. (UTas)	Alteration and exploration in volcanic settings	100
Dr Dima Kamenetsky, PhD (Vernadsky Inst.)	Petrology and geochemistry of melt inclusions	50
Dr Peter McGoldrick, BScHons, PhD (UMelb)	Geochemistry of ore deposits and their halos	75
Associate Professor Jocelyn McPhie, BAHons (MacqU), PhD (UNE)	Volcanic facies architecture and volcanic textures	50
Dr Sebastien Meffre, BScHons, PhD (USyd)	Petrology and tectonics of the SW Pacific	50
Dr Andrew Rae, MSc (UOtago), PhD (UTas)	Ore deposit geology and hydrothermal processes	100
Dr Michael Roach, BScHons (UNewc), PhD (UTas)	Electrical geophysical responses of sulfide ores	50
Dr Robert Scott, BScHons, PhD (MonU)	Structural geology	100
Dr David Selley, BScHons (UAdel), PhD (UTas)	Structural geology and basin analysis	100
Dr Robina Sharpe, BScHons, PhD (UTas)	Ore deposit geology and geochemistry	100
Dr Michael Solomon, MSc, PhD (UTas), DSc (ULondon)	Geochemistry and genesis of mineral deposits	25
Dr Andrew Tunks, BScHons (MonU), PhD (UTas)	Masters Coordinator. Structure and minerals industry	100
Dr Jianwen Yang, BEng (GuilinU), PhD (UTor)	Hydrogeology and geophysics	70
Dr Khin Zaw, BSc (YangonU), PhD (UTas)	Fluid inclusions and SE Asian metallogenesis	100
Technical/Administrative Staff		
Mr Michael Blake, BSc (UTas)	Research Assistant	100
Mr Alistair Chilcott, BComp (UTas)	Computer Systems Officer	70
Dr Fernando della Pasqua, PhD (UTas)	Curator and Research Assistant	50
Ms Sarah Gilbert, BScHons (UTas)	Research Assistant	100
Ms Christine Higgins, Grad. Cert. Management (UTas)	Finance Manager	50
Ms Nilar Hlaing, BSc (YangonU)	Research Assistant; Publications Officer	90
Ms Loreto Lazcano-Frikken, B.Soc. Sci. (GabrielaMistralU)	Administrative Assistant	100
Ms Tanzi Lewis, BA (UTas), GradDipPR (DeakinU)	Public Relations Officer (to September 2002)	100
Mrs Katie McGoldrick	Laboratory Assistant	80
Ms June Pongratz	Publications Manager	50
Mr Phil Robinson	Analytical Services Manager	70
Mrs Dianne Steffens	Finance Assistant	100
Ms Lynne Vaudrey, BA (USyd), BAHons (UTas)	Administrative Officer	100

% in CODES



CODES administrative and technical staff (left to right): June Pongratz, Christine Higgins, Katie McGoldrick, Sarah Gilbert, Di Steffens, Lynne Vaudrey, Peter Cornish, Loretto Lazcano-Frikken, Phil Robinson and Simon Stevens

RESEARCH



PROGRAM 1 TECTONICS, MAGMAS AND FLUIDS

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

PROGRAM 2 VOLCANIC FACIES ARCHITECTURE AND ORE- FORMING ENVIRONMENTS

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

PROGRAM 3 ORES IN VOLCANIC ARCS

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

PROGRAM 4 ORES IN CONTINENTAL RIFT BASINS

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

PROGRAM 5 HYDROLOGY AND CHEMISTRY OF HYDROTHERMAL SYSTEMS

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

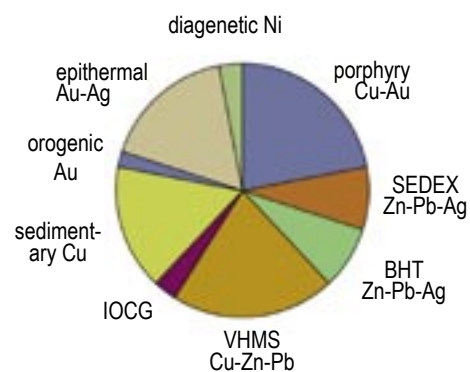
CODES research activities are grouped into five major programs. Our philosophy is for each CODES researcher to participate in at least two of the major programs, as this encourages a team approach in a multi-disciplinary environment.

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

CORE RESEARCH ACTIVITIES

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

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



ORE DEPOSIT RESEARCH CATEGORIES

Major industry–CODES collaborative projects

CODES is committed to developing and maintaining strong collaborative links with the mining and exploration industry at all levels of our research and teaching operations, from Honours projects to large multi-disciplinary research projects.

Projects of >\$100,000 pa are shown.

1
Isotopic response of fluid flow in submarine volcanic-hosted hydrothermal systems and implications for prospectivity: Mount Read Volcanics case study (Project 3.12)
completed August 2002

Investigators: R Large, G Davidson, W Herrmann; G Green, D Green, M McLenaghan, J Taheri (MRT); M Solomon, B Gemmell, M Blake.
Student projects: K Bassano, A Woolford, S Herrmann

Partners: AurionGold, MRT, Pasminco Exploration

2
AMIRA P511: Giant porphyry Cu deposits (Project 5.7)
completed December 2002

Investigators: D Cooke, P Hollings; J Walshe (CSIRO), P Gow (CSIRO), G Midgley (CSIRO)
PhD projects: J Cannell, P Friksen and G Masterman

Partners: Anglo American Exploration, AngloGold, BHP Billiton, Centaur Mining, Codelco-Chile, Falconbridge, GFL Mining Services, Goldfields Exploration, Homestake/ Barrick, Newcrest, Normandy, PacMin Mining/Sons of Gwalia, Phelps Dodge Exploration, Placer Dome Asia Pacific, TeckCominco, WMC Resources.

3
AMIRA P603: Geological, tectonic and metallogenic relations of South China (Project 1.8)
completed December 2002

Investigators: K Zaw; C Burrett (SES), R Berry (SES); R Large; E Bruce (GES)

Partners: AngloGold, BHP Billiton, Teck Cominco, Rio Tinto, Pasminco, Sino Mining International

4
Regional stratigraphy, basin evolution and setting of Zn, Pb, Cu, Ag and Au deposits in the Bergslagen district, Sweden (Project 4.4)

Investigators: S Bull, R Allen (LuleaU)

Partners: Geological Survey of Sweden, Boliden AB, Lulea University

5
AMIRA P588: Epithermal Au-Ag deposits: geological, geochemical and isotopic vectors to target major deposits (Project 3.9)
completed December 2002

Investigators: B Gemmell, W Herrmann, J McPhie, J Yang, R Scott, R Sharpe, M Blake; S Simmons (UAuckland).
Students: A Wurst, D Olberg; G Cater, B Young (UAuckland)

AngloGold, Aurora Gold, AurionGold, Barrick, Lihir Gold, Newcrest, Newmont

6
Trace element analysis of sulfides by LA-ICPMS: new applications for exploration vector geochemistry

Investigator: G Davidson

Partners: Placer, Newmont, AngloGold, Anglo American, BHP Billiton, Newcrest

7
Geology of the Escondida district, Chile

Investigator: A Tunks. Student: F Urzura

Partner: BHP Billiton

8
AMIRA P552: Fluid flow in the Mount Isa Basin (Project 5.2)
completed December 2002

Investigators: R Large, J Yang, S Bull, P Southgate (GA), S Golding (UQld), K Kyser (QueensU)

Partners: Anglo American, Cameco, Cominco, Rio Tinto, MIM, Pasminco, Western Metals, GA, CSIRO, QueensU, UQld

9
AMIRA P544: Proterozoic sediment-hosted Cu deposits: a comparison of Zambian and Australian environments (Project 4.6)

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

Partners: Anglo American (Zamanglo), AngloVaal Minerals, BHP Billiton, PIRSA, First Quantum-Mopani, INCO, MIM Exploration, Outokumpu, Phelps Dodge Exploration, Rio Tinto, Straits Resources. Teck Cominco, WMC

Benchmarking of CODES

In order to gain more quantitative data about CODES' publication output relative to other national and international geoscience research centres, research organisations and university departments we undertook a benchmarking exercise. The results of this exercise are summarised here.

Twenty-five research groups were chosen, 14 in Australia and 11 overseas. These groups all specialise in one or more of the three key areas of CODES research (ore deposit geology, volcanology and petrology). The number of first-authored publications from CODES and these groups were compared in eight leading journals:

- Ore deposits journals: *Economic Geology* (published in USA) and *Mineralium Deposita* (Germany). These are the top two journals in this field.
- Volcanology journals: *Bulletin of Volcanology* (Germany) and *Journal of Volcanology and Geothermal Research* (Netherlands). These are the two specialist journals in this field.
- Petrology journals: *Journal of Petrology* (England), *Contributions to Mineralogy and Petrology* (Germany) and *Earth and Planetary Science Letters* (Netherlands).

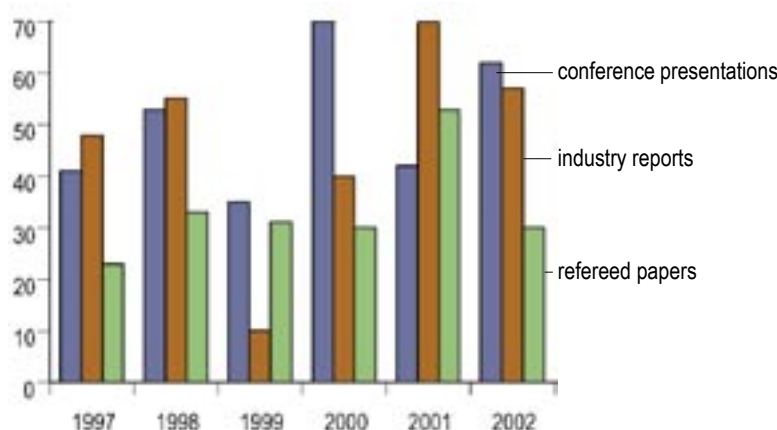
These are the three top journals in this field.

- General national journal: *Australian Journal of Earth Sciences*. This is the only general Australian geoscience journal.

The results of this exercise are presented in the graphs. They depict the number of first authored papers for CODES and the comparative research groups in the three research fields, and the general Australian field over the period 1997 to 2001 inclusive. Conclusions relevant to CODES are:

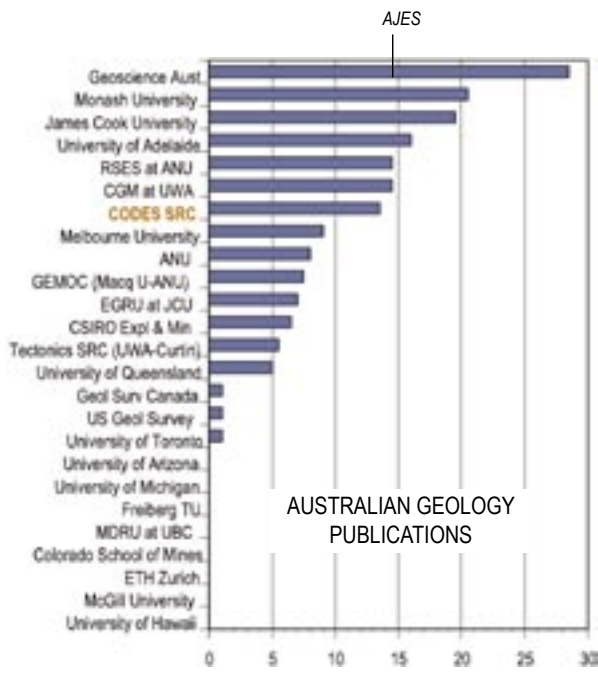
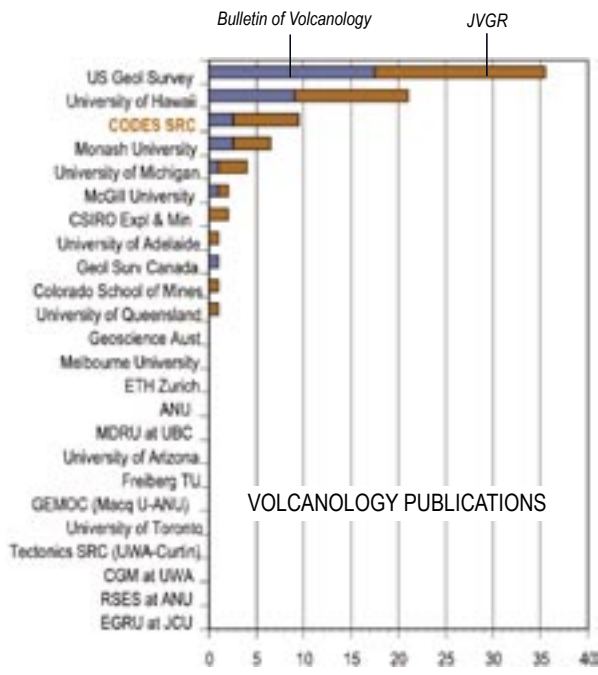
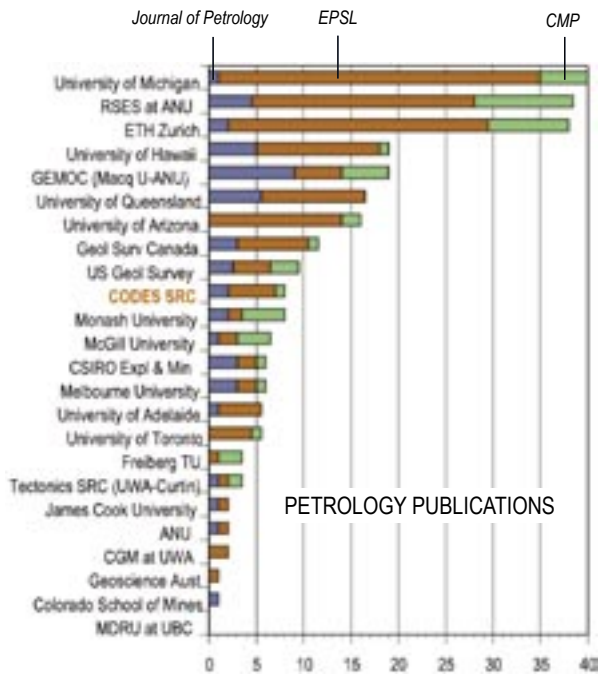
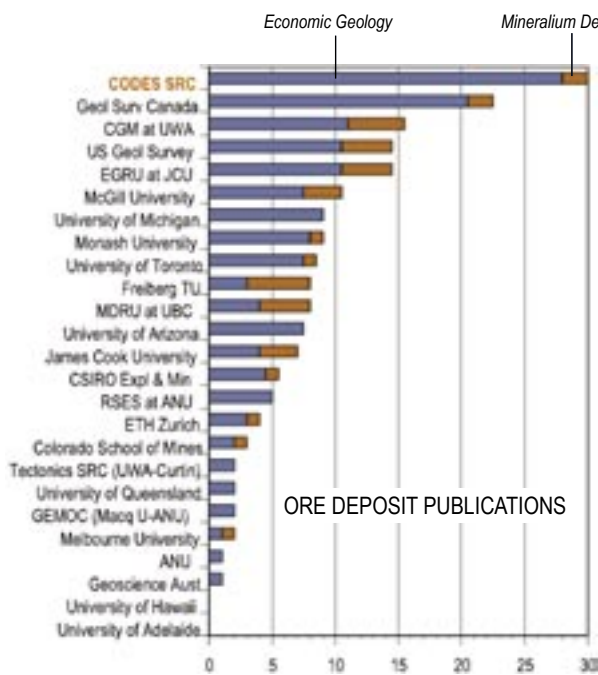
- CODES has the highest number of first authored papers in the top two ore deposit journals, with the Geological Survey of Canada a close second.
- CODES is the leading Australian research group publishing in volcanology journals, ahead of Monash University, but well behind Hawaii and USGS (the largest concentrations of volcanologists in North America). Other volcanology groups, such as Open University, and GEOMAR, that are not in our comparator list, are also ahead of CODES in volcanology publication.

- In petrology, CODES is in the middle of the field, being the fourth Australian group behind the Research School of Earth Sciences (ANU), GEMOC (MacquarieU) and University of Queensland, all of which specialise in petrology/geochemistry as core business.
- In general Australian geoscience published in AJES, we hold a healthy position in the top half of the comparators, ahead of the University of Melbourne, Australian National University and the Tectonics SRC (UWA and CurtinU). As to be expected, Geoscience Australia tops this list.

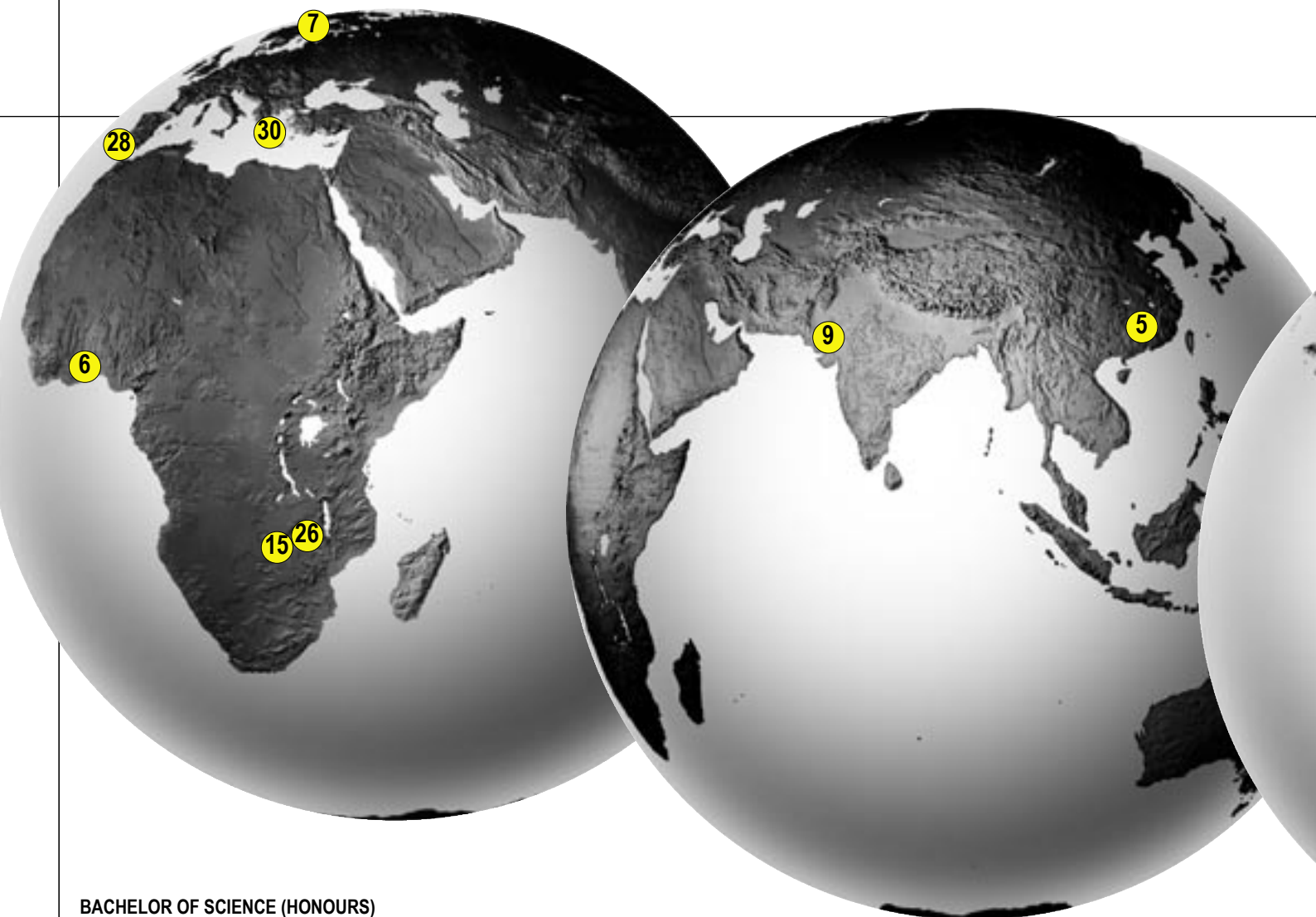


CODES RESEARCH OUTPUT

research output



NUMBERS OF FIRST AUTHORED PUBLICATIONS IN THE PERIOD 1997–2001



BACHELOR OF SCIENCE (HONOURS)

Rebecca Carey

Volcanology of 1886 Tarawera eruption, Taupo Volcanic Zone - New Zealand

1

Bronwyn Kimber

Understanding relationships between electromagnetic properties and sea ice thickness, Antarctica

2

MASTER OF ECONOMIC GEOLOGY

Michael Buchanan

Geology, geochemistry and genesis of the Fenton Zone VHMS prospects, Snow Lake, Manitoba, Canada

3

Richard Cotton

Geology of the Ross alluvial Au deposit, New Zealand

4

Paul Cromie

Geological setting and mineralisation characteristics of the Funning micro-disseminated Au occurrences Yunnan Province, China

5

Michael Fletcher

Structural Geology of Damang region Ghana

6

Ian Laurent

Synthesis of the geology and geophysics of the Svartliden Au deposit, Sweden

7

Gem Midgley

Isotopic variations in Carlin-type Au deposits, Nevada

8

Nalin Shah

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

9

Spencer Summers

Geology and mineralisation styles of the Sekatak project, northeast Kalimantan, Indonesia

10

MASTER OF EXPLORATION GEOSCIENCE

Albert Chong

Geology, mineralisation, metal distribution, and genesis of the polymetallic Ridge and Marshall Zones, Battle Lake Camp, Vancouver Island, Canada.

11

Felipe Urzua

Geology of the Escondida District, Chile

12

DOCTOR OF PHILOSOPHY

James Cannell

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

13

Dene Carroll

Tectono-magmatic evolution of eastern Viti Levu, Fiji

14

Mawson Croaker

The geology and genesis of the Neoproterozoic Cu-Co Nkana-Mindola deposit, Zambia

15

Paul Davidson

Fluid phase immiscibility in late magmatic systems and its relation to the magmatic fluid to hydrothermal fluid transition

16

Andrew Davies

Geology and genesis of the Kelian Au deposit, east Kalimantan, Indonesia

17

Peter Frikken

Breccia-hosted Cu-Mo mineralisation at Rio Blanco, Chile

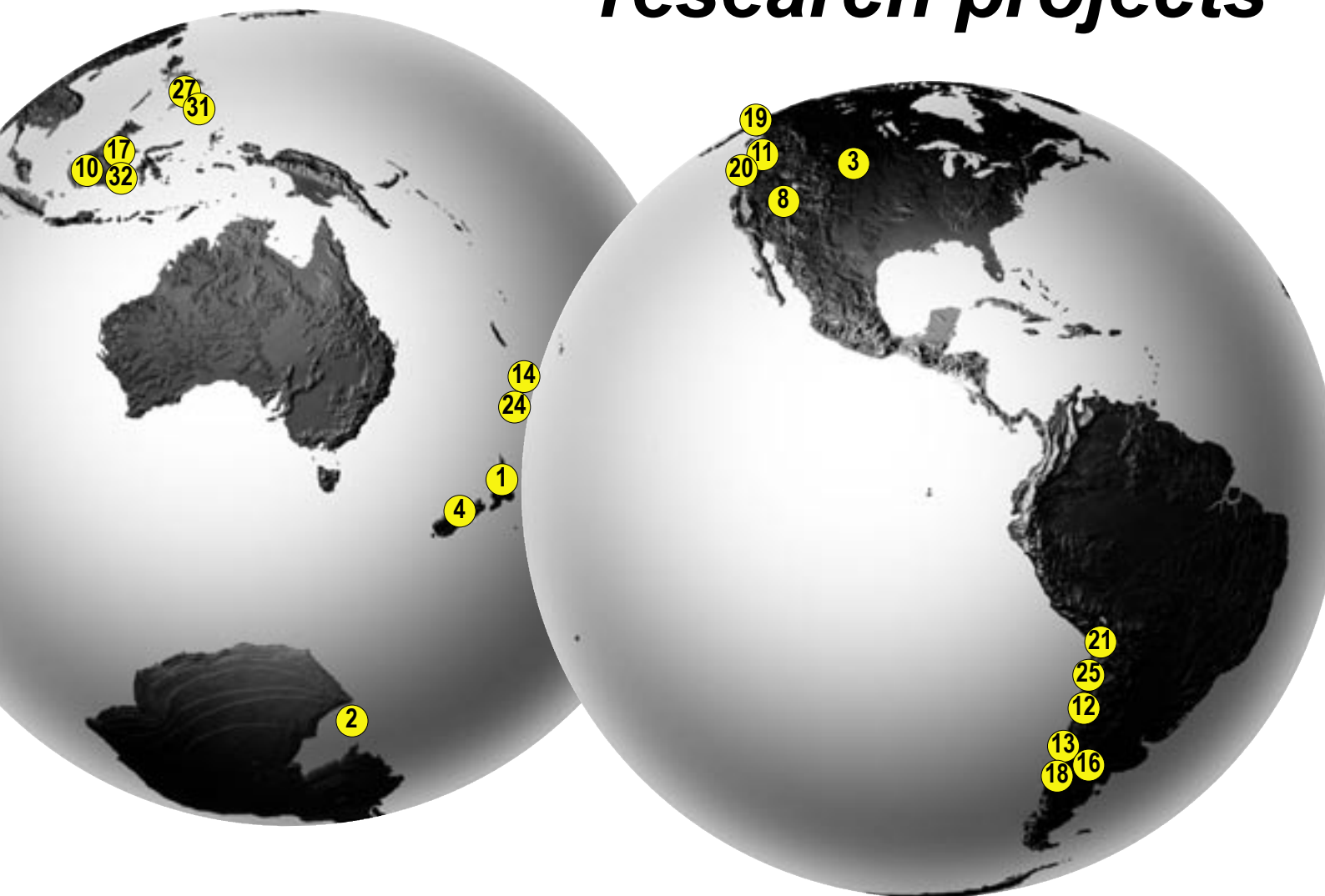
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Russell Fulton

Geology and geochemistry of the hangingwall argillite, Greens Creek VHMS deposit, Alaska: Implications for ore genesis and exploration

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International student research projects



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Geology and geochemistry of the 'caprocks' above the VHMS deposits at Myra Falls, Vancouver Island, British Columbia, Canada 20

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Genesis of the Antapaccy Cu-Au porphyry deposit, Peru 21

Maya Kamenetsky

Apatite-hosted melt inclusions and apatite geochemistry 22

Lyudmyla Koziy

Numerical simulation of fluid flow and fluid chemistry in sedimentary basins 23

Roman Leslie

Petrogenesis and volatile evolution of primitive shoshonitic magmas 24

Glen Masterman

Genetic relationships between the Rosario porphyry Cu-Mo deposits and the high-sulfidation Cu-Au veins, Collahuasi district, Chile 25

Nicki Pollington

Sedimentology, mineralisation and geochemistry of the Konkola North Cu deposit, Zambia 26

Andrew Rae

Alteration sytematics and mineralising potential of the Palinpinon geothermal field, Negros Island, Philippines 27

Carlos Rosa

Submarine volcanic successions in the Iberian Pyrite Belt, Portugal 28

Christian Schardt

Controls on hydrothermal fluid migration by volcanic facies architecture: Implications for massive sulfide deposit formation 29

Andrew Stewart

Facies architecture of a mineralised arc volcanic island, Milos, Greece 30

Rohan Wolfe

The Dinkidi Cu-Au porphyry: Geology of the Didipio region and paragenesis of the Dinkidi Cu-Au porphyry deposit 31

Andrew Wurst

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BACHELOR OF SCIENCE (HONOURS)

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Genesis and alteration vectors around the Bimurra
epithermal deposit, Drummond Basin 1

John Stacpoole

Sedimentology of the Blue Bush sediment-hosted Zn
prospect, Northern Territory 2

MASTER OF ECONOMIC GEOLOGY

Leon Bagas

Geology of the Paterson Orogen 3

Julian Bartlett

Alteration within the Barkly River greenstones, Whisky
Knob Window, eastern Victoria 4

Mitchell Bland

Exploration geology and mineralisation of the Rowan
Brae, Four Mile Creek, Barton Park and Ashleigh Park
prospects, Cadia, NSW 5

Allan Kneeshaw

Deformation and structural history of the south eastern
margin of the Laverton Basin, northeastern goldfields,
WA 6

David Nixon

Au mineralisation in the Tanami region 7

Dan Power

Au mineralisation at Groundrush, Tanami 8

Michael Priestly

Perseverance Au prospect, Cobar, NSW 9

Philip Tornatora

Structural architecture and the relationship of structure
to mineralisation, Cleo deposit, northeastern goldfields,
WA 10

TASMANIA

BACHELOR OF SCIENCE (HONOURS)*

Alex Aitken

Structure of the Mt Julia Zone at the Henty Au deposit,
Tasmania

Darren Andrews

Seismic microzonation of Hobart environs

Kate Bassano

Hercules Pb-Zn mine, western Tasmania — geology,
isotopic characteristics, and genesis

Mary Bessell

Groundwater and salinity of the Swan River Tertiary
Basin, Tasmania

Jody Cutler

Seismic magnetic and paleontological interpretations of
North West Bay, Tasmania

Darren Griggs

Geophysical interpretation of an airborne electromagnetic
survey of west coast sequences, Tasmania

David Hartney

Comparison of metamorphism and structure of
metamorphic inliers, northeast Tasmania

Paul Henson

Structural and metamorphic geology of the Port Sorell
area, Tasmania

John Hooper

Characteristics and genesis of the volcanic-hosted
Firetower prospect, Cethana area, Tasmania

Paul Lane

The Longford sub-basin architecture and economic
potential based on seismic, potential field and drill-hole
data

MASTER OF EXPLORATION GEOSCIENCE

Garry Ferris

The geology and geochemistry of granitoids in the
Childara region, western Gawler Craton, South Australia:
Implications for the Proterozoic tectonic history of the
western Gawler Craton and development of lode-style
Au mineralisation at Tunkillia 11

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Geology of the Mount Kirk Formation, Norseman, WA 12

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of the komatite-hosted Silver Swan deposit and
environs, WA 14

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DOCTOR OF PHILOSOPHY

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Volcanic setting, lithogeochemistry and genesis of the
Lewis Ponds massive sulfide deposits, NSW 16

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Cannington Broken Hill Type Ag-Zn-Pb deposit, Mt Isa
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Iron oxide Cu-Au related alteration history of the Mt
Woods Inlier, South Australia, with special emphasis on
the Prominent Hill prospect 18

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Character, setting and significance of Early Devonian
volcanic successions in the western Lachlan Fold Belt,
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western Tasmania

Sophie Osterloh

Origin of the Maydena silica flour and bedrock
silicification, Tasmania

Monica Osuchowski

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

Cynthia Palfreyman

Hydrogeology of the Dolphin Sands sand spit, Tasmania

Phil Potter

Structural and economic geology of the Lisle area,
northeast Tasmania

Andrew Tyson

Gravity interpretation of the Woolnorth area, Tasmania

Luke Wallace

Aqueous geochemistry of the constructed wetlands
treating AMD, Rosebery, Tasmania

Suzanne Witteveen

Hydrogeology of the host rocks and contaminant
potential of the Circular Head waste disposal site,
northwest Tasmania

Darryl Clark

Geology and genesis of the Mammoth Cu deposit,
Mount Isa Inlier, Australia 20

Andrew Fitzpatrick

Scale-dependent electrical properties of sulfide rocks 21

Owen Hatton

Basin configuration, sedimentology and volcanology of
the Toole Creek Volcanics, Mount Isa region, Qld 22

Vanessa Lickfold

The intrusive history and volatile evolution of the
Endeavour porphyry Cu-Au deposits, Goonumbra
district, New South Wales 23

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The structure and sedimentology of the Curdimurka
Subgroup, Willouran Range, South Australia 24

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Waterloo–Agincoourt Cu–Pb–Zn deposit, Mount Windsor
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Germany 25

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Formation and carbonate-associated base metal
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Structural evolution of the Broken Hill Pb-Zn-Ag
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Alan Wilson

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GRADUATE DIPLOMA OF SCIENCE*

Stuart Dawes

Morphology and compositional variation of alluvial Au
from Tobacco Creek, northeastern Tasmania

MASTER OF ECONOMIC GEOLOGY*

Brett Butlin

Gold mineralisation

Adrian Byass

Course work masters program

Andrew Dacey

Coursework masters program

Adrian Fabris

Not decided

Simon Henderson

Coursework masters program

Anthony Johnston

Not decided

Robert Reid

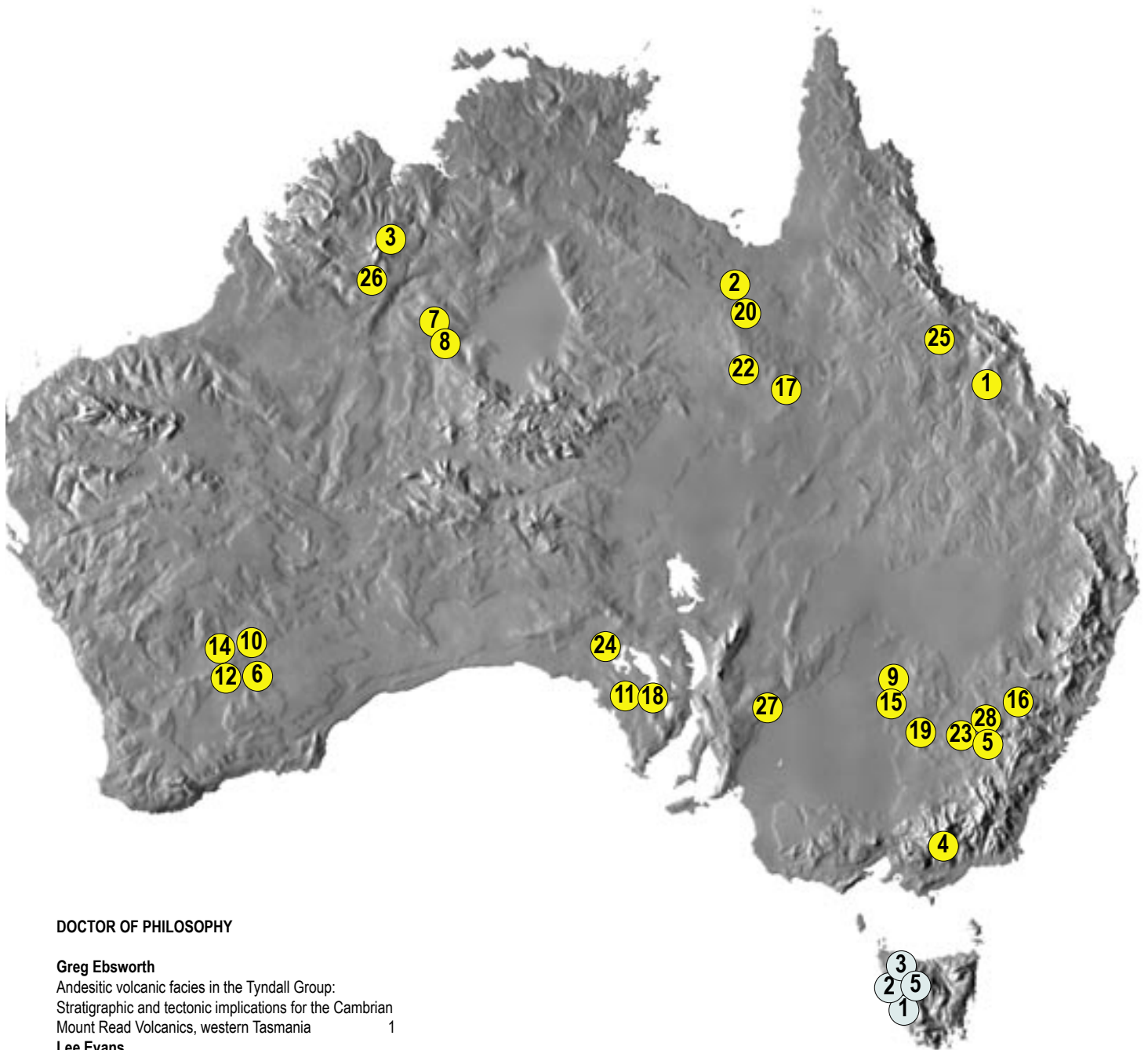
The Thomas Creek Cu prospect, western Tasmania

Steven Richardson

Geology and geochemistry of the Que River footwall
alteration zone, western Tasmania

* these projects not shown on map

Australian mainland and Tasmanian student research projects



DOCTOR OF PHILOSOPHY

Greg Ebsworth

Andesitic volcanic facies in the Tyndall Group:
Stratigraphic and tectonic implications for the Cambrian
Mount Read Volcanics, western Tasmania 1

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) 2

Oliver Holm

Structural and metamorphic evolution of the Arthur
lineament, western Tasmania 3

Steven Lewis

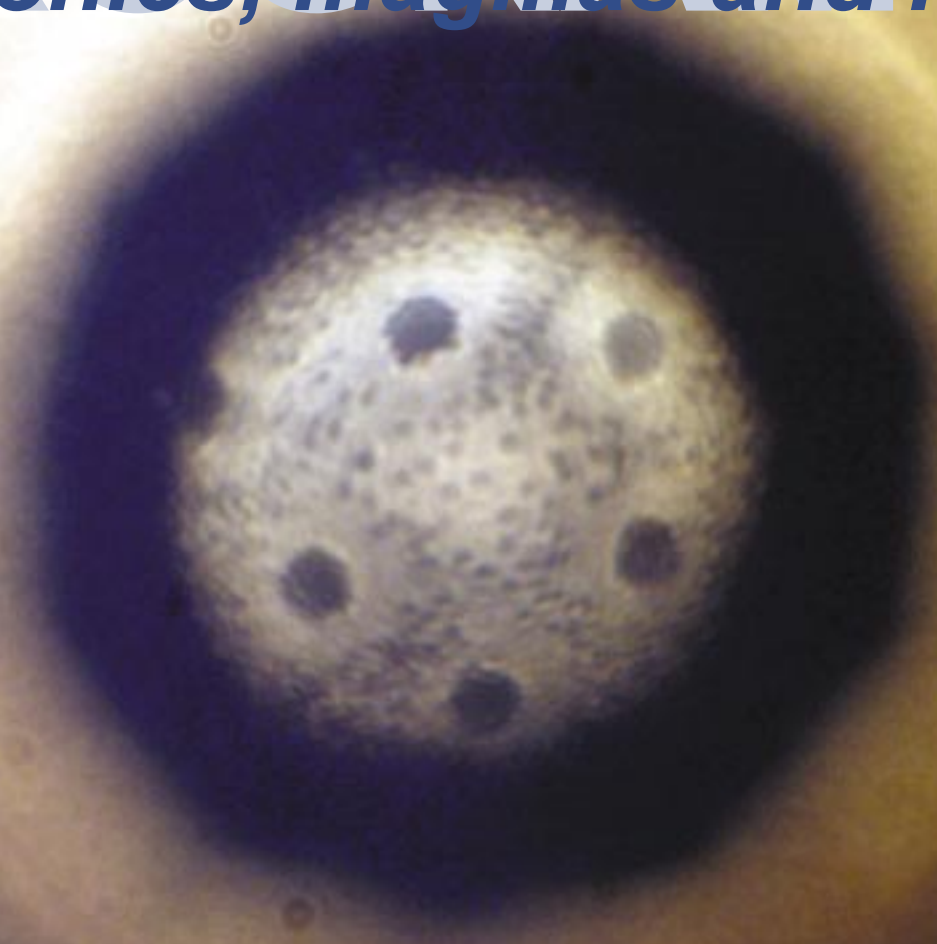
Hydrothermal alteration of the upper oceanic crust of
Macquarie Island 4

Neil Martin

Genesis of the Rosebery VHMS deposit, western
Tasmania 5

PROGRAM 1

Tectonics, magmas and fluids



Fluid bubble in a North Fiji Basin basaltic glass with sulfide decorations on the walls

HIGHLIGHTS

Researchers in Program 1 authored 18 publications in peer-reviewed international journals in 2002, including papers in *Geology*, *Economic Geology*, *Chemical Geology*, *Geostandards Newsletter: Journal of Geostandards and Geoanalysis*, *Journal of Petrology*, *Earth and Planetary Science Letters*, *Mineralogy and Petrology*, *Mineralogical Magazine*, *The Island Arc*, and *Lithos*. Another eight papers have been accepted for publication in 2003.

Successful construction and installation of a new laser ablation cell, and application of the CODES LA-ICPMS system in determining element ratios in the fluid inclusions of magmatic and hydrothermal quartz.

Two ARC Discovery grants: Tony Crawford (Cretaceous history of the eastern margin of the Australian plate) and Leonid Danyushevsky (Petrogenesis of adakites and melting of the subducted slab).

A successful ARC Linkage-Infrastructure proposal (Crawford et al.) to fund a new electron microprobe for the Central Science Laboratory.

PhD degrees awarded to Oliver Holm (Structural and metamorphic evolution of the Arthur Lineament, western Tasmania) and Vanessa Lickfold (The intrusive history and volatile evolution of the Endeavour porphyry Cu-Au deposits, Goonumbla district, New South Wales).

TEAM MEMBERS

Ron Berry, David Cooke, Leonid Danyushevsky, Garry Davidson, Fernando della Pasqua, Anthony Harris, Wally Herrmann, Dima Kamenetsky, Sebastien Meffre, Phil Robinson, Robert Scott, Khin Zaw; David Steele (CSL)

PHD STUDENTS

Dene Carroll, Paul Davidson, Ben Jones, Maya Kamenetsky, Roman Leslie, Vanessa Lickfold, Oliver Holm, Neil Martin

COLLABORATORS

Central Science Laboratory, Geoscience Australia, CSIRO Division of Exploration and Mining, Geological Survey of New South Wales, Australian National University, University of Naples, University of Pisa, Oregon State University, Max Planck Institute for Geochemistry (Germany), Vernadsky Institute.

CORE PROJECTS

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



TONY CRAWFORD, LEADER OF PROGRAM 1

Research in Program 1 has three broad themes:

- The application of geochemical signatures of magmatic rocks in ancient fold belts to interpret their tectonic setting of eruption/emplacement and better understand the tectonic setting of magmatic-related mineral deposits.
- To use melt and fluid inclusions to elucidate and compare the magmatic-hydrothermal transition in mineralised and unmineralised systems.
- To address fundamental questions on the genesis of magmatic rocks.

OBJECTIVES

- To apply state-of-the-art ideas and techniques in 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 that are responsible for porphyry Cu-Ag, and high-sulfidation epithermal Au-Ag systems.
- To continue our fundamental research on magmatism in arc, backarc and ocean floor settings, and thus better understand the genesis of ore deposits in the context of the evolution of these environments.
- To document the geochemical and petrological signatures of ancient (Tertiary to Archaean) volcanic successions that host major ore deposits, in order to understand their tectonic settings of eruption, and to enable predictive exploration and identification of potentially fertile volcanic belts.

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

D Kamenetsky, A Harris, A Crawford, D Cooke, L Danyushevsky; T Mernagh (GA), D Steele (CSL), C Ryan (CSIRO DEM), S Garwin (Newmont), N White (consultant); PhD students P Davidson, B Jones, R Leslie, V Lickfold

This project aims to compare the fluid evolution path and fluid compositions of melt and fluid inclusions in quartz phenocrysts, in both mineralised and barren porphyry systems. It uses a combination of high-temperature heating stage techniques linked with electron microprobe and scanning electron microscopy, LA-ICPMS, laser Raman (with T Mernagh at GA), and PIXE probe (with C Ryan at CSIRO DEM) microanalytical protocols.

A major focus is to gain a better understanding of how magmatic immiscibility affects the major and minor element budgets of a cooling

magma. Anthony Harris joined the team in September, and worked with Dima Kamenetsky on using melt and fluid inclusions to monitor the volatile evolution during crystallisation of the Alhumbrera deposit (Argentina).

Paul Davidson continued his PhD study comparing melt and fluid inclusions in quartz phenocrysts from the mineralised Rio Blanco-Los Bronces porphyry Cu deposit (Chile) with those in the unmineralised Okataina rhyolite from the Taupo graben (New Zealand).

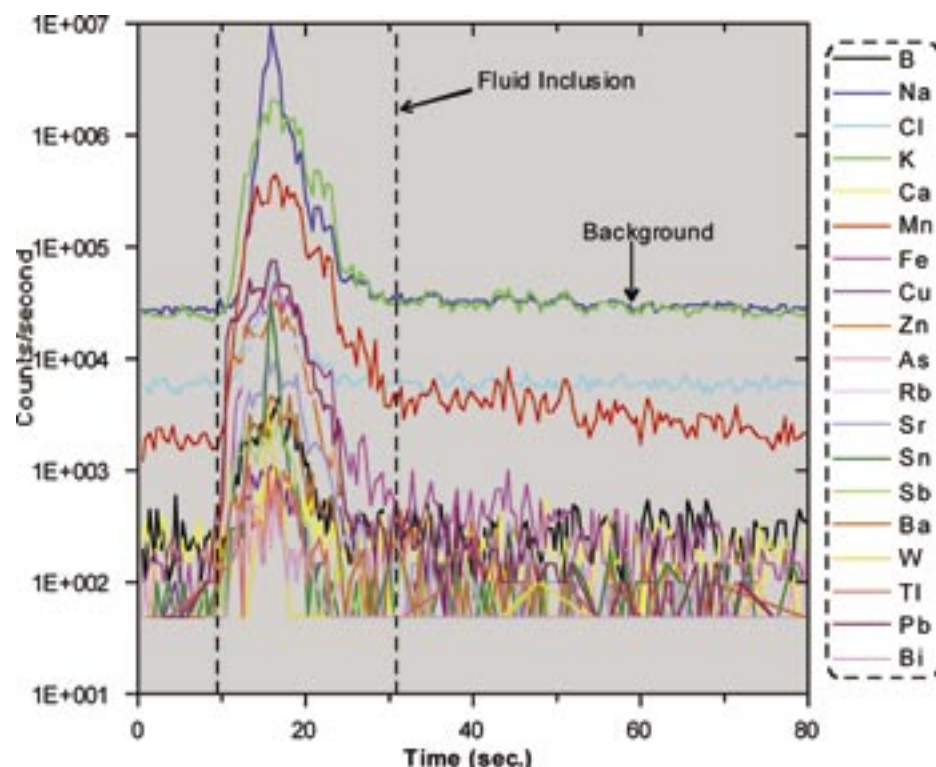
A detailed study of the melt and fluid inclusions in quartz phenocrysts from the Batu Hijau deposit (Indonesia) has commenced (Crawford, Kamenetsky and Garwin). This is one of the few significant porphyry Cu-Au deposits occurring in a low-K (tonalitic) felsic suite, and it offers the potential to compare fluids exsolving from this K-poor suite with those exsolving from medium-K (Rio Blanco) and high-K (Emperor, Didipio, North Parkes and Cadia) suites. Two Batu Hijau tonalites are being studied in detail: one pre-mineralisation, the other syn-mineralisation. Quartz phenocrysts

in both samples contain complex multiphase inclusions. The mineralised sample hosts inclusions that often contain magnetite, hematite and chalcopyrite, in addition to diverse salts and silicate phases. Preliminary LA-ICPMS micro-analysis of fluid inclusions show significant boron contents. Spectra are currently being evaluated to compare pre- and post-mineralisation fluid inclusion compositions.

Ben Jones collected representative wholerock analytical data for mineralised and unmineralised rocks from the Antapaccay porphyry Cu deposit (Peru) for his PhD study. He has also assembled a large global database of wholerock geochemical data for rocks associated with porphyry Cu deposits. His work at Antapaccay has detailed the temporal and chemical evolution of various pre-, syn- and post-mineralisation intrusive units, providing an excellent framework for recently commenced micro-analytical studies of fluid evolution during crystallisation of intrusive units in this region.

Vanessa Lickfold was awarded her PhD for her study of fluid evolution during crystallisation of the Ordovician monzodioritic to monzonitic intrusive rocks hosting the North Parkes Cu-Au porphyry in central western New South Wales. A paper documenting the petrogenesis of these rocks was submitted to the *Australian Journal of Earth Sciences* thematic issue on the mineralised Ordovician volcanics in western New South Wales, to be published in late 2003. A second paper, describing the intrusive history, volatile evolution and alteration at North Parkes, was submitted to *Economic Geology*.

Dima Kamenetsky, Paul Davidson and colleagues from Russia and CSIRO DEM published a paper in *Geology*, in which they examined the temporal evolution of hydrothermal fluids during growth of a single large quartz crystal from a Russian greisen. The method of study was very similar to those applied to porphyry Cu hydrothermal fluid studies at CODES and remarkably the hydrothermal fluid adjacent to the growing quartz crystal was compositionally heterogeneous.



An example of an ICPMS signal recorded during laser analysis of a fluid inclusion in quartz. (Project 1.1)

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

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

Diverse parameters (such as SiO₂ content, FeO*/MgO, K₂O content, etc.) are used to discriminate among, and classify magmatic suites. For example, within the basaltic compositional range, mid-ocean ridge basalts (MORB) are the lowest-K and most H₂O-poor magmatic suite, whereas subduction-related basalts are usually subdivided on the basis of K₂O content at any SiO₂ level, into low-, medium, and high-K and shoshonitic suites. We have been assembling a major database for magmatic S, Cl, H₂O and chalcophile element (Cu, Pb, Zn) contents in diverse basaltic suites. This project includes MORB, backarc basin basalts, and arc basalts from the southwest Pacific, ranging from low-K to shoshonitic. Electron microprobe analyses of S and Cl in melt inclusions are complemented by measurements of chalcophile element abundances determined by LA-ICPMS. However, the data is complicated and many melt inclusions in olivines in arc-type lavas may not represent the dominant (host) magma in the system, but may be derived from ephemeral melts of wallrocks in magma channels or chambers where irregular crystallisation conditions lead to more effective trapping of melt inclusions in growing olivine crystals. This theme has been detailed in a series of presentations by Leonid Danyushevsky, Tony Crawford and Roman Leslie at national (16AGC, Adelaide) and international conferences (AGU, New Zealand and USA).

Another aim of this project is to document the behaviour of S, Cl and the chalcophile metals during extended fractionation (basalt to dacite) of diverse suites from different subduction-related tectonic settings. Suites include a low-K arc tholeiite suite (Troodos Lower Pillow Lavas, Cyprus), a medium-K arc tholeiite suite from Tanna volcano (Vanuatu arc), a K-rich Fijian shoshonite suite, and a suite of arc-like backarc basin basalts. For the Tanna suite, ten samples varying from primitive basalt to dacite and

showing a tightly constrained, comagmatic compositional spread, were selected, and mineral separates (olivine, clinopyroxene and plagioclase) made for each sample. Detailed mineralogical and melt inclusions studies are in progress on these samples.

PhD student Roman Leslie completed a detailed study of major element compositions of melt inclusions in primitive olivine phenocrysts in the Tavua shoshonites (Fiji). Together with work in progress on melt inclusion compositions in more evolved olivine and clinopyroxene phenocrysts, this work will help us to understand the complex fractionation history of shoshonitic magmas, particularly the behaviour of Cl, H₂O, S and chalcophile metals during fractionation of shoshonitic magmas.

Dima Kamenetsky and colleagues published a paper (in *Chemical Geology*) detailing the occurrence of sulfide-bearing precipitates on the walls of fluid bubbles in pillow basalts from different tectonic settings. They propose that the chemical components that formed these precipitates in fluid bubbles were originally dissolved in the magmatic fluid and that these fluids, rich in dissolved metals and other non-volatile elements, may be precursors to ore-forming hydrothermal fluids.

Leonid Danyushevsky was an invited convenor of a melt inclusions symposium of the American Geophysical Union in Wellington, New Zealand.

Project 1.3 CORE Development of analytical techniques

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

A major development in our analytical capabilities was designing a new, small-volume (diam. 2.55 cm, vol. ~5 cm³) ablation cell for the UP213 laser ablation system connected to the existing quadrupole ICPMS. The new cell reduces the transport time of the ablated material to the mass spectrometer (to ~1 sec), and the flush time (the time interval between switching off the laser and the return to background levels of the signal on the ICPMS) to ~2 sec for most elements. This allows for higher count rates on the ICPMS and for effectively 'real-time'

depth profiling during analysis. This is particularly important for quantitative analysis of highly heterogeneous materials, such as hydrothermal sulfides and fluid inclusions.

We continued to develop analytical standards for LA-ICPMS of sulfides. Five fused lithium-borate glass disks containing sulfides with different proportions of major metals (Fe, Cu, Zn, Pb) were prepared and their compositions analysed using solution ICPMS. Analysis of these disks using LA-ICPMS is currently in progress to establish the effect of variable matrices on the analytical uncertainty. Leonid Danyushevsky visited the California headquarters of New Wave Technology, makers of our laser, and the leading LA-ICPMS group at ETH Zurich.

An ARC Linkage-Infrastructure proposal to replace the existing 14 year-old electron microprobe in the CSL was successful. A new Cameca SX100 microprobe has been ordered, with contributions from ARC (\$750,000), the University of Tasmania and CODES, and will be installed in the second half of 2003. With five spectrometers and advanced imaging capabilities, including a cathodoluminescence spectrometer, the new probe will be exceptionally valuable for dating monazites, and imaging the internal structure of phases such as zircon, a vital prerequisite to the successful dating using LA-ICPMS.

Analyst Phil Robinson contributed two articles to the geoanalysis literature in 2002, including a review in *Geostandards Newsletter* of the book 'Laser-ablation-ICPMS in the earth sciences: Principles and applications' (ed. P Sylvester) and the article 'The black art of sample digestion' in *The Geoanalyst*.

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

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

This project was completed in early 2001. It was funded by an ARC SPIRT project involving six exploration companies

(Newcrest, Alkane, Homestake, Goldfields, Hargraves Resources/DRD and North) to investigate the mineralised Ordovician volcano-plutonic belts in central western New South Wales, to provide a regional synthesis of the lithostratigraphy, geochemistry, structure, volcanic facies architecture and regional alteration. This work has provided tighter constraints on the tectonic, volcanic and structural setting of the major ore deposits in the region, including the North Parkes and Cadia-Ridgeway systems.

A Thematic Issue of the *Australian Journal of Earth Sciences* containing 16 papers derived from this project is scheduled for publication in late 2003, following expiry of the confidentiality period (see box below).

Papers appearing in the *Australian Journal of Earth Science* Special Issue on the Ordovician Macquarie Arc in NSW, resulting from the ARC NSW Ordovician SPIRT project: editors AJ Crawford, R Glen and DR Cooke. (Project 1.4)

I Percival and R Glen	Stratigraphy of the Ordovician Macquarie arc, NSW
R Glen, AJ Crawford, I Percival and L Barron	Earliest Ordovician lithostratigraphy and magmatism in the Macquarie Arc
AJ Crawford, S Meffre, C Simpson and R Squire	Middle and Late Ordovician lithostratigraphy and magmatism in the Macquarie Arc
R Squire and AJ Crawford	Magmatic characteristics and geochronology of the Ordovician igneous rocks of the Cadia-Neville region, Lachlan Fold Belt
C Simpson and R Scott	Evolution of an Ordovician marine volcanic centre, Cargo block, Macquarie Arc, NSW
S Meffre	Middle and Late Ordovician geology of the Rockley-Gulgong Volcanic Belt and Kiandra Volcanic Belt, Macquarie Arc, NSW
L Barron, D Ohnenstetter and D Suppel	Geology of the Fifield Alaskan intrusive complexes, Macquarie Arc, NSW
S Meffre, R Scott, R Squire and R Glen	Relationships between the Ordovician quartz-rich turbidite and Ordovician volcanics in the eastern Lachlan Fold Belt
R Scott	Structural and stratigraphic relations in the Parkes-Forbes region, NSW: implications for the tectonic evolution of the Macquarie Arc
V Lickfold, AJ Crawford and D Cooke	Magmatism associated with the North parkes Cu-Au mineralisation
R Spencer and R Glen	Geophysical modelling of major faults cutting the Macquarie Arc
D Cooke and W Herrmann	Overview of style of alteration in the Ordovician belts of NSW
L Barron and S Meffre	Significance of the Kabadah Formation
R Glen, S Meffre and R Scott	The Banambran deformation of the eastern Lachlan Orogen: response to progressive 'soft' arc-backarc collision and the cause of porphyry Cu-Au mineralisation in the early Silurian
AJ Crawford, S Meffre, R Glen, R Scott and R Squire	Tectono-magmatic evolution of the Macquarie Arc
AJ Crawford, R Glen, D Cooke, S Meffre, R Scott, V Lickfold and R Squire	Tectonic setting of porphyry Cu mineralisation in the Ordovician Macquarie Arc

**Project 1.5
Modern and ancient fold belt volcanics**

A Crawford, S Meffre, L Danyushevsky, D Kamenetsky; P Hollings (LakeheadU), R Keays (LaurentianU and UMelb); PhD students D Carroll, O Holm

Modern settings

Program 1 actively maintains diverse petrological-geochemical and tectonic research in the Pacific realm, particularly in the south west Pacific arc-backarc basin systems. These studies serve to inform, and better constrain complementary studies of the tectonic and magmatic development of fold belts, especially the Late Neoproterozoic to Carboniferous Lachlan Fold Belt of eastern Australia. Published research included:

- Two papers by Leonid Danyushevsky and colleagues (*Chemical Geology, Journal of Petrology*) providing essential details of the techniques applied and potential pitfalls in melt inclusion studies.
- A paper by Dima Kamenetsky and colleagues (*Chemical Geology*) describing the first study of melt inclusions hosted within chromite crystals in boninites (Cape Vogel, Papua New Guinea).
- A paper by Dima Kamenetsky and Maas (*Journal of Petrology*) proposing a new mantle melting model constrained by the isotopic and trace element compositions of pillow basalts from Macquarie Island.
- A paper by Marc Norman, Dima Kamenetsky and others (*Chemical Geology*) in which the petrogenesis of picrites from Hawaii is elucidated via a detailed melt inclusion study.
- A paper by Reubi, Dima Kamenetsky et al. (*Journal of Volcanology and Geothermal Research*) documenting magma mixing and mingling at Slamet volcano in Java.
- A paper by Lo, Howard, Sebastien Meffre and colleagues reporting Ar-Ar dating of Darwin glass, western Tasmania (*Meteoritics and Planetary Science*).

Fold belt studies

Program 1 researchers are actively involved in a number of studies on fold belts, mainly using the geochemistry of meta-igneous rocks to constrain the tectonic evolution of the fold belt. Although most work continues to focus on the Tasman Fold Belt in eastern Australia, work also continues in New Caledonia, Vanuatu and Fiji. A Memorandum of Understanding has been drafted linking CODES Program 1 with researchers from the National Institute of Geological Sciences (Philippines).

Significant output includes:

- A paper by Oliver Holm and Ron Berry (*Australian Journal of Earth Sciences*) describing the structural history of the Arthur Lineament in northwest Tasmania.
- A paper (Crawford, Meffre and Symonds: 120–0 Ma tectonic evolution of the southwest Pacific, and analogous geological evolution of the 600–220 Ma Tasman Fold Belt System) in press



Final meeting of AMIRA P603 in December 2002 (left to right): Ron Berry, Wayne Spillsbury, Alan Goode, Khin Zaw, Roric Smith, Eleanor Bruce, Ross Andrew, Susan Jungawalla, Ross Large and Greg Mackay. (Project 1.6)

in the new joint Geological Society of Australia–Geological Society of America volume ‘The Australian Plate’.

- A paper by Cluzel and Sebastien Meffre (*Comptes Rendus Geosciences*) reporting new dates for zircons from the Boghen terrain (New Caledonia) and their tectonic implications.

Ongoing petrology-geochemistry research projects include:

- A collaboration with Geoscience Australia aboard CSIRO’s research vessel RV *Southern Surveyor*, to investigate the geology of the basement of the Norfolk and Three Kings Ridges, east of Australia, by dredging scarps and steeper slopes. A 25-day cruise will leave Hobart in February 2003, and will include investigators from Geoscience Australia (N Exon), and the Institute of Geological and Nuclear Sciences (R Herzer), and the University of New Caledonia (M Allenbach).
- Nd-Sr isotopic compositions of around 25 felsic rocks within the Cambrian Mount Read Volcanics (western Tasmania) have been determined (A Crawford and P Hollings). This data is the basis for a publication in *Economic Geology* that addresses the tectonic setting of the Mount Read Volcanics before and during the major period of mineralisation.
- Dene Carroll continued his PhD study of the Cenozoic magmatic rocks of south eastern Viti Levu (Fiji). He obtained new Ar-Ar dates on key units, and Sr-Nd-Pb isotopic data for all

magmatic units.

- Sebastien Meffre, Tony Crawford and Dima Kamenetsky continued their work with Nick Direen (UAdel) on the geochemistry and tectonic significance of Neoproterozoic volcanics along the western margin of the Tasman Fold Belt system, with particular emphasis on the well-exposed volcanic sections on King Island.

Project 1.6 Tectonics and metallogenesis of South China (AMIRA P603) and related projects in South East Asia

Khin Zaw, R Large, R Berry; C Burrett (SES); E Bruce (GES)

The AMIRA P603 ‘Geological, Tectonic and Metallogenic Relations of South China’ was initiated in December 1999 to build on a previous project on mainland South East Asia (AMIRA P390A). It was sponsored by nine national and international mining companies. The project area was designed to cover the major crustal terranes and the mineralised districts of South China and included the provinces of Yunnan, Sichuan, Guizhou, Guangxi, Hunan, Guangdong, Hubei, Jiangxi, Fujian, Anhui, Zhejiang, Jiangsu, Shanghai and Shandong. P603 was completed in December 2002, successfully integrating the geology, geochronology and mineral deposit data of South China using GIS technology. Combined with the results of the previous research in

South East Asia, this new work provides a powerful GIS framework for detailed stratigraphic correlation, synthesis of fault history and metallogenic relations. It will help predict and locate the world-class ore deposits in the region, from Singapore to Shanghai.

PhD PROJECTS IN PROGRAM 1

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

Paul Davidson: Fluid phase immiscibility in late magmatic systems and its relation to the magmatic fluid to hydrothermal fluid transition.

Oliver Holm: Structural and metamorphic evolution of the Arthur lineament, western Tasmania. PhD awarded December 2002.

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

Maya Kamenetsky: Apatite-hosted melt inclusions and apatite geochemistry.

Roman Leslie: Petrogenesis and volatile evolution of shoshonitic magmas.

Vanessa Lickfold: The intrusive history and volatile evolution of the Endeavour porphyry Cu-Au deposits, Goonumbla district, New South Wales. PhD awarded December 2002.

PROGRAM 2

Volcanic facies architecture and ore-forming environments



Climbing down from the summit dome on Mont Pelée, Martinique

HIGHLIGHTS

CODES volcanology research was presented at the Chapman Conference on Explosive Subaqueous Volcanism (Dunedin) and the 16th Australian Geological Convention (Adelaide).

A new research project began on the volcanology of the Iberian Pyrite Belt (Portugal).

A Special Issue of the *Journal of Volcanology and Geothermal Research* on peperite was published.

Dr Yoshi Goto joined CODES for two months as Visiting International Research Fellow.

Major progress was achieved towards completing a new book on alteration in submarine volcanic successions that host massive sulfide deposits.

TEAM MEMBERS

Sharon Allen, Stuart Bull, Cathryn Gifkins, Wally Herrmann, Jocelyn McPhie; Carol Simpson; Rod Allen (LuleaU, Volcanic Resources)

PhD STUDENTS

Michael Agnew, Katharine Bull, Greg Ebsworth, Sarah Jones, Karin Orth, Carlos Rosa, Andrew Stewart

COLLABORATORS

Research Centre for Marine Geosciences (Christian Albrechts University, Kiel, Germany), Instituto Geologica e Minerio (Lisbon, Portugal), University of Auckland, Geological Survey of New South Wales, University of Northern Arizona, Idaho Geological Survey, Geological Survey of Vanuatu, Lulea University, Geological Survey of Sweden, University of Lisbon, Institute of Geology and Mineral Exploration (Athens, Greece), Tohoku University, Silver and Baryte SA, Primary Industries and Resources (South Australia), Research School of Earth Sciences at the Australian National University

CORE PROJECTS

- 2.1 Facies architecture models for submarine volcanic successions that host seafloor massive sulfide ore deposits in arc environments.
- 2.2 Facies characteristics and textural evolution of submarine-emplaced rhyolitic pumice breccias.
- 2.3 Facies architecture of volcanic successions that host porphyry Cu-Au ore deposits in arc settings.
- 2.6 Phenocrysts and melt inclusions in arc lavas: textural and petrogenetic implications.
- 2.7 Experimental simulations and textural analysis of submarine volcanoclastic mass-flow deposits that result from large-scale eruption and failure events.



JOCELYN McPHIE, LEADER OF PROGRAM 2

Program 2 explores the connection between volcanic processes and the architecture of volcanic environments most suitable for ore deposit formation. Current projects in this program focus on the facies architecture of submarine successions that host massive sulfide ore deposits, primary and alteration textures in volcanic rocks, facies models for volcanic successions in epithermal Au-Ag districts and the physical volcanology of extensive rhyolites.

OBJECTIVES

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

Project 2.1 CORE

Facies architecture models for submarine volcanic successions that host seafloor massive sulfide ore deposits in arc environments

S Allen, S Bull, C Gifkins, W Herrmann, J McPhie; R Allen (LuleaU, Volcanic Resources), Y Goto (TohokuU), S Meakin (GSNSW), J Relvas (ULisbon); PhD students M Agnew, K Bull, G Ebsworth, K Orth, C Rosa, A Stewart

Research for this project involves a combination of volcanic facies analysis and textural studies both in ancient, deformed and young, well preserved successions. The work is carried out in the context of PhD projects and projects undertaken by Research Fellows, Sharon Allen, Stuart Bull, Cathryn Gifkins and Wally Herrmann. In 2002, this project included six PhD projects (summarised below), one of which was completed. Several of these projects combine volcanic facies architecture and textural studies with investigations of alteration related to massive sulfide mineralisation (Project 3.5). Study areas included the Mount Read Volcanics (western Tasmania), the Koongie Park Formation (WA), the Anson Formation at Lewis Ponds (NSW), Milos (Greece), the Urals Volcanics (NSW) and the Iberian Pyrite Belt (Portugal).

Michael Agnew continued his PhD study of the setting and origin of stratabound massive sulfide lenses at Lewis Ponds (NSW). Michael has used drillhole data and lithofacies analysis to interpret the structure and volcanic facies architecture of the area. He has identified volcanic centre defined by shallow intrusions in the footwall of the massive sulfide deposits.

Kate Bull completed her first field season, working on the Ural Volcanics (central western NSW). Kate's project aims to advance understanding of the volcanology and mineral potential of Early Devonian volcanic successions in the Lachlan Fold Belt, in collaboration with the GSNSW. She has produced a new 1:10000 geological map of the Ural Volcanics south of Lake Cargelligo that will provide a framework for volcanic facies analysis. Her fieldwork also involved extensive sample collection and textural and geochemical analyses of these are underway. In 2003, she plans to extend

her research to include the Mount Hope Volcanics (western NSW).

Greg Ebsworth's research in the Mount Read Volcanics (western Tasmania) progressed significantly following extensive fieldwork and drill core logging. Greg generated a series of graphic logs that reveal the regional complexity and variety of volcanic and other facies in the youngest part of the Mount Read Volcanics. He found that distinctive crystal-rich volcanic sandstone units are particularly widespread, and he has been testing their use in correlating among the major lithostratigraphic units that host some of the larger mineral deposits in the district.

Sarah Jones' PhD thesis on Myra Falls VHMS deposit (Canada) was under examination at the close of 2001 but has since been accepted. She graduated in 2002. Sarah provided detailed textural, mineralogical and geochemical information on siliceous fine-grained rocks (cap rocks) that overlie the Myra Falls massive sulfide orebodies. Her research has improved our understanding of ore formation and suggested new exploration criteria.

Karin Orth submitted her PhD thesis on the volcanic and sedimentary setting of massive sulfide prospects in the Palaeoproterozoic Koongie Park Formation (WA). Karin clarified the stratigraphy and structure of the strongly-deformed and metamorphosed succession hosting the prospects. She produced a new interpretation of the facies architecture and showed how the volcanic and mineralising hydrothermal processes were interrelated. A manuscript (Orth and McPhie) on cooling and crystallisation of a rhyolitic sill in the Koongie Park Formation has been submitted to the *Journal of Volcanology and Geothermal Research*. Karin's thesis is currently under examination.

Andrew Stewart concentrated on analytical work and writing-up his PhD research on the volcanic facies architecture of Milos (Greece). A major achievement was successfully dating the succession, using SHRIMP U-Pb in zircon analyses performed by Marc Norman (RSES ANU). The new dates provide a check on field stratigraphy, and give information on the longevity of the volcanic field as a whole, the longevity of single volcanic centres and the age of Au- and Ag-rich quartz veins. He also undertook geochemical analyses of representative

samples from the major volcanic facies associations, and made major progress in unravelling the complicated facies architecture. This research has been conducted in collaboration with Dr Georges Vougioukalakis of the Institute of Geology and Mineral Exploration, (Greece) and with Silver and Baryte SA, an exploration company active on the island of Milos. Andrew has submitted two manuscripts based on his research: one deals with the origin of extremely coarse pumice clasts in submarine pyroclastic deposits (Stewart and McPhie, *Bulletin of Volcanology*), and the other describes a large dacitic cryptodome (Stewart and McPhie, *Journal of Volcanology and Geothermal Research*).

Carlos Rosa joined CODES in 2002 and commenced a new PhD project in the Iberian Pyrite Belt (Portugal). Carlos previously graduated from the University of Lisbon and has worked both in industry and geological survey positions in Portugal. He has completed one field season, mapping the best-exposed and least-deformed sections through the volcanic succession of the Iberian Pyrite Belt. This succession hosts world-class massive sulfide ore deposits, many of which have been studied in considerable detail. The host rocks, however, are poorly understood, and Carlos' project is one of the first volcanological projects to be attempted. This research is jointly supervised by Jorge Relvas (ULisbon) and receives support from the Portuguese Science and Technology fund, and from the Mining and Geological Institute of Portugal.

Team members made significant contributions to a Special Issue of the *Journal of Volcanology and Geothermal Research* on peperite published early in 2002. The Special Issue includes papers by Rod Allen, Cathryn Gifkins, Rick Squire and Jocelyn McPhie. Several team members also participated in the AGU Chapman Conference on explosive subaqueous volcanism, held at University of Otago in Dunedin. Papers by Sharon Allen, Rod Allen, Cathryn Gifkins, Jocelyn McPhie, Alison Raos, Kirstie Simpson and Andrew Stewart were presented at the meeting. Sharon, Rod, Jocelyn, Alison and Andrew have all submitted manuscripts to the American Geophysical Union Monograph based on the meeting and due for publication

in 2003 or 2004. Program 2 is a strong supporter of the fledgling specialist group in volcanology of the Geological Society of Australia (LAVA). The LAVA symposium at the 16AGC in Adelaide included contributions from Sharon Allen, Kate Bull, Greg Ebsworth, Jocelyn McPhie, and Carol Simpson (also Project 2.4).

Stuart Bull and Rod Allen (LuleaU and Volcanic Resources) completed the final field season for their project in the Bergslagen district (central Sweden) (also Project 4.4). This project involves collaboration with the Swedish Geological Survey and Boliden AB. It aims to improve the current understanding of interbedded volcanoclastic-carbonate sequences that host ore deposits in the region. Stuart, Rod and colleagues completed logs of regional sections that include contacts between the volcanic and carbonate facies in order to constrain the nature and setting of the carbonate facies. They are using additional data from thin-section studies, wholerock geochemical analyses and oxygen isotope analyses to determine the origin of the Bergslagen carbonates and their role in base metal mineralisation.

Cathryn Gifkins, Wally Herrmann and Ross Large are the authors of a new book on the textural, mineralogical and compositional changes that accompany alteration of volcanic successions. The book focusses on alteration associated with VHMS deposits, and incorporates many of the outcomes of AMIRA project P439 'Studies of VHMS-related alteration: geochemical and mineralogical vectors to ore'. It introduces the common processes responsible for alteration in submarine volcanic successions and includes case studies. Substantial progress was made during 2002 and the book is nearing completion.

Yoshi Goto joined CODES for two months in 2002 as Visiting International Research Fellow. Yoshi has previously held a post-doctoral position at CODES (1995) and has collaborated with Jocelyn McPhie in research on submarine volcanic successions in Japan and Australia. His expertise is in submarine lavas, especially pillow lava. He has completed a field study of Tertiary pillow lavas at Stanley (northwestern Tasmania). A new model for pillow lava propagation was presented in a manuscript (Goto and McPhie) submitted to the *Journal of Volcanology and Geothermal Research*.



Sharon Allen, conducting an experimental simulation of a hot volcanic mass flow entering water at the Experimental Volcanology Laboratory, GEOMAR, Germany. (Project 2.7)

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

S Allen, C Gifkins, J McPhie; R Allen (Volcanic Resources, LuleaU); PhD students K Bull, A Stewart

Pumice breccia is a characteristic component of submarine volcanic successions and forms the host to several important massive sulfide deposits. Major textural and compositional changes occur in glassy, porous pumice breccias during compaction, diagenesis, hydrothermal alteration and metamorphism. This project involves studies of modern (Greece), Tertiary (Japan and Vanuatu) and Palaeozoic (Cambrian, western Tasmania; Early Devonian, NSW) pumice breccias.

A paper on the textural and facies characteristics of pumiceous peperite and pumiceous hyaloclastite by Cathryn Gifkins, Jocelyn McPhie and Rod Allen was published in the *Journal of Volcanology and Geothermal Research*. This paper includes examples from the Mount Read Volcanics (western Tasmania), and the Green Tuff Belt (Japan). Andrew Stewart and Jocelyn McPhie submitted a manuscript to the *Bulletin of Volcanology* on the origin of coarse pumice breccias in the submarine, felsic volcanic succession on Milos (Greece, also Project 2.1).

Alison Raos and Jocelyn McPhie have submitted a manuscript to the *American Geophysical Union Monograph* series describing and interpreting very thick successions of submarine pumice breccia and shard-rich mud exposed on Efate (Vanuatu). Parts of some pumice



Program 2 team: (back row) Sharon Allen, Jocelyn McPhie, Wally Herrmann, (front row) Michael Agnew, Andrew Stewart, Fernando della Pasqua and Kate Bull.

breccia beds have been diagenetically altered, exemplifying the earliest stages in textural and compositional modification of submarine-emplaced pumice. A manuscript by Sharon Allen and Andrew Stewart, exploring the facies characteristics of pumice breccias generated by explosive eruptions from vents in different settings, was submitted to the *American Geophysical Union Monograph* series.

Ancient pumice breccias commonly display a bedding-parallel foliation defined by fiamme and interpreted to result from early diagenetic compaction and alteration of glassy pumice. The Early Devonian Ural Volcanics (NSW), include extensive and thick units of submarine pumice breccia intercalated with rhyolitic and dacitic lavas. Kate Bull mapped and logged pumice breccias that include conspicuous fiamme and also recognised similar fiamme in a variety of other facies. Part of Kate's PhD research involves a detailed examination of these fiamme, and she summarised the preliminary results in a paper presented at the 16AGC in Adelaide.

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

C Simpson, W Herrmann, J McPhie, PhD student R Squire

Members of Program 2 participated in a major research project with Program 1 (Project 1.4) on the Ordovician volcanic successions of central western New South Wales. The final report was presented in 2001 but output continued in 2002.

The project included a major study of the Forest Reefs Volcanics (NSW) by Rick Squire. Rick presented a new interpretation of the Ordovician volcanic succession and clarified relationships among the principal lithostratigraphic units. A manuscript (Squire and McPhie) on the facies architecture of the Forest Reefs Volcanics and constraints on tectonic interpretations has been submitted to the *Journal of Volcanology and Geothermal Research*. Carol Simpson prepared a manuscript on her research into the character and setting of the Fairbridge Volcanics (NSW).

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

S Allen, J McPhie, D Kamenetsky; C Simpson; S Daly, E Jagodzinski (PIRSA)

The Mesoproterozoic Gawler Range Volcanics (SA) comprise a major felsic intraplate volcanic province that is considered highly prospective, hosting the giant Roxby Downs Au-Cu-U ore deposit and two Au prospects at Tarcoola. Although major funding for this project has ceased, research activity and output continued in 2002. The project has focussed on the upper part of the succession, which is dominated by poorly understood, very extensive, 'lava-like' dacitic and rhyolitic units.

A paper by Sharon Allen and Jocelyn McPhie on the Eucarro Rhyolite was published in the *Geological Society of America Bulletin*. The Eucarro Rhyolite is one of three voluminous (>500 km³) and widespread felsic units in the Gawler Range Volcanics previously thought to be ignimbrites. New data from field mapping and textural analysis strongly suggest the Eucarro Rhyolite is in fact a lava. A multi-author review of the stratigraphy and geochemistry of the three main widespread felsic units is in press in the *Australian Journal of Earth Sciences*. Another manuscript on the volcanology of the Yardea Dacite is currently in preparation. The team also presented three papers at the 16AGC in Adelaide.

Jocelyn McPhie was awarded a grant from the Australian Academy of Science that supported fieldwork in the voluminous and widespread felsic lavas of the Snake River Plain (Idaho, USA). The Miocene felsic lavas of the Snake River Plain are well exposed, much younger analogues of the voluminous lavas discovered in the Gawler Range Volcanics. Jocelyn's visit was hosted by Nancy Riggs (Northern ArizonaU) and Bill Bonnicksen (Idaho Geological Survey). Samples collected from several different lavas will be used for textural studies and comparison with the lavas in the Gawler Range Volcanics.

Project 2.4 has generated a new 1:250000 map of the Gawler Range Volcanics and a great deal of textural and



Sharon Allen and Greg Ebsworth, examining andesite-derived volcaniclastic units in the Mount Read Volcanics, western Tasmania. (Project 2.1)



Collaborators Bill Bonnicksen and Curtis Manley (Idaho Geological Survey) and Nancy Riggs (U Northern Arizona), on the Badlands Rhyolite, Idaho, an extensive rhyolitic lava similar to those in the Gawler Range Volcanics, South Australia. (Project 2.4)

geochemical data that support important new interpretations of the nature of the Mesoproterozoic volcanism. Funding for further research was secured in 2002 and a two-year project will commence in 2003 to test hypotheses regarding the location of source vents for the Eucarro Rhyolite (SA).

Project 2.5 Facies architecture of volcanic successions that host epithermal Au-Ag ore deposits in arc settings (AMIRA P588)

JB Gemmell, W Herrmann, J McPhie, R Scott, R Sharpe; S Simmons (UAuckland); students Andrew Wurst (PhD), Dan Olberg (MEconGeol)

Program 2 has contributed to a three-year research project on 'Epithermal Au-Ag deposits: geological, geochemical and isotopic vectors to target major deposits' funded by AMIRA and ARC-Linkage grants. This project involves collaboration between Programs 2 and 3 (Project 3.9), the Geothermal Institute at the University of Auckland and industry sponsors. 2002 was the last year of the project, culminating in a final meeting with sponsors in December. A major aim of the project was to accurately define the context of each of the deposits in volcanic provinces, and this aim was fully achieved. The final report provided descriptions

of the volcanic settings of the case study sites, including graphic logs, cross-sections and maps, as well as textural and compositional data on both unaltered and altered samples. This new information allowed interpretation of the relationships among volcanic facies, alteration and mineralisation.

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

S Allen, D Kamenetsky, J McPhie; PhD student Paul Davidson

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

Facies analysis of ancient volcanic rocks, especially those that are altered and deformed, relies on the assumption that phenocryst populations and distributions in lavas differ significantly from those in crystal-rich volcaniclastic facies. In particular, we assume that phenocrysts in the coherent parts of lavas (and shallow intrusions) are dominantly euhedral,

evenly distributed and uniform in mineralogy and size. However, the validity of this assumption has not been tested. Models for fractionation processes in arc magmas also rely on an understanding of phenocryst populations and of phenocryst-melt relationships. Although considerable attention has been paid to fractionation processes in mafic and intermediate porphyritic magmas, much less is known about porphyritic felsic magmas. There is increasing recognition that such magmas contribute significantly to mineralising hydrothermal systems (Project 1.1).

Forty-six samples of fresh, mainly rhyolitic, porphyritic lavas were collected from the Taupo Volcanic Zone (New Zealand), and the Aegean Arc (Greece). These samples include a range of phenocryst sizes, phenocryst abundances and textural facies. For comparison, 12 rhyolitic pyroclastic samples from the Taupo Volcanic Zone were also examined. The phenocryst populations were investigated by computer-aided image analysis, yielding data on the total phenocryst content and the proportion of phenocryst fragments in each sample. The data confirm that fragments are much less abundant in lavas than in pyroclastic deposits, and that fragment abundance is a reliable distinguishing criterion, at least for rhyolites. On average, fragments in lavas amount to ~5% of the total phenocryst population, regardless of the



total phenocryst content, groundmass texture or distance from source. It is clear that fragments in lavas are generated by disintegration of whole (but fractured) phenocrysts, with decompression of melt inclusions being a prime cause of fracturing, as is also the case for crystal fragments in pyroclastic deposits. These results were summarised in a manuscript submitted to the *Journal of Volcanology and Geothermal Research* (Allen and McPhie).

Paul Davidson discovered that melt inclusions in quartz phenocrysts in the New Zealand samples can exsolve an aqueous hypersaline fluid phase. These unevolved, uncontaminated primary magmatic fluids are probably important in the transfer of metals from fractionating arc magmas to hydrothermal systems. Paul presented his preliminary results at the 16AGC in Adelaide (Davidson, Kamenetsky and Allen, 2002).

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; B Hayward (UAuckland), A Freundt (GEOMAR)

This project began in May 2001, with the appointment of Sharon Allen to an ARC Post-Doctoral Research Fellowship. Sharon's research involves new experiments, as well as textural analysis of submarine volcanoclastic mass-flow deposits. Explosive eruptions and mass-failure events on volcanic islands deliver large quantities of volcanic particles to the sea. Deposits from such events are found throughout ancient submarine volcanic successions, including those that host massive sulfide deposits. However, there are presently no physical constraints linking deposit features with origin.



Top: Simone Meakin (GSNSW) and Kate Bull working in the Ural Volcanics, NSW. (Project 2.1)
 Bottom left: Andrew Stewart completing a log of the Filakopi Pumice Breccia on Milos, Greece. (Project 2.2)
 Bottom right: Aletha Buchsman (Barrick, Canada) and Jocelyn McPhie modelling the latest field fashions on Ruapehu volcano, New Zealand, while on the CODES MEconGeol volcanology shortcourse.

Sharon's experimental research was conducted in collaboration with Armin Freundt at the Experimental Volcanology Laboratory, GEOMAR. Sharon designed experiments that simulate volcanoclastic mass flows in shallow marine environments. The experiments involve releasing the starting material, a natural pyroclastic deposit, into a water flume. Experimental conditions were varied in order to test the influence of starting-material temperature (18°–350°C), mass, water content and componentry, as well as the slope angle (up to 26°) and slope length, on the textural characteristics of the deposits. Twenty experiments were successfully completed and all produced at least one mass flow. Video cameras recorded the experiments, allowing determination of mass-flow velocity and particle-support mechanisms. After each experiment, the deposits were sampled for textural analysis. The experimental data will allow identification of links between starting conditions, mass-flow type and deposit characteristics.

Sharon's field research focussed on well-exposed examples of submarine volcanoclastic mass-flow deposits in the Miocene Waitemata Group, New Zealand, in collaboration with Bruce Hayward, (UAuckland). She identified the principal down-current facies variations using a series of detailed sections at proximal (<30 km from the source), medial (~40 km) and distal (>60 km) locations. The main changes are increases in matrix proportions, bed thickness, and the non-volcanic component, and decreases in the proportion of coarse volcanic clasts. Her results were presented at the IAVCEI meeting held on Martinique ('Mount Pelee 1902-2002: Explosive volcanism in subduction zones, May 2002').

Project 2.8 Plagioclase ultraphyric lavas on Tanna, Vanuatu

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

This project was funded by a University of Tasmania Internal Research Grant awarded to Sharon Allen, Fernando della-Pasqua and Tony Crawford. The principal aim was to elucidate the links between ultraphyric basalts and more evolved

pyroclastic deposits in arc volcanoes, using a blend of volcanology (Program 2) and geochemistry (Program 1). The project focussed on the Upper Pleistocene to Recent Siwi Group, Tanna (Vanuatu) and involved mapping and sampling of several coastal sections. The ultra-phyric basalts are lavas that contain very coarse plagioclase phenocrysts. These lavas immediately underlie and are intercalated with trachyandesitic pyroclastic deposits. Sharon completed a detailed volcanological study of the trachyandesitic pyroclastic deposits of the Siwi Group and submitted a manuscript to the *Bulletin of Volcanology*. Mafic- and intermediate-composition pyroclastic deposits are relatively uncommon in arc volcanic successions and there are few well-described examples. The examples in the Siwi Group are associated with formation of a 4-km-wide caldera and unusual in being composed of both non-vesicular spatter and highly vesicular pumice. Lateral and vertical facies variations are particularly marked in the Siwi Group pyroclastic deposits, reflecting the importance of syn-eruptive agglutination and welding of hot, low-viscosity pyroclasts.

Other achievements

- Sharon Allen was appointed to the Editorial Board of *Australian Journal of Earth Sciences*. She is already on the Editorial Board of the *Journal of Volcanology and Geothermal Research*.
- At the 16AGC in Adelaide, CODES volcanologists were elected to lead the Geological Society of Australia Specialist Group on Volcanology (LAVA): Sharon Allen, Chair; Greg Ebsworth, Treasurer; Rick Squire (now UMelb), Secretary.
- International visitor - Dr Yoshi Goto from the Department of Geoscience and Technology at Tohoku University joined CODES for two months in 2002 (February and March); Yoshi and Jocelyn McPhie undertook research on complex submarine basaltic lavas at Stanley (northwestern Tasmania).

PhD PROJECTS IN PROGRAM 2

Michael Agnew: Volcanic setting, lithogeochemistry and genesis of the Lewis Ponds massive sulfide deposits, NSW

Kate Bull: Character, setting and significance of Early Devonian volcanic successions in the western Lachlan Fold Belt, New South Wales

Greg Ebsworth: Andesitic volcanic facies in the Tyndall Group: Stratigraphic and tectonic implications for the Cambrian Mount Read Volcanics, western Tasmania

Sarah Jones: Geology and geochemistry of the 'cap rocks' above the VHMS deposits at Myra Falls, Vancouver Island, British Columbia, Canada. PhD awarded August 2002.

Karin Orth: Setting of the Palaeoproterozoic Koongie Park Formation and carbonate-associated base-metal mineralisation at Koongie Park, northwestern Australia. Thesis submitted December 2002.

Carlos Rosa: Submarine volcanic successions in the Iberian Pyrite Belt, Portugal. New in 2002.

Andrew Stewart: Facies architecture of a mineralised arc volcanic island, Milos, Greece.

PROGRAM 3

Ores in volcanic arcs



Storm clouds over Cerro Vanguardia epithermal Au district, Argentina

HIGHLIGHTS

Completion of highly-successful ARC-AMIRA P588 project ('Epithermal Au-Ag deposits: geological, geochemical and isotopic vectors to target major deposits'). (Project 3.9)

The industry-ARC funded project on the applications of stable and radiogenic isotopes to ranking mineral prospects in volcanic successions was completed with a case study in the Mount Read Volcanics. (Project 3.12)

Sarah Jones and Andrew Rae graduated. Sarah's thesis was on the geology and genesis of the cap rocks overlying the Myra Falls VHMS deposits (Canada). Andrew's thesis was on the Palinpinon geothermal field, Negros Island (Philippines).

Valeriy Maslennikov (Russian Academy of Sciences, Urals Division) visited CODES for six months to collaborate on the genesis of VHMS deposits of the southern Urals (Russia). (Project 3.5)

Bruce Gemmell, Russell Fulton and Christian Schardt participated in three oceanographic cruises in the southwest Pacific. These investigated modern seafloor hydrothermal deposits. (Projects 3.3 and 3.8)

TEAM MEMBERS

Michael Blake, David Cooke, Garry Davidson, Cari Deyell, Wally Herrmann, Dima Kamenetsky, Ross Large, Jocelyn McPhie, Rob Scott, Robina Sharpe, Michael Solomon, Khin Zaw

PHD STUDENTS

Michael Agnew, Andrew Davies, Russell Fulton, Sarah Jones, Neil Martin, Thomas Monecke (UFreiberg), Karin Orth, Andrew Rae and Andrew Wurst

COLLABORATORS

CSIRO Division of Exploration and Mining, Geoscience Australia, University of Toronto, Mineral Resources Tasmania, AMIRA International, Laurentian University, ITG–Spain, GEODE, University of Michigan, Duke University, University of Arizona, Freiberg University, Geological Survey of Canada, University of Auckland, Volcanic Resources, University of Southampton, Instituto Geológico y Minero de Espana, Geological Survey of Japan, University of Queensland, Chinese Academy of Geological Sciences, Nanjing University, British Geological Survey, Instituto Geológico e Mineiro (Portugal).

CORE PROJECTS

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



BRUCE GEMMELL, LEADER OF PROGRAM 3

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

OBJECTIVE

To determine the relationships between magmatism, volcanism and ore formation in volcanic arc settings, especially on the nature, diversity and genesis of massive sulfide Cu–Pb–Zn and epithermal Au–Ag in modern and ancient, subaerial and subaqueous environments in Australia and the Pacific Rim.

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

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

Dima Kamenetsky continued his studies on fluid bubbles trapped inside glassy melt inclusions in primitive olivine phenocrysts and pillow-rim glasses from basaltic magmas. Samples come from different tectonic environments, including mid-ocean ridges (Macquarie Island, SW Pacific and Mid-Atlantic Ridge 43°N Fracture Zone), ocean islands (Hawaii) and a variety of modern and ancient backarc–island arc settings (eastern Manus Basin, Okinawa and Vanuatu Troughs, Troodos, New Caledonia and Hunter Ridge Fracture Zone). A study of fluid bubbles from these localities, using electron microscopy with EDS and laser Raman spectroscopy (LRS), found that they are composed of CO₂(±H₂O±S)-bearing vapour and contain significant amounts of amorphous and crystalline phases. The crystals are mainly carbonates, sulfates and sulfides. The chemical components that later formed precipitates in fluid bubbles must have been dissolved in the magmatic fluid, and were not supplied from the host after entrapment. This magma-related fluid, rich in dissolved metals and other non-volatile elements, may be a potential precursor to mineralising hydrothermal fluid. These results were published in a paper in *Chemical Geology* (Kamenetsky et al., 2002).

Khin Zaw continued research on the ore fluid chemistry, using PIXE, LRS and microthermometry, of ancient and modern VHMS systems. A paper on the Mount Chalmers VHMS deposit (Queensland)

was accepted (Khin Zaw et al., in press) in *Chemical Geology*. Mount Chalmers is a mound-style VHMS deposit. The high base-metal content and presence of CO₂ in the fluid inclusions imply that metals may have been sourced from both magmatic fluid and seawater leaching of the footwall volcanic succession. A shallow-water environment(<300 m) of ore formation has been suggested for the Mount Chalmers deposit based on the presence of trace fossils in the footwall and hanging wall sedimentary rocks and volcanic facies analysis. However, the lack of evidence for boiling in the fluid inclusion studies suggests that a moderate to deeper submarine environment cannot be ruled out.

Researchers from CODES, University of Queensland and Perilya Mine continued an integrated collaborative research project on the Devonian Mount Morgan deposit (Queensland), particularly on the newly-delineated Zn-rich Car Park mineralised zone. The project uses a multi-disciplinary approach, including textural analysis, mineral paragenesis, isotopic composition and variations in the concentration of volatile and trace element in fluid inclusions, in order to understand the source(s) of ore-forming fluids, mechanism of ore deposition and the style of mineralisation. The results of recent quantitative LA-ICPMS, LRS, trace elements and new Pb- and S-isotope data suggest that a seawater-dominated fluid resulted in barren sub-seafloor massive sulfide, whereas magmatic volatile-bearing fluids enriched intrusive-related mineral zones. These results were presented at the 16AGC (Adelaide) and in a paper published in *Ore Geology Reviews* (Ulrich et al., 2002).

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

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

Manus Basin, Papua New Guinea
The actively forming hydrothermal deposits (PACMANUS and SuSu) in the eastern Manus Basin (Papua New Guinea)

are considered regional-scale modern analogues for the ancient VHMS districts now exposed on land, such as the Mount Read Volcanics and Mount Windsor Subprovince (Australia) and the Kuroko district (Japan).

The PACMANUS hydrothermal field is located near the crest of Pual Ridge, a 500-700-m-high felsic neovolcanic ridge with negligible sediment cover. The top of the ridge is constructed of dacite, andesite occurs at the base of the ridge, whereas the 2200-m-deep valley to its east is floored by basaltic andesite. Four principal fields of hydrothermal activity, which include sulfide chimneys, and several smaller sites have been delineated. These are named Roman Ruins, Satanic Mills, Tsukushi and Snowcap Knoll.

Bruce Gemmell participated in the German CONDRILL oceanographic cruise aboard the RV *Sonne* (SO-166) (see Project 3.8) in collaboration with Peter Herzig (FreibergU) and Mark Hannington (GSC). A portion of this cruise was devoted to using the British Geological Survey's Rockdrill to test the top 5 m of the Roman Ruins hydrothermal site. Of the 10 holes drilled in various areas of the hydrothermal field, a total of 11.07 m of core was recovered. The surficial portion of the Roman Ruins site consists of an upper 1-2-m-thick zone dominated by sphalerite and anhydrite, and containing beehive chimney fragments. This overlies a fragmental pyrite and chalcopyrite zone cemented by anhydrite. Conventional and laser ablation S-isotope analyses are planned for these new samples.

The CSIRO Chairman's Gold Medal for 2002 was awarded to Dr Ray Binns and his Seabed Ore Systems team (CSIRO EM) for their work on active mineral formation on the deep ocean floor. Since 1991, researchers from CODES (Bruce Gemmell, Gary Davidson, Robina Sharpe, Christian Schardt and Russell Fulton) have been collaborating with Ray and his team on modern seafloor research in the western Pacific Ocean.

Western Bismarck Island Arc, Papua New Guinea

In March 2002, Russell Fulton participated in an oceanographic cruise (FR02) on the CSIRO vessel RV *Franklin* to investigate subduction-related submarine hydrothermal and volcanic activity in the Western Bismarck Island



Program 3 team: Back row (left to right) Neil Martin, Ross Large, Robina Sharpe, Rob Scott, Dima Kamenetsky, Mike Solomon, Wally Herrmann. Front row: Andrew Rae, Garry Davidson, Russell Fulton, Bruce Gemmell, Andrew Wurst, Michael Agnew.

Arc. This cruise located, studied and sampled submarine volcanoes with active hydrothermal systems, in particular those with high-K characteristics and where summit calderas occur. Although there was abundant evidence for hydrothermal activity in the area, no active hydrothermal sites were discovered during the cruise.

Solomon Island chain

Christian Schardt participated in the March-April 2002 SOLAVENTS oceanographic cruise (FR03) on the CSIRO vessel RV *Franklin* to examine submarine hydrothermal activity and volcanic petrogenesis associated with the birth of island arcs in the Solomon Islands. The significant results of this cruise were, firstly, the confirmation that the chain of seamounts at $\sim 10^{\circ}$ – 30° S in the San Cristobal Arc includes a number of recently magmatically active (and currently hydrothermally active) volcanoes that vary in composition from basaltic andesite through to rhyodacite. Secondly, the discovery of four new hydrothermally active submarine seamounts, two in the central portion of the San Cristobal magmatic arc and two in the northern New Hebrides volcanic arc.

Okinawa Trough, Japan

Khin Zaw in collaboration with researchers from Institute of Mineral Resources, Chinese Academy of Geological Sciences (Beijing) and the Geological Survey of Japan, has been studying modern seafloor systems, in particular the JADE hydrothermal field, with the aim of understanding the magmatic contribution to ore fluids and metals in modern seafloor systems. A paper outlining the results of the fluid inclusion and isotope geochemistry study was submitted to *Mineralium Deposita*.

Middle Valley, Juan de Fuca Ridge, Canada Collaborative research between the Geological Survey of Canada (Peter) and CODES (Khin Zaw, Large and Gemmell) on the nature and chemical composition of Middle Valley ore fluids is progressing. Preliminary LRS and PIXE analyses of the Middle Valley fluid inclusions have yielded an interesting dataset for the mixing of fluids in the mineralised zone. There are two types of fluid inclusions, tabular-shaped inclusions with significant H_2S and CH_4 and elevated Ca, Pb and Zn, and circular to round inclusions high in CO_2 , K and Cu but with less Pb and Zn.

These two types of fluid inclusions occur adjacent to one another in quartz crystals suggesting that Cu-rich (end-member-magmatic origin?) fluids mixed with Zn-rich (end-member-seawater leached origin) fluids.

Project 3.5 CORE The nature, diversity and genesis of ancient massive sulfide Cu–Pb–Zn–Ag–Au deposits in volcanic arc settings

JB Gemmell, R Large, M Solomon, Khin Zaw, J McPhie; PhD students M Agnew, R Fulton, S Jones, N Martin, T Monecke (UFreiberg), K Orth

There are many styles of ancient VHMS deposits. These include mounds, pipes, sheets, layered, stacked, stock-work and disseminated, distal re-worked and cyclic layered deposits. Our research suggests that a spectrum of massive sulfide deposits develops in submarine volcanic environments. This spectrum ranges from typical seafloor VHMS (Zn–Pb–Cu–Ag–Au) deposits, to sub-seafloor, shallow-water, replacement Au-rich epithermal styles, to deep sub-volcanic intrusion-related Cu–Au-rich styles.



Thomas Monecke and Bruce Gemmell (third and fourth from the right, respectively) and the research team for the German CONDRILL oceanographic cruise aboard the RV *Sonne*. (Project 3.8)

To improve our understanding of the formation of VHMS deposits, a variety of ancient and modern deposits have been selected for detailed studies. These studies concentrate on the geological and geochemical attributes of the deposits, with the aim of characterising the spectrum of VHMS deposits, and their origins in submarine volcanic environments.

During 2002, research was undertaken on the following deposits: Rosebery, Hellyer (Tasmania), Waterloo, Mount Morgan, Mount Chalmers (Queensland), Koongie Park (WA), Lewis Ponds (NSW), Myra Falls, Kidd Creek (Canada), Greens Creek (Alaska), Yaman Kasi (southern Urals, Russia) and Feitais (Aljustrel, Portugal), Neves Corvo (Portugal), Tharsis (Iberian Pyrite Belt, Spain). Brief reports on the individual sub-projects within this overall study of VHMS and related deposits are given below.

Neil Martin continued his PhD study at the Rosebery mine, Tasmania. The aim of his work is to determine the mode of ore formation. Work completed included further LA-ICPMS and electron microprobe analysis of ore samples, so as to determine elemental variation within ore lenses and hence possible environmental

controls at the time of ore formation. A S-isotope study was also undertaken to gain insight into fluid dynamics and composition at various scales. Additional fieldwork helped refine a stratigraphy for the mine host sequence, and proposed geochemical modelling of the ore forming process. A poster focussing on relict primitive sulfide textures found in the Rosebery ore was presented at the CODES Giant Ore Deposits workshop in June (Martin et al., 2002).

Mike Solomon, with contributions from Bruce Gemmell and Khin Zaw, submitted a manuscript on the Hellyer VHMS deposit to *Mineralium Deposita*. This paper attempted to reconstruct the geology at depth below the deposit, the nature and source of the fluids involved in mineralisation, and their likely flow paths. It used previously published and new data on fluid inclusions, and stable and radiogenic isotopes in ore and footwall rocks. The paper postulates a dioritic pluton, at a depth of at least 3 km, which released fluid intermittently up an active fault system. The result was varying degrees of mixing with convecting, modified seawater.

In a collaborative study with Freiberg University (Germany), Thomas Monecke

completed his research on the Waterloo VHMS prospect in the Mount Windsor Subprovince (Queensland). This study concentrated on the geology, alteration mineralogy and wholerock geochemistry. Thomas used volcanic facies architecture of the host succession to unravel the temporal and spatial relationships between volcanism and massive sulfide formation. Investigations of the alteration halo determined that the mantle-derived volcanism at Waterloo not only provided heat to drive the hydrothermal system, but likely acted as a source of chemical components.

As part of his PhD, Michael Agnew conducted a detailed mineralogical and textural study on the massive sulfide lenses at Lewis Ponds (NSW). Lewis Ponds is an unusual hybrid, polymetallic massive to disseminated sulfide deposit with carbonate-hosted replacement, VHMS and Cobar-style characteristics. Michael's project has involved determining the volcanic-sedimentary facies architecture of the host succession and a mineralogical and geochemical study of the hydrothermal alteration halo surrounding the massive sulfide lenses. Major and trace element compositions of sulfide minerals in each of the massive sulfide

lenses were determined by microprobe analyses. Primitive, diagenetic textures (such as pyrite framboids, bladed, radial and colloform textures) occur throughout the mineralised zones despite intense deformation and recrystallisation of the sulfide minerals.

Robina Sharpe and Bruce Gemmell published a paper in *Economic Geology* on the Archean magnetite-rich Gossan Hill VHMS deposit (WA) detailing the genesis of a multistage hydrothermal system.

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

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

Bruce Gemmell, in collaboration with Mark Hannington (GSC) and Falconbridge, completed a S-isotope study of pyrite and pyrrhotite in barren and mineralised graphitic argillite horizons associated with the giant Kidd Creek VHMS deposit (Canada). This study analysed 492 sulfide separates from argillite horizons in the Kidd Creek region. Most analyses (420) fell within the previously determined metamorphic pyrite and regional pyritic argillite field, however, 72 analyses were within the target Archean VHMS field. These analyses were combined with coincident sulfide trace element geochemistry to determine prospective regions for further exploration.

Russell Fulton continued his PhD research on the geology and geochemistry of the hangingwall argillite, and its implications for ore genesis and exploration at the Greens Creek Zn–Pb–Ag–Au deposit on Admiralty Island in southeastern Alaska, USA. Greens Creek is a major Ag-producing VHMS that

contains several massive sulfide to silica-carbonate barite-rich orebodies, which occur along the contact between footwall ultramafic rocks and hangingwall argillite. The hangingwall argillite consists of two main units, slaty argillite (SA) and massive argillite (MA). The SA is a dark gray to black, sooty phyllite, whereas the MA is a grey to dark grey dolomitic or calcareous rock which occurs in very distinctive, thin 5–50 cm (rarely up to 1m) beds. MA appears to be more common towards the base of the hangingwall sequence, proximal to the ore. The rare barian mineral, cymrite ($\text{BaAl}_2\text{Si}_2\text{O}_8 \cdot \text{H}_2\text{O}$), was identified in significant quantities in some MA adjacent to ore in one part of the Greens Creek deposit.

A collaborative research program on VHMS deposits in China by Khin Zaw with researchers from Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing (Hou Zhengqian) and Nanjing University (Gu Lianxing and Ni Pie) has been completed. The research results on VHMS mineralisation in the Jinshajiang Orogenic Belt, southwestern China have been accepted for publication in *Ore Geology Reviews* (Zengqian et al.).

Valeriy Maslennikov of the Institute of Mineralogy (Miass, Russia) visited CODES for six months to develop collaborative research on the Siluro-Devonian massive sulfide deposits of the southern Urals. Some of these deposits (Sibay, Uchaly and Gai) are the largest of their type in the world, and show many similarities with the VHMS deposits in the Mount Read Volcanics (western Tasmania). The southern Urals deposits are important for research, because of their large size and their incredibly well preserved primary sulfide textures. These textures include sulfide chimney fragments and clastic sulfide debris deposits. The first collaborative project between CODES and the Institute at Miass, was a detailed study of trace-element zonation in sulfide chimneys from the Yaman Ksay and Alexandrinka deposits, utilising the LA-ICPMS. The study has demonstrated a systematic variation in a range of trace elements, in particular Mn, Tl, As, Au, Pb, Te, Ag and Bi, from the central conduit to the outer rim of the chimneys. The zonation is interpreted to relate to temperature and fO_2 gradients between the fluid and chimney walls during growth. A manuscript resulting from this work has



British Geological Survey 'Rockdrill' used to drill Conical Seamount and PACMANUS modern seafloor hydrothermal systems from the RV *Sonne*. (Project 3.8)

been submitted to the 2003 SGA meeting in Athens. The second collaborative project on the Southern Urals deposits (Khin Zaw and Maslennikov) is on the temperature and chemistry of ore fluids deduced from fluid-inclusion studies of selected minerals in the chimney fragments. This research will apply PIXE, LRS and IR techniques to understand the nature and source of ore fluids, and mixing and boiling processes during sulfide chimney formation.

Mike Solomon continued to lead a strong research program on the VHMS deposit of the Iberian Pyrite Belt of Spain and Portugal. One project is investigating the genesis of the Feitais (Aljustrel) deposit (Portugal). This is a collaborative project with Carlos Inverno (Instituto Geológico e Mineiro), Mark Barton (UArizona) and John Foden (AdelaideU) and Eurozinc Ltd. Research included mineralogical and textural studies, metal distributions, S isotopes of sulfides and barite, C and O isotopes of ore-related carbonates, O isotopes of stockwork vein quartz, fluid inclusions in stockwork quartz and carbonate, and strontium isotope studies of barite. A second project, with Orlando Gaspar (consultant), Nelson Pacheco, Paulo Caetano da Noiva, and Alfredo Ferreira of Somincor Ltd, is investigating



Program 3 geologists in the field (top to bottom): Sarah Jones — Myra Falls, Canada; Russell Fulton — Greens Creek, Alaska; and Robina Sharpe — Cerro Vanguardia, Argentina.

the origin of the S in the economic and uneconomic lenses of the Neves Corvo deposit (Portugal). The first sampling program has been completed, and textural and mineralogical studies, and S-isotope analysis are underway. A third project is examining the origin of the fluids responsible for the Tharsis deposit (Spain) with Fernando Tornos and Spiro Baruch (Instituto Geológico y Minero de Espana). New isotopic data on siderites within and near the sulfide ore, on sulfides, and on the host shales, have been completed. Another project is determining the characteristics of Zn-Pb-Cu massive sulfide deposits formed in brine pools (in the MRV and the IPB) as distinct from those forming from black smokers, such as those in the Hokuroku Basin. This project is in collaboration with Ross Large, Ross Both (consultant) and Khin Zaw.

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

R Large, JB Gemmell, C Gifkins, W Herrmann, J McPhie, G Davidson, R Sharpe; R Allen (LuleaU, Volcanic Resources)

Cathryn Gifkins, Wally Herrmann and Ross Large are nearing completion of a book on alteration in ancient submarine volcanic successions. Titled 'Altered Volcanic Rocks: a guide to description and interpretation', the book is a culmination of years of research into VHMS deposits, volcanic facies analysis and alteration studies. It will incorporate many of the outcomes of AMIRA project P439, and provides an introduction to the processes of alteration in submarine volcanic successions with emphasis on hydrothermal alteration associated with VHMS deposits. This book will provide examples of alteration facies, assemblages and compositional changes associated with the different processes of alteration that occur in submarine volcanic successions. Short case studies are presented for both regional alteration styles and hydrothermal alteration associated with a variety of VHMS. The case studies incorporate data sheets used to present the mineralogical, textural, photographic and compositional

characteristics of each of the main alteration facies or zones. A critical aspect of these case studies is the multi-disciplinary approach combining volcanic facies analysis, alteration mineralogy, textures, intensity, and alteration geochemistry (including wholerock, mineral chemistry and stable isotopes) to constrain the features of different alteration styles.

Project 3.7 Sulfur geochemistry of hydrothermally altered volcanic terrains

G Davidson, R Berry; PhD student S Lewis; J Alt (UMichigan); J Karson, P Rivazzigno (DukeU); A Brown (MRT); D Teagle (USouthampton)

Studies of hydrothermal S cycling in oceanic crust, particularly those related to fault processes, continued in 2002. This project is aimed at acquiring the S-isotope signature and S abundance data for a spectrum of hydrothermally altered materials derived from slow-spread mid-ocean ridges. This information is being used to determine how S is added and removed from the ocean crust, with a view to constructing better models of S dynamics in high permeability hydrothermal settings. Macquarie Island is ideal for this work because many different structural levels of oceanic crust are exposed, and the Australian Antarctic Division has an excellent scientific research support network to facilitate different types of research on the island.

A highlight of this work in 2002 was seven months of fieldwork by PhD student Steve Lewis on the hydrothermal effects of large northwest-directed grabens (these were discovered by collaborators Karson and Rivazzigno in 2000). Steve has determined that these features have very distinct hydrothermal zonation in time and space, and that both upflow and downflow zones existed in different portions of the same structural system. Fluid flow produced obvious major zones of silicification and elevated S in the Majors Lake and Caroline Cove areas. This project is also determining the hydrothermal influence of the major fault systems on the surrounding porous pillow basalts. Much of Steve's field investigations involved examining the

geochemical and mineralogical features of the distal fringes of the fault-related alteration. Steve is funded by an ASAC grant (1318) 'Tectonic, magmatic and hydrothermal evolution of ocean floor spreading at Macquarie Island' (Davidson, Brown, Karson and Varne) for the 2002-2003 season and an APA scholarship.

The results of funding applications for future research on Macquarie Island are awaited. Our group, in collaboration with Jeffrey Karson, has submitted a proposal to undertake a major aero- and ground-magnetic program on the island over the next five years, with the aim of determining the distribution of altered rocks, improving the stratigraphy of the basaltic succession, which makes up 70% of the island geology, and relating the tectonic features on shore to those of the plate boundary 5 km to the west. It is hoped that improved knowledge of these features will underpin a study of fundamental hydrothermal processes in mid-ocean ridge settings.

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

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

Bruce Gemmell and Robina Sharpe, in collaboration with Ian Jonasson and Mark Hannington of the Geological Survey of Canada, investigated the S isotope characteristics of subaqueous epithermal mineral prospects at Conical Seamount, Tabar-Feni island chain, Papua New Guinea. Polymetallic epithermal-style veins and associated pyritic stockwork occur on the summit of Conical Seamount, a subaqueous alkaline volcano south of Lihir Island. This prospect is a unique new type of seafloor mineral deposit, with epithermal-like characteristics, and has important implications for understanding the metallogenic history of the Lihir area. Mineralised rock from Conical Seamount is similar to ore currently being mined at the Ladolam deposit on the island of Lihir. A paper outlining the results of this research was submitted to *Economic Geology*.

Jeff Karson (left), Steve Lewis (middle) and Pete Rivazigno inspecting silica-sulfide alteration overlooking Sandell Bay, Macquarie Island. (Project 3.7)

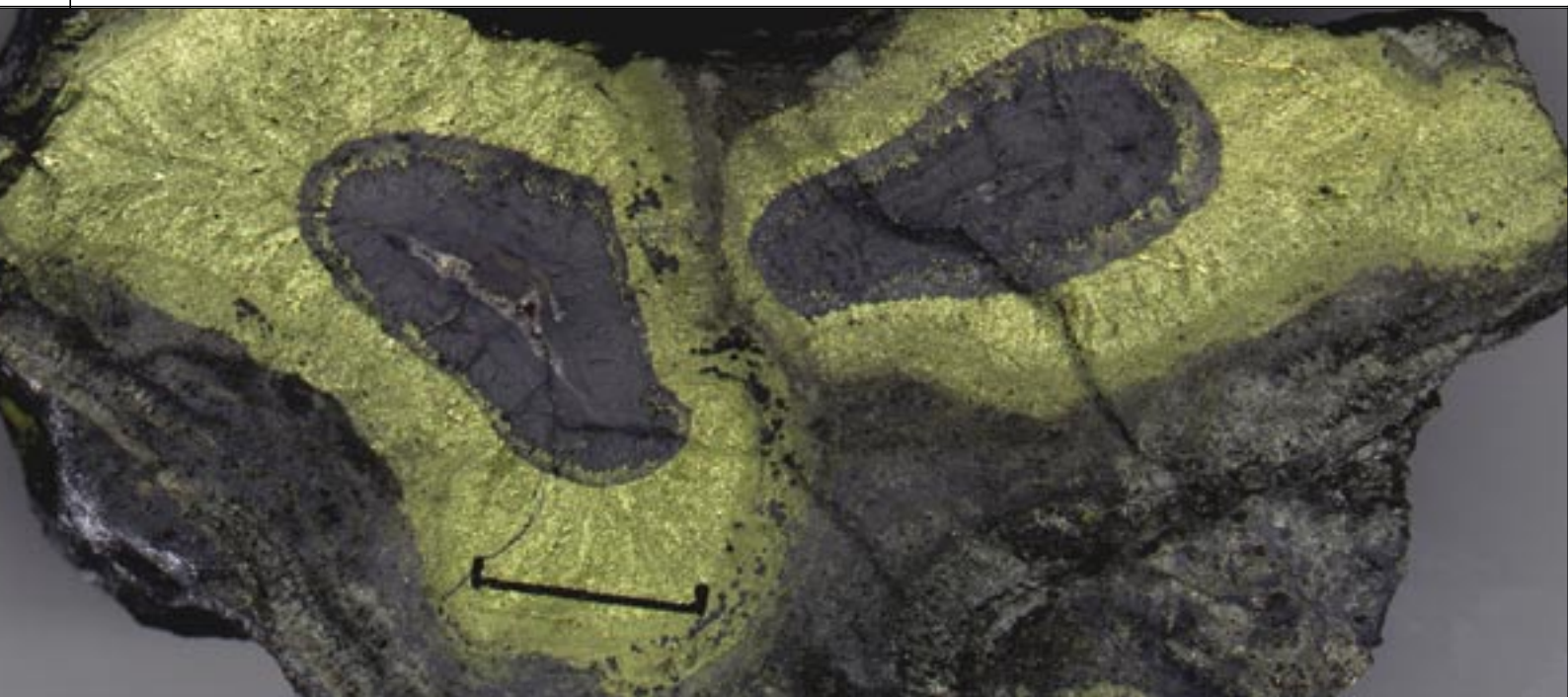


Bruce Gemmell participated in the German CONDRILL oceanographic cruise aboard the RV *Sonne* (SO-166) in collaboration with Peter Herzig (FreibergU) and Mark Hannington (GSC). The aim of this cruise was to test the top 5 m of the mineralised zone at Conical Seamount using the British Geological Survey's Rockdrill. Forty-three holes were drilled with a total recovery of 21.41 m of core. This was the first time the Rockdrill had been used to drill a seafloor hydrothermal mineral prospect and proved to be a new and valuable tool in the investigation of seafloor hydrothermal activity. Drilling at Conical Seamount confirmed the subsurface presence of the Au-rich zone and expanded the lateral extent of the mineralisation and alteration zones. Laser ablation S-isotope studies are planned for the new samples.

Project 3.9 Epithermal Au-Ag deposits: geological, geochemical and isotopic vectors to target major deposits (AMIRA P588)

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

Research on the mineralogical and geochemical characteristics of altered rocks associated with low-sulfidation epithermal Au and Ag deposits in Australia and the Pacific Rim region was completed in 2002. The objectives of this project were to (1) substantially increase our knowledge of the mineralogical and wholerock geochemical characteristics of hydrothermal alteration associated with low sulfidation epithermal deposits, (2) develop a set of criteria to discriminate potential ore grade epithermal



Silurian vent chimneys from Yaman-Kasy VHMS deposit. Sphalerite conduit (dark grey), chalcopyrite encrustation (yellow) with an outer wall of colloform pyrite. Scale bar = 1 cm. (Project 3.5)

systems from barren or low grade systems and (3) propose a range of district- and deposit-scale vectors that point toward ore, and which can be used by companies exploring in epithermal environments in Australia and the southwest Pacific.

This project has made major advances in our understanding and interpretation of alteration related to low-sulfidation epithermal deposits. We have identified the distribution, mineralogy, mineral chemistry, wholerock geochemistry and isotopic (O, C-O, S,) characteristics of hydrothermal alteration, volcanic facies architecture, structure and fluid flow at selected epithermal Au-Ag districts and deposits, and modern geothermal systems. Six projects located at five sites were investigated: Cerro Vanguardia (Argentina), Ladolam (Papua New Guinea - two projects), Mount Muro and Gosowong (Indonesia), and Twin Hills and Bimurra (Queensland). Modern geothermal systems in the Taupo Volcanic Zone (New Zealand) were also studied.

The major accomplishments of this project were:

- Development of the volcanic and sedimentary architecture of host successions for each case study, leading to a better understanding of the controls on the development of alteration and mineralisation.
- Determination of the stratigraphic sequence at Cerro Vanguardia and the production of a new geologic map (1:50,000) for the district. The identification of the stratigraphy has had a major impact on the development of a new structural model for the Cerro Vanguardia district.
- Studies of fracture-controlled epithermal systems at Gosowong, Mt Muro, Cerro Vanguardia and Bimurra reveal a relationship between deposit size and dimension of the largest associated co-active fault(s). This scaling relationship is interpreted to reflect feedback between fracturing and fluid supply in these systems. The size of the largest faults and fractures that tap over-pressured fluid reservoirs is an important control on the maximum fluid flux along these and connected subsidiary structures. An estimated 0.6–6 km³ of fluid are required to form a 1 M oz epithermal Au deposit.
- Detailed mineralogical and geochemical alteration models have been developed for the following six epithermal deposits; Gosowong, Cerro Vanguardia, Mt Muro, Ladolam, Twin Hills and Bimurra. This is the first time that a set of epithermal alteration models that include volcanic facies, lithogeochemistry, alteration zonation, halo geochemistry, and mineral chemistry has been presented.
- The deposit case study reports include a series of alteration data sheets that combine geological, geochemical, textural and mineralogical information, with photos, all on one page. This facilitates easy comparison of the main alteration characteristics.
- A geochemical database for samples from the six ore deposit case studies and for modern geothermal systems in the Taupo Volcanic Zone has been compiled. The database includes 822 wholerock analyses, 236 microprobe mineral analyses, 122 LA-ICPMS analyses and 211 stable isotopes analyses.
- The Alteration Box Plot (Large et al., 2001) was applied to altered rocks from low-sulfidation epithermal systems for the first time. This way of plotting wholerock geochemical data in relation to alteration mineralogy is a very effective way of assessing the degree of alteration a sample has undergone.
- Criteria and vectors useful for regional- and deposit-scale exploration were developed for each epithermal deposit. These will facilitate more effective exploration at the deposit and district scales. A set of discriminators to distinguish potential ore grade epithermal systems from barren or low-grade systems was proposed.

This project was supported by AngloGold and Cerro Vanguardia SA, Aurora Gold, AurionGold, Barrick Gold of Australia, Lihir Management, Newcrest Mining, Newmont Exploration, University of Auckland, CODES, University of Tasmania, AMIRA and the Australian Research Council.

Project 3.10 **Global comparisons of VHMS deposits**

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

The Global VMS Project is a major international project that will study and compare 12 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 deposits. The project will explore the connection between VHMS ore formation, volcanism, and extensional tectonics in each district. It will develop criteria to recognise this connection in the field, and to identify the volcanic intervals that are most likely to host major deposits in any given district.

The 12 districts participating in the project comprise seven major VHMS mining districts: Skellefte (Sweden); Iberian Pyrite Belt (Spain and Portugal); Southern Urals (Russia); Green Tuff Belt (Japan); Mount Read Volcanics (Tasmania); and Bathurst, New Brunswick and Abitibi (central Canada); four less-established but highly prospective regions in Peru, Greenland, Canada (Nunavut) and India; and modern analogs in the Manus and Lau Basins.

Multi-disciplinary scientific teams will work concurrently in each of the 12 districts under a common theme. The collaboration will enable the project to compare and contrast the results from each region. The aim is to determine those features that are essential for VHMS deposits to occur compared with features that are only locally important. The information from the 12 districts will be

synthesized to produce innovative scientific papers, new databases and ore deposit models for mineral exploration.

The Global VMS Project has the support of the major research groups involved in VHMS and modern ocean-floor massive-sulfide studies. It is clear that this project will be the major vehicle for VHMS research over at least the next five years. Rod Allen (Global VMS Project Manager) has submitted a proposal to the Metal Mining Agency of Japan soliciting core funding to support this project for the next five years.

Project 3.11 **Epithermal deposits of the Pacific Rim**

JB Gemmell, D Cooke, PhD students A Davies, A Rae, A Wurst

The geology and genesis of epithermal deposits are being investigated at a number of locations in the southwest Pacific. Research concentrated on determining the geological and geochemical constraints of formation of epithermal deposits, which will lead to improved genetic and exploration models.

Andrew Wurst is in the final year of his PhD research into the low-sulfidation Au–Ag epithermal systems at Mount Muro, in Central Kalimantan, Indonesia. Investigations have been carried out on two orebodies; the Ag–Au quartz vein systems of Permata-Batu Badingding-Hulubai and the Ag–Au carbonate-quartz, breccia and stockwork vein systems of Kerikil. Andrew has determined the alteration mineralogy and zonation, both laterally and vertically, for both deposits. Discrete alteration zonation exists, however disruption to the vertical and lateral zonation occurs where fluid has infiltrated beds that were permeable or reactive. Alteration ranges from advanced argillic (halloysite-kaolinite-silica) and argillic (illite-adularia-silica-pyrite) at shallow depths and at the immediate margins of the veins to phyllic (sericite-phengite-pyrite) and propylitic (chlorite-epidote-carbonate-albite) at the distal margins and at depth. A set of deposit- and district-scale exploration vectors has been derived from alteration mineralogy and zonation wholerock geochemistry and O isotopes.

Andrew Davies' PhD research on the Kelian deposit, East Kalimantan,

Indonesia, was completed in 2002. Kelian is a bulk tonnage, breccia- and vein-hosted, structurally controlled, base-metal sulfide-rich, low-sulfidation, epithermal Au–Ag deposit. Detailed facies mapping has delineated the subsurface facies and remnants of the eruptive facies of a maar-diatreme complex, and genetically related, mineralised phreatic and hydraulic breccias. The Kelian Breccia Complex records the effects of magma intrusion into an active hydrothermal system and the ensuing disruption, reorganisation and enhancement of that system. There is an overall progression through the paragenetic sequence from pyrite-dominated to base metal-sulfide-dominated and finally sulfosalt-dominated mineralisation. A reduced, H₂S-rich, saline fluid is inferred to have entered the base of the hydrothermal system at Kelian and to have transported Au, Pb and Zn. Gold deposition at Kelian is inferred to have resulted from a combination of (1) boiling; (2) desulfidation due to stripping of H₂S by base-metal sulfide deposition; (3) isothermal mixing between a reduced, S-rich, saline fluid and a reduced, S-deficient, dilute fluid; and (4) wall-rock sulfidation.

Andrew Rae was awarded his PhD for his study of alteration and mineralisation associated with the active Palinpinon geothermal system in the Philippines. New ideas on geological evolution of porphyry- and epithermal-related mineral districts evolved from studying the trace metal fluid chemistry of the geothermal waters, along with 3-D modelling of the intrusive bodies, downhole water temperatures, and alteration and mineralisation zones.

Project 3.12 **Stable and radiogenic isotope applications to ranking prospects in volcanic terrains: Mount Read Volcanics case study**

G Davidson, W Herrmann, M Solomon, M Blake, R Large; Honours student K Bassano; M Barton (UArizona); D Green, G Green, M McLenaghan, J Taheri (MRT)

This project was completed in August 2002. It evaluated the usefulness of stable and radiogenic isotopes of altered Mount Read Volcanics rocks for tracing VHMS hydrothermal fluid pathways and

establishing exploration vectors. Carbon-O, wholerock O, sulfide and sulfate S, and Sr isotope ratios were employed. The project began as a Pasminco Exploration, Goldfields and Mineral Resources Tasmania pilot collaboration with CODES, but for most of its life, funds were swelled by an ARC-Linkage grant. Most major prospects in the belt were characterised. New analyses were obtained from Hellyer (Pb-Zn; S, C-O), Hercules (Pb-Zn; S, O), Que River (Pb-Zn; S), Comstock (Cu-Au; S, C-O, O), Chester (Fe; S, O), Southern Trenches (Pb-Zn; S, C-O, O), Western Tharsis (Cu-Au; C-O, O, S), Boco (S, O), and Basin Lake (Cu-Au; S, C-O, O). Highlights of the final reporting period were (1) a detailed appraisal of the unusually heavy wholerock O-isotope composition of least-altered MRV volcanic rocks, and the implications for exploration vectoring; (2) mineralogical and stable isotope zonation within the hyper-acid alteration assemblages of the Chester pyrite deposit; (3) an overview of the use of sulfide and sulfate isotopes for exploration in the MRV; (4) detailed characterisation of stable isotope signatures around the Comstock and Hercules deposits; and (5) an explanation for the cryptic C-O isotope patterns in vein carbonates in the Hellyer Basalt, above and distal to the Hellyer Pb-Zn deposit. Project results are confidential until February 2004, however permission has been granted for Nick Williams and Garry Davidson to publish their work on the Basin Lake system in a paper titled 'Submarine high-sulfidation epithermal alteration and isotope geochemistry at the Basin Lake prospect, western Tasmania' in *Economic Geology*.

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

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

This project evaluates the usefulness of (mainly) pyrite and pyrrhotite geochemistry for enhancing trace-element patterns around hydrothermal ore deposits, particularly lode Au, porphyry Cu-Au, epithermal Au, VHMS Pb-Zn, Broken Hill-type Pb-Zn-Ag, and Fe-oxide Cu-Au styles. 2002 was the first full

year of this project, supported by Anglo American, AngloGold, BHP Billiton, Delta Gold, and Newmont. During the year, Newcrest Mining joined the sponsor group, and the team was also successful in obtaining ARC-Linkage support for the remaining two years of the project (2003–04).

The major activity in the reporting period was a study of the Cleo-Sunrise Dam lode Au deposit. This study will be used to guide our approach to the project. As a result, we spent more time than originally anticipated on the Cleo-Sunrise Dam deposit. At the December meeting, sponsors responded with great enthusiasm to the results from this site. Preliminary results have also been completed on Cannington base-metal sulfides from different ore zones, Carlin-style pyrite from Leederville, and pyrite fingerprint results from a range of systems. The Carlin-style work was undertaken to determine the applicability of the technique to very fine-grained materials, and results are very positive.

Project 3.14
Transitions and zoning in porphyry-epithermal districts: indicators, discriminators and vectors

D Cooke, JB Gemmell, C Deyell, R Sharpe; N White (consultant)

This is a new project that was initiated in 2002. Porphyry-related mineral districts host many major ore deposits of diverse styles and metal associations. These include porphyry (Cu-Mo-Au), epithermal (Au-Ag), skarn (Cu-Au), carbonate replacement (Zn-Pb-Ag), and sediment-hosted Au deposits. These districts continue to be major targets for both Cu and Au 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.

This project aims to develop and test criteria that can be used by explorers to indicate prospective environments, discriminate between mineralisation styles, and determine vectors toward ore zones — be they porphyry, epithermal, and/or other peripheral styles. We envisage a maximum of four research modules (lithocap domain,

transitional environments, carbonate environments and alkalic systems), based on the diversity of environments that can occur in porphyry-epithermal districts. Each module will involve a rigorous assessment of lateral and vertical zonation, with techniques varying depending on the nature of the host rocks, veins and alteration systems.

Cari Deyell joined CODES in 2002 as a Research Fellow dedicated to developing this project. An AMIRA proposal has been distributed and an application for ARC-Linkage funds will be submitted in early 2003. It is anticipated this project will begin in mid-2003.

PhD PROJECTS IN PROGRAM 3

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

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

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

Sarah Jones: Geology and geochemistry of the 'cap rocks' above the VHMS deposits at Myra Falls, Vancouver Island, British Columbia, Canada. PhD awarded August 2002.

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

Thomas Monecke: Waterloo—Agincourt Cu—Pb—Zn deposit, Mount Windsor Subprovince, Queensland. Based at FreibergU, Germany. Thesis submitted October 2002.

Karin Orth: Setting of the Palaeoproterozoic Koongie Park Formation and carbonate-associated base metal mineralisation at Koongie park, northwestern Australia. Thesis submitted December 2002.

Andrew Rae: Alteration systematics and mineralising potential of the Palinpinon geothermal field, Negros Island, Philippines. PhD awarded August 2002.

Andrew Wurst: Volcanic architecture, structure, mineralisation and alteration of the Permata-Batu Badinding-Hulubai and Kerikil low sulfidation epithermal Au-Ag deposits, Mt Muro, central Kalimantan, Indonesia: Implications for ore genesis and exploration.



Top: Tracks and nest of female leatherback turtle on the geothermally warmed sand at Luise Harbour, Lihir Island, PNG. The Ladolum Au deposit lies in the middle distance, in the floor of the crater formed by sector collapse of Luise volcano.
 Middle: Gosowong epithermal Au deposit, Halmahera Island, Indonesia.
 Bottom: Rob Scott, Stuart Simmons (UAuckland) and Alan Goode (AMIRA) examining an ore sample at the Martha epithermal Au deposit, New Zealand. (AMIRA P588/Project 3.9)



PROGRAM 4

Ores in continental rift basins



The Pinnacles palaeo hot springs, southern Panamint Valley, California, USA

HIGHLIGHTS

It was the second year of CODES largest industry-funded research project: AMIRA-ARC P544 (Proterozoic sediment-hosted Cu deposits). Sponsors meetings were held in Golden (USA), Hobart and Adelaide. The Adelaide meeting concluded with a field trip to Olympic Dam and the northern Flinders Ranges in South Australia. (Project 4.6)

Two major peer-reviewed papers were presented at the Giant Ore Deposits workshop ('Iron oxide Cu-Au deposits' – Davidson 2002, and 'Sediment-hosted Zn-Pb deposits' – Large et al., 2002).

Stuart Bull and Ross Large were invited contributors to a workshop on sediment-hosted Zn-Pb deposits held in conjunction with the Prospectors and Developers Association of Canada annual meeting in Toronto in March. Ross Large summarised the results of Program 4 sedimentary Zn-Pb research in an invited keynote presentation at the International Association for the Genesis of Ore Deposits meeting, Namibia.

PhD degrees were awarded to Steve Bodon (The geodynamic evolution and genesis of the Cannington Broken Hill Type Ag-Zn-Pb Deposit, Mt Isa Inlier) and to David Rawlings (Sedimentology, volcanology and geodynamics of the Redbank Package, McArthur Basin, northern Australia).

Rob Scott attended the Applied Structural Geology for Mineral Exploration and Mining meeting in Kalgoorlie in September and presented a paper entitled 'Statistically assessing the reliability of core orientation methods'.

TEAM MEMBERS

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

PHD STUDENTS

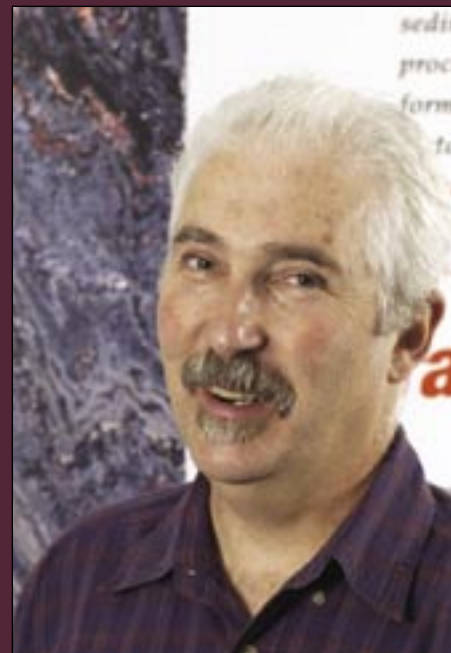
Stephen Bodon, Bryan Bowden, Mike Blake, Darryl Clark, Mawson Croaker, David Rawlings, Owen Hatton, Wallace Mackay, Nicky Pollington, Tony Webster

COLLABORATORS

Colorado School of Mines, Geoscience Australia, Geological Survey of Canada, Lulea University, Swedish Geological Survey, Johns Hopkins University, Boliden Mineral AB, AMIRA International, University of Adelaide, University of Queensland, Primary Industries and Resources (South Australia), Research School of Earth Sciences-Australian National University, Simon Fraser University, James Cook University, Queens University, CSIRO Division of Exploration and Mining, Geological Survey of New South Wales, University of Western Australia.

CORE PROJECTS

- 4.1 Geological environment of stratiform Zn-Pb deposits in the Proterozoic basins of northern Australia
- 4.2 Nature, timing and significance of fluid flow in Proterozoic sedimentary basins, and relationship to stratiform Zn-Pb-Ag ore formation
- 4.4 Regional stratigraphy, basin evolution and setting of Zn-Pb-Cu-Ag-Au deposits in the Bergslagen district (Sweden).
- 4.5 Textural and isotopic studies of sediment-hosted Zn-Pb-Ag base metal deposits
- 4.9 Development of novel laser and ICPMS techniques for microanalysis of trace elements and isotopes in sulfide mineralised samples
- 4.10 Microbes and the origin of Proterozoic Sedex Zn-Pb-Ag deposits.



PETER MCGOLDRICK, LEADER OF PROGRAM 4

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. Program 4 will emphasise the application of these results to refine and develop techniques used in the search for new resources.

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

S Bull, P McGoldrick, R Large, D Cooke,
R Scott, D Selley; Honours student
J Stacpoole

This project continues the work begun several years ago in a major AMIRA ARC project that ran from 1992 to 1998 (P459). Although not presently a major focus for Program 4 research, some targeted investigations continue in specific areas or deposits.

A number of presentations based on our previous research were made during 2002. In March, prior to the PDAC meeting, Stuart Bull and Ross Large jointly with the GSC, presented a workshop on the nature and genesis of stratiform Zn-Pb-Ag deposits in Toronto (Canada). Ross Large made keynote presentations based on much of this research at the IAGOD meeting in Namibia in July and at the Giant Ore Deposits workshop in Hobart in June.

Tim Ireland (Honours 2001) completed writing-up a manuscript on the environment and genesis of the McArthur River Zn-Pb-Ag deposit for publication. Another paper on the sedimentology of mass-flow breccias interbedded with the ore lenses was accepted by *Mineralium*

Deposita. The laterally continuous mass-flow deposits are an important feature of the McArthur River succession. At HYC, the mass-flow deposits are interbedded with sheet-like mineralised lenses in a carbonaceous dolomitic siltstone host rock. Tim proposed, based on mass-flow geometry and detailed clast petrography, that the processes of mass-flow emplacement constrain stratiform mineralisation to the top metre of the sediment pile.

In 2002, an Honours project was carried out by John Stacpoole on the Bluebush prospect (northwest Queensland). Bluebush is a large sub-economic Zn-Pb body hosted in pyritic and Mn-carbonate-bearing siltstones of the Upper McNamara Group. This research concentrated on the sedimentary facies and paragenesis of pyrite and Zn mineralisation.

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

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

This is a joint project with Program 5 and is reported under Project 5.1.

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

S Bull, R Allen (LuleaU, Volcanic
Resources), R Jonsson, H Christoffersson
(Boliden Mineral AB), M Ripa (SGS)

The Bergslagen district of southern Sweden contains historically important and currently mined Zn-Pb deposits that are hosted in metamorphosed pelitic and calcareous metasediments in a thick Palaeoproterozoic felsic volcanic succession. This project is a three-year collaboration between CODES, the Swedish Geological Survey, Lulea University and Boliden Mineral AB. It aims to provide a modern, integrated volcanic, sedimentary, structural and geochemical interpretation of the interbedded volcanoclastic-carbonate sequences that host the ore deposits of the Bergslagen district. The project is based on detailed fieldwork involving facies analysis and structural interpretation of volcanic and sedimentary strata to determine deposits settings and provide a framework for lithogeochemical studies. These studies will increase the understanding of the regional geological evolution of Bergslagen and in particular the geological setting of the sulfide ores.

A seven-week field visit to Bergslagen in mid-2002 completed the field component for this project. During this period, detailed stratigraphic profiles across volcanic carbonate contacts were completed in the Garpenberg and Viker areas, and a section within the main marble horizon was measured at Sala. These profiles, in combination with analysis of 140 thin sections, >200 wholerock geochemical samples and 46 C and O isotopic analysis of the carbonates will form the basis for the final report due for presentation in March 2003. This report will comprise two parts that are intended for publication as manuscripts. The regional data will be used to document the setting and genesis of the Bergslagen carbonate horizons and their role as a focus for base metal mineralisation of varying styles. Preserved textures and the isotopic data suggest that the marbles formed as stromatolitic reefs. Facies analysis show that these developed



Program 4 team (left to right): Garry Davidson, Wallace Mackay, Bryan Bowden, David Cooke, Peter McGoldrick, Ross Large, Mawson Croaker, Nicky Pollington and Rob Scott.

almost entirely within sub-wave-base environments. This is in contrast to most Proterozoic carbonate successions, where microbial communities also colonise shallow water to emergent environments. It appears that the abundance of unconsolidated volcanoclastic debris, which is being actively reworked in the shallow water parts of the Bergslagen system, mitigated against microbial sedimentation. The second part of the final report is a detailed analysis of the Garpenberg Norra deposit. This suggests the base metals accumulated initially by sub-seafloor replacement of thick-bedded stromatolitic limestone reefs in an intra-caldera setting, followed by structural upgrading during regional deformation.

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

R Large, S Bull, M Blake, P McGoldrick;
J Foden (AdelaideU); Honours students
J Stacpoole, T McGilvray

Tim Ireland submitted a manuscript to *Economic Geology*, based on his Honours research on textural interpretation and S-isotope patterns of the McArthur River number 3 and 4 ore lenses. The study has revealed concentric distribution patterns in the occurrence of nodular carbonates, the S-isotope composition of sphalerite, and microscopic ore textures throughout the number 3 ore lens. The correlation of previously documented lateral metal zonation patterns with these other zonation patterns precludes post-sedimentation mineralisation and provides some insight into the mechanisms and controls on mineralisation. A syn-sedimentary to early diagenetic origin is supported by new C-O isotope analyses, recognition of two stages of isotopically-distinct sphalerite and re-interpretation of complex sulfide textures.

An Honours project (commenced mid-2002 by Todd McGilvray) is investigating ore textures and host-rock alteration at the Oceana carbonate-replacement Zn deposit in western Tasmania.

Project 4.6 Proterozoic sediment-hosted Cu deposits

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

The major research focus of Program 4 in 2002 was an industry- and ARC-funded project Proterozoic sediment-hosted Cu deposits (AMIRA ARC-Linkage P544). This non-core project has 13 individual sponsor companies or organisations and is CODES largest industry-funded research project. It is a collaboration with researchers from Colorado School of Mines and its principal aim is to compare Neoproterozoic sedimentary sequences containing Cu orebodies in Zambia and Australia. The project has three full-time PhD students based at CODES, and a fourth at Colorado School of Mines. It is a three-year project with 2002 being the second full year of activity.

The main aims of the project are:

- To understand the processes responsible for transporting, concentrating and fixing Cu and other ore constituents during sedimentary basin evolution.
- To document the various stages and paragenesis of Cu deposition and remobilisation during basin evolution.
- To develop a range of geological, geochemical and isotopic vectors that point toward ore, both on a district and a deposit scale.
- To determine what is different about the setting and geological evolution of the African Copperbelt, compared to Australian Proterozoic sedimentary basins, that may explain the difference in Cu (and Co) endowment in these areas.
- To apply research results from both Africa and Australia to produce better empirical exploration models for Proterozoic sediment-hosted Cu deposits.

Important findings were presented to sponsors at meetings held in Adelaide, Golden (USA) and Hobart. The Adelaide meeting was followed by a trip to visit the Olympic Dam deposit and field research areas in the Willouran Ranges (SA), led by Wallace Mackay, David Selley and Stuart Bull.



Mawson Croaker in Mindola pit (Zambia).
Desiccated recent silts flood the pit floor.
(Project 4.6)

David Broughton (CSM) completed logging core from two sections of deep drillholes around the Kafue Anticline (northern Zambia), which is where the major known Zambian deposits occur. Work continued on the two CODES Zambian PhD projects, with both students undertaking field work in Zambia. Mawson Croaker spent several months at Nkana mine mapping underground and logging drill core for his study of this structurally complex deposit. Nicky Pollington completed logging drill core from the Konkola North deposit and presented a preliminary facies analysis at the May sponsors meeting.

David Selley continued the systematic documentation of the structural and sedimentological setting of several deposits in the Chambishi Basin (northern Zambia). Robert Scott completed a detailed analysis of drillcore from the arenite-hosted Cu zone in the Ndola West area (northern Zambia).

Initial results of chemostratigraphic and ore shale geochemistry were presented at a meeting of CODES Gold Sponsors by Ross Large, Peter McGoldrick and Nicky Pollington.



Bryan Bowden logging drill core at Prominent Hill, South Australia. (Project 4.8)

Mapping during Wallace Mackay's second extensive field season has demonstrated previously unrecognised structural complexity in the Curdimurka Subgroup in the northern Willouran Ranges (SA).

Project 4.7 **The geological environment and origin of Broken Hill type deposits**

G Davidson, R Large, R Berry, P McGoldrick; PhD students S Bodon, A Webster, O Hatton; MEconGeol student N Shah

This project has now been absorbed into the new project on 'Giant BHT and SEDEX Zn-Pb-Ag deposits' (Project 4.11).

Project 4.8 **Cu-Au-Fe oxide geology and geochemistry**

G Davidson; R Berry (SES UTas); D Thorkelson (Simon FraserU); T Baker (JCU); P Heithersay, M Schwarz (PIRSA); R Skirrow (GA); students B Bowden (PhD), G Ferris (MSc), I Ledlie (MSc); J Hunt (PhD; JCU)

This non-core project includes several studies aimed at understanding the origin of Fe-oxide Cu-Au deposits. Areas of active work include:

- Mount Woods Inlier (SA) Bryan Bowden), with special emphasis on the new discovery at Prominent

Hill. PIRSA, Geoscience Australia, Minotaur Resources, and Goldstream NL have collaborated to financially support this project, with Geoscience Australia providing a very large in-kind component.

- Eastern Succession (Queensland): Garry Davidson is writing-up past project results for publication.
- Gawler craton (SA): Garry Ferris, the geology and geochemistry of granitoids in the Childara region.
- Wernecke Mountains (Canada): collaboration with Derek Thorkelson, Tim Baker and Julie Hunt on geochemical assessment of several large breccia pipes. Julie completed her first field season in 2002, and a large number of carbonate samples were analysed for C and O isotopes at the University of Tasmania in support of this work.
- Chilean Fe belt: write-up of studies of the Theresa Del Colmo Cu-Fe deposit by Ian Ledlie.

Garry Davidson was a keynote speaker at the Giant Ore Deposits workshop (Hobart) in June. He presented a review paper detailing structural and tectonic controls on the styles and size of Fe-oxide Cu-Au deposits. He was also the first author of a major paper detailing the geology of the Monakoff Cu-Au-U-Zn-Pb-REE-Ag deposit from the Eastern Succession (Queensland) (Davidson et al., 2002), and contributor to another paper (Skirrow et al., 2002) that presented a synthesis of the hydrothermal Fe-oxide Cu-Au geology of the Olympic sub-domain (SA). These papers appeared in a publication arising from the Australian Mineral Foundation Fe-oxide Cu-Au meeting (Perth) in December 2001.

Without doubt the major achievement of the year was the successful commencement of the Mount Woods Inlier project by Bryan Bowden. The project was delayed early in 2001 due to difficulties in attracting a suitable student, but the sponsor group waited patiently, with the result that the work commenced in September. Bryan won an overseas student IPRS scholarship in December, which will greatly assist project finances. The first field season was devoted to core logging at Prominent Hill (SA). In 2003, the project will extend to key outcrops and other mineralised sites in the inlier, with a view to developing a regionally applicable

robust paragenesis that will underpin a detailed program of geochronology. This program is intended to dovetail with similar Geoscience Australia-Primary Industries and Research (South Australia) research across the Olympic Sub-domain. It is hoped that the Fe-oxide Cu-Au research program will continue to grow in the coming year, with a new major research project in the development stage.

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

P McGoldrick, M Norman, L Danyushevsky, K Harris, F Della Pasqua

The ability to analyse small quantities of minerals and rocks for trace elements and stable and radiogenic isotopes is fundamental to much of the work being carried out in the CODES (see Projects 1.3 and 3.13). This project aims to optimise ICPMS techniques for the *in situ* analysis of sulfides.

An important focus in 2002 was making an assessment of the accuracy and precision of the laser ablation technique pioneered by Marc Norman and Darryl Clark at CODES two years ago. To do this new primary and secondary standards needed to be developed. Also a sulfide reference material, produced by the United States Geological Survey, was obtained and subjected to solution and LA-ICPMS analysis at CODES and CSL.

A paper by Marc Norman, Philip Robinson and Darryl Clark describing the synthetic glass used as the reference standard for all CODES LA-ICPMS work was accepted for publication in *Canadian Mineralogist*.

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

P McGoldrick, S Bull, R Large; Honours student J Stacpoole

This project has developed from work previously undertaken in Projects 4.1 and 4.5. It is aimed at recognising textural and isotopic (C and S) evidence for microbial

activity associated with the northern Australian Proterozoic SEDEX Zn-Pb deposits. The work aims to determine if microbes played an active or passive role in the origin of these important deposits.

An important part of John Stacpoole's Honours project (see also Project 4.1) at Bluebush (Qld) involved description and interpretation of ore textures. He described crinkly and laminated pyrite, and crinkly and nodular carbonate textures that are similar to those in other northern Australian Proterozoic Zn-Pb deposits. In the other deposits, these textures have been interpreted to be microbial trace fossils and a similar origin is proposed for the Bluebush textures.

Peter McGoldrick presented the results of a LA-ICPMS study of microbially-laminated pyrite from the hanging wall and footwall sequences at the Lady Loretta (Queensland) deposit during visits to the University of Texas (Austin) and University of Missouri (Columbia) in March.

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

R Large, S Bull, G Davidson,
W Herrmann, D Selley, A Crawford,
P McGoldrick, M Roach, R Berry;
W Goodfellow, J Peter, J Lydon, C van
Staal, S Piercey (GSC)

This year, groundwork was completed for a major new industry-funded collaborative project between CODES and GSC.

Detailed discussions were held with AMIRA, CAMIRO and a number of exploration companies with the aim of developing a global research project on stratiform sediment-hosted Zn-Pb-Ag deposits.

This project brings together two world-class research teams at the GSC and CODES, both with considerable experience in the study of basin-hosted ore deposits, in a collaboration with industry, to develop more efficient exploration strategies and outcomes for the discovery of BHT and SEDEX deposits. The project will focus on three major research and exploration objectives:

- To develop exploration criteria to discriminate sedimentary basins that host large and high-grade deposits (super giants) from those that are barren or host smaller and/or lower grade

deposits (basin architecture theme).

- To understand the geological controls and petrophysical, mineralogical and textural properties of high-grade metal zones within deposits (high-grade theme).
- To develop a series of geochemical, geological and geophysical vectors to ore, from basin scale down to drill-target scale (exploration vectors theme).

Research will be conducted in three world-class districts: Brooks Range (Alaska), Curnamona (NSW) and one other (to be selected by the final sponsor group), in conjunction with studies on two potential basins with no known deposits. Brooks Range and Curnamona have been selected as they contain the largest deposits (in terms of both grade and tonnes): Red Dog and Broken Hill. The two potential basins will be selected in consultation with the final sponsor group, but must include at least one Canadian basin and preferably also an Australian basin.

The research timetable is designed to provide annual deliverables that can be fed directly into on-going exploration for BHT and SEDEX ores. A compendium of reports will be completed in the final year of the project. These will include (1) criteria for productive basins, (2) exploration vectors for BHT and SEDEX, (3) controls on high-Ag grades, (4) synthesis of Red Dog, (5) petrophysical properties of SEDEX and BHT, (6) genetic and fluid flow models, (7) exploration criteria for BHT and SEDEX and (8) database of all geochemical and petrophysical measurements.



AMIRA P544 meeting held at CODES in December 2002 (left to right): Stuart Bull, Ross Andrew, Mawson Croaker, Ian Garsted, Rob Rutherford, Nicky Pollington, David Selley, Wolfgang Preiss, Peter McGoldrick, Galvin Dawson, Stuart Robinson and Wallace Mackay. (Project 4.6)

The research proposal will be circulated by AMIRA and CAMIRO in January 2003. Application will be made for ARC-Linkage and NSERC matching funding.

PhD STUDENTS IN PROGRAM 4

Stephen Bodon: The geodynamic evolution and genesis of the Cannington Broken Hill Type Ag-Zn-Pb Deposit, Mt Isa Inlier (Australia). PhD awarded December 2002.

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

Darryl Clark: Geology and genesis of the Mammoth Cu deposit, Mt Isa Inlier, Australia. Thesis under examination.

Mawson Croaker: The geology and genesis of the Neoproterozoic Cu-Co Nkana-Mindola deposit, Zambia.

Owen Hatton: Basin configuration, sedimentology and volcanology of the Toole Creek Volcanics, Mt Isa Inlier (northwest Queensland).

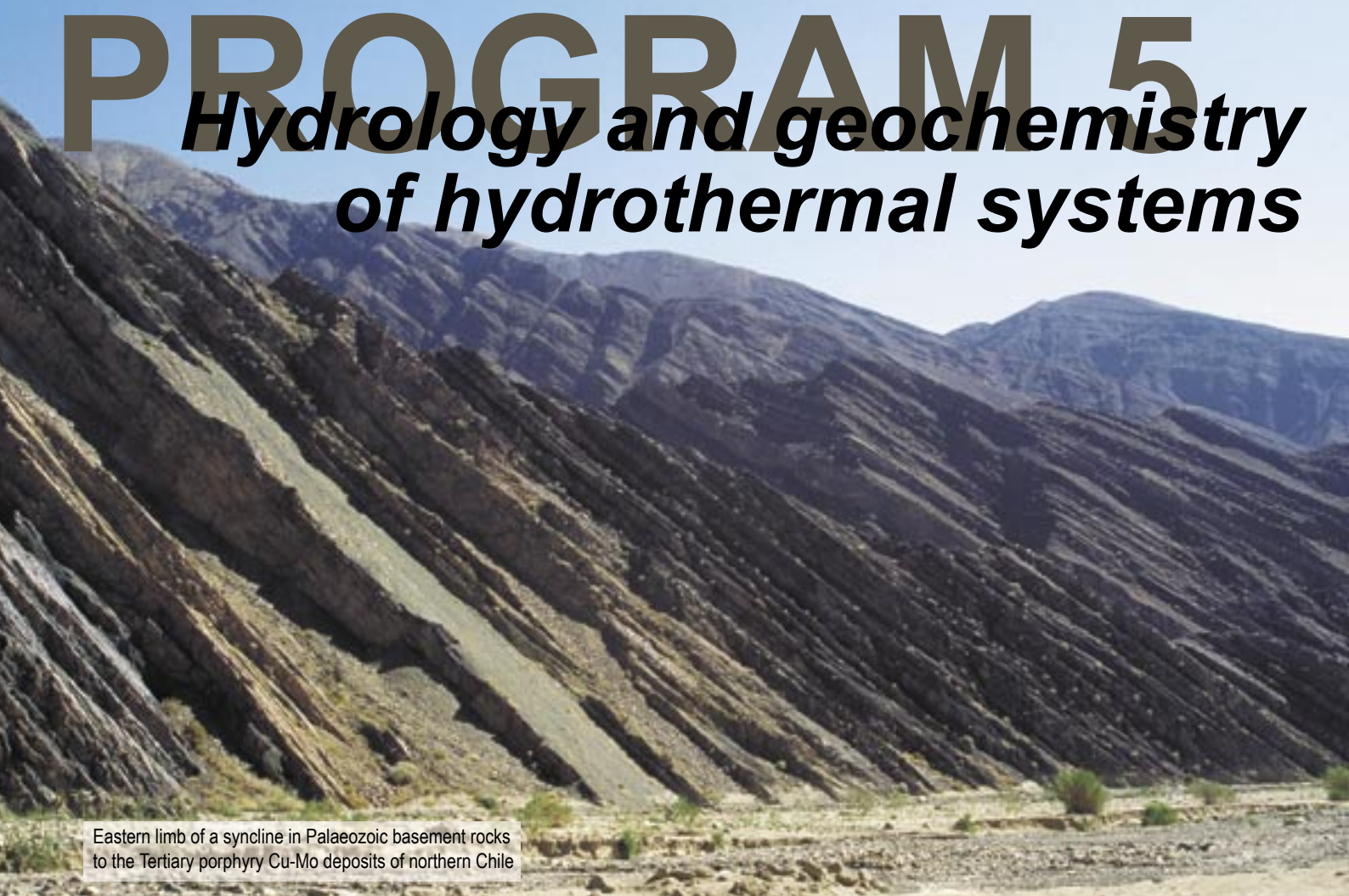
Wallace Mackay: The structure and sedimentology of the Curdimurka Subgroup, Willouran Range, South Australia.

Nicky Pollington: Sedimentology, mineralisation and geochemistry of the Konkola North Cu deposit, Zambia.

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

PROGRAM 5

Hydrology and geochemistry of hydrothermal systems



Eastern limb of a syncline in Palaeozoic basement rocks to the Tertiary porphyry Cu-Mo deposits of northern Chile

HIGHLIGHTS

Successful completion of AMIRA P511, with a two-day final sponsors meeting run in conjunction with the three-day international Giant Ore Deposits workshop. (Project 5.7)

Invited international conference presentations by Alan Wilson and David Cooke on the New South Wales alkalic porphyry province, and a one-week field excursion to the alkalic porphyry deposits of British Columbia (Canada). (Project 5.15)

Successful completion of AMIRA P552 'Fluid flow in Mount Isa Basin', with final research meetings for sponsor companies held in Kingston (Canada) and Canberra.

Publication of a manuscript in the *Society of Economic Geology Newsletter* summarising the characteristics and exploration significance of high-sulfidation epithermal mineralisation at Peak Hill (NSW) by Glen Masterman (Project 5.5).

Numerical simulations of fluid flow in modern and ancient submarine basins, and their relevance to the formation of VHMS bodies by Christian Schardt, with evaluation of the potential tonnage of metal resources that can be produced by individual convection cells (Project 5.8).

TEAM MEMBERS

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

PHD STUDENTS

Andrew Davies, James Cannell, Lee Evans, Peter Frikken, Ben Jones, Lyudmyla Koziy, Vanessa Lickfold, Glen Masterman, Andrew Rae, Christian Schardt, Alan Wilson and Rohan Wolfe

COLLABORATORS

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

CORE PROJECTS

5.1 Nature, timing and significance of fluid flow and fluid chemistry in Proterozoic sedimentary basins, and relationship to stratiform Zn-Pb-Ag ore formation.
5.3 Software development.
5.5 Numerical modelling of precious metal transport and deposition in high- and low-sulfidation epithermal and subaerial geothermal systems.
5.8 Controls on hydrothermal fluid migration by volcanic facies architecture: implications for massive sulfide deposit formation.



DAVID COOKE, LEADER OF PROGRAM 5

Program 5 focusses 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.



Program 5 team (left to right): Glen Masterman, Andrew Wurst, Alan Wilson, Ross Large, Anthony Harris, Lyudmyla Koziy, Andrew Rae, Peter Frikken, David Cooke, James Cannell, Ben Jones and Cari Deyell.

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

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

This collaborative project with Grant Garven (Johns HopkinsU) and Jianwen Yang (UWaterloo) continues to be a significant focus for our research in Program 5. It is pleasing to report that substantial research output, through publications and workshops, is now coming from this project.

Results of our numerical simulations of ore transport and deposition pertaining to the sediment-hosted Zn-Pb deposits of northern Australian have been summarised in a manuscript submitted to the convenors of the 2003 Geofluids Conference. This manuscript has been

accepted and will be published in the *Journal of Geochemical Exploration* in 2003. Our work has shown that the Century model, late diagenetic massive sulfide deposition involving metal-laden brines interacting with hydrocarbon reservoirs, has potential as an ore-forming process, providing that acidity can be buffered through carbonate dissolution.

Two papers were completed and submitted for publication from our fluid flow and Zn-Pb genesis research in the McArthur Basin (northern Australia). A study of the factors controlling fluid discharge and recharge in fault systems in sedimentary basins and implications for ore genesis, by Jianwen Yang, Ross Large and Stuart Bull was submitted to *Geofluids* in December. A second paper by the same authors on the importance of salinity in controlling convective fluid flow patterns in sedimentary basins was submitted to *Geology*.

David Cooke gave a one-day workshop on the stratiform Zn-Pb-Ag ore deposits of northern Australia at James Cook University in February. Ross

Large and Stuart Bull, in collaboration with Geological Survey of Canada and TeckCominco geologists, gave a two-day workshop on stratiform sediment-hosted Zn-Pb mineralisation at the PDAC conference in Toronto (Canada) in March 2003. Grant Garven visited CODES for one week in mid-2002 to teach a short course on reactive transport modelling.

Lyudmyla Koziy is undertaking a PhD study on multi-dimensional numerical simulations of ore-forming fluid transport in sedimentary basins, northern Australia. Lyudmyla's first year of PhD study was completed in 2002, with emphasis on gaining experience with the numerical methods and software relevant to her research. A decision will be made in early 2003 as to whether Lyudmyla will need to develop new software, or can use existing packages for her simulations of coupled fluid flow and chemical mass transfer.

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

J Yang, S Bull, R Large; P Southgate (AGSO); K Kyser (QueensU); S Golding (UQld); A Ord (CSIRO DEM)

This has been a collaborative project with Geoscience Australia, the University of Queensland, Queens University (Canada) and CSIRO DEM to investigate brine evolution in the Mount Isa and McArthur basins (northern Australia). Our contribution has been to undertake numerical simulations of fluid flow in the Lawn Hill Platform based on geological cross section models developed by Geoscience Australia from geological and geophysical datasets. Two final sponsors meetings were held for this project in 2002. The penultimate meeting was held at Queens University (Ontario) in October, and the final meeting at Geoscience Australia in Canberra in December.

This has been a particularly fruitful project which has benefited from multi-disciplinary collaborations utilising geology, geophysics, sequence stratigraphy, geochronology, sediment petrography, stable isotopes, organic maturation, fluid inclusions, coupled fluid flow and temperature numerical modelling. The major outcome is an integrated series of models to explain the history of fluid flow and Zn-Pb-Ag deposits in the northern Mount Isa basin. The study is being written up in a series of papers that will form a Special Issue of *Economic Geology*.

Project 5.3 CORE Software development

D Cooke, J Yang; PhD student L Koziy

With the departure of Jianwen Yang in June 2002 to take up a faculty position at Windsor (Ontario), most of the hydrological software development at CODES has ceased for the time being. Despite a global advertising campaign, no suitable candidate has been found as yet to replace Jianwen.

As part of her PhD study (project 5.1) Lyudmyla Koziy has commenced software development by writing finite-element code for 1-D simulations of vertical infiltration, and also developing

supplementary codes for *Fastflo* data file reformatting.

Project 5.5 CORE Numerical modelling of precious metal transport and deposition in high- and low-sulfidation epithermal and subaerial geothermal systems

D Cooke, JB Gemmell, C Deyell, A Rae; PhD students A Davies, G Masterman

Cari Deyell joined CODES as a Post-doctoral Fellow in the second half of 2002. During that period, she chemically modelled the conditions of ore formation in the Tambo high-sulfidation epithermal Au deposit (Chile), and presented these results at the October Geological Society of America meeting (Denver). Mineralogical and S-isotope studies of the Kelly epithermal vein (Philippines) also commenced, and preliminary results will be summarised in a paper submitted for the SGA meeting (Athens) in August, 2003. Work also commenced on developing a new template for describing epithermal mineral occurrences. A paper summarising this scheme and how it can be used in conjunction with the results of chemical modelling, to infer conditions of ore formation, was submitted to the Athens SGA meeting.

Andrew Rae completed his PhD study of the Palinpinon geothermal system (Philippines) in 2001. Some results of that study were presented at the New Zealand Geothermal Workshop in November 2002. A manuscript describing the spatial and temporal relationships of alteration assemblages at Palinpinon has been accepted for publication in the *SEG/Geochemical Society Gignenbach* memorial volume, scheduled for publication in 2003. A second manuscript summarising petrological and tectonic aspects of the Palinpinon geothermal field was submitted to the *Journal of Volcanology and Geothermal Research*. In 2003, more of the results from this study will be presented at the GAC-MAC meeting (Vancouver, Canada), and at the Goldschmidt conference (Japan).

Andrew Davies' PhD study of the Kelian deposit (Indonesia), also part of Project 3.11, was completed in December 2002. Chemical modelling of ore transport and deposition has

highlighted the processes most likely to have caused ore formation, based on the observed geological relationships, infill and alteration assemblages, and stable isotope geochemistry. A short paper summarising some of the results of this study was submitted to the SGA meeting (Athens).

Glen Masterman wrote a paper on the Peak Hill high-sulfidation epithermal Au deposit (NSW). This paper summarised the key characteristics of the Peak Hill system, their implications for fluid chemistry and ore genesis, and implications for exploration. It was published as the lead article in the *SEG Newsletter* in October 2002.

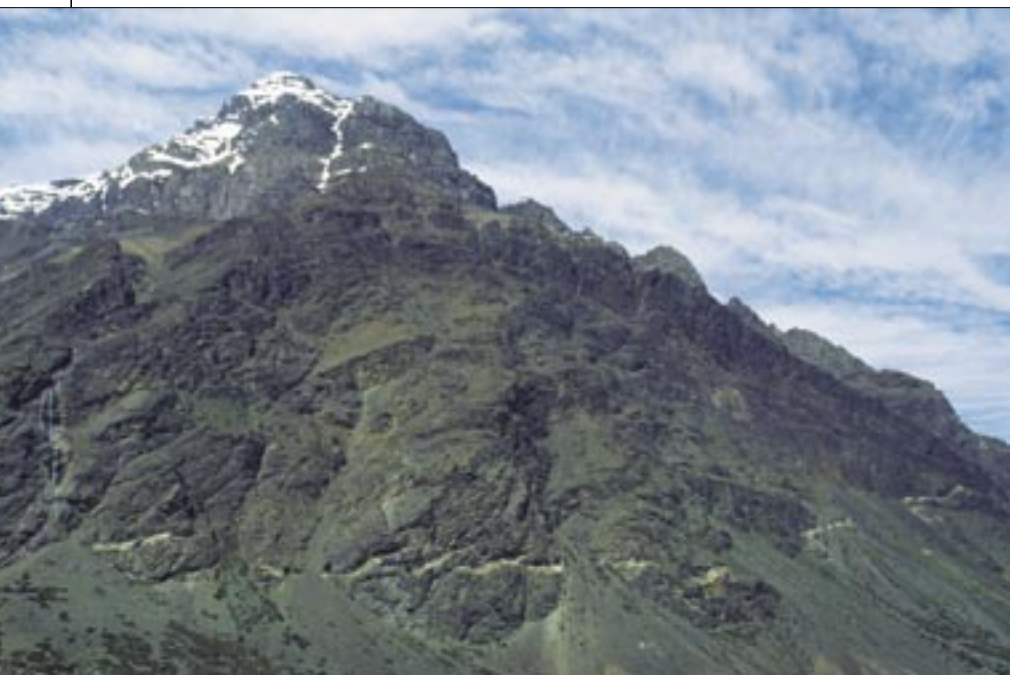
Project 5.7 Giant porphyry Cu deposits (AMIRA P511)

D Cooke; J Walshe (CSIRO DEM), P Hollings (LakeheadU); A Clark (QueensU); PhD students J Cannell, P Friksen, G Masterman

AMIRA P511 (Giant Ore Deposit Systems - GODS) has been an industry-funded project involving collaborative research between CSIRO Division of Exploration and Mining, CODES and the Centre for Global Metallogeny at the University of Western Australia. The project consists of three modules, which have focussed on Archean lode Au, Papua New Guinean Ag-Cu and Chilean porphyry Cu-Mo deposits. The Archean lode Au module commenced in 1998 and has been managed by CSIRO and CGM, with an emphasis on the Yilgarn Craton (WA). Research on the Papua New Guinean Ag-Cu deposits by the CSIRO DEM also commenced in 1998, and has focussed principally on the Porgera and Grasberg systems in the Papua New Guinea - Irian Jaya foldbelt. The porphyry Cu module was managed by CODES and CSIRO DEM and commenced in March 1999. Research has been conducted on the two major Cu-Mo provinces of Chile: the Eocene-Oligocene metallogenic belt of northern Chile and the Late Miocene-Pliocene belt of central Chile.

The major research themes for the Cu module were outlined in the original AMIRA proposal as follows:

- Magnetite distribution, mineral and wholerock geochemistry.
- Fluid inclusions and vein paragenesis.



Segmented syntectonic felsic dyke in Los Pelambres Formation, Rio Blanco district, central Chile. (Project 5.7)

- Sulfur isotope systematics.
- District-scale alteration.

These topics were chosen because they were considered to have the best potential to answer some of the key questions pertaining to giant porphyry ore formation. To place the information gathered from these detailed studies in context, additional research techniques that were undertaken include:

- Detailed core logging and sampling of selected deposits (El Teniente, Rosario and Rio Blanco in Chile).
- Geochemical sampling of fresh and altered volcanic rocks at the district and regional scales in central and northern Chile.
- Structural mapping and geochronology at Collahuasi in Chile.
- Re-interpretation of regional-scale geophysical and geological datasets.
- Radiogenic isotope studies.

A two-day industry sponsors field meeting for P511 was held in Kalgoorlie (WA) in February 2002. This meeting primarily focussed on the lode Au module, with progress reports on CODES research activities. The final industry sponsors meeting for P511 in Australia was held in Hobart (Tasmania) in June. This meeting was preceded by the Giant Ore Deposits workshop, where a series of invited international speakers described and compared six major classes

of hydrothermal ore deposits. A one-day meeting was held in Santiago, Chile, in early November, for the benefits of the South American sponsors unable to attend the final meeting in Australia. Sponsors were provided with an eight-volume final report that summarised the results of all modules of P511. CODES prepared two of these volumes (*Chile Atlas v.1 and v.2*), and contributed to the final synthesis document. Results of the porphyry module from P511 are now being written up for a Special Issue of *Economic Geology*, scheduled for publication in late 2004.

While P511 has formally completed its reporting requirements for industry, the three PhD studies of Chilean porphyry Cu-Mo deposits are on-going, and are scheduled for completion in 2003. With regards 2002 research activities, Glen Masterman, in his study of the Collahuasi district, completed his fluid inclusion, wholerock geochemical and radiogenic isotope studies, co-authored a manuscript for the Giant Ore Deposits workshop volume, and submitted a manuscript on the geochronology of Collahuasi porphyry district to *Economic Geology*. A key component of Glen's work has been the fluid inclusion-based modelling of uplift history at the Rosario deposit (Chile), which has been integrated into his structural analysis of the district-scale geological evolution.

James Cannell continued his research into the Teniente porphyry Cu-Mo system (Chile), through detailed alteration petrography and generation of cross sections detailing the alteration and veining styles and intensities for the different paragenetic stages. Fluid inclusion microthermometry and PIXE analyses were used to develop a fluid evolution model for this deposit, and further PIXE and LA-ICPMS samples were prepared to extend this work. Oxygen-D samples were submitted, and Sr-Nd-Pb radiogenic isotope data were received and interpreted. A Re-Os geochronological study is underway in collaboration with Holly Stein (Colorado State University). Two manuscripts were prepared for submission to *Economic Geology* in 2003. One summarises the structural and fluid evolution of the Teniente deposit (Chile). The other documents the new Re-Ps geochronology.

Peter Frikken has nearly completed his PhD study of the Rio Blanco porphyry Cu-Mo system (Chile). Efforts in the later half of 2002 focussed on thesis writing and synthesis of all geological and analytical data generated during this study. A manuscript summarising mineral and S isotope zonation in the Sur-Sur breccia, and their implications for ore formation, was submitted to *Economic Geology* in late 2002.

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

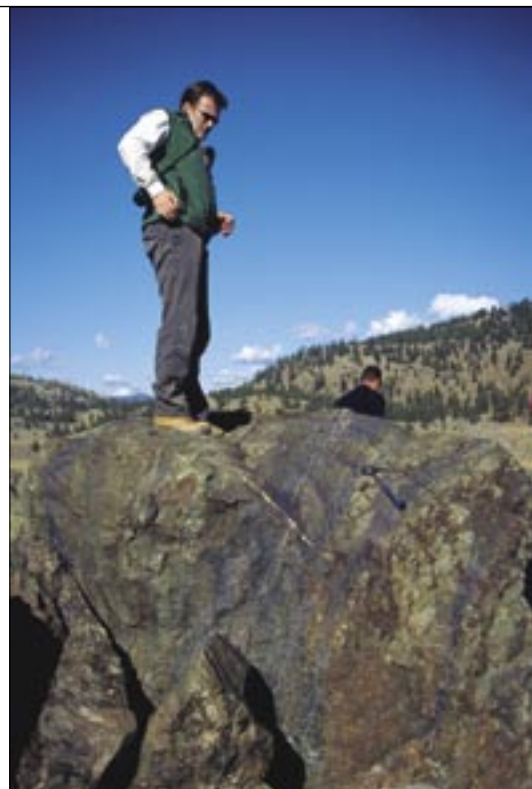
J Yang, R Large, J McPhie; G Garven
(Johns HopkinsU); PhD student C
Schardt

Christian Schardt's PhD study is the driving force behind Project 5.8. This year saw the completion of the numerical modelling of the Panorama massive sulfide district (WA). Results show that the constructed numerical model is capable of reproducing many features of this ancient hydrothermal system. In particular, it replicates the general alteration zonation, temperature distribution and discharge temperatures inferred from O-isotope studies. The main factors influencing fluid flow and discharge duration are rock and fault permeability, whereas a specific fault distribution was found to produce all orebodies recognised in the field. The model also predicts the formation of an additional orebody, potentially awaiting discovery. Heuristic calculations predict the formation of ore deposits in less than 5000 years from a conservative hydrothermal fluid (10 ppm base metals and 10% deposition efficiency). A genetic model was developed describing the evolution of the Panorama hydrothermal system and proposes distinct fluid flow pathways and suggests that massive sulfide deposits are likely to form in fresh volcanic rocks that have not experienced significant alteration or compaction. Based on mass calculations it was concluded that the Panorama district did not have the conditions to produce a world-class deposit (≥ 2 Mt Cu; ≥ 1.7 Mt Zn). This work has been synthesised into a paper to be submitted to *Economic Geology* in 2003. It was also summarised in an abstract presented at the Goldschmidt conference (Switzerland) 2002.

As a step towards a better understanding of modern submarine hydrothermal systems, a model of convection in the Lau basin (Papua New Guinea) was developed to simulate heat and fluid flow in a modern submarine setting. Results indicate that heat and fluid flow pathways are governed by buoyancy-driven fluid flow with fluids recharging

Glen Masterman atop a massive magnetite-apatite vein, Iron Mask Batholith, British Columbia, Canada. (Project 5.15)

at topographic lows and discharging at elevated topographic locations. This is in agreement with field observations from the Lau basin. Discharge temperatures are high (350°–400°C) as observed by recent studies in the Lau basin. Many features of the Panorama model have been confirmed through this work (i.e. permeability control), however other features (e.g. porosity) do not influence the hydrothermal system. This is attributed to the scale, geometry and scope of the model (an aspect judged to be of great significance when constructing and using numerical models). Also the magmatic-hydrothermal interface has been investigated (thermal cracking of rocks). The results predict local changes but not as significant as argued by other researchers. A more 'realistic' Lau basin model is currently being developed (disrupted stratigraphy, real topography) to investigate the fluid flow and potential for orebody formation under these conditions. To gain a better perspective on modern seafloor hydrothermal systems, Christian participated in the last voyage of the *RV Franklin* (March–April 2002) from Rabaul (Papua New Guinea) to the Solomon Islands and to Sydney. This cruise discovered three new hydrothermally active areas and took valuable samples from deep-sea trenches and other locations.



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

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

This project is a collaboration between programs 4 and 5, and is outlined in detail in Project 4.6. Highlights included the mid-year sponsors field meeting (SA), and the October sponsors meeting (Colorado). Research has now advanced to the point where chemical modelling can now be used to test hypotheses of ore formation. The final sponsors meeting is scheduled for mid-2003.

Project 5.15 Fluid chemistry in porphyry Cu- Au-Mo deposits

D Cooke, A Harris; PhD students B Jones, V Lickfold, A Wilson, R Wolfe

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

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

Anthony Harris joined CODES on a short-term contract as a joint Program 1–Program 5 Research Fellow in late 2002. His research activities focused on extending the results of his PhD study at the University of Queensland, by investigating the magmatic-hydrothermal transition as preserved in rocks from Bajo de la Alumbrera (northwest Argentina). This work has included petrographic descriptions of melt inclusions and co-existing fluid inclusions found in quartz phenocrysts from different porphyritic intrusions. He also investigated the longevity of hydrothermal alteration in porphyry Cu deposits using relatively new techniques such as (U-Th)/He zircon geochronology (via a collaboration with Yale University). This research is endeavoring to constrain the processes (e.g. tectonic uplift) that influence the resultant hydrothermal alteration and potentially mineralisation, in these magmatic-hydrothermal ore deposits.

Alan Wilson is studying the four porphyry Au-Cu deposits of the Cadia district (NSW). During 2002, research focused on the genetic aspects of the Cadia porphyry Au-Cu deposits. Work completed included detailed petrography, stable- (S, O, H) and radiogenic- (Pb, Sm-Nd) isotope studies, fluid inclusion analysis (microthermometry, laser Raman analysis), wholerock geochemistry and U-Pb zircon dating (SHRIMP). Available results indicate that mineralisation is related to high-temperature, highly saline fluids that have not undergone phase separation before metal deposition. A zoned alteration pattern, from a calc-potassic core through two assemblages of propylitic alteration to outer sodic alteration, appears typical of the Cadia porphyry deposits. The characteristics and fluid chemistry of the Ridgeway deposit (NSW) were summarised in a paper scheduled for publication in *Economic Geology* in 2003.

Alan Wilson organised and co-ordinated a one-week field excursion to the alkalic porphyry Cu-Au deposits

(Canada), for CODES staff and students and Newcrest geologists in October 2002. This field excursion provided an excellent perspective on the characteristics of the world's best-known alkalic porphyry province, which will prove very useful in comparisons with the alkalic porphyry province of New South Wales. Alan was invited by the Mineral Explorers Group of Vancouver to give a keynote presentation on the New South Wales porphyry province in October 2002. David Cooke was invited to give a presentation on the characteristics of the New South Wales alkalic deposits at the Australasian Institute of Mining and Metallurgy meeting (Auckland) in September 2002.

Vanessa Lickfold's PhD study of volatile evolution at Goonumbla (NSW) was completed in March 2002. Her major findings were that the four deposits had a common sequence of intrusive activity and mineralisation, even though each was a separate magmatic-hydrothermal centre. A paper was accepted for publication in *Economic Geology* summarising the intrusive history and fluid chemistry at the four porphyry Cu-Au deposits. A second manuscript is in preparation for submission to a Special Issue of the *Australian Journal of Earth Sciences*, summarising the igneous geochemistry and isotope systematics of the intrusions. A short paper summarising the characteristics of comb quartz layers and their melt inclusions at Goonumbla and Cadia was written in collaboration with Alan Wilson, Anthony Harris and David Cooke and submitted to the SGA meeting (Athens) in August, 2003.

Rohan Wolfe's PhD investigation into the Dinkidi porphyry Cu-Au deposit (Philippines) was completed in December 2001. An abstract summarising some of the key findings of this work was presented at the Giant Ore Deposits workshop in June 2002.

Ben Jones is undertaking a PhD study of the Antapaccay porphyry Cu-Au deposit (Peru). This project aims to investigate the genesis of Antapaccay deposit and improve our understanding of the relationship between mineralisation and the evolution of magmatic-hydrothermal systems. A particular focus will be a combined fluid and melt inclusion study to investigate the link between the evolution of the magmatic system and generation of hydrothermal fluids and to test if there

is a change in the fertility of the melt with time. Work completed to date has included detailed petrography, wholerock geochemistry, PIMA and S-isotope analyses. Collaborative work in progress includes LA-ICPMS U/Pb geochronology with the Ore Genesis Group (RSES ANU) to determine the ages of individual magmatic events and Pb, Sr and Nd radiogenic isotope determinations with John Foden at the Department of Geology and Geophysics (UAdelaide) to investigate the source of magma. Compilation of wholerock geochemical data of igneous rocks related to porphyry Cu deposits globally is also in progress. 'Los Porfidos de Cu-Au de Antapaccay en el Distrito Mineralizado de Tintaya, Peru' by Jorge Fierro, Ben Jones and Gary Lenzi was presented at the XI Congreso Peruano de Geologia (Lima) in September 2002.

Project 5.16 Fluid mixing in hydrothermal systems

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

This three-year project, funded by an ARC Discovery grant, commenced in 2002. It is being managed by Nick Oliver and Peter Williams at James Cook University. Post-doctoral Research Fellow (Bin Fu) at James Cook University is being partly funded by this project. Research activities have focussed on selection and initial analysis of fluid inclusions from the Cloncurry district Fe-oxide Cu-Au deposits (northern Australia) to test fluid mixing hypotheses. A paper summarising the preliminary findings was submitted to the SGA conference (Athens).

Project 5.17 Hydrology and chemistry of mine drainage waters

D Cooke, G Davidson, J Reid, S Gilbert; P Hollings (LakeheadU); Students L Evans (PhD), L Wallace (Hons)

CODES and SES have been supervising Honours studies of acid drainage for several years. Although not core business of the SRC, these projects incorporate the fundamental themes of Program 5 research (fluid chemistry and fluid flow).

In 2002, Lee Evans commenced his PhD 'Groundwaters in wet, temperate, sulfide mining districts: delineation of modern fluid flow and predictive modeling to improve management after mine closure (Rosebery, Tasmania)'. The first year involved collation and spatial representation of existing physical, geological and environmental data. Several piezometers were installed and field work included a regional drillhole survey involving hydraulic testing, aqueous geochemistry sampling and piezometric height observations.

Sarah Gilbert submitted a manuscript to *Environmental Geology* summarising the results of column leach experiments designed to test the stability of hardpan layers in the Renison Bell tailings dam (western Tasmania) under a variety of conditions likely to be encountered after mine closure. This manuscript was accepted for publication in mid-2003.

Luke Wallace undertook an Honours thesis studying the constructed wetlands filter system at the Rosebery mine (western Tasmania). This project was completed in December 2002, and included a detailed appraisal of the chemistry and hydrology of drainage waters passing through the wetlands, numerical simulations of absorption processes and how they affect heavy metal mobility within the wetlands.

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

D Cooke, JB Gemmell, C Deyell, R Sharpe; N White (consultant), J Reid, M Roach (SES UTas)

In late 2002, we sent out a new AMIRA project proposal (P765) to potential industry sponsors. If this project is successful in attracting funding, our aim will be to improve exploration success in porphyry-epithermal districts. We will develop and test criteria that can be used by explorers to indicate prospective environments, discriminate between mineralisation styles, and vector towards ore zones – be they porphyry, epithermal, and/or other peripheral styles. This project will be a collaboration between Program 3 (Project 3.14) and Program 5, and we hope to commence research in late 2003, contingent on funding.



Pierina high-sulfidation Au deposit, Peru. (Project 5.15)

PHD PROJECTS IN PROGRAM 5

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

Andrew Davies: Geology and genesis of the Kelian Au deposit, east Kalimantan, Indonesia. Submitted January 2003.

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

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

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

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

Vanessa Lickfold: The intrusive history and volatile evolution of the Endeavour porphyry Cu-Au deposits, Goonumbla district, New South Wales. PhD awarded December 2002.

Glen Masterman: Genetic relationships between the Rosario porphyry Cu-Mo

deposits and the high-sulfidation Cu-Au veins, Collahuasi district, Chile.

Andrew Rae: Alteration systematics and mineralising potential of the Palinpinon geothermal field, Negros Island, Philippines. PhD awarded August 2002.

Christian Schardt: Controls on hydrothermal fluid migration by volcanic facies architecture: Implications for massive sulfide deposit formation.

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

Rohan Wolfe: The Dinkidi Cu-Au porphyry: Geology of the Didipio region and paragenesis of the Dinkidi Cu-Au porphyry deposit. PhD awarded August 2002.

Giant Ore Deposits workshop

Characteristics, genesis and exploration



GODs workshop participants

The third Giant Ore Deposits (GODs) workshop was hosted by CODES in Hobart in June 2002. This was the first time that the GODs workshop had been held outside of Canada and it was a tremendous success. The meeting attracted strong interest with 164 delegates attending the three-day workshop. Delegates included academics, mining and exploration geologists, geological survey geologists, and postgraduate students from Australia, Canada, China, Chile, Fiji, Ghana, India, the Philippines, Russia, South Africa and the United States.

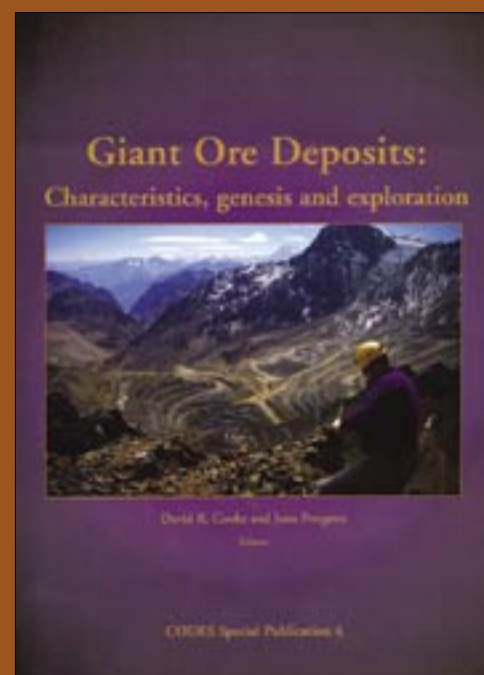
Twelve ore deposit specialists, from the minerals industry and academia, gave invited keynote presentations. These one-hour presentations focussed on the characteristics of six major classes of hydrothermal ore deposits, giant ore deposit case studies, and the exploration history that led to their discovery.

Each half-day session concluded with a forum on exploration strategies for the future discovery of giant ore deposits. These forums included informal presentations by industry geologists on recent discoveries, followed by animated group discussions on the requirements for finding new giant ore deposits and our ability to discriminate giant ore deposits from smaller ore deposits. Although participants often failed to agree on ore deposit interpretations or models, these open discussions were thought provoking and generated ideas, to help in the search for future deposits.

Following the workshop, a two-day fieldtrip to western Tasmania was held in conjunction with the G3 Masters course 'Ore deposits and exploration strategies'. The trip was lead by Bruce Gemmell, Cathryn Gifkins and Andrew Tunks, and included visits to the large Cambrian Mount Lyell and Rosebery VHMS deposits, the Cambrian volcanic-hosted Henty Au deposit, and the Devonian Rension Sn deposit.

In conjunction with the GODs workshop, CODES produced a special publication, 'Giant Ore Deposits: Characteristics, genesis and exploration' (CODES Special Publication 4) edited by David Cooke and June Pongratz,

which contains 12 peer-reviewed papers. Eight of the papers summarise the characteristics of giant deposits: porphyry Cu (Camus), Fe-oxide Cu-Au (Haynes, Davidson), sediment-hosted Zn-Pb (Large et al.), Carlin-type Au (Thompson), magmatic Ni-Cu (Naldrett), lateritic Ni (Elias) and Witwatersrand Au (Frimmel and Minter). The other four papers describe the history of discovery of particular giant ore deposits (Collahuasi – Moore and Masterman; Red Dog – Jennings and King; Goldstrike – Bettles; Witwatersrand – Fox). To obtain a copy of the CODES special publication contact the CODES Publications Officer.



EDUCATION



Honours class of 2002

OBJECTIVES

- To produce outstanding postgraduates who are able to identify and pursue new fundamental research initiatives and lead industry in exploring for new mineral resources.
- To develop an internationally recognised, high-quality postgraduate and postdoctoral program, which involves the integration of ore deposit and mineral province studies, especially concentrating on geological processes, geological environments and ore formation.
- To enhance the career opportunities of postdoctoral research fellows by actively involving them in the planning, supervision and management of CODES research.

POSTDOCTORAL AND RESEARCH FELLOWS

During 2002, the number of Postdoctoral and Research Fellows at CODES increased to 15 during 2002, with the arrival of Cari Deyell (from UBC, Canada) and Anthony Harris (UQld), and the departure of Peter Hollings for a lecturing position at Lakehead University in Ontario. Both Cari and Anthony are concentrating on porphyry Cu-style mineralisation and are working with Programs 3 and 5 (Deyell) and Program 1 (Harris). Mike Solomon continues as a Research Associate actively investigating VHMS systems. He has developed strong links with Portuguese and Spanish groups studying the Iberian Pyrite Belt. An early result of this collaboration was the commencement of a Portuguese student, Carlos Rosa, in our PhD program (see below).

- Postdoctoral Fellows continue to be the main drivers of much of CODES industry-related research, with Rob Scott, Stu Bull and Dave Selley working on the Zambian copper belt project, Khin Zaw on his AMIRA-supported

China project, and Wally Herrmann, Robina Sharpe and Rob Scott on the AMIRA epithermal project.

- Volcanology Postdoctoral Research Fellow Sharon Allen is now on the editorial boards of the *Journal of Volcanology and Geothermal Research* and *Australian Journal of Earth Sciences*.
- Leonid Danyushevsky and Dima Kamenetsky represented CODES at the Third International Melt Inclusions Symposium in Italy, and Leonid convened a melt inclusions session at the American Geophysical Union meeting in Wellington (NZ).
- Cathryn Gifkins and Wally Herrmann have made significant progress on the new CODES-sponsored book 'Altered Volcanic Rocks: a guide to description and interpretation'.
- Fernando della Pasqua balanced his duties as part-time Curator with research on arc volcanics in Vanuatu, and analyst to several other CODES projects.
- During 2002, CODES Postdoctoral and Research Fellows authored or co-authored 18 papers in peer-reviewed journals.

PHD PROGRAM

Following the submission of 13 PhD theses during 2001–02, and despite the arrival of four new PhD students (Singoyi Blackwell, Maya Kamenetsky, Carlos Rosa, Bryan Bowden), the number of CODES PhD candidates dropped slightly to 28 students at the end of 2002. This reflects the downturn in the minerals industry since early 2001. The new PhD students are from Zambia, Russia, Portugal and the UK respectively.

Current and recently completed (2002) CODES PhD students authored or co-authored six papers during 2002, with contributions from Alan Wilson (2), Glen Masterman (2), Oliver Holm and Paul Davidson.

An on-going problem at CODES has been that many graduating PhD students move immediately into employment, and have little or no time to publish the results of their PhD studies. To address this problem, CODES initiated 'writing-up scholarships' to encourage present and recently completed PhD students to publish their work. This has been extremely successful. Twenty-five papers were submitted and are presently under review in international journals. We look forward to a greatly enhanced PhD publication list in the next Annual Report.

MASTERS PROGRAM

2002 saw strong growth in the G3 collaborative Masters program, with the enrolment of ten new students into either the course-work Master of Economic Geology or the more research-focussed Master of Exploration Geoscience. The strong growth in student numbers during the year shows that the minerals industry still supports postgraduate training of its employees. With the gradual turn-around in the Australian mining and exploration sector over the previous 12 months and improved precious metal prices, it is hoped this growth will continue throughout 2003. It was also pleasing to note the enrolment of two new international students and increased enquiries from potential overseas Masters candidates.

Another highlight of the year was the submission of several theses for examination. Excellent research on a variety of deposits was completed by Mitchell Bland, Mike Buchanan, Paul

Cromie, Allan Kneeshaw, Ian Laurent, Dan Olberg and Phillip Tornatora. In addition, Paul Cromie has been awarded a postgraduate scholarship to commence a PhD in 2003.

Two successful short courses were run in 2002. The first, 'Ore deposits and exploration strategies', was held in conjunction with the Giant Ore Deposits workshop. Many workshop participants stayed on to complete a field trip to the west coast of Tasmania. The 'Ore Deposit Models' course and workshop attracted quality international experts, including Francisco Camus (CODELCO), Keith Bettles (Barrick), Mick Elias (CSA and Associates), Tony Rovira (Jubilee Mines), John Thompson (Teck Cominco), Richard Moore (Falconbridge), Tony Belperio (Minotaur), Scott Jennings (Teck Cominco), Nick Fox (AngloGold), Steve Walters (Geodiscovery), Peter Muhling (CSA and Associates), Greg Hall (Placer), Douglas Haynes (Consultant) and Graeme Broadbent (Rio Tinto). There was also a strong contingent of senior academics including David Groves (UWA), Tony Naldrett (UToronto), Lawrie Minter (UCapetown), Tommy Thompson (Colorado) and Tim Baker (JCU).

In November, Jocelyn McPhie ran the 'Volcanology and Alteration of Mineralised Terrains' field-based course, which commenced in the North Island of New Zealand and concluded on the west coast of Tasmania. This short course again proved popular, drawing a large number of industry personnel as well as Masters students. Stuart Simmons from the University of Auckland provided the group with some insight into the chemical processes occurring in active geothermal areas.

HONOURS PROGRAM

CODES staff are actively involved in the School of Earth Sciences Honours program. In 2002, 23 Honours students completed or partially completed their Honours degrees in the School of Earth Sciences. This included six mid-year students, one part-time completion, and one graduate diploma. Of these, 12 students undertook economic geology projects, and 20 students were supervised by CODES staff members. Four of the projects had field sites outside Tasmania; in exotic locations, such as central, eastern

CODES PhD students who submitted or graduated in 2002 and where they are now ...

Steve Bodon – Consultant, South Africa
Darryl Clarke – AngloGold, Sunrise Dam, Western Australia
Andrew Davies – AngloGold Peru
Oliver Holm – Geoscience Australia, Canberra
Sarah Jones – Geological Survey of Western Australia, Kalgoorlie
Vanessa Lickfold – Kumba Resources, South Africa
Karin Orth – CODES
Andrew Rae – CODES Program 3
David Rawlings – Northern Territory Geological Survey, Darwin
Rohan Wolfe – Ivanhoe Mines, Mongolia



Participants take a break at Sheffield during the combined Giant Ore Deposits workshop and Masters short course field trip to western Tasmania.

and northwestern Queensland, New Zealand, and the Southern Ocean ice shelves.

Marking requirements for five 2002 Honours students were incomplete at the time of writing. However, the high standard of these studies is indicated by eight first class Honours results within the group, and all other results in the 2A class.

SEG STUDENT CHAPTER

The University of Tasmania's SEG Student Chapter completed a very successful and busy 2002, with active participation by the executive committee and all members. The assistance and guidance of CODES Director, Ross Large, during the year was greatly appreciated. Highlights for 2002 included:

- The organisation of social and student activities at the Giant Ore Deposits workshop held in Hobart in June.
- A field trip to the Mount Isa region in northern Queensland in October.
- Financially assisting an academic research geologist from Poland to

attend the Mount Isa field trip.

- The presentation of special lectures at James Cook University and CODES.
- Informal weekly seminars by students and academics at CODES.
- A social cricket match at the beginning of the year.

In 2002, the Giant Ore Deposits workshop was the main fund raising activity for the Student Chapter. The Student Chapter hosted a wine tasting for all workshop participants, organised the workshop dinner, and bottled a commemorative wine series (GODs 2002 porphyry shiraz, Fe-oxide shiraz, SEDEX shiraz, Ni-laterite shiraz, Carlin chardonnay and Wits chardonnay) for sales at the conference. Many postgraduate students also presented posters at the workshop.

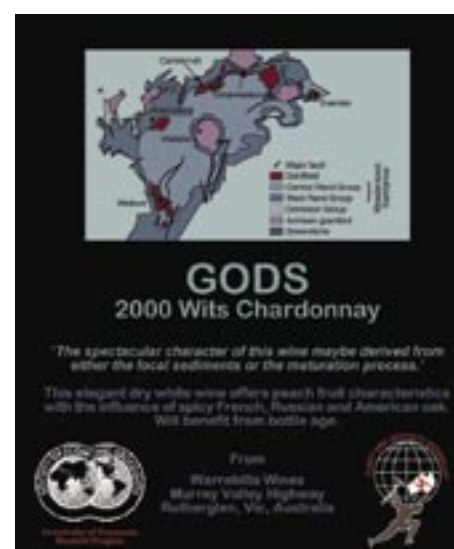
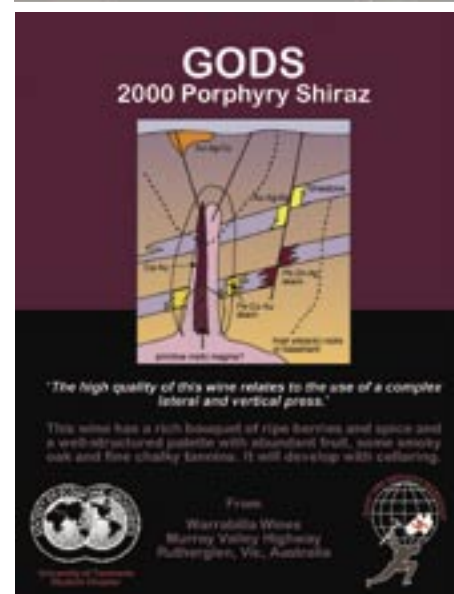
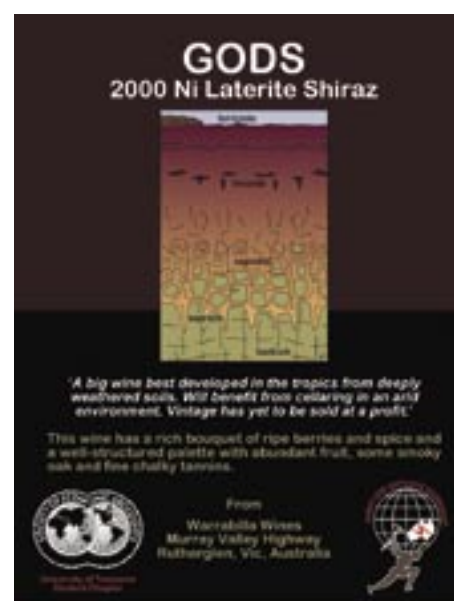
In October the Student Chapter held the '2002 road trip – Charters Towers to Mount Isa'. The ten-day field trip visited seven base-metal and Au deposits in the complex early Proterozoic to mid-Phanerozoic sequences of northern Queensland. Trip participants recognised the huge potential within this region for

both small and large discoveries, as well as the need for ongoing research to answer many fundamental question related to ore genesis at the various sites.

The success of the trip relied on the support of the hosting companies and personnel. The Student Chapter thanks Shaun Schneider and Veronica Brown (Newmont Pajingo), Joshua Byrant (MIM Ernest Henry), David Sleigh, Colin Sinclair and Stuart Mathews (Selywn Mining), Stephen Guy (BHP Billiton Cannington), Damien Keys (MIM Mount Isa), Alan Blackburn and Phil Agnew (Placer Dome Osborne), Paul Habermann (Pasminco Century), and Matt Brown and Nick Oliver (JCU). The time, support and excellent tours given by the company representatives was greatly appreciated by all participants. We also thank the Society of Economic Geologists and the Geological Society of Australia Tasmania Division for granting special travel allowances to assist with travel expenses.

The Student Chapter provided financial assistance for Professor Zbigniew Sawlowicz (Head of Institute for Geological Sciences, Jagiellonian

University, Krakow, Poland) to attend the trip. As well as attending the field trip, Zbigniew gave special presentations at James Cook University (Townsville) and at CODES on the Kuperschiefer Cu and Ag deposits of Poland. Zbigniew and the Student Chapter are now collaborating in the organisation of a 2003 field trip to Poland in conjunction with the Student Chapter at the Colorado School of Mines (USA) and the Institute for Geological Sciences at Jagiellonian University.



SEG Student Chapter commemorative wine labels for the Giant Ore Deposits workshop.

INDUSTRY LINKS

Delamerian folding of the Burra Group, Willouran Range, South Australia.

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.

STRATEGY

There are five elements in our industry links strategy:

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

CODES CORPORATE SPONSORS

BHP Billiton
Newcrest
AurionGold
Barrick
MIM Exploration
Anglo American
Rio Tinto
WMC
Newmont
AngloGold

CORPORATE SPONSORS PROGRAM

There were several changes in corporate sponsors in 2002. AurionGold ceased to be a sponsor after being taken over by Placer Dome. Barrick took over the previous sponsorship held by Homestake, and Newmont and AngloGold joined as new sponsors. Sponsorship funds are vitally important in maintaining critical mass at CODES and to ensure the development of strategic and applied research projects that are relevant to industry.

AMIRA RESEARCH PROJECTS

The majority of our large multi-disciplinary applied research projects involve collaboration with a number of mining and exploration companies under the umbrella of AMIRA. The association with AMIRA has been very beneficial to both parties and fostered greater links with both Australian and international companies.

Four of the five current AMIRA projects were completed during the year:

- P588 (Project 3.9) – ‘Epithermal Au-Ag deposits: Geological, geochemical and isotopic vectors to target major deposits’ led by Bruce Gemmell had its final research meeting with the industry sponsor group in Hobart in December.

At the completion of the meeting AMIRA Research Co-ordinator Alan Goode congratulated the research team for an outstanding project in terms of data acquisition, documentation, presentation and analysis. The project was also completed on time and within budget.

- P511 (Project 5.7) – ‘Giant porphyry copper deposits’, led by David Cooke and John Walshe (CSIRO) conducted final research meetings in Hobart in June and in Santiago (Chile) in November. Sponsors were provided with a two volume final report covering many aspects of the character and genesis of the giant porphyry Cu deposits of the Chilean Andes. The results of research by the CODES team is currently being written-up for a Special Issue of *Economic Geology*.
- P552 (Project 5.2) – ‘Fluid flow modelling in the Mount Isa and McArthur Basins’ led by Peter Southgate (GA), Jianwen Yang, Kurt Kyser (QueensU), Sue Golding (UQld) and Alison Ord (CSIRO), had final research meetings in Kingston (Canada) and Canberra. This very innovative project combined expertise on basin analysis and fluid modelling from a diverse international group to develop techniques and conclusions relevant to Zn and U explorers.
- P603 (Project 1.6) – ‘Tectonics and metallogenesis of south China’, led by Khin Zaw, had its final meeting in Hobart in December. This project has developed a powerful GIS data framework for southern China, which enables stratigraphic correlations, a synthesis of fault histories and metallogenic/tectonic relationships. This will be an invaluable tool for mineral explorers in the region.

The on-going AMIRA P544 (Project 4.6) led by Peter McGoldrick and Murray Hitzman (CSM) is focussed on Proterozoic sediment-hosted Cu deposits in Zambia and Australia. The project held successful research meetings with sponsor companies in Adelaide (May), Denver (USA, November) and Hobart (December). This project is on-track and due for completion in July 2003.

A dramatic drop in CODES AMIRA and ARC-Linkage funding is projected for 2003 due the successful completion of all





Progress meeting of the LA-ICPMS S-trace element project (left to right): Ross Large, Garry Davidson, Fernando della Pasqua, Peter McGoldrick, Ian Tedder, Phil Tornatora, Nigel Brand, Scott Halley, Nigel Radford, Andrew Rae, Roric Smith and John Hammond.

current projects over the 2002/03 period. This has stimulated a major effort by our research team to develop new projects for funding by AMIRA and ARC. Two major new projects, one on porphyry Cu and epithermal Au systems, and the other on BHT and Sedex Zn-Pb-Ag systems, were discussed and developed in close collaboration with potential industry partners during the year. Meetings were held with exploration companies in Perth, Sydney, Brisbane, London, Vancouver, Denver and Santiago to refine the proposals which were submitted to AMIRA in December. An AMIRA research proposal on the application of melt inclusion research to Ni-PGE exploration was developed and will be submitted to AMIRA in early 2003.

ARC LINKAGE PROJECTS

During 2002, CODES researchers held nine ARC-Linkage grants. Three of these grants are linked to major AMIRA projects discussed above (Projects 3.9, 4.6, 5.7),

one is for an industry collaborative project (Project 3.12), and the remaining five are industry-supported PhD scholarships. A full list of grants is given in an appendix, and progress on each project is discussed under the relevant program section.

INDUSTRY LINKED STUDENT PROJECTS

Over 60% of our postgraduate students are working on projects that involve industry support and/or collaboration. This support varies from providing access and in-kind logistics assistance to full scholarship support.

The Tasmanian Government Mining Scholarship Scheme supports PhD and Honours students to undertake research in collaboration with industry partners, which is directly relevant to the Tasmanian mining industry. In 2002, one PhD student and three Honours students were funded by this scheme. A new PhD project on the geology and genesis of the Mount Lyell deposit will be funded

from the Tasmanian Government Mining Scholarship scheme to start in early 2003.

SHORT COURSES FOR INDUSTRY AND ACADEME

CODES holds a series of short courses and workshops each year in order to increase our national and international profile and transfer recent research results to fellow academics, government scientists and members of the exploration and mining industry.

In 2002, the following courses were held and involved the participation of CODES staff and invited national and international speakers:

- Exploration skills mapping (Leader: Andrew Tunks), February 2002.
- Stratiform Zn-Pb-Ag deposits. Joint PDAC-SEG workshop. (Leaders: Ross Large and Wayne Goodfellow), March 2002.
- Ore deposit models for mineral exploration (Leader: Ross Large) May 2002.



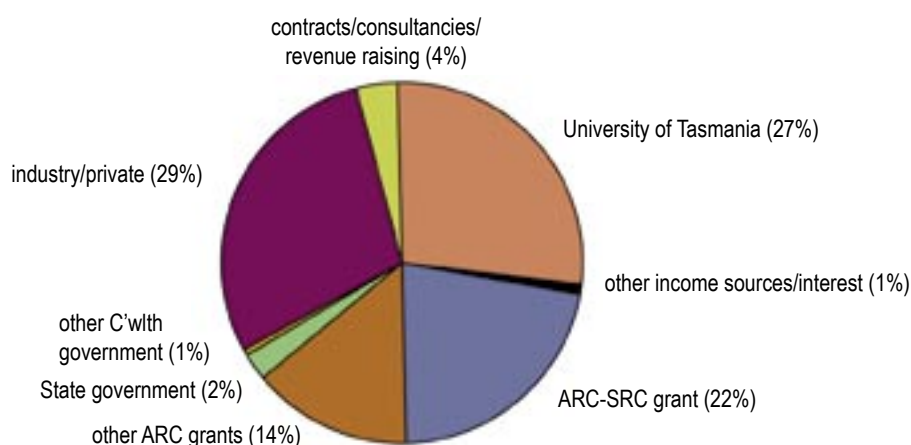
Isotope devotees gather around the stable isotope mass spectrometer in expectation of another data point (left to right): David Green and Geoff Green (MRT), Garry Davidson, Wally Herrmann and Ross Large. (Project 3.12)

- Giant Ore Deposits workshop (Leader: David Cooke) June 2002.
- Ore deposit models and exploration strategies (Leader: Bruce Gemmell) July 2002.
- Volcanology and mineralisation in volcanic terrains (Leaders Jocelyn McPhie and Stuart Simmons) November, 2002.
- Stratiform Zn-Pb-Ag deposits of Northern Australia (Leader: David Cooke) February 2002.



Progress meeting of P544 in Golden (USA) (left to right): Brock Riedell (BHP Billiton), Ricardo Presnell (Rio Tinto), Murray Hitzman (CSM), Dave Broughton (CSM), Ross Large, Will Wilkinson (Phelps Dodge), Noelle Shriver (INCO), Graham Begg, Cam Allen (Teck Cominco), Dave Kelley (WMC), Peter McGoldrick, Jim Pickell (Anglo American), Dave Selley, Nicky Pollington, Alan Goode (AMIRA) and Miguel Miranda (MIM), and mule. (Project 4.6)

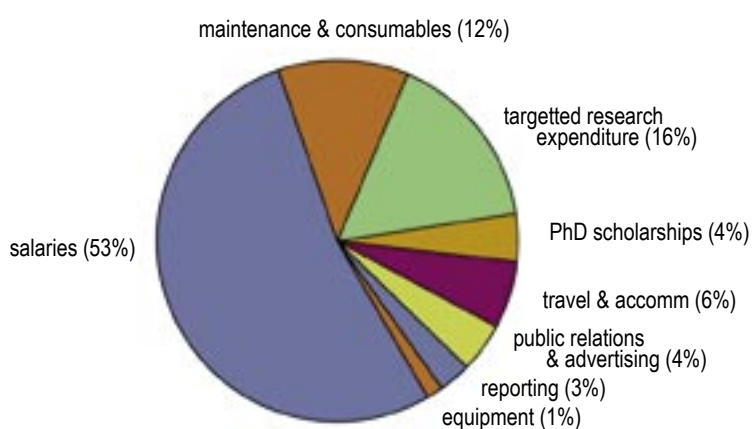
FINANCES



CODES INCOME 2002

Total income from all sources was \$4.1 million, the same as for 2001. Income sources are shown in the pie chart.

Even though our overall income was maintained at \$4.1 million, there were considerable shifts in the income streams. For example, AMIRA income decreased by \$205,000, whereas other industry project funding increased by \$147,000 compared with the previous year. There were also increases in income from the Tasmanian Government, MCA and the return on short courses, however ARC funding for Linkage grants and Fellowships was down.



CODES EXPENDITURE OF SRC GRANT 2002

SRC GRANT - FINANCIAL REPORT - 2002

INCOME

SRC Grant	903,834
End of year balance brought forward from previous year	(26,240)
Commitments brought forward from previous year (SRC a/c)	0
Total budget	877,594

EXPENDITURE

Salaries	(470,621)
Equipment	(13,099)
Travel and Accommodation	(53,224)
Maintenance/consumables	(103,726)
Other	
PhD Scholarships	(37,935)
Public Relations and Advertising	(39,534)
Reporting	(25,730)
Targetted Research Expenditure	(144,097)
Total Expend	(887,966)
	(10,372)
Commitments unspent to be carried forward to next year	0
Account balance at 31.12.2002	(10,372)

INSTITUTIONAL SUPPORT

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

CODES earned \$211,533 from the Universities Research Infrastructure Block Grant in 2002. Most of this contributed toward the purchase of a new electron microprobe for the Central Science Laboratory, also supported by ARC REIF and a University central equipment grant.

NOTES TO AND FORMING PART OF THE FINANCIAL STATEMENTS FOR THE YEAR ENDED 31 DECEMBER 2002

CODES financial reports for 2002 were prepared by CODES Finance Manager and audited by the University of Tasmania. Data was extracted from the University of Tasmania's Financial Management Information System and CODES finance databases. Income figures shown represent all income 'due' (invoiced) in 2002. Expenditure figures shown represent 'actual' expenditure in 2002.

The following two ARC grants have changed name in 2002: 'ARC Small Grants' — now called 'Institutional Research Grants', and 'ARC SPIRT Grants' — now called 'Linkage Grants'

The following Annual Report income categories have been changed from 2002 onward: University of Tasmania 'Equipment Grants' are now called 'Infrastructure Grants'. Under the heading 'Industry/Private Funds', the two previous categories called 'Industry - Directly Funded Projects' and 'SPIRT Grant Matching Funds' are now obsolete. These funds have been merged then split into two new categories. The two new categories are called 'Industry - Student Funded Projects' and 'Industry Other Projects'.

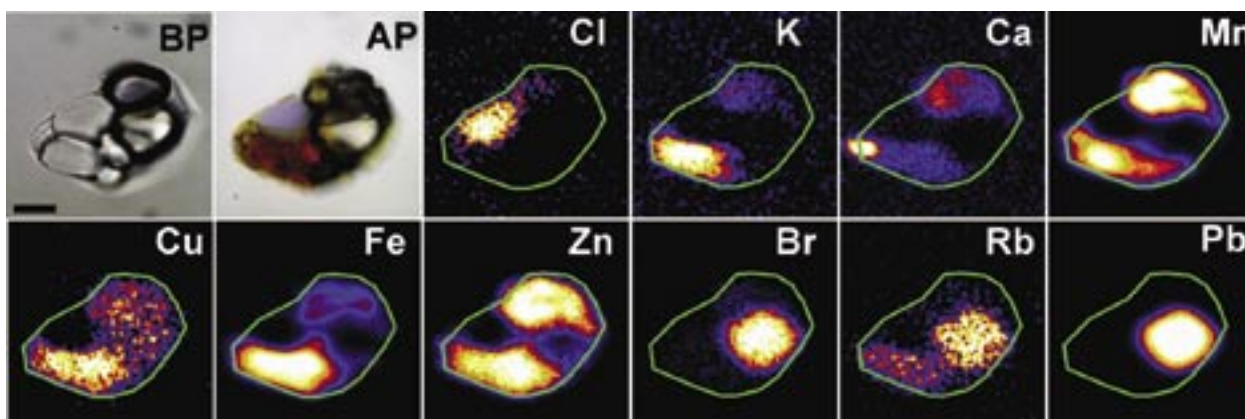
SUMMARY OF ALL CODES INCOME IN 2002

ARC - SRC Grant		903,834
Other ARC Grants		
Linkage Grants and Collaboratives	332,092	
Large Grants	0	
Fellowships	251,942	
Institutional Research Grants (were called Small Grants)	8,000	
RIEF Grant	0	592,034
Other Commonwealth Government Funds		
Scholarships	15,842	
Miscellaneous	8,020	23,862
State Government Funds		
Tasmanian State Govt. - Scholarships (2002-2003)	68,000	
Directly funded research projects	33,761	
Miscellaneous	479	102,240
Local Government Funds		0
Industry/Private Funds		
AMIRA	566,069	
Industry - Other Projects	190,073	
Industry - Student Funded Projects	234,592	
CODES Industry Sponsors	90,000	
Minerals Council of Australia (MTEC)	109,234	
Miscellaneous	4,522	1,194,490
Contracts/Consultancies/Revenue Raising		
Short Courses	121,398	
Book Sales	23,488	
Consulting	0	
Miscellaneous	7,269	152,155
University of Tasmania - Host Institution Support		
University Support to Salaries	692,614	
General Operating Grant	90,869	
Infrastructure Grants (includes RIBG)	211,533	
University Strategic and Tasmanian Scholarship	118,861	
Faculty Scholarships	8,804	
Research Excellence Grant	0	
Staff Development	0	
Study Leave	4,440	
Minor Works Grant	0	1,127,121
Other Income Sources/Interest		
Vehicle Sale	22,367	
Miscellaneous	14,888	37,255
Grand Total		4,132,991

PUBLICATIONS

CODES REFEREED PUBLICATIONS IN 2002

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- Holliday, J.R., Wilson, A.J., Blevin, P.L., Tedder, I.J., Dunham, P.D. and Pfizner, M.**, 2002. Porphyry gold-copper mineralisation in the Cadia district, eastern Lachlan Fold Belt, New South Wales, and its relationship to shoshonitic magmatism. *Mineralium Deposita* 37, 100-116.
- Hollings, P.**, 2002. Archean Nb-enriched basalts in the northern Superior Province. *Lithos* 64, 1-14.
- Holm, O.H. and Berry, R.F.**, 2002. Structural history of the Arthur Lineament, northwest Tasmania: an analysis of critical outcrops. *Australian Journal of Earth Sciences* 49, 167-185.
- Kamenetsky, V.S., Davidson, P., Mernagh, T.P., Crawford, A.J., Gemmell, J.B., Portnyagin, M.V. and Shinjo, R.**, 2002. Fluid bubbles in melt inclusions and pillow-rim glasses: high-temperature precursors to hydrothermal fluids? *Chemical Geology* 183, 349-364.
- Kamenetsky, V.S. and Maas, R.**, 2002. Mantle-melt evolution (dynamic source) in the origin of a single MORB suite: a perspective from magnesian glasses of Macquarie Island. *Journal of Petrology* 43, 1909-1922.
- Kamenetsky, V.S., Sobolev, A.V., Eggins, S.M., Crawford, A.J. and Arculus, R.J.**, 2002. Olivine-enriched melt inclusions in chromites from a low-Ca boninite, Cape Vogel, Papua New Guinea: evidence for ultramafic primary magma, refractory mantle source and enriched components. *Chemical Geology* 183, 287-303.
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- Large, R.R., Bull, S., Selley, D., Yang, J., Cooke, D., Garven, G. and McGoldrick, P.**, 2002. Controls on the formation of giant sediment-hosted Zn-Pb-Ag deposits: with particular reference to the north Australian Proterozoic. In: *Giant Ore Deposits: characteristics, genesis and exploration*, Vol. CODES Special Publ. 4 (Eds, Cooke, D.R. and Pongratz, J.), Centre for Ore Deposit Research, Hobart, 107-150.
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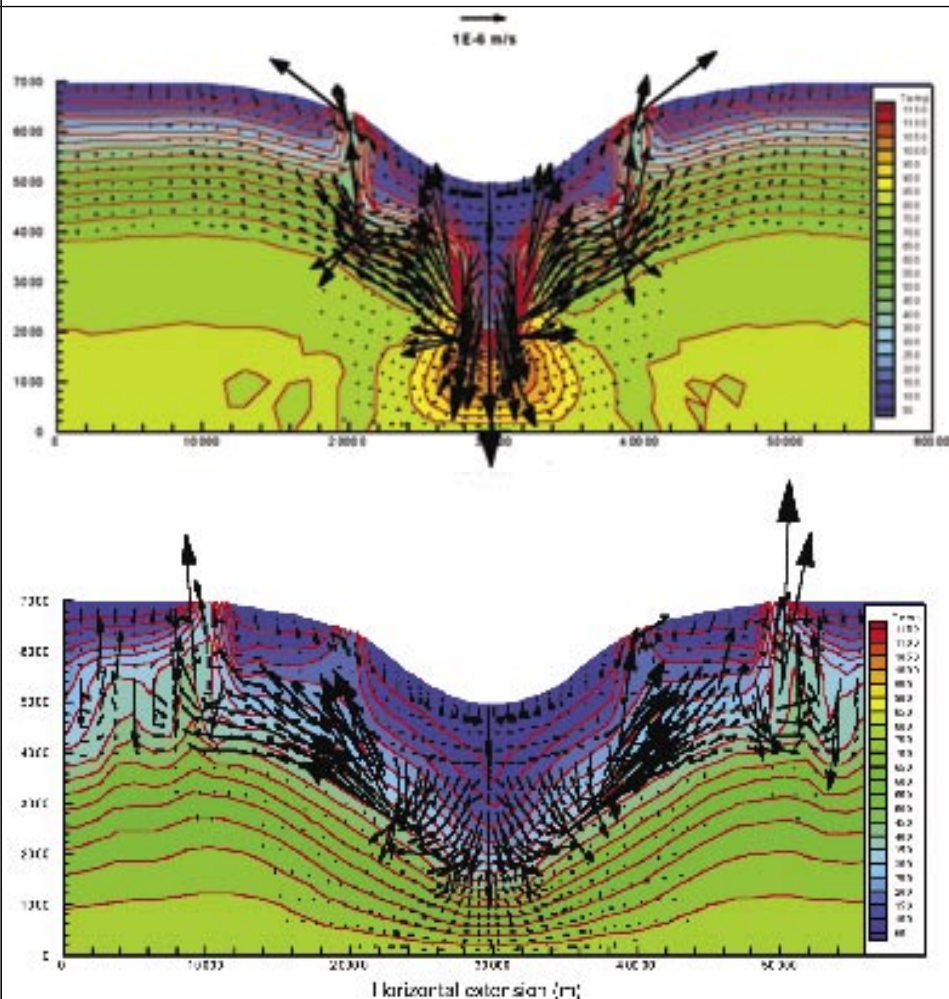
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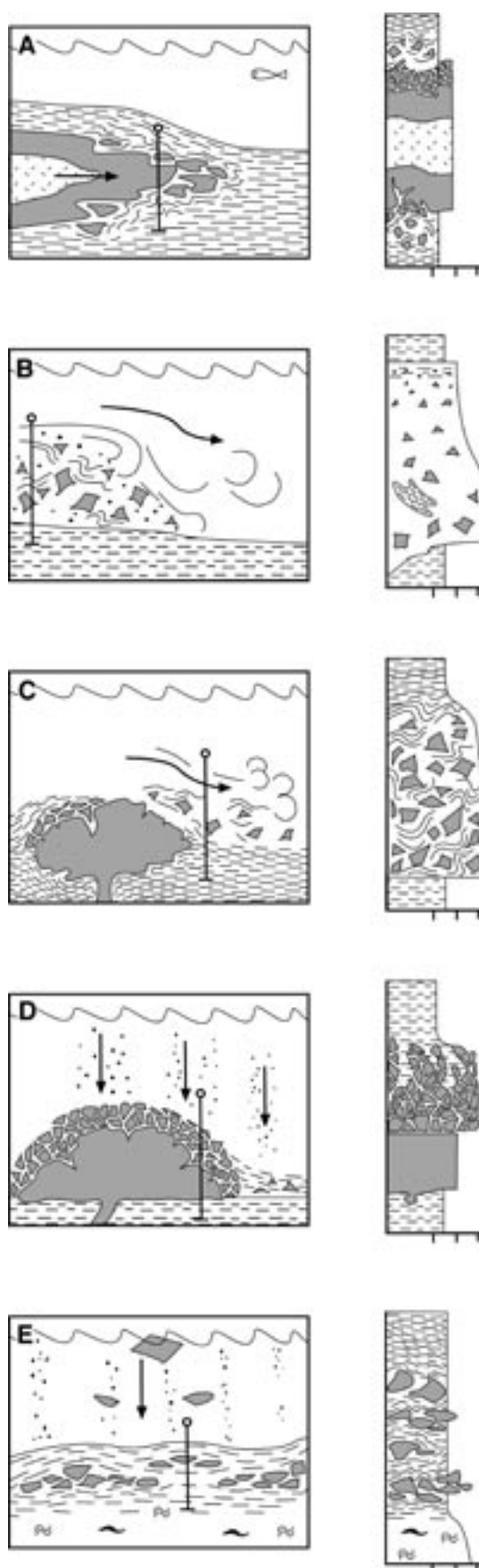
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Cartoons of the different mechanisms that may generate pumice-sediment mixtures in the submarine environment and schematic logs through the resulting deposits. (A) The intrusion of pumiceous rhyolite into wet unconsolidated sediment. (B) Pumiceous mass flow incorporating intrabasinal sediment. (C) Infiltration of sediment into pumiceous hyaloclastite or autobreccia. (D) Resedimentation of dome margin debris and sediment cover above an emerging cryptodome. (E) Outsized water-logged pumice clasts in fine-grained suspension sediment. (Gifkins, McPhie and Allen, 2002. Journal of Volcanology and Geothermal Research 114: 181-203)

APPENDICES

CODES STUDENTS 2002

Name	Supervisors	Project	Industry /Govt support
BACHELOR OF SCIENCE (HONOURS)			
Alex Aitken*	R Scott, W Herrmann	Structure of the Mt Julia Zone at the Henty Au deposit, Tasmania	Aurion Gold
Darren Andrews§	M Roach	Seismic microzonation of Hobart environs	Aust. E'quake Eng. Society
Kate Bassano*	G Davidson, W Herrmann	Hercules Pb-Zn mine, western Tasmania — geology, isotopic characteristics, and genesis	ARC-SPIRT
Mary Bessell#	G Davidson, M Roach	Groundwater and salinity of the Swan River Tertiary Basin, Tasmania	Glamorgan Spring Bay Council and Landcare groups
Joe Booth#	B Gemmell, R Sharpe	Genesis and alteration vectors around the Bimurra epithermal deposit, Drummond Basin	AMIRA
Rebecca Carey#	J McPhie, S Allen	Volcanology of 1886 Tarawera eruption, Taupo Volcanic Zone - New Zealand	
Jody Cutler*	M Roach, J Reid, P Quilty	Seismic magnetic and paleontological interpretations of North West Bay, Tasmania	
Darren Griggs*	M Roach, J Reid	Geophysical interpretation of an airborne electromagnetic survey of west coast sequences, Tasmania	Tas. Govt Mining Scholarship
David Hartney§	R Berry	Comparison of metamorphism and structure of metamorphic inliers, NE Tasmania	
Paul Henson*	R Berry	Structural and metamorphic geology of the Port Sorell area, Tasmania	
John Hooper§	W Herrmann, M Solomon	Characteristics and genesis of the volcanic-hosted Firetower prospect, Cethana area, Tasmania	AurionGold
Bronwyn Kimber*	J Reid	Understanding relationships between electromagnetic properties and sea ice thickness, Antarctica	ASAC grant
Paul Lane#	C Burrett, M Roach	The Longford Sub-basin architecture and economic potential based on seismic, potential field and drill-hole data	Great Southland Minerals Tas. Govt Mining Scholarship
Todd McGilvray§	P McGoldrick	Sedimentology and mineralisation at Oceana Zn deposit, Western Tasmania	Great Southland Minerals
Sophie Osterloh#	G Davidson, W Herrmann	Origin of the Maydena silica flour and bedrock silicification, Tasmania	Macdonald Mining and Sons
Monica Osuchowski#	G Davidson, M Roach, J Reid	Land stability of the Knights Creek catchments and control upon the turbidity of the Knights Creek Reservoir	Hobart Water Governors Env. Scholarship Tas. Govt Mining Scholarship
Cynthia Palfreyman#	G Davidson, M Roach, J Reid	Hydrogeology of the Dolphin Sands sand spit, Tasmania	Glamorgan Spring Bay Council and Landcare groups
Phil Potter§	R Berry, G Davidson, J Reid	Structural and economic geology of the Lisle area, NE Tasmania	
John Stacpoole*	S Bull, R Large	Sedimentology of the Blue Bush sediment-hosted Zn prospect, Northern Territory	Anglo American
Andrew Tyson*	M Roach	Gravity interpretation of the Woolnorth area, Tasmania	
Luke Wallace#	D Cooke, G Davidson, J Reid	Aqueous geochemistry of the constructed wetlands treating AMD, Rosebery, Tasmania	Pasminco
Suzanne Witteveen*	G Davidson, J Reid	Hydrogeology of the host rocks, and contaminant potential, of the Circular Head waste disposal site, NW Tasmania	Australian Bulk Minerals, Circular Head Council
GRADUATE DIPLOMA OF SCIENCE			
Stuart Dawes	P McGoldrick	Morphology and compositional variation of alluvial Au from Tobacco Creek, northeastern Tasmania	
MASTER OF ECONOMIC GEOLOGY			
Leon Bagas°	R Scott, A Tunks	Geology of the Paterson Orogen	GSWA
Julian Bartlett	W Herrmann, T Crawford	Alteration within the Barkly River greenstones, Whisky Knob Window, eastern Victoria	
Mitchell Bland*	D Cooke, W Herrmann	Exploration geology and mineralisation of the Rowan Brae, Four Mile Creek, Barton Park and Ashleigh Park prospects, Cadia, NSW	Newcrest

CODES STUDENTS 2002 cont

Name	Supervisors	Project	Industry /Govt support
Michael Buchanan#	B Gemmell, R Berry	Geology, geochemistry and genesis of the Fenton Zone VHMS prospects, Snow Lake, Manitoba, Canada	Hudson Bay Exploration, Anglo American
Brett Butlin°	A Tunks	Gold mineralisation	Barrick Gold of Australia
Adrian Byass		<i>Course work masters program</i>	
Richard Cotton	R Berry, B. Gemmell	Geology of the Ross alluvial Au deposit, New Zealand	L&M Mining
Paul Cromie*	K Zaw, D Cooke, N White (Consultant)	Geological setting and mineralisation characteristics of the Funning micro-disseminated Au occurrences Yunnan Province, China	BHP Billiton
Andrew Dacey		<i>Coursework masters program</i>	
Adrian Fabris°		<i>Not decided</i>	PIRSA
Michael Fletcher°	A Tunks	Structural Geology of Damang region Ghana	Goldfields Ghana
Simon Henderson	B Gemmell	Coursework masters program	
Anthony Johnston°		<i>Not decided</i>	
Allan Kneeshaw*	R Scott	Deformation and structural history of the south eastern margin of the Laverton Basin, northeastern goldfields, WA	AngloGold
Ian Laurent#	M Roach, R Scott	Synthesis of the geology and geophysics of the Svartiden Au deposit, Sweden	Viking Gold
Gem Midgley	D Cooke	Isotopic variations in Carlin-type Au deposits, Nevada	AngloGold
David Nixon°	A Tunks	Au mineralisation in the Tanami region	Barrick Gold of Australia
Dan Power°	A Tunks	Au mineralisation at Groundrush, Tanami	Newmont
Michael Priestly	R Scott, R Large	Perseverance Au prospect, Cobar, NSW	Rio Tinto
Robert Reid*	R Large, D Cooke	The Thomas Creek Cu prospect, western Tas	
Steven Richardson	B Gemmell, R Large	Geology and geochemistry of the Que River footwall alteration zone, western Tas	
Nalin Shah	P McGoldrick, G Davidson	Geology and dating of the Mangalwar Complex, with reference to Rampura Agucha, Rajasthan, India	BHP Billiton
Spencer Summers	B Gemmell, K Zaw	Geology and mineralisation styles of the Sekatak project, northeast Kalimantan, Indonesia	Goldfields Indochina, Jakarta
Philip Tornatora*	R Scott	Structural architecture and the relationship of structure to mineralisation, Cleo deposit, northeastern goldfields, WA	AngloGold

MASTER OF EXPLORATION GEOSCIENCE

Albert Chong		Geology, mineralisation, metal distribution, and genesis of the polymetallic Ridge and Marshall Zones, Battle Lake Camp, Vancouver Island, Canada.	Boliden-Westmin
Garry Ferris*		The geology and geochemistry of granitoids in the Childara region, western Gawler Craton, South Australia: Implications for the Proterozoic tectonic history of the western Gawler Craton and development of lode-style Au mineralisation at Tunkillia	Mines and Energy SA
Matthew Hope		Geology of the Mount Kirk Formation, Norseman, WA	Central Norseman Gold
Terry Hoschke		Geophysical signature of Cu-Au porphyry systems.	Normandy
Pamela Italiano		A geophysical petrophysical and petrological study of the komatite-hosted Ag deposit and environs, WA	Mining Project Investors
Craig Stegman		Review of controls on Au-base metal mineralisation in the Cobar gold field, NSW	Rio Tinto
Felipe Urzua°		Geology of the Escondida District, Chile	Anaconda and BHP Billiton

CODES STUDENTS 2002 cont

Name	Supervisors	Project	Industry /Govt support
DOCTOR OF PHILOSOPHY			
Michael Agnew	S Bull, R Large	Volcanic setting, lithogeochemistry and genesis of the Lewis Ponds massive sulfide deposits, NSW	Tri Origin
Steve Bodon*	G Davidson, R Large	The geodynamic evolution and genesis of the Cannington Broken Hill Type silver-zinc-lead deposit, Mt Isa Inlier, Australia	BHP Billiton
Bryan Bowden°	G Davidson, R Berry	Iron oxide Cu-Au related alteration history of the Mt Woods Inlier, South Australia, with special emphasis on the Prominent Hill prospect	Minotaur Resources, Goldstream, PIRSA, GA
Katharine Bull	J McPhie, A Crawford	Character, setting and significance of Early Devonian volcanic successions in the western Lachlan Fold Belt, NSW	GSNSW
James Cannell	D Cooke, P Hollings, J Walshe (CSIRO)	El Teniente porphyry Cu-Mo deposit, Chile: geology, geochemistry and genesis	Codelco, AMIRA P511
Dene Carroll	A Crawford, S Meffre	Tectono-magmatic evolution of eastern Viti Levu, Fiji	
Darryl Clark#	B Gemmell, P McGoldrick	Geology and genesis of the Mammoth Cu deposit, Mt Isa Inlier, Australia	Western Metals
Mawson Croaker	D Selley, P McGoldrick	The geology and genesis of the Neoproterozoic Cu-Co Nkana-Mindola deposit, Zambia	AMIRA P544
Paul Davidson	V Kamenetsky, A Crawford	Fluid phase immiscibility in late magmatic systems and its relation to the magmatic fluid to hydrothermal fluid transition	
Andrew Davies#	D Cooke, B Gemmell	Geology and genesis of the Kelian Au deposit, east Kalimantan, Indonesia	PT Kelian Equatorial Mining, Rio Tinto Indonesia
Greg Ebsworth	J McPhie, A Crawford	Andesitic volcanic facies in the Tyndall Group: Stratigraphic and tectonic implications for the Cambrian Mount Read Volcanics, western Tasmania	Tas. Govt Mining Scholarship
Lee Evans	G Davidson, J Yang, D Cooke	Groundwaters in wet, temperate, sulfide mining districts: Delineation of modern fluid flow, and predictive modelling to improve management after mine closure (Rosebery, Tasmania)	Pasminco
Andrew Fitzpatrick	M Roach	Scale-dependent electrical properties of sulfide rocks	Normandy, Western Metals, Rio Tinto, MIM, ARC
Peter Frikken	D Cooke, P Hollings, J Walshe (CSIRO)	Breccia-hosted Cu-Mo mineralisation at Rio Blanco, Chile	Codelco, AMIRA P511
Russell Fulton	B Gemmell, R Berry	Geology and geochemistry of the hangingwall argillite, Greens Creek VHMS deposit, Alaska: Implications for ore genesis and exploration	Kennecott Greens Creek Mining Company
Owen Hatton	G Davidson, S Bull	Basin configuration, sedimentology and volcanology of the Toole Creek Volcanics, Mt Isa region, Qld	BHP Billiton
Oliver Holm*	R Berry, A Crawford	Structural and metamorphic evolution of the Arthur lineament, western Tasmania	MRT, Goldstream
Sarah Jones*	B Gemmell, G Davidson	Geology and geochemistry of the 'caprocks' above the VHMS deposits at Myra Falls, Vancouver Island, British Columbia, Canada	Boliden-Westmin
Ben Jones	R Large, A Crawford, N White	Genesis of the Antapaccy Cu-Au porphyry deposit, Peru	BHP Billiton
Maya Kamenetsky°	A Crawford, L Danyushevsky	Apatite-hosted melt inclusions and apatite geochemistry	
Lyudmyla Koziy	R Large, D Cooke, J Yang	Numerical simulation of fluid flow and fluid chemistry in sedimentary basins	AMIRA P552
Roman Leslie	L Danyushevsky, A Crawford	Petrogenesis and volatile evolution of primitive shoshonitic magmas	
Steven Lewis	G Davidson, R Berry	Hydrothermal alteration of the upper oceanic crust of Macquarie Island	ASAC grant
Vanessa Lickfold*	D Cooke, A Crawford	The intrusive history and volatile evolution of the Endeavour porphyry Cu-Au deposits, Goonumbla district, New South Wales	Rio Tinto
Neil Martin	R Large, S Bull	Genesis of the Rosebery VHMS deposit, western Tasmania	Pasminco
Glen Masterman	D Cooke, R Berry	Genetic relationships between the Rosario porphyry Cu-Mo deposits and the high-sulfidation Cu-Au veins, Collahuasi district, Chile	Compania Minera Dona Ines de Collahuasi, AMIRA P511

CODES STUDENTS 2002 cont

Name	Supervisors	Project	Industry /Govt support
Wallace MacKay	D Selley, S Bull	The structure and sedimentology of the Curdimurka Subgroup, Willouran Range, South Australia	
Thomas Monecke (UFreiberg)	B Gemmell, P Herzig (UFreiberg)	Waterloo– Agincourt Cu–Pb–Zn deposit, Mount Windsor Subprovince, Queensland. Based at UFreiberg, Germany.	
Karin Orth#	J McPhie, P McGoldrick	Setting of the Palaeoproterozoic Koongie Park Formation and carbonate-associated base metal mineralisation at Koongie park, northwestern Australia	
Nicki Pollington	P Mc Goldrick, S Bull	Sedimentology, mineralisation and geochemistry of the Konkola North Cu deposit, Zambia	AMIRA P544
Andrew Rae*	D Cooke, B Gemmell	Alteration sytematics and mineralising potential of the Palinpinon geothermal field, Negros Island, Philippines	Inmet, Newcrest, BHP Billiton, North
David Rawlings*	S Bull, D Cooke	Sedimentology, volcanology and geodynamics of the Redbank Package, McArthur Basin, northern Australia	Rio Tinto
Carlos Rosa°	J McPhie	Submarine volcanic successions in the Iberian Pyrite Belt, Portugal	Portuguese Science and Technology fund, Mining and Geological Institute of Portugal
Christian Schardt	R Large, J Yang	Controls on hydrothermal fluid migration by volcanic facies architecture: Implications for massive sulfide deposit formation	
Andrew Stewart	J McPhie	Facies architecture of a mineralised arc volcanic island, Milos, Greece	
Tony Webster	R Berry, G Davidson, R Large	Structural evolution of the Broken Hill Pb-Zn-Ag deposit, NSW	
Alan Wilson	D Cooke, R Large, J Holliday	The genesis and exploration context of porphyry Cu-Au deposits in the Cadia district, NSW	Newcrest
Rohan Wolfe*	D Cooke, G Davidson	The Dinkidi Cu-Au porphyry: Geology of the Didipio region and paragenesis of the Dinkidi Cu-Au porphyry deposit	Climax-Arimco
Andrew Wurst	B Gemmell, D Cooke	Volcanic architecture, structure, mineralisation and alteration of the Permata-Batu Badinding-Hulubai and Kerikil low sulfidation epithermal Au-Ag deposits, Mt Muro, central Kalimantan, Indonesia: Implications for ore genesis and exploration	PT Indo Muro Kencana, AMIRA P588

* Graduated in 2002

Submitted in 2002

° New in 2002

§ Part time student/mid year start

COLLABORATIONS

International			
Institution	Researcher	CODES collaborators	Project
Colorado School of Mines	Murray Hitzman, Dave Broughton	Peter McGoldrick, Stuart Bull, Dave Selley	Proterozoic sediment-hosted copper deposits
Colorado State University	Holly Stein	David Cooke, James Cannell, Alan Wilson	Giant porphyry Cu deposits
DNRE, Bathurst Canada	Steve McCutcheon	Ross Large, Bruce Gemmell, Garry Davidson	Global VMS Project
Duke University	Jeff Karson, Pete Rivazzigno	Garry Davidson, Ron Berry	Sulfur geochemistry of hydrothermally altered volcanic terrains
Freiburg University	Peter Herzig	Bruce Gemmell, Robina Sharpe	Modern submarine hydrothermal systems
Freiburg University	Thomas Monecke	Bruce Gemmell	Waterloo VHMS prospect, Mount Windsor
Freiburg University	Peter Herzig	Bruce Gemmell, Ross Large, Garry Davidson	Global VMS project
GEODE, Royal Holloway College, London	Derek Blundell	Ross Large, Bruce Gemmell, Garry Davidson	Global VMS project
Geological Survey of Canada	Mark Hannington, Ian Jonasson	Bruce Gemmell	Modern submarine hydrothermal systems
Geological Survey of Canada	Jan Peter	Khin Zaw, Bruce Gemmell, Ross Large	Ore fluids, Middle Valley, Juan de Fuca Ridge, Canada
Geological Survey of Japan		Khin Zaw	JADE hydrothermal field, Okinawa Trough
Geological Survey of Spain	Fernando Tornos	Mike Solomon, Ross Large	Iberian Pyrite Belt VHMS deposits
Geological Survey of Sweden	Magnus Ripa	Stuart Bull	Sedimentary and volcanic geology of the Bergslagen District, Sweden
Geological Survey of Vanuatu	Douglas Charlie	Sharon Allen, Fernando Della Pasqua	Plagioclase ultraphyric lavas on Tanna, Vanuatu
GEOMAR	Armin Freundt	Sharon Allen	Experimental simulations of volcanoclastic mass flows
Idaho Geological Survey	Bill Bonnicksen	Jocelyn McPhie	Volcanology of extensive felsic lavas
Institute of Geology and Mineral Exploration IGME, Greece	Georges Vougioukalakis	Jocelyn McPhie	Volcanic geology of Milos, Greece
Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing	Hou Zhengqian	Khin Zaw	Modern sea floor systems, Okinawa Trough
Institute of Mineralogy, Miass, Russia	Valeriy Masslenikov	Bruce Gemmell, Ross Large	Ancient sea floor systems, Russia
Institutio Geologica Minerio, Lisbon	Carlos Inverno	Mike Solomon	Research on Iberian Pyrite Belt
Instituto Geologica Minerio (IGM), Lisbon	Luis Martins	Jocelyn McPhie	Volcanic facies architecture of the Iberian Pyrite Belt, Portugal
Johns Hopkins University	Grant Garvin	Ross Large, David Cooke	Fluid flow modelling
Johns Hopkins University	Mike Simms	Ross Large, David Cooke	Fluid flow and fluid chemistry
Lakehead University, Canada	Peter Hollings	David Cooke	Giant porphyry Cu deposits, AMIRA P511
Lakehead University, Canada	Peter Hollings	Tony Crawford	Modern and ancient fold belt volcanics
Laurentian University, Canada	Harold Gibson	Ross Large, Bruce Gemmell, Garry Davidson	Global VMS Project
Laurentian University, VIEPS	Reid Keays	Tony Crawford	Modern and ancient fold belt volcanics
Lulea University, Sweden	Rod Allen	Stuart Bull	Sedimentary and volcanic geology of the Bergslagen district, Sweden
Max Planck Institute for Geochemistry	Alex Sobolev	Dima Kamenetsky, Maya Kamenetsky, Leonid Danyushevsky	Melt inclusions in mafic rocks and kimberlites
Nanjing University	Gu Lianxing, Ni Pie	Khin Zaw	VHMS Deposits in China
Natural History Museum, UK	Richard Herrington	Ross Large, Bruce Gemmell, Garry Davidson	Global VMS Project
Northern Arizona University	Nancy Riggs	Jocelyn McPhie	Large felsic lavas, Gawler Range Volcanics and Snake River Plain Idaho

COLLABORATIONS cont

Institution	Researcher	CODES collaborators	Project
Queens University	Kurt Kyser	Stuart Bull, Ross Large	Fluid flow in the Mt Isa Basin
Queens University	Alan Clark, Thomas Ulrich	David Cooke, Glen Masterman, Vanessa Lickfold	Giant Porphyry Cu Deposits
Simon Fraser University	Derek Thorkelson	Garry Davidson, Ron Berry	Cu-Au-Fe oxide geology and geochemistry
Sweden Geological Survey	Per Weihed	Ross Large, Bruce Gemmell, Garry Davidson	Global VMS Project
Tohoku University, Japan	Yoshi Goto	Jocelyn McPhie	Submarine basaltic lavas, Tasmania
University of Arizona	Mark Barton	Garry Davidson, Wally Herrmann, Mike Solomon, Mike Blake, Ross Large	Isotope applications, Mount Read Volcanics study
University of Auckland	Bruce Hayward	Sharon Allen	Facies characteristics of volcanoclastic mass-flow deposits
University of Auckland	Stuart Simmons, Greg Cater, Ben Young	Jocelyn McPhie, Bruce Gemmell	Epithermal systems
University of Leeds	Bruce Yardley	David Cooke	Fluid mixing in hydrothermal systems
University of Lisbon	Jorge Relvas	Jocelyn McPhie	Volcanic facies architecture of the Iberian Pyrite Belt, Portugal
University of Michigan	Jeff Alt	Garry Davidson, Ron Berry	Sulfur geochemistry of hydrothermally altered volcanic terrains
University of Naples	Benedetto De Vivo	Dima Kamenetsky	Melt inclusions in Roman Province volcanics
University of Pisa	Alessandro Sbrana	Dima Kamenetsky	Vesuvius skarns
University of Southampton	Dick Teagle	Garry Davidson, Ron Berry	Sulfur geochemistry of hydrothermally altered volcanic terrains
University of Toronto	Steve Scott	Bruce Gemmell, Robina Sharpe	Submarine volcanism
Vernadsky Institute of Geochemistry and Cosmochemistry	A.V. Sobolev, N.M. Sushchevskaya, V.B. Naumov	Tony Crawford, Dima Kamenetsky	Melt inclusions
National			
Consultant	Noel White	David Cooke, Bruce Gemmell, Cari Deyell, Robina Sharpe	Transitions and zoning in porphyry-epithermal districts
Central Science Laboratory	Keith Harris	Peter McGoldrick, Leonid Danyushevsky, Fernando Della Pasqua, Phil Robinson	Development of sulfide standards for LA-ICPMS techniques
Central Science Laboratory, University of Tasmania	David Steele	Dima Kamenetsky, Anthony Harris, Tony Crawford	Volatiles and chalcophile elements in porphyry Cu-Au hosting magmas
Consultant	Carol Simpson	Tony Crawford, David Cooke, Wally Herrmann, Sebastien Meffre, Rob Scott, Jocelyn McPhie	Origin and metallogenesis of Ordovician volcanic belts in central NSW
CSIRO	Ray Binns, Tim McConaghy	Bruce Gemmell	Submarine volcanism
CSIRO	Alison Ord	Stuart Bull, Ross Large	Fluid flow in the Mt Isa Basin
CSIRO	John Walshe	David Cooke	Giant porphyry Cu deposits
CSIRO	Chris Ryan	David Cooke	Fluid mixing in hydrothermal systems
CSIRO	Chris Ryan	Dima Kamenetsky, Anthony Harris, Tony Crawford	Volatiles and chalcophile elements in porphyry Cu-Au hosting magmas
GSNSW	Simone Meakin, Roger Cameron	Jocelyn McPhie	Early Devonian volcanic successions in the Lachlan Fold Belt
Geoscience Australia	Peter Southgate	Ross Large, Stuart Bull	Fluid flow in the Mt Isa Basin
Geoscience Australia	Roger Skirrow	Garry Davidson, Ron Berry	Cu-Au-Fe oxide geology and geochemistry
Geoscience Australia	Terry Mernagh	Dima Kamenetsky, Anthony Harris, Tony Crawford	Volatiles and chalcophile elements in porphyry Cu-Au hosting magmas

COLLABORATIONS cont

Institution	Researcher	CODES collaborators	Project
GSNSW	Dick Glen, Ian Percival, Larry Barron	Tony Crawford, David Cooke, Wally Herrmann, Sebastien Meffre, Rob Scott	Origin and metallogenesis of Ordovician volcanic belts in central NSW
James Cook University	Nick Oliver	David Cooke	Fluid mixing in hydrothermal systems
James Cook University	Pat Williams	David Cooke	Fluid mixing in hydrothermal systems
James Cook University	Bin Fu	David Cooke	Fluid mixing in hydrothermal systems
James Cook University	Julie Hunt	Garry Davidson, Ron Berry	Cu-Au-Fe oxide geology and geochemistry
Mineral Resources Tasmania	Tony Brown	Garry Davidson, Ron Berry	Sulfur geochemistry of hydrothermally altered volcanic terrains
Mineral Resources Tasmania	David Green, Geoff Green, Marcus McLenaghan, Jafar Taheri	Garry Davidson, Wally Herrmann, Mike Solomon, Mike Blake, Ross Large	Isotope applications, Mount Read Volcanics study
PIRSA	Paul Heithersay, M Schwarz	Garry Davidson, Ron Berry	Cu-Au-Fe oxide geology and geochemistry
PIRSA	Wolfgang Priess, Stuart Robertson	Peter McGoldrick, Stuart Bull, Dave Selley	Proterozoic sediment-hosted Cu deposits
PIRSA	Sue Daly, Liz Jagodzinski	Jocelyn McPhie, Sharon Allen	Facies architecture of the Gawler Range Volcanics
RSES, ANU	Marc Norman	Jocelyn McPhie	Zircon dating of young arc volcanic units on Milos, Greece
RSES, ANU	Marc Norman	Garry Davidson, Andrew Rae, Ross Large, Peter McGoldrick	Trace element analysis of sulfides by LA ICPMS
University of Adelaide	John Foden	David Cooke, Anthony Harris, Glen Masterman, Vanessa Lickfold, Peter Frikken, James Cannell, Alan Wilson	Fluid chemistry in porphyry Cu-Au-Mo deposits
University of Adelaide	John Foden	Ross Large, Stuart Bull, Mike Blake, Peter McGoldrick	Textural and isotopic studies of sediment-hosted base metal deposits
University of Adelaide	Nick Direen	Sebastien Meffre, Tony Crawford, Dima Kamenetsky	Geochemistry and tectonic significance of Neoproterozoic volcanics
University of Queensland	Sue Golding	Stuart Bull, Ross Large	Fluid flow in the Mt Isa Basin
University of Western Australia	Mark Doyle	Bruce Gemmell	VHMS-related alteration

VISITORS TO CODES 2002

Name		Position	Organisation	Purpose of visit	Date
ACADEMIC (International)					
Coffin	Mike	Professor	University of Tokyo, Japan	Collaboration with T Crawford	March
Garvin	Grant	Professor	Johns Hopkins University, USA	Collaborative work	March
Goto	Yoshi		Tohoku University, Japan	Collaborative work with J McPhie and program 2	February-March
Hollings	Peter	Assistant Professor	Lakehead University, Canada	GODs workshop, P511 meeting	June
Lui	Xianbio	Associate Professor	China University of Earth Resources	Skarn and porphyry-type ore deposits	2002
Masslennikov	Valeriy	Professor	Miass University, Russia	Collaborative work	April-August
Masslennikova	Svetlana	PhD student	Miass University, Russia	Collaborative work	April-August
Minter	Lawrence	Emeritus Professor	University of Cape Town, South Africa	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Mosher	Sharon		University of Texas, USA		March
Naldrett	Tony	Emeritus Professor	University of Toronto, Canada	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Price	Richard	Professor	University of Waikato, New Zealand	Collaborative work with T Crawford	March
Sawlowicz	Zbigniew	Professor	Jagiellonian University, Poland	SEG field trip to Mt Isa, lectures at CODES	November
Simmons	Stuart	Lecturer	University of Auckland, New Zealand	AMIRA P588 meeting	December
Thompson	Tommy	Director	Ralph J Roberts Centre for Research in Economic Geology, Mackay School of Mines, Nevada, USA	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Yang	Jianwen	Assistant Professor	University of Windsor, Canada	Collaborative work	September
ACADEMIC (National)					
Arif	Johan	Student	James Cook University	Volcanology short course	November
Baker	Tim	Lecturer	James Cook University	Ore Deposit Models and Exploration Strategies short course	June
Beresford	Steve	Lecturer	Monash University	Nickel workshop	November
Bruce	Eleanor	Lecturer	University of Sydney	AMIRA P 603 meeting	December
Gleadow	Andrew	Professor	University of Melbourne	CODES Advisory Board	May
Groves	David	Director, CGM,	University of Western Australia	GODs workshop, Ore Deposit Models and Exploration Strategies short course, CODES Advisory Board, Science Planning Meeting and other meetings	various
Harris	Anthony	PhD student	University of Queensland	Present paper on research	August
Keays	Reid	Professor of Geology	VIEPS and Laurentian University	Nickel workshop	November
Maas	Roland	Research Fellow	University of Melbourne	Collaborative work with D Kamenetsky	December
Maier	Rod	Student	University of Newcastle	PhD applicant	December
Mustard	Roger		James Cook University	Collaborative work with D Kamenetsky	June
Nicholls	Ian		Monash University		March
Norman	Marc	Snr Research Fellow	Research School of Earth Sciences, ANU	Collaborative work	October
Reid	Jim	Professor	University of Tasmania	CODES Advisory Board	May
Schaeffer	Bruce	Lecturer	Monash University	Nickel workshop	November

VISITORS TO CODES 2002 cont

GOVERNMENT

Name	Position		Organisation	Purpose of visit	Date
Bagas	Leon		Geological Survey of Western Australia	GODs workshop and Ore Deposits shortcourse, Volcanology short course	June and December
Barnett	Guy	Senator	Government of Australia	Familiarisation visit	April
Brown	Tony	Director	Minerals Resources Tasmania	CODES Advisory Board, Science Planning Panel and other meetings	May
Cram	Lawrence	Professor	ARC	ARC Triennial review	July
Denwer	Kim	Research Geologist	pmd*CRC	Collaborative work with W Herrmann	December
Direen	Nick	Research Geologist	Geoscience Australia	Collaborative work with T Crawford	October
Drummond	Barry	Research Group Leader	Geoscience Australia	Collaboration with T Crawford	February
Fabris	Adrian		PIRSA	GODs workshop and Ore Deposits shortcourse, Volcanology short course	June and November
Green	Geoff	Managing Geologist	Minerals Resouces Tasmania	3D mapping project Tasmania, Science Planning Day, GODS workshop	various
Green	David	Senior Geologist	Minerals Resouces Tasmania	Science Planning Day, GODs workshop	various
Huston	Dave	Project Leader	Geoscience Australia	Collaborative work	various
Johnson	Anthony		Geological Survey of NSW	GODs workshop and Ore Deposits short course	June
Southgate	Peter		Geoscience Australia	AMIRA P552 meeting	February
Stevens	Barney	Mapping Geologist	Geological Survey of NSW	Collaboration with T Crawford	
Walshe	John	Senior Research Scientist	CSIRO	AMIRA P511	various
Wyborn	Lesley		Geoscience Australia	CODES Advisory Board, Science Planning Panel	May

INDUSTRY

Allingham	Darren		AurionGold Exploration	GODs workshop and Ore Deposits shortcourse	June
Andrew	Ross		Rio Tinto	AMIRA P603 Meeting, AMIRA P544 meeting	December
Belperio	Tony	Chief Geologist	Minotaur Gold	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Bettles	Keith	Exploration Manager	Barrick Goldstrike Mines	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Broadbent	Graeme	Exploration manager	RioTinto	Ore Deposit Models and Exploration Strategies short course, GODS Workshop	June
Buchsman	Aletha		Barrick	Volcanology short course	November
Butlin	Brett		Barrick Gold of Australia	GODs workshop and Ore Deposits shortcourse, Volcanology short course	June and December
Camus	Francisco	Manager, Exploration Strategies	CODELCO	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Creenaune	Patrick		Newcrest Mining	AMIRA P588 meeting	December
Cucuzza	Joe		AMIRA	GODs workshop, AMIRA meetings, Advisory Board, Science Planning Panel	various
Davies	Brett		Newmont Exploration	AMIRA P588 meeting	December
Dearden	Penny	Geologist	AngloGold	Volcanology short course	November
Elias	Mick	Manager	Mick Elias Associates	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Encina Montenegro	Victor	Projects Leader	Institute for Innovation in Mining and Metallurgy (IMZ), Chile	potential collaborative work	May
Eshuys	Ed	Managing Director			

VISITORS TO CODES 2002 cont

Name	Position		Organisation	Purpose of visit	Date
Fox	Nick	Chief Geologist	AngloGold	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Garwin	Steve	Chief Geologist-Nevada	Newmont Mining Corporation		March
Goode	Alan	Research Director	AMIRA	AMIRA meetings, GODs workshop	various
Groves	Iain		Perillya	Collaborate on Broken Hill research	
Hale	Humphrey		AngloGold	Volcanology short course	November
Hall	Greg	Chief Geologist	Placer Dome Ltd	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Halley	Scott		AurionGold	AMIRA P511, GODs workshop, Science Planning Day	various
Haynes	Douglas	consultant	Douglas Haynes Discovery P/L	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Holliday	John				
Hoskins	Bill		Newmont Exploration Ltd	AMIRA P588 meeting	December
Howard	Will				
Ignacio	Allan	Geologist	Anglo American	GODs workshop, Ore Deposits and Volcanology short courses	June, November
Jennings	Scott	Exploration Manager	Teck Cominco	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Johnson	Craig	Geologist	AurionGold	GODs workshop and Ore Deposits short course	June
Kitto	Paul		AurionGold	AMIRA P511, GODs workshop	June
Krcmarov	Rob		Barrick Gold of Australia	AMIRA meetings, GODS Workshop, Science Planning Panel	various
Langmead	Roger		Newcrest Mining	GODs workshop and Ore Deposits short course	June
Lopez	Gloria		Codelco	GODs workshop and Ore Deposits short course	June
MacDonald	James		BHP Billiton	CODES Advisory Board	May
Maroney	Marion		Barrick Gold of Australia	AMIRA meetings, Ore Deposit short course, GODs workshop	various
McCracken	Stuart		Anglo American	AMIRA P552	February
McKay	Greg		Phelps Dodge	AMIRA P 603 meeting	December
McLeod	Ray		Newcrest Mining	CODES Advisory Board and Science Planning Panel	May
Midgley	Gem		AngloGold	GODs workshop and Ore Deposits short course	June
Moore	Richard	Director of Exploration Technical Support	Falconbridge	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Moroney	Marian		Barrick Gold of Australia	GODs workshop and Ore Deposits short course	June
Muhling	Peter	Industry Geologist	CSAAustralia	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Nixon	Dave		Barrick Gold Mines of Australia	GODs workshop and Ore Deposits short course, Volcanology course	June, November
Olubas	Peter		Emperor Gold Mines	GODs workshop and Ore Deposits short course	June
Power	Dan		Newmont Australia	GODs workshop and Ore Deposits short course, Volcanology short course	June
Pring	Petger		Newmont	Volcanology short course	November
Richardson	Steven		Macarthur Ore Deposits	GODs workshop and Ore Deposits short course	June

VISITORS TO CODES 2002 cont

Name		Position	Organisation	Purpose of visit	Date
Rovira	Tony	General Manager- Exploration	Jubilee Mines	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Skarmeta	Jorge		CODELCO	AMIRA P511, GODs workshop, Ore Deposits short course	June
Smith	Roric		AurionGold	AMIRA meetings, GODs workshop	various
Snow	Gary		AurionGold	GODs workshop and Ore Deposits short course	June
Spilsbury	Wayne		Teck Cominco	AMIRA P544 Meeting, GODs workshop, AMIRA P603 Meeting	various
Stainforth	Bruce		Goldfields	GODs workshop and Ore Deposits short course	June
Stegman	Craig			collaborative work, Master's thesis	August
Tedder	Ian		Newcrest Mining	AMIRA P588 Meeting	December
Thompson	John	Chief Geoscientist	Teck Cominco	GODs workshop, Ore Deposit Models and Exploration Strategies short course	June
Walters	Steve	Industry geologist	Geodiscovery	Ore Deposit Models and Exploration Strategies short course	June
Watts	Robert		BHP Billiton	ARC review of CODES	July
White	Noel	Consultant		collaborative work with staff and students	various
Willis	Ian		Anglo American	CODES Advisory Board, Science Planning Meeting	May

FELLOWSHIPS: QUEEN ELIZABETH II/AUSTRALIAN POST-DOCTORAL FELLOWSHIPS/INDUSTRY FELLOWSHIPS 2002

Principal Investigator	Project	Period	Total ARC Funds
L Danyushevsky	Melt inclusion constraints on the compositions (including volatile and chalcophile element contents) of primitive subduction-related and mid-ocean ridge magmas.	1998-2002	\$362,865
D Kamenetsky	Novel applications of melt inclusion studies: insights into the magmatic history of porphyry Cu-Au deposits and provenance of volcanoclastic sediments.	1999-2003	\$313,970
S Allen	Experimental simulations and textural analysis of submarine volcanoclastic mass flow deposits that result from large scale eruption and failure events	2001-2003	\$183,261

ARC LINKAGE PROJECTS: APA-I 2002

Investigators	Project	Partners	Period	ARC Funding over three years	Industry Funding over three years
G Davidson, D Cooke, J Yang (PhD project: L Evans)	Ground waters and fluid flow predictive modelling for management after mine closure	Pasminco	2001-2004	\$66,876	\$15,000

AMIRA/ARC (LINKAGE) PROJECTS 2002

Investigators	Project	Partners	Period	ARC funding over 3 years	Industry funding over 3 years
D Cooke, P Hollings; J Walshe (CSIRO), P Gow (CSIRO), G Midgley (CSIRO) PhD projects: J Cannell, P Frikken and G Masterman	AMIRA P511: Giant porphyry Cu deposits (Project 5.7).	Anglo American Exploration, AngloGold, BHP Billiton, Centaur Mining, Codelco-Chile, Falconbridge, GFL Mining Services, Goldfields Exploration, Homestake/ Barrick, Newcrest, Newmont, PacMin Mining/ Sons of Gwalia, Phelps Dodge Exploration, Placer Dome Asia Pacific, Teck Cominco, WMC Resources.	1999-2002	\$124,536	\$211,200
B Gemmell, W Herrmann, J McPhie, J Yang, R Scott, R Sharpe, M Blake; S Simmons (UAuckland), Students: A Wurst, D Olberg (CODES), G Cater, B Young (UAuckland)	AMIRA P588: Epithermal Au-Ag deposits: geological, geochemical and isotopic vectors to target major deposits (Project 3.9).	AngloGold, Aurora Gold, AurionGold, Barrick, Lihir Gold, Newcrest, Newmont	1999-2002	\$291,812	\$365,700
P McGoldrick, S Bull, D Selley, R Scott, D Cooke, R Large, M Blake, M Hitzman (CSM); PhD projects: D Broughton (CSM), N Pollington, M Croaker, W Mackay (CODES).	AMIRA P544: Proterozoic sediment-hosted Cu deposits: a comparison of Zambian and Australian environments (Project 4.6).	Anglo American (Zamanglo), AngloVaal Minerals, BHP Billiton, PIRSA, First Quantum-Mopani, Inco Exploration, Mount Isa Mines Exploration, Outokumpu, Phelps Dodge Exploration, Rio Tinto, Teck Cominco, WMC	2000-2003	\$393,000	\$1,092,000

ARC (LINKAGE) PROJECTS: LARGE COLLABORATIVE PROJECTS 2002

Investigators	Project	Partners	Period	ARC funding over 3 years	Industry funding over 3 years
R Large, G Davidson, W Herrmann, M Solomon, B Gemmell, M Blake; G Green, D Green, M McLenaghan, J Taheri (MRT); Student projects: K Bassano, A Woolford, S Herrmann	Isotopic response of fluid flow in submarine volcanic-hosted hydrothermal systems and implications for prospectivity: Mt Read Volcanics case study. (Project 3.12)	AurionGold, MRT, Pasminco Exploration	2000-2002	\$60,000	\$60,000
G Davidson, M Norman, R Large, A Rae, L Danyushevsky	Trace element analyses of sulfides by LA-ICPMS: exploration vectors	Anglo American, AngloGold, BHP Billiton, Placer Dome, Newcrest, Newmont	2002-2004	–	\$198,000

OTHER RESEARCH GRANTS 2002

Investigators	Project	Partners	Period	Funding
G Davidson	Tectonic, magmatic and hydrothermal evolution of ocean floor spreading at Macquarie Island	ASAC 1318	2002	\$8580
D Teagle (U.Southampton), J Alt (U.Michigan), M Bickel (UCambridge), R Coggon (USouthampton), G Davidson (CODES), S Roberts (USouthampton).	Tracing the interaction of seawater with the ocean crust during mid-ocean ridge hydrothermal alteration: unique opportunities from exposed oceanic basement on Macquarie Island		2002	The grant is for ship time, and station time
D Kamenetsky	The distribution of volatile and metallic elements in the Macquarie Island glasses and melt inclusions: Implications for fractional crystallisation and degassing during seafloor basaltic magmatism		2002	\$8,000

ABBREVIATIONS

16AGC	16th Australian Geological Convention
AGU	American Geophysical Union
AMIRA	Australian Mineral Industry Research Association
ANU	Australian National University
ARC	Australian Research Council
ASAC	Australian Antarctic Science Advisory Commission
CAMIRO	Canadian Mining Industry Research Organisation
CSIRO	Commonwealth Scientific & Industrial Research Organisation (DEM: Division of Exploration & Mining)
CSL	Central Science Laboratory, University of Tasmania
CSM	Colorado School of Mines
GA	Geoscience Australia
GEMOC	Key Centre for Geochemical Evolution and Metallogeny of Continents, Macquarie University
GEODE	Geodynamics and Ore Deposit Evolution program of the European Science Foundation
GEOMAR	Research Centre for Marine Geosciences at Kiel University, Germany
GES	School of Geography and Environmental Science, University of Tasmania
GIS	Geographical information systems
GSA	Geological Society of Australia
GSC	Geological Society of Canada
GSNSW	Geological Survey of New South Wales
IAGOD	International Association of the Genesis of Ore Deposits
IAVCEI	International Association of Volcanology & Chemistry of the Earth's Interior
IOCG	Iron-oxide Cu-Au
IPB	Iberian Pyrite Belt
ITGE	Instituto Tecnológica Geominero de Espana
JCU	James Cook University
LA-ICPMS	Laser ablation inductively coupled plasma mass spectrometer
LaTU	La Trobe University
LAVA	Learned Australian Volcanologists Association
LRS	Laser Raman spectroscopy
MDRU	Mineral Deposits Research Unit, University of British Columbia
MonU	Monash University
MRT	Minerals Resources Tasmania
MRV	Mount Read Volcanics
NHM	National Heritage Museum, London
PDAC	Prospectors & Developers Association of Canada
PIRSA	Primary Industries & Resources, South Australia
PIXE	Proton-induced X-ray emission (microprobe)
RAS	Miass University, Russia
PRISE	RSES research facilities
RSES	Research School of Earth Sciences, Australian National University
SEG	Society of Economic Geologists
SES	School of Earth Sciences, University of Tasmania
SGA	Society for Geology Applied to Mineral Deposits
SPIRT	Strategic Partnerships with Industry-Research and Training Scheme
UBC	University of British Columbia
UNE	University of New England
UTor	University of Toronto

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