The past year has been another exceptional period for CODES. Our successes have been many, as this Annual Report attests. In particular, the successful completion and opening of the Newcrest Laser Ablation Analytical Facility, which significantly increases our capacity for laser ablation analyses for both footprint and geochemical research. All our research activities are underpinned by our technological capabilities, and this new facility will help cement our position as leaders in ore deposit characterization. We thank Newcrest for its considerable support in helping this laboratory come to fruition.

We also thank all our industry partners for their ongoing support, including Peninsula, who we are pleased to say has joined the group as a Gold Sponsor. I believe that it is a sign of confidence in the future of CODES that one of South America’s largest precious metal mining companies has invested in our research. It is also good that it widens the global spread of our group.

There were a number of individual achievements during the year. The Society of Economic Geologists (SEG) announced that the SEG Gold Medal for 2013 will be awarded to Honorary Research Professor Noel White, and the Silver Medal to Deputy Director David Cooke. This is tremendous recognition to both Noel and David and cements their places with the greats of economic geology.

It was another exceptional year for our graduate research and training program, and first mention must go to Jacob Mulder, who received the highest grade for any Honours student studying the earth sciences since UTAS records began. Jacob’s grade of 95% led to him being nominated for the highly prestigious University Medal.

The higher degree by research program had a healthy enrolment figure of 52 students. This figure included 40 international students representing 24 nationalities, bearing further testament to the fact that students come from all around the world to seek a CODES qualification.

It was also a good year for our Master of Economic Geology Program, which had a very healthy figure of 49 UTAS-based students active in the program.

Three units were presented during the period, which were either at capacity or had record enrolments. This was an outstanding performance, especially as this was the first year without MTEC funding.

I am very pleased to report that in 2013 the Centre had more refereed journal articles published than in any other year in our 24-year history. The figure of 69, and the fact that our researchers have consistently exceeded the ARC Performance Indicator, is all the more commendable when one considers the high number of industry reports that they produce each year. Among this year’s figure were 45 papers from the Program One team, demonstrating that, while CODES has a focus on industry-driven outcomes, it still has a very strong base of fundamental research.

There were numerous research highlights during the period. The final meeting of AMIRA P843A was held in Brisbane, bringing to a close the Geometallurgy Mapping and Mine Modelling (GeMM) project to a close. This highly successful project has made a significant contribution to the testing and application of geometallurgy protocols that define mine variability in processing performance. During its final year, the team compiled eight years of research into a ‘compendium of results’ and presented it to sponsors.

Case studies of Chiquicamata, Escondida, Andina and Los Bronces were also completed, with the reports being submitted to sponsors as technical reports.

The value of our PhD students to our research activities was again in the spotlight when Jeff Steadman made a highly significant discovery of gold-bearing sedimentary pyrite nodules in the Black Flag Beds, well south of Kalgoorlie, Western Australia. This discovery has major implications for gold ore genesis models in the Yilgarn Terrane. A paper on the studies has been published in Precambrian Research.

Also in the Discovery Program, the VpHem3D modelling and inversion program was completed for ground, downhole, or airborne TEM. The program performs 3D inversions of TEM data more than 10 times faster than previously available methods. And the AMIRA P1041 project (Application of new technologies to deposit discovery) was successfully completed, with sponsors deeming that all objectives had been met. The team has published several papers during the year, including an article in Economic Geology on the gold deportment and genesis of the Cripple Creek-Victor deposit in the Victor-Rosebud district, South Africa. Two of our finest researchers, Associate Professor Ron Berry and Dr Peter McGrick, retired at the end of 2013 after many years of distinguished service to both CODES and the School of Earth Sciences. They have made substantial contributions to research and teaching and will be sorely missed. I wish them all the very best in their well-earned retirements.

As an offshore research facility, it is a sign of confidence in the future of CODES that one of South America’s largest precious metal mining companies has invested in our research. It is also good that it widens the global spread of our group.
CODES attained Australian Research Council (ARC) Centre of Excellence (CoE) status in 2005, and successfully applied for an extension in 2008, taking its tenure as a CoE to the end of 2013. In accordance with ARC rules, no further extensions are permitted.

During this period, the Centre has consistently exceeded virtually all the Performance Indicators set by the ARC. Areas where it has excelled include:

• Building an extensive network of national and international collaborations.
• Consistently exceeding targets for publications, while delivering an exceptionally high number of reports to industry.
• Establishing a worldwide reputation for excellence in postgraduate training, with a high proportion of graduates progressing to senior positions within the minerals industry.
• Achieving integration between fundamental and applied research through a team-based series of Programs.
• Garnering strong industry support through a highly collaborative, outcome-driven research model, which has been reflected in a consistently high ratio of industry funding.

Success in these areas is illustrated by the statistics in the tables below:

<table>
<thead>
<tr>
<th>AREA</th>
<th>TARGETS 2006 TO 2013</th>
<th>ACHIEVED FIGURES 2006 TO 2013</th>
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<tbody>
<tr>
<td>PUBLICATIONS</td>
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<tr>
<td>Refereed journal articles</td>
<td>360 (45)</td>
<td>439 (55)</td>
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<tr>
<td>Papers at national and international meetings</td>
<td>520 (65)</td>
<td>800 (100)</td>
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<tr>
<td>Invited keynotes</td>
<td>80 (10)</td>
<td>107 (13)</td>
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</table>

*ARC targets changed during the period. Therefore, bracketed figures and percentages are yearly averages. Other figures are totals over the period of the CoE.

GRADUATE RESEARCH AND TRAINING

- Percentage of HDR students attracted from interstate: 40% (30%)
- Percentage of HDR students attracted from overseas: 35% (62%)
- Honours students in Centre programs: 80 (10) vs. 106 (13)
- Percentage of students in projects linked to industry: 50% (74%)
- Employment of graduates by the minerals industry: > 65% (77%)

COLLABORATIONS

- Percentage of Australian cross institutional projects: 30% (42%)
- Collaborative projects with other global centres/groups: 80 (10) vs. 137 (17)
- International and national visitors: 320 (40) vs. 837 (105)

TECHNOLOGY TRANSFER

- Reports to industry: 520 (65) vs. 1,139 (142)
- Professional short courses/workshops for industry: 40 (5) vs. 158 (20)
- Registrants at the abovementioned courses/workshops: 600 (75) vs. 6,028 (753)
- Industry visitors: 520 (65) vs. 660 (82)
- Frequency of meetings with industry representatives: 100 (12) vs. 167 (21)
- Frequency of meetings with AMIRA Research Co-ordinator: 80 (10) vs. 104 (13)

FINANCE

- Matched funding: One-to-one ratio (i.e. ARC funds should be matched by funds from other sources)
- ARC funds were matched, and exceeded, by an average of 1 to 2.3
CODES was formed in 1989, and has been the Australian Research Council (ARC) Centre of Excellence in Ore Deposits since 2005. Based at the University of Tasmania, the Centre has grown substantially over the years and is now widely regarded as a global leader in ore deposit research and postgraduate training. It is home to 59 highly qualified research staff and 123 postgraduate students, further cementing its position as the largest university-based team of ore deposit researchers in the world.

Highly productive worldwide collaborations have been developed with over 70 industry companies, plus a host of joint research initiatives with 116 institutions and universities – 22 in Australia and 94 overseas. It currently has major research projects spanning 30 countries, and is the leading academic group to publish in Economic Geology. In 2013, it maintained its reputation for delivering excellence in technology transfer by producing 84 reports to industry and conducting 17 workshops and short courses in 10 countries, spread across all six permanently inhabited continents.

THE FIVE PROGRAMS

The Centre has adopted an holistic approach to the science that encompasses all areas of the research cycle. This has been achieved throughout its tenure as a Centre of Excellence through five major research programs – Location, Formation, Discovery, Recovery and Technology. In very basic terms, these programs can be explained as follows:

- LOCATION seeks to improve our knowledge of the tectonic and geological controls on the location of ore deposits.
- FORMATION develops practical, process-based ore genesis models to help explorers understand the formation of deposits.
- DISCOVERY focuses on the acquisition, processing and interpretation of scientific ore deposit data to assist in the discovery of minerals.
- RECOVERY is an integrated, cross-disciplinary field that seeks to enhance mineral processing techniques and optimise mineral recovery rates.
- The TECHNOLOGY Program uses a combination of traditional and cutting-edge technological developments to improve the understanding and, subsequently, advance the exploration and exploitation of minerals.

These five programs, together with a team-based approach, have formed the foundations of CODES’ ability to provide a seamless transition between fundamental and applied research.

TRANSITION TO A FOUR MODULE MODEL

At the end of 2013, CODES’ tenure as an ARC-funded Centre of Excellence came to an end. As part of its strategic planning, management decided to adopt a four module structure for 2014, and beyond.

Key objectives in developing this model were to ensure all the well established and valued research capabilities were maintained, while enhancing the structure to better reflect the Centre’s strengths. This model would also position it to meet the evolving needs of the minerals industry and other stakeholder groups.

The new integrated research modules provide the opportunity for a step-change in exploration techniques for metal discovery, new practices for sustainable mining, a steady supply of world class geoscience graduates, as well as creating a platform to meet the training and up-skilling needs of the minerals industry.

Opposite: Fe-oxide material from near the Kul-Yurt-Tau pyrophyllite deposit, Urals, Russia.
THE NEW MODULES FOR 2014

- **ORE DEPOSIT CHARACTERISATION** will provide end-users with process-based models for the formation of high value metalliferous ore deposits and a framework to develop innovative new tools for determining the most prospective regions for exploration (fertility), and for targeting buried ore deposits (vectoring).

- **GEOMETALLURGY**. Building on the success of the GeM project, this module will transform how explorers and miners plan and predict mining and environmental activities, by providing new tools to guide these activities from the initial discovery stage, rather than during feasibility assessment.

- **ENABLING TECHNOLOGIES** will produce innovative analytical and computational tools, and facilitate technology transfer to the minerals exploration and geoanalytical industries.

- **TRAINING** will build on CODES ability to produce highly-skilled Honours, Masters and PhD graduates, and provide professional development short courses and workshops for re- and up-skilling of the minerals industry workforce.

NEWCREST MINERAL RESEARCH FACILITY OPENS

The Newcrest-funded laser ablation facility opened in August, further enhancing CODES capabilities in ore characterisation. The Centre now has four cutting-edge laboratories catering for LA-ICP-MS analysis. In addition, it has reciprocal arrangements with the UTAS Central Science Laboratory, which has an extensive suite of complementary equipment, particularly in the areas of electron microscopy, ICP-MS, and Mineral Liberation Analysis (MLA).

The R&D program within the new facility is aimed primarily at developing calibration standards for sulfide analysis and LA-ICP-MS data reduction software for multi-standard calibrations and image quantification, including identification and size determination of micro-inclusions.

HUB, NODES AND INTERNATIONAL PARTNERS

CODES is based at the University of Tasmania, with satellite facilities, known as nodes, at the University of Queensland, University of Melbourne, Australian National University, and CSIRO. This structure has provided an exceptionally strong mix of skills and facilities by combining the research strengths of CODES’ UTAS Hub with the diverse range of expertise available through the nodes. The nodes’ strengths have included:

- Metallurgy and mineral processing (University of Queensland).
- Structure of ore deposits (Australian National University).
- Isotope geochemistry (University of Melbourne).
- Micro-beam analytical techniques (CSIRO).

The strengths of these Australian nodes have been complemented by four strong partnerships with the University of British Columbia, the Colorado School of Mines, Imperial College London and the Russian Academy of Sciences, which have provided an ideal platform for international research projects and augmented the Centre’s access to the latest technology.

Although the Hub and Nodes structure ceased at the end of its tenure as an ARC-funded Centre of Excellence, CODES will continue to build strong collaborative relationships with its key collaboration partners.
STAFF AND MANAGEMENT

CENTRE DIRECTOR
Centre Director, Professor Bruce Gemmell, is responsible for the scientific leadership and operational management of the Centre. He is supported in these duties by David Cooke (Deputy Director), the Advisory Board and the Executive Committee.

ADVISORY BOARD
The Advisory Board meets at least once a year to review the progress of the Centre and to advise on future directions. The Board is composed of representatives from major industry partners, University of Tasmania senior management, and key national geoscience organisations. It is chaired by Dr Paul Heithersay, who has extensive experience in the minerals industry and the public service. Paul Agnew from Rio Tinto is Deputy Chair.

SCIENCE PLANNING PANEL
The Science Planning Panel meets annually for a one-day forum of presentations relating to the Centre’s scientific research progress and to discuss potential new research projects. The membership is wider than that of the Advisory Board and includes a representative from all partner companies. The Panel is designed to provide industry with an opportunity to influence future research directions of the Centre.

CENTRE RESEARCH COMMITTEE
The Centre Research Committee includes all collaborating partner chief investigators. It meets annually to discuss research progress, new research opportunities and particularly to focus on effective collaborative activities across all Centre partners.

EXECUTIVE COMMITTEE
The Executive Committee consists of the Centre Director, Deputy Director, Graduate Research Co-ordinator, five program leaders and administrative managers. It meets approximately six times a year, working closely with the Director to develop the Centre’s goals, strategies and performance indicators.

STAFF MOVEMENTS 2013

APPOINTMENTS
Dr Ivan Belousov has been appointed as a mineralogist. Mary Frey was appointed on a short-term contract in a business development role.

Dr Jane Higgins has been appointed as PA to the Director, Bruce Gemmell.

Tokayuki Manaka submitted his PhD thesis during the year and was appointed as a junior research fellow, working on the Ore Deposits of SE Asia project.

Dr Paul Olin has been appointed as a laboratory analyst within the LA-ICP-MS facilities. Dr Olin was formerly with Boise State University, Idaho, USA.

Dr David Selley has returned to CODES after a period working for BHP Billiton in Singapore. David has been appointed as a research fellow and the co-ordinator for Honours coursework.

DEPARTURES
Five academic staff and six professional staff members left the CODES Hub during the year.

ACADEMIC STAFF
David Hutchinson, Andrew McNeill, Abhisit Salam, Ralf Schaa, and Helen Thomas.

PROFESSIONAL STAFF
Three professional staff were relocated to centralised administration hubs as part of a general UTAS restructuring program. Those affected were finance staff Claire Rutherford and Helen Scott, IT Officer Keith Dobson. In addition, Deborah Macklin and Karen Molross took up positions within other areas of UTAS, and Christine Higgins left the university. Mary Frey’s short-term contract in the role of business development came to an end in December.

CODES STAFF

NAME %

Director, Professor J Bruce Gemmell, BSc (UTAS), MA, PhD (Monash) VHMS deposits and epithermal Au-Ag 100

Deputy Director, Professor David Cooke, BSc Hons (La Trobe), PhD (Monash) Porphyry-Cu-Au, fluid-rock geochemistry 100

ACADEMIC/RESEARCH STAFF AT UTAS

NAME %

Dr Sharyn Allen, BSc (Massey), MSc (Auckland), PhD (Monash) Volcanic facies analysis 40

Dr Mike Boulton, BSc Hons (Sydney), PhD (UTAS) Igneous petrology, mineral chemistry 100

Dr Ivan Belousov, BSc, MSc (Moscow), PhD (UQ) Igneous petrology, geochemistry, volcanology, LA-ICP-MS analysis 100

Associate Professor Ron Berry, BSc, PhD (Flinders) Structure of mineralised provinces, CHIME dating, geotagging Hon

Dr Daniel Bombardieri, BSc Hons, PhD (UTAS) 3D potential field modelling 60

Dr Stuart Bull, BSc Hons, PhD (Monash) Clastic and carbonate sedimentology and volcanology Hon

Dr Rebecca Carey, BSc Hons (UTAS), PhD (SI Hawai) Volcanology 100

Professor Tony Crawford, BSc Hons, PhD (Melbourne) Petrology, geochemistry and texturics of volcanic arcs Hon

Professor Leonid Danyushkevich, PhD (UQ) Petrology, geochemistry, LA-ICP-MS analysis 100

Dr Garry Davidson, BSc Hons (ANU), PhD (UTAS) Sulfur isotope geochemistry and Cu-Au ores 50

Dr Paul Davison, BSc Hons, PhD (UTAS) Melt and fluid inclusions Hon

Dr Torren Fawson, BSc Hons (Canterbury), BTeaching, PhD (UTAS) Marine geoscience, petrology Hon

Dr Matthew Fox, MSc Hons (Imperial, PhD (UTAS)) Porphyry-Cu-Au and HS epithermal 100

Dr Jacqui Halpin, BSc Hons, PhD (Sydney) Metamorphic petrology, geochemistry 100

Dr Julie Hunt, MSc (UC), PhD (UTAS) Geometallurgy, ROG deposits 100

Dr Nic Jannels, BSc Hons (St Mary’s), PhD (UTAS) Porphyry-Cu-Au and HS epithermal 100

NAME %

Dr Maga Kametensky, PhD (UTAS) MLA-ESR, geologists, geochemistry 100

Professor Vadim Kametensky, BSc Hons (Moscow), PhD (Vernadsky Inst.) Petrology and geochemistry of melt inclusions 100

Professor Khan Zaeo, BSc (Baku), BSc (Queen’s), PhD (UTAS) Fluid inclusions, SE Asian metamorphics 100

Dr Lyudmila Kosty, PhD (UTAS) Fluid flow modelling 50

Dr Chun Kit Lai, BSc, MPhil (HKU), PhD (UTAS) Petrology, geochemistry and textonics of SE Asia 100

Professor Ross Large, BSc Hons (UTAS), PhD (UQ) Volcanic hosted and sediment-hosted base metal and gold ores 100

Dr Takayuki Manaka, MSc, PhD (UTAS) Ore deposits of SE Asia 100

Dr Peter McGoldrick, BSc Hons (Melbourne) Ore deposits and their halos Hon

Professor Jocelyn McPhie, BA Hons (Macquarie), PhD (UQ) Volcanic facies architecture and volcanic textures 100

Dr Sebastian Melfi, BSc Hons, PhD (Sydney) Petrology and textonics of the SW Pac.Ris 100

Dr Karen Orth, BSc Hons (Monash), PhD (UTAS) Volcanology 100

Dr Anya Reading, BSc Hons (Edinburgh), PhD (Sweden) Geophysics, seismology, computational methods 100

Dr Michael Roach, BSc Hons (Monash) Geophysical responses of ore deposits 50

Dr Rob Scott, BSc Hons, PhD (Monash) Structural geology, gold deposits / MTNETs Lecturer and Masters Programs Coordinator 50

Dr Aleksandr Stepanov, MSc (Novosibirsk), PhD (UTAS) Geohysics of rare metals 100

Dr Lejun Zhang, BSc, PhD (HFUT) Porphyry-Cu-Au and HS epithermal 100
## ACADEMIC/RESEARCH STAFF BASED AT COLLABORATIVE INSTITUTIONS

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<thead>
<tr>
<th>NAME</th>
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<tr>
<td>Dr Grant Ballantyne</td>
<td>15</td>
<td>JKMRC, University of Queensland</td>
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<tr>
<td>Dr Stacey Borg</td>
<td>70</td>
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<tr>
<td>Professor Dendre Bradshaw</td>
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<td>JKMRC, University of Queensland</td>
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<tr>
<td>Mr Alan Cockr</td>
<td>20</td>
<td>WH Bryan Mining Geology Research Centre, University of Queensland</td>
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<tr>
<td>Professor Stephen Cox</td>
<td>30</td>
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<td>Professor Mark Haments</td>
<td>40</td>
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<tr>
<td>Professor Peter Holfings</td>
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<td>Associate Professor Janet Hergt</td>
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<td>Professor Murray Hitman</td>
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<td>Colorado School of Mines</td>
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<td>Mr John Jackson</td>
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<td>Mr Harry Kokkonen</td>
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<tr>
<td>Dr Jaime Land</td>
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<td>JKMRC, University of Queensland</td>
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## EXECUTIVE COMMITTEE

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<td>Director, CODES</td>
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<tr>
<td>Ron Berry</td>
<td>Recovery (6) Program Leader</td>
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<tr>
<td>Steve Calladine</td>
<td>Communications Manager</td>
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<tr>
<td>David Cooke</td>
<td>Formation (7) Program Leader &amp; Deputy Director, CODES</td>
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<tr>
<td>Leonid Danyushevskiy</td>
<td>Technology (5) Program Leader</td>
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## ADVISORY BOARD

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<td>DMITRE-Geological Survey of SA</td>
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<td>Rio Tinto Exploration</td>
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<td>Ben Ackerman</td>
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<td>Margaret Britz</td>
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<td>Andrew Davies</td>
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## SCIENCE PLANNING PANEL (ALSO INCLUDES THE EXECUTIVE COMMITTEE AND ALL CODES RESEARCH STAFF AND STUDENTS)

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<tr>
<td>Cynthia Ansch</td>
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<tr>
<td>Kathryn Dicknes</td>
<td>St Barbara</td>
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## TECHNICAL/ADMINISTRATIVE STAFF

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<tr>
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<tr>
<td>Mr Steve Calladine</td>
<td>Communications Manager 100</td>
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<tr>
<td>Mrs Michele Chapple-Smith</td>
<td>Lapidary Technician 40</td>
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<td>Mr Peter Comish</td>
<td>Laboratory Manager 50</td>
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<tr>
<td>Mr Alex Cusson</td>
<td>Laboratory Technician 80</td>
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<tr>
<td>Ms Sarah Gilbert, BSc, Honours (UTAS)</td>
<td>Laboratory Manager ICP-MS 100</td>
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<tr>
<td>Dr Jane Higgins, BSc, BA (Hons), PhD (UTAS)</td>
<td>Personal Assistant to the Director 80</td>
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<tr>
<td>Mr Ian Little, BSc, Honours (UTAS)</td>
<td>Laboratory Analyst 100</td>
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<tr>
<td>Ms Elena Lounejeva</td>
<td>Laboratory Analyst 100</td>
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<tr>
<td>Mrs Katie McGoldrick</td>
<td>Laboratory Assistant 40</td>
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<tr>
<td>Ms Caroline Mordaunt, BA, Honours (King’s College London)</td>
<td>Administrative Assistant 20</td>
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<tr>
<td>Dr Paul Obol, BA, SOU, MSc, PhD (Wisconsin)</td>
<td>Laboratory Analyst 100</td>
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<tr>
<td>Ms June Pongsrat</td>
<td>Publications 15</td>
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<tr>
<td>Mr Jay Thompson, BSc, Honours, MSc (University of Iowa)</td>
<td>Laboratory Analyst 100</td>
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<tr>
<td>Mrs Jannette Thompson, BSc, (Dip. Chem), MSc (University of Iowa)</td>
<td>Laboratory Analyst 100</td>
<td></td>
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<tr>
<td>Ms Isabella von Lichtman, BSc, Honours (UTAS)</td>
<td>Curator / Administrative Assistant 25</td>
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GRADUATE RESEARCH AND TRAINING

Students enrolled in the UTAS Higher Degree by Research (HDR) Program make a major contribution to the research activities of the Centre of Excellence. Ninety per cent of HDR projects are integrated into the Centre’s five research programs and about two-thirds of the projects involve collaborations with the minerals industry. Although most students are based at UTAS in Hobart, a small number work with partner institutions.

In addition to the main HDR Program, the Centre plays a key role in up-skilling industry-based employees through courses such as those offered by the Master of Economic Geology Program. CODES also has a highly regarded Honours program, which includes students conducting a range of industry-sponsored projects in Tasmania, mainland Australia and overseas. Many of these students use this degree as a stepping stone to an HDR, or sensor positions within the minerals industry.

HDR PROGRAM

CODES’ success in attracting HDR students from overseas is underpinned by its international reputation as a research training centre. The 2013 HDR cohort included 40 international students representing 24 nationalities, 22 of whom were at least partly funded by Centre of Excellence scholarships. In addition, the HDR program has been generously supported by UTAS in the form of living allowance scholarships for Australian students, and tuition fee waivers for international students. On the termination of the ARC Centre of Excellence grant at the end of 2013, CODES PhD scholarships can no longer be offered to international students, and the Centre will be dependent on ongoing UTAS and industry support to recruit internationally.

There were 52 students enrolled in the UTAS HDR Program during 2013 (48 PhD and 4 MSc), which included thirteen new PhD students – Ben Cave (Australia), Jing Chen (China), Angela Escolme (Australia), Esaime Cherghi (Iran), Jodi Fox (Australia), Martin Gal (Australia), Sam Holt (Australia), Peter Morse (Australia), Lina Serrano (Colombia), Subira Sharma (India), Nathan Stevens (Canada), Irma Vejelyte (Lithuania), and Daniele Vergani (Italy). Paula Montoya (Colombia) and Stephanie Sykora (Canada) began as MSc students. Twelve PhD students and one MSc student had theirses under examination, seven of whom graduated: Mathieu Argeneau, Victoria Braniff, Lindsay Clark, Gina Cobenas, Abhisat Salam, Brono Sutopo, and Stacey Leichliter (MSc).

The number of thesis submissions and graduations reduced the effective PhD workforce to 39. In addition, two students suspended their candidature for part of the year, further reducing the effective PhD workforce slightly. Notwithstanding this natural attrition, both the figures for the effective workforce and new enrolments were significantly higher than 2012. It should also be noted that the intake of five Australian HDR students in 2013 was a record high, possibly reflecting the tighter employment situation in the minerals industry.

SEG STUDENT CHAPTER

The CODES SEG Student Chapter plays a vital role in the social integration and professional development of the cosmopolitan mix of students that make up the postgraduate cohort. The international nature of the chapter is suitably reflected by its recent Presidents. In 2011, it was Pedro Fonseca (Portugal) and Jeff Steadman (USA). In 2012, it was Dan Gregory (Canada) and Francisco Testa (Argentina), and in 2013 Francisco continued in the role until the election in October when Scotsman Sean Johnson took over the reins. Sean is currently supported by a committee with an equally international mix, which includes two Canadians, plus representatives from Australia, India and England – and the committee prior to October included members from Russia and China.

Working as a team, the students have organised a wide range of social and professional development activities during the year. Recreational pursuits included ice hockey, wine tasting, barbecues, house warmings, weekly meetings at a local watering hole, and dragon boat racing – with a lot of help from former student member (Dr) Nic Jansen.

The centre point of the professional development activities was the field excursion in July and August to Russia, with a particular focus on the mineral-rich Southern Urals. The group visited a number of mines, which were mainly exploiting VHMS and mesothermal gold deposits. Included in the trip was the Ore Genesis Conference at the Russian Academy of Sciences and a short stint of sightseeing in Moscow. Each of the students on the trip, plus the two industry participants, delivered oral and poster presentations at the conference.

The excursion was organised by the Student Chapter, led by Peter McGoldrick from CODES, plus Valeriy Maleninikov and Igor Zhukov from the Russian Academy of Sciences, and sponsored by AngloGold Ashanti, Barrick Australia, CODES, Data Metallogenica and the SEG.

It was good to welcome back former PhD student Andrea Aguani, who visited CODES again late in the year, and included a talk as part of the chapter’s ongoing seminar series. Andrea is now working at the University of Johannesburg. Erin Lawlis and Sean Johnson were successful in gaining SEG Fellowship Awards.

Opposite: PhD students Olga Apukhtina, Francisco Testa and Dan Gregery examining high grade VHMS ore during the SEG Student Chapter’s excursion to the Southern Urals, Russia.
The total number of UTAS Honours enrolments was 14, counting students in the year of their completion. This is lower than the previous year’s figure of 16, but that was a year in which the intake was much higher than average. Out of this year’s cohort, Sam Poker and Sam Cross joined the group from Monash University, Greg Clarke from the University of Western Australia, and Vikraman Selvaraja from ANU. The remaining ten students were graduates from UTAS.

There was a reasonable spread of projects amongst the disciplines, but with a bias towards economic geology (6), and to a lesser extent geophysics (3) and metamorphic petrology/geochronology (2). There were also single projects in the fields of sedimentology, and geomaterials. Seven of the projects were based in mainland Australia, with five in Tasmania – including Jacob Mulder’s project in the island’s remote deep-south. This year’s most exotic location was chosen by Vikraman Selvaraja, who was working in Indonesia (Gosowong). The Tasmanian projects were supported by Mineral Resources Tasmania, MMG Rosebery and Unity Mining, with the mainland and overseas projects being supported by Independence Group, Lynas Corporation, Newcrest Mining, Rio Tinto Exploration, Signature Gold, and Sirius Resources. CODES gratefully acknowledges the support of these sponsors.

The Honours year was again administered by Garry Davidson, with Peter McGoldrick supervising the coursework aspects. Peter retired at the end of 2013, and the Centre, and particularly everyone involved in the Honours program, thank him for the huge contribution he has made over many years.

Student supervision roles were widely shared between Garry Davidson (1), Michael Roach (3), Rob Scott (2), David Cooke, Ron Berry, Tony Crawford, Jocelyn McPhee, and Nic Jensen. Additional co-supervision was provided by Anya Reading (3), Julie Hunt, Sebastian Maffei, Andrew McNeill (MRT), Mark Duffett (MRT), Stuart Bull, Ron Berry, Nic Jensen, Nathan Fox, David Cooke, Ross Large, Bruce Gemmell and Jacqui Halpin. Although it is not usual to cover student grades in this report, an exception is being made in the case of Jacob Mulder, who produced the highest grade for any UTAS Earth Sciences Honours student on record – stretching back over 22 years. Jacob received a remarkable 93% for his thesis titled Structure and metamorphism of the Cox Bight-Red Point area, south west Tasmania. In recognition of his achievement, Jacob has been nominated for the prestigious UTAS University Medal, which he will receive in January 2014. The Exploration and Skills Mapping Course was again held twice during the year, attracting a high number of students from UTAS and mainland universities.

The Centre’s Master of Economic Geology Program continued the positive trends of recent years, with another strong performance in 2013, presenting three coursework units that were either at capacity or had record enrolments. Fourteen new students enrolled during the year, bringing the total number of UTAS-based students active in the national program to 49. It was also another good year for completions, with six students graduating: Margaret Hawke, Yungu Lim, Jonathan Robbson, Linda Spigg, Yong Zhang and Stanley Zatua. A further three students completed their degrees late in the year, and are eligible to graduate in 2014: Corrie Chamberlain, Tatjana Pucko and Michelle Psukas.

In March, David Cooke, Lejun Zhang and Michael Roach led a large group comprising fifteen Masters students, five industry participants and four CODES PhD students to Chile and Peru for the Centre’s most enterprising and logistically challenging short course, Ore Deposits of South America. This highly practical, field-based course gave students first-hand experience of the remarkable giant ore bodies of the Andes, and included visits to the world’s largest open-cut and underground mines. Deposit types visited included porphyry, epithermal, IOCG, skarn and MVT. The mix of adventure, breathtaking scenery, expert tuition, and exposure to extraordinary geology make this biennial course one of the most popular and memorable on the Masters Program calendar.

In June, David Cooke took the helm again to lead the second short course for the year, Ore Deposit Geochemistry, Hydrology and Geochronology. The course is designed to introduce participants to a range of geochemical, isotopic, hydrogeological and geochronological techniques used to interpret ore genesis and ore forming environments. David was assisted by expert teaching staff from CODES, various research institutes, and the minerals industry. Included in a long list of invited speakers were Shaun Barker (University of Waiato), Phil Blevin (GGNWR), Joss Robertson and Graham Carr (ECU/QLD), Lesley Wyborn (Geoscience Australia), plus leading mineral consultants Scott Hailey and Nick Oliver.

Although this is always one of the more popular courses on the calendar, no one was quite expecting to receive a record enrolment of 33 Masters students – the largest ever for a course in the national Minerals Geoscience Masters program. The two-week course was also attended by two industry participants, plus a healthy number of staff and students from CODES, which meant that the sixty-seater venue was full to capacity on most days.

The final Master of Economic Geology unit for the year was Geometallurgy, which built on the success of the inaugural course, held in March of the previous year. The course was originated to meet a need from industry, which has increasingly focused on this highly specialised field to increase the efficiency and profitability of its operations. The course program started in late October and was again led by Julie Hunt and Ron Berry from CODES. Julie and Ron were ably assisted by Dee Bradshaw from UQ, consultant Tori Kojovic, and Anita Parbukar-Fox and Taryn Noble from UTAS/CRC ORE.

Over 12 intensive days, the course covered all the key aspects of this highly specialised field, including rock properties, sample selection, mineralogy, comminution and mineral processing, statistical analysis and modelling, environmental issues, and finances. One of the most popular features of the inaugural course was a short, two-day field trip to western Tasmania. As a result of the positive feedback about this portion of the course, the excursion was expanded this year to three full days, encompassing visits to Metals X’s Renison tin mine, Grange Resources’ Savage River iron ore mine and Port Latta operation, and the ALS Laboratory in Burnie. Once again, this was a well attended course with 27 participants, comprising 23 Masters students, two industry participants and two CODES PhD students.

It is pleasing to note that the positive predictions made in last year’s report have come to fruition, despite this being the first year without MTEC funding. Although significant challenges still lie ahead, the attendance and enrolment figures over the past twelve months provide ample evidence that the Master of Economic Geology Program at CODES has a positive future.

THE PROGRAM FOR 2014:

- 16 – 30 March: Volcanology and Mineralisation in Volcanic Terrains (KEA703)
- 2 – 13 June: Exploration in Brownfield Terrains (KEA705)
- 20 – 31 October: Ore Deposit Models and Exploration Strategies (KEA701)
IN AUSTRALIA

Project locations are shown in capitals. Unless marked otherwise, student projects shown here are field and lab-based PhD projects.

1. **Andersen, Michael, SA (Hons)**
   - Analysis of wide angle reflection and refraction data, Mount Woods area, South Australia.

2. **Apukhtina, Olga, SA**
   - Stable isotopes (C, S and O) and halogens (Cl, F) in gangue and ore minerals at Olympic Dam: Evaluation of mantle and crustal contributions to mineralisation.

3. **Arnold, Sam, TAS (Hons)**

4. **Baker, Wayne, TAS (GDipSci)**
   - The correlations and exploration significance of the Natone Volcanics, Rosebery Group, western Tasmania.

5. **Barbosa De Souza, Luzianne, NSW (Masters)**
   - Webb’s silver project, NSW.

6. **Barratt, Victoria, TAS**
   - Integration of geological and structural data from Savage River Mine, Tasmania.

7. **Cavill, Chloe, VIC (Masters)**
   - Geochemical classification of orebearing/metaliferous fluids of the Costerfield region.

8. **Chandraprasert, Natnaree, TAS (Hons)**
   - Stratigraphy, structure and volcanology between the Mount Black Fault and the Rosebery Fault in the north-end of Rosebery Mine, western Tasmania.

9. **Clarke, Andrew (ANU), NSW (Hons)**
   - Vein formation at Endeavour 48 porphyry Cu-Au deposit, eastern Australia.

10. **Clarke, Greg, SA (Hons)**
    - Origin of breccias in the Vulcan South IOCG prospect, Gawler Craton, South Australia.

11. **Cross, Sam, QLD (Hons)**
    - A geochemical assessment of the prospectivity of the Fletchers Awl region, Queensland.

12. **Diemar, Glen, SA (Masters)**
    - Geochronology of hydrothermal REE minerals and their relationships with economic mineralisation at the Olympic Dam breccia complex, South Australia.

13. **Eshaghi, Esmaeil, TAS**
    - Petrophysical and geophysical investigation of western Tasmania.

14. **Ferguson, Matthew, WA (Hons)**
    - Mineral paragenesis and geometallurgical characteristics of the Karlawinda Deposit, Western Australia.

15. **Fox, Jodi, TAS**
    - The volcanic history of Heard Island.

16. **Gilmour, Phil, NSW (Masters)**
    - An aspect of the geology of the Koonenberry Belt, NSW.

17. **Gregory, Daniel, WA**
    - The trace element composition of sedimentary pyrite: Factors affecting uptake and uses of the data for determining pale-ocean conditions.

18. **Hawke, Margo, WA**
    - Geology of the DeGussa VMS deposit, WA.

19. **Hong, Wai, TAS**
    - Magmatic-hydrothermal volatile exsolution and mineralisation in Tasmanian Sn granites.

20. **Huang, Qiyue, SA**
    - Mafic dykes at Olympic Dam.

21. **Kyne, Roisin, NSW**
    - Genesis and structural architecture of the CSA Cu-Ag (Pb-Zn) mine, Cobar, NSW.

22. **Lewes, Chantelle, SA (Masters)**
    - An aspect of the geology of the Olympic Dam deposit.

23. **Lynam, Alexey, TAS**
    - The geology, geochemistry and genesis of the Avebury Ni deposit, Tasmania.

24. **Mulder, Jacob, TAS (Hons)**
    - The structure and metamorphism of the Cox Bight-Red Point Area, southwest Tasmania.

25. **Officer, Caitlyn, TAS (Hons)**
    - Stable isotope (S + C-O) and pyrite trace element anatomy of the Henty Gold Deposit, Tasmania, with emphasis on the zonation around the high grade Read Zone.

26. **Pascual, Michelle, TAS**
    - The characteristics and role of colloidal silica fluids in the formation of the Griesesiding Zn-Pb prospect, western Tasmania.

27. **Pereira da Fonseca, Pedro, TAS**
    - Facies analysis and correlations in complex mineralised submarine volcanic successions: Mount Read Volcanics, western Tasmania.

28. **Phythian, Daniel, WA (Hons)**
    - Geophysical investigation of Mt. Weld carbonatite, Laverton, Western Australia.

29. **Poker, Sam, TAS (Hons)**
    - A geophysical investigation of the northern extent of the Meredith Granite, northwest Tasmania.

30. **Rowlands, Will, VIC (Hons)**
    - Petrophysical properties and geophysical response of the Benambra (VHMS) deposits, Victoria.

31. **Rush, Jacqueline, NSW (Hons)**
    - Geology of the Mardsen Cu-Au porphyry deposit, NSW.

32. **Sharma, Subira, QLD**
    - Evaluation of links between Merlin-style Mo-Re mineralisation and magnetism in the Cloncurry fold belt, Queensland. Implications for exploration.

33. **Steadman, Jeffrey, WA**
    - BIFs, black shales, and gold deposits: A re-evaluation.

34. **Thomas, Lauren, WA (Hons)**
    - Geochronology and metamorphosis of the magmatic Ni-Cu Nova deposit, Albany-Fraser Range, WA.

35. **Veijalane, Irma, SA**
    - Mafic magnetism in the Gawler Craton: Distribution, composition, timing, sources and tectonic setting.

36. **Wu, Selina, TAS**
    - Volcanic hosted massive sulfide deposits of the Que-Hellyer Volcanics, western Tasmania.

LAB-BASED PROJECTS

**Chauhan, Mitesh (KMIC)**
- Application of small scale flotation testing.

**Cracknell, Matthew**

**Davidson, John (GDipSci)**
- Magnetic anomalies in continent ocean transition zones.

**Escolme, Angela**
- Predicting recovery in porphyry deposits: A geological perspective.

**Gal, Martin**
- The development of array methods for the analysis of on-land ambient seismic signals from deep ocean storms and coastal sources.

**Gilbert, Sarah**
- Development of analytical methods and standard reference materials for the determination of trace element concentrations and isotopic ratios in sulfur-rich minerals and silicate glasses.

**Hinge, Myall (Masters)**
- Approximate Inverse Mapping (AIM) inversion of Transient Electromagnetic (TEM) data.

**McMahon, Claire**
- Distribution of, and controls upon, pyrite trace element content of hydrothermal alteration zones at Hercules VHMS ore deposit, Tasmania and NICO IOCG ore deposit, Northwest Territories, Canada.

**Morse, Peter**
- Combined computational and human interaction strategies in knowledge generation from spatial and spatiotemporal information.

**Wells, Lydia (GDipSci)**
- Long-term assessment of the weathering characteristics of sulfide materials.
OUTSIDE AUSTRALIA

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

1. Ageneau, Mathieu. PNG
   Geology of the Kapit ore zone and comparative geochemistry with Minifie and Lanietz ore zones, Ladolam Gold Deposit, Lihir Island, Papua New Guinea.

2. Baker, Fabian. ARMENIA (Master)
   Amulsar HSE Au deposit, Armenia.

3. Basori, Mohd Basilr Iswadi Bin. MALAYSIA
   Geology of volcanic hosted massive sulfide (WHMS) deposits in Central Belt, Peninsular Malaysia.

4. Beas Caceres, Billy. PERU (Master)
   Petrography and mineralogy of volcanic rocks and age dating of La Zanja Mine, Peru.

5. Berkensbosch, Heidi. NEW ZEALAND
   Geochemistry of hydrothermal mineral chimneys from Brothers volcano, Kermadec Arc.

6. Calderon-Tipiani, Cesar. PERU (Master)
   Chancas low sulfidation deposit, Peru.

7. Cave, Ben. NEW ZEALAND
   A metamorphic source for tungsten in metasedimentary-hosted orogenic gold deposits; Insights from Otago, New Zealand.

8. Chen, Jing. CHINA
   The geology, mineralisation, alteration and fluid evolution of Zijinshan ore field, Fujian Province, China.

9. Clark, Lindsay. INDONESIA
   The geology and genesis of the Kencana epithermal Au-Ag deposit, Goowong Goldfield, Halmahera island, Indonesia.

10. Cobenas Benites, Gisela. SW PACIFIC
    The behaviour of metals during differentiation of subduction-related lavas: A case study of active submarine volcanoes on the Hunter Ridge, SW Pacific.

11. Erskine, Tobias. MYANMAR (Hons)
    Geochemistry, structure and mineralisation characteristics of the Mod Taung gold deposit, Myanmar.

12. Galván Gutiérrez, Víctor Hugo. MEXICO
    Palmarojo carbonate-base metal epithermal Ag-Au district, Chihuahua, Mexico.

13. Guan, JianXiang. CHINA, USA
    Origin of associated magnetite and sulfide mineralisation in large gabbroic intrusions: An LA-ICP-MS study of minerals and melt inclusions from the Paranhua and Taihe intrusions in Emeshan LiP and Duliush Complex.

14. Harrison, Rachel. INDONESIA (Master)
    Tujuh Bakti Cu porphyry-epithermal deposit, Java, Indonesia.

15. Holt, Sam. USA
    Understanding of basaltic eruption dynamics and mechanisms: Eruptive and explosive eruptions in Hawaii.

16. Jimenez Torres, Carlos Andres. PHILIPPINES
    Bantug lithocap, Negros Island, Philippines: Mineralogy, textures, and chemistry.

17. Johnson, Sean. FINLAND, ESTONIA, SWEDEN, RUSSIA
    The effect of metamorphic grade on trace element mobility in black shales.

18. Kamvong, Teera. THAILAND, LAOS
    Geology and genesis of porphyry-skarn Cu-Au deposits at the Northern Loei and Truong Son Fold Belts, Thailand and Laos.

19. Lawlis, Erin. PNG
    Au-bearing pyritic ore of Lihir, Papua New Guinea: Its physiochemical character and nature of the causative fluids.

20. Le, Xuan Truong. VIETNAM (Master)
    Mineralisation of Me Xi gold deposit, Vietnam.

21. Leichliter, Stacey. COLOMBIA (Master)
    Gold deportment and geometallurgical recovery model for the La Colosa, porphyry gold deposit, Colombia.

22. Lim, Yongu. CAMBODIA (Master)
    Geological setting and mineralisation characteristics of the Kratе North deposit, central Cambodia.

23. Makoundi, Charles. MALAYSIA
    Trace element variation in Phanerozoic shale sequences in Malaysia: implications for gold metallogeny of Sibumasu terrane.

24. Manaka, Takayuki. JAPAN
    Geochemistry and mineralisation characteristics of the Phuoc Son goldfield, central Vietnam.

25. McClelland, Rebecca. NEW ZEALAND (Master)
    Reefion Goldfield, New Zealand.

26. Montoya, Paula. COLOMBIA (Master)
    Commination studies: La Colosa case study.

27. Musialike, Michael. ZAMBIA (Master)
    Controls on gold mineralisation at Matala and Dunrobin, Zambia (Lusigold).

28. Nuanla-Ong, Saranya. MYANMAR (Master)
    Paragenesis, pyrite geochemistry and ore fluids at Htongyi gold veins, Myanmar.

29. Orovan, Evan. FLA
    Geology, geochemistry and genesis of the Namois porphyry Cu-Au deposits, Fiji.

30. Paipana, Supitchaya. THAILAND (Hons)
    Geochemistry and mineralisation characteristics of Bo Thong antimony-gold deposit, Chonburi province, eastern Thailand.

31. Piquer Romero, Jose Moulenes. CHILE
    Structural geology of the Andes of Central Chile: Evolution, controls on magmatism and the emplacement of giant deposits and implications for exploration.

32. Redi, Daniele. ITALY
    A contribution to the understanding of the eruptive behaviour of Somma-Vesuvius, A mineral chemistry perspective.

33. Rinne, Marc. PNG
    Geology and genesis of the contrasting Wafi-Golpu porphyry-epithermal deposit, Papua New Guinea.

34. Salam, Abhisit. THAILAND
    Geology and genesis of the contrasting Wafi-Golpu porphyry-epithermal deposit, Papua New Guinea.

35. Selvaraja, Vikraman. INDONESIA (Hons)
    Determining the nature and zonation of advanced argillic alteration and applying suitable geochemical exploration vectors in the Gosowong epithermal district, Indonesia.

36. Serrano, Lina. ARGENTINA, MAURITANIA, MALI
    The magmatic province of Patagonia and sills from Maunitania and Mali: Examples of silicic and basaltic large igneous provinces.

37. Steadman, Jeffrey. USA
    BIFs, black shales, and gold deposits: A re-evaluation.

38. Strickland, Nathan. USA
    One genesis of the Greens Creek WHMS Deposit, Alaska: Implications for mining, milling and exploration.

39. Sutopo, Bronto. INDONESIA
    The Martabe Au-Ag high-sulfidation epithermal mineralisation in the Tapianuli Selatan district, North Sumatra Province, Indonesia: Implications for ore genesis and exploration.

40. Sykora, Stephanie. PNG (Master)
    The geological, geochemical and genetic significance of the anhydrite seal, Ladam gold deposit, Lihir, PNG.

41. Testa, Francisco. ARGENTINA, CHILE
    Tourmaline breccia pipes: San Francisco de los Andes, Argentina and Rio Blanco-Los Bronces, Chile.

42. Vergani, Daniele. FRANCE
    The 2007 explosive activity at Piton de la Fournaise volcano (Reunion): Constraints on the eruptive processes by the volcanological study of the erupted deposits.
OBJECTIVE
To understand the links between tectonic setting, magmatism, basin evolution and ore deposit formation in modern and ancient settings.

INTRODUCTION
The Location Program focuses on igneous petrology and geochemistry, tectonics, and volcanology and their application to ore forming processes. Researchers work across microscopic to regional scales, and undertake laboratory and field-based studies, to better understand the major controls on the location, timing and size of ore deposits, particularly those in arc-backarc settings and continental rift basins. The program includes fundamental and more strategic projects, several of which are conducted in close collaboration with industry colleagues.

This is the final year that this research will be reported under the Location Program banner. From 2014, these activities will fall under the newly-formed Ore Characterisation Module, which will focus on providing end-users with process-based models for the formation of high value metalliferous ore deposits, and the tools to determine prospective regions for exploration and vectoring.

This new module enables the excellent research performed within Program One to continue and grow, while providing a broader, end-user focused platform for the research team.

HIGHLIGHTS
• The team published 45 refereed papers in 2013.
• A Special Issue on the “Tectonics and Metallogeny of mainland SE Asia” was published by Gondwana Research (online only at that stage). This volume contains 13 papers by Program One team members, and presents outcomes of research conducted in the Ore Deposits of SE Asia project, led by Professor Khin Zaw.
• Vadim Kamenshky and colleagues published a paper in Nature Communications on recently discovered kimberlites in Antarctica. The discovery demonstrates that Cretaceous kimberlite volcanism occurred contemporaneously over a vast area, on all Gondwanan continents.
• Peter McGoldrick presented an invited keynote paper at the Russian Academy of Sciences International Conference on Ore Genesis, held in Miass. Peter summarised the ‘Biological and geochemical features of ~1.6 Ga sea floor vents from northern Australia’, using results of research on global ocean chemistry, marine basins and mineralisation (Project P1A3).
• Gisela Cobenas and JianXiang Guan submitted their PhD theses.
• Three new volcanology PhD projects were initiated on Heard Island, Piton de la Fournaise (Reunion Island) and Kilauea, Hawaii.
Weidong Sun
GEOLOGICAL SURVEY OF FINLAND
GNS, NEW ZEALAND
Chris Adams, Mike Rosenberg
CHIANG MAI UNIVERSITY, THAILAND
GUANGZHOU INSTITUTE OF GEOCHEMISTRY, CHINA
Jakob Keiding, Rainer Thomas
GEOSCIENCE AUSTRALIA
Kenzo Sanematsu
JOHN LONG
FLINDERS UNIVERSITY
Chaodumrong, Somboon Khositanont
CONSULTANT, THAILAND
COLORADO STATE UNIVERSITY, USA
Sampan Singharajwarapan, Weerapan Srichan
BRITISH GEOLOGICAL SURVEY
Mike Crow
Kathy Ehrig
UNIVERSITY OF ADELAIDE
Cristiana Ciobanu, Nigel Cook
IRAN
UNIVERSITY COLLEGE OF SCIENCE, SCHOOL OF GEOLOGY, UNIVERSITY KEBANGSAAN, MALAYSIA
TERRAMIN AUSTRALIA
Ken Cross
SMITHSONIAN INSTITUTION, USA
Valeriy Maslennikov
Ian Roy
ROYAL HOLLOWAY, UNIVERSITY OF LONDON, UK
ISLAND PITON DE LA FOURNAISE OBSERVATORY, REUNION
Grahame Oliver
NATIONAL OCEANOGRAPHY CENTRE, UK
Alexander Belousov, Marina Belousova, Chris Newhall
MURORAN INSTITUTE OF TECHNOLOGY, JAPAN
Monash University
Geoff Clarke, Simon Williams
UNIVERSITY OF WESTERN AUSTRALIA
Geoff Clarke, Simon Williams
UNIVERSITY OF SYDNEY
Vasconcelos Andrea Marzoli
UNIVERSITY OF PADOVA, ITALY
UNIVERSITY OF PADJADJARAN, INDONESIA
UNIVERSITY OF NEW SOUTH WALES
Ray Coveney
UNIVERSITY OF MELBOURNE
Tim Lyons, Noah Planavsky
YUKON GEOLOGICAL SURVEY, CANADA
Mark Kendrick, Jon Woodhead
UNIVERSITY OF MISSOURI, USA
Jarl Gabrielsson, Paul Wallwork
UNIVERSITY OF OTAGO, NEW ZEALAND
James White
UNIVERSITY OF PAPADJARAN, INDONESIA
Mega Rosana
UNIVERSITY OF PADOVA, ITALY
Andrea Marzoli
UNIVERSITY OF WESTERN AUSTRALIA
Mark Barley
UNIVERSITY OF WESTERN SYDNEY
Lin Sutherland
VS SOBOLEV INSTITUTE OF GEOLOGY AND MINERALOGY, RUSSIA
Sergei Smirnov, Victor Thomas
YALE UNIVERSITY, USA
Noah Planavsky
LEADER JOCELYN McPHIE

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BRITISH GEOLOGICAL SURVEY Mike Crow
BROWN UNIVERSITY, USA Alberto Saal
CHIANG MAI UNIVERSITY, THAILAND Phisit Limtrakun, Sampan Singhjarawaran, Weerapan Shihan
COLORADO STATE UNIVERSITY, USA Holly Steen
CONSULTANT, THAILAND Clive Burnett
DEPARTMENT OF MINERAL RESOURCES, THAILAND Pol Chaojunmoeng, Somboon Khostanont
FLINDERS UNIVERSITY John Long
GNS, NEW ZEALAND Chris Adams, Mike Rosenberg
GEOLGICAL SURVEY OF FINLAND Peter Soerjonen-Ward
GEOLGICAL SURVEY OF JAPAN Kenzo Sanematsu
GEOECOSCIENCE AUSTRALIA David Huston, Terry Memagh
GFZ GERMAN RESEARCH CENTRE FOR GEOSCIENCES Jakob Keiding, Rainer Thomas
GUANGZHOU INSTITUTE OF GEOCHEMISTRY, CHINA Wedong Sun
HANOI UNIVERSITY OF GEOLOGY AND MINING, VIETNAM Hai Thanh Tran
HAWAIIAN VOLCANO OBSERVATORY, USA Michael Poland
IMPERIAL COLLEGE LONDON, UK Andrew Berry
INSTITUTE FOR FRONTIER RESEARCH ON EARTH EVOLUTION, JAPAN Yoshi Tamura
INSTITUTE OF GEOCHEMISTRY, RUSSIA Vladimir Naumov, Natalia Suchinchakova
INSTITUTE OF GEOLOGY OF ORE DEPOSITS, PETROGRAPHY, MINERALOGY AND GEOCHEMISTRY, RUSSIA Irina Andreieva, Alexander Bonsor, Yevgeni Plotkov
INSTITUTE OF TECHNOLOGY, INDONESIA Andri Subandrio
JAMSTEC, JAPAN Konishio Tan
KAGOSHIMA UNIVERSITY, JAPAN Kazushiko Kano
LAMONT-DOHREY EARTH OBSERVATORY, COLUMBIA UNIVERSITY, USA Enrico Bonatti
MACQUARIE UNIVERSITY Nathan Daczko
MAX PLANK INSTITUTE FUR CHEMIE, GERMANY Dmitry Kuzmin
MCGILL UNIVERSITY, CANADA Olga Vasyukova
MINERAL RESOURCES TASMAMIA Clive Calve, John Everard
MINING INDUSTRY, CANADA Kim Demmer
MONASH UNIVERSITY Ray Cas, Reid Keays, Massimo Raveggi
MURORAN INSTITUTE OF TECHNOLOGY, JAPAN Yoshio Goto
NANYANG TECHNOLOGICAL UNIVERSITY, SINGAPORE Alexander Belousov, Marina Belousova, Chris Newhall
NATIONAL OCEANOGRAPHY CENTRE, UK Martin Jutzeler
NATIONAL UNIVERSITY OF SINGAPORE Grahame Oliver
PITON DE LA FOURNAISE OBSERVATORY, REUNION ISLAND Andrina Di Muro
ROYAL HOLLOWAY, UNIVERSITY OF LONDON, UK Ian Watsonson
RUSSIAN ACADEMY OF SCIENCES Valery Maslennikov
SMITHSONIAN INSTITUTION, USA Richard Fiske
TERRAMIN AUSTRALIA Ken Cross
UNIVERSITI KEBANGSAAN MALAYSIA Wan Fuad Wan Hassan, Mohd Rozai Umar
UNIVERSITY COLLEGE OF SCIENCE, SCHOOL OF GEOLOGY, IRAN Minaheh Mirmohammadi
UNIVERSITY OF ADELAIDE Cristiana Ciobanu, Nigel Cook

PROJECT SUMMARIES

THEME 1A GEODYNAMIC CONTROLS ON THE FERTILITY OF FOLDBELTS, CRATONS AND SEDIMENTARY BASINS

P1A3 Global ocean chemistry, marine basins and mineralisation
P1AA Ore deposits of SE Asia
P1AT Geochronology of the Rocky Cape Group
P1AB Trace element and oxygen trends in the ocean through time*

THEME 1B MAGMAS, VOLATILES AND METALS
P1B1 Pelagic magma in volcanic arcs and intraplate volcanic provinces – eruption style, degassing processes, fluid evolution and links to mineralisation
P1B3M Melt-melt immiscibility and the origin of magmatite-apatite deposits
P1B4 The distribution of volatile and metallic elements in oceanic glasses and melt inclusions: Implications for fractional crystallisation and degassing during seafloor basaltic magmatism*

THEME 1C FOLDBELTS, CRATONS AND SEDIMENTARY BASINS

P1A4 Geodynamic controls on the fertility of foldbelts, cratons and sedimentary basins

P1A3 GLOBAL OCEAN CHEMISTRY, MARINE BASINS AND MINERALISATION
LEADER Peter McGoldrick

COLLABORATORS Tim Lyons, Noah Planavsky, Donna Satterthwait

The three aims of this project are to:
- Decipher processes that controlled the sulfur chemistry and redox state of oceans that existed in northern Australia approximately 1.65 billion years ago.
- Understand how coeval ocean water interacted with hydrothermal fluids responsible for forming the giant northern Australian Proterozoic SEDEX Zn-Pb-Ag deposits.
- Understand the role played by (micro-)organisms during seafloor venting of fluids responsible for Proterozoic sedimentary Zn mineralisation.

Peter McGoldrick has discovered a number of distinct microorganisms preserved on bedded surfaces of carbonaceous shales from the 1.59 Ga Century Zn deposit, using a scanning electron microscope (SEM). Several of these fossils are large and morphologically complex, and could be eukaryotes (of unknown affinities). Further work will
The GaRer Group samples was in
ever attempting to separate fossils from the rock using
the Cr isotope study of 1.4 Ga Roper Group samples was in
in order to characterise the Cr (and other trace
element) distribution in these samples.

McGoldrick in order to characterise the Cr (and other trace
mapping on several Roper samples was carried out by Peter
abeyance for most of 2013, partly due to Noah Planavsky’s

The Cr isotope study of 1.4 Ga Roper Group samples was in
involve attempting to separate fossils from the rock using

Subandrio, Lin Sutherland, Hai Thanh Tran, Paulo Vasconcelos,
Singharajwarapan, Weerapan Srichan, Holly Stein, Andri
Mega Rosana, Mohd Rozi Umor, Kenzo Sanematsu, Sampan
Limtrakun, Terry Mernagh, Chris Newhall, Grahame Oliver,
Teh Guan Hoe, David Huston, Somboon Khositanont, Phisit
Fuad Wan Hassan, Azman Ghandi, Sue Golding, Ian Graham,
Tea Khun Foo, Dave Huston, Somboon Khotisatont, Pris
Litttmakes, Terry Mennagh, Chris Newhall, Graham Oliver,
Gega Rosana, Mohd Rozi Umor, Kenzo Sanematsu, Sampam
Singharajwarapan, Weeraporn Srichan, Holly Stein, Anida
Subandrio, Lin Sutherland, Hai Thanh Tran, Paolo Vasconcellos,
Ian Watkinson

This project commenced in October, 2011, building on the
successful outcomes of two previous projects that examined
the age, style and origin of key ore deposits in SE Asia in the
context of regional tectonic and magmatic cycles. The scope
of the research has been extended to encompass the whole
of mainland SE Asia and Sumatra.

The aims to:

• Undertake a regional tectonic and metallogenic analysis of
  the mineralised fold belts in mainland SE Asia.
• Undertake deposit-scale studies to characterise many of
  the important ore deposits.
• Provide sponsor companies with an increased understanding
  of ore deposit location, formation and evolution.
• Provide a new understanding of the geological and tectonic
  events that formed ores deposits.
• Provide a new, well-constrained, dated, and documented
  geological framework to enable better exploration targeting.

Substantial field work was completed during the year in
southern and central Myanmar, at the Me Xie gold deposit in
Vietnam, and in eastern Thailand and central Malaysia. Of the
415 samples collected throughout the region, 181 samples
have been dated and geochemically characterised.

Three quarterly reports were submitted in 2013, which
included the following highlights:

• Detrital U-Pb zircon evidence suggests that South
  China (including NE Vietnam) was attached to the
  Tethyan Himalaya section of Gondwana, consistent with
  palaeoceilmatic and palaeoecological evidence from South
  China, NW Vietnam and central Laos. It also suggests that
  the Siberian was attached to NW Australia, as indicated by the
  Palaeoproterozoic zircons in clasts from the glaciomarine
  Kaeng Krachan Group of Phuket Island.

• The Ha Lang-Song Hien Boundary Zone and Tam Ky-Phuoc
  Son Suture Zone are two of the most important Palaeozoic
  sutures in eastern Indochina, hosting important orogenic
  gold deposits.

• The Indochina Terrane includes at least five Cu-Au
  metallogenic belts/zones and a variety of Cu- and
  Au-bearing deposits are present, indicating the high
  prospectivity of the region.

• Within Mogok Metamorphic Belt (MMB) in Myanmar, three
  distinct magmatic metamorphic and mineralisation events
  were recorded: Jurassic (200–170 Ma), Early Cretaceous
  (140–105 Ma) and Late Cretaceous to Cenozoic (75–15 Ma).

• Granitoids in southeastern Myanmar can be classified into
  I-type mafic-series, I-type ilmenite-series, fractionated
  I-type ilmenite-series and S-type granites. U-Pb zircon ages
  of the granites become gradually younger (85 to 48 Ma)
  from east (back-arc side) to west (island-arc side).

PIA4 GEOCHRONOLOGY OF THE ROCKY CAPE GROUP

LEADERS Peter McGoldrick, Jacqui Halpin

Collaborators

PIA6 TRACE ELEMENT AND OXYGEN TRENDS IN THE OCEAN THROUGH TIME

LEADER Ross Large

TEAM MEMBERS Stuart Bull, Leonid Danyushevsky, Jacqui
Halpin, Elena Lounejeva, Peter McGoldrick

STUDENTS Dan Gregory, Sean Johnson, Charles Makoundi,
Jeff Steadman

Collaborators

This project is using the technology developed by
CODES to analyse trace elements in hydrothermal pyrite in
ore systems to investigate sedimentary pyrite in seafloor
organic-bearing sedimentary rocks. Sedimentary pyrite
is the focus as it adsorbs a vast array of trace elements
from seawater, and thus can be used as a proxy for ocean
chemistry. The aim is to build a history of 25 trace element
concentration curves for the global ocean and to use
these curves to interpret how atmosphere O2 has varied
through time.

• To date, over 2,000 sedimentary pyrites from 131 black shale
  samples have been analysed, covering 77 time intervals from
  3,515 million years ago to the present day. Preliminary results
  have been accepted for publication in Earth and Planetary
  Science Letters.

In general, the trace element patterns show significant
variation of several orders of magnitude in the Archean and
Phanerozoic, but less variation on longer wavelengths in
the Proterozoic. Certain trace elements (e.g. Ni, Co, As, Cr)
have generally decreased in the oceans through time, other
elements (e.g. Mo, Zn, Mn) have generally increased, and a
further group initially increased and then decreased (Se, U, V).
These changes appear to be controlled by many factors,
particularly the oxygenation cycles of the Earth’s atmosphere/
oceans, the composition of exposed crustal rocks, and cycles
of ocean anoxia. The findings show that Ni and Co content of
seawater is affected by global Large Igneous Province events,
whereas redox sensitive trace elements, such as Se and Mo,
are affected by atmosphere oxygenation. Positive jumps in
Mo and Se concentrations prior to the Great Oxidation Event
(GOE1, c. 2.5 Ga) suggest pulses of oxygenation as early as
2,950 Ma, whereas similar rises in the same elements at 660
Ma place the rise of Neoproterozoic oxygenation (GOE2)
earlier than previously considered. A flat to declining pattern
of several redox sensitive trace elements (Se, Mo, U, Co, Ni)
in pyrite through most of the Proterozoic suggests the
possibility that a gradual drop in atmosphere oxygenation,
reaching a minimum in the Cryogenian, prior to GOE2.

The team propose that the Se content of sedimentary pyrite is
a robust proxy for oxygenation of the atmosphere. Se content
of pyrite is preferred to other redox sensitive proxies (e.g. Mo,
Zn, U, V) because it is concentrated in pyrite times
compared to the black shale matrix, it is evenly distributed
through the structure of sedimentary pyrite, and it is tightly
held by substitution for S, and thus the concentration is not
easily changed by diagenesis or metamorphism.
THEME 1B MAGMAS, VOLATILES AND METALS

P1B1 FELISC MAGMAS IN VOLCANIC ARCS AND INTRAPLATE VOLCANIC PROVINCES – ERUPTION STYLE, DEGASSING PROCESSES, FLUID EVOLUTION AND LINKS TO MINERALISATION

LEADERS Jocelyn McPhee, Vadim Kamenetsky
TEAM MEMBERS Sharon Allen, Rebecca Carey, Karsten Goemann, Maya Kamenetsky, Roland Maas, Sebastien Meffre
STUDENTS Olga Apukhtina, Glen Diemar, Pedro Fonseca, Jodi Fox, Sam Holt, Qiuyue Huang, Daniele Redi, Lina Serrano, Irma Vejelyte, Daniele Vergani

COLLABORATORS Andrea Agangi, Wolfgang Bach, Ray Cas, Kathy Cashman, Hamish Cattell, Jim Cole, Ken Cross, Kim Denwer, Kathy Ehrl, Richard Fiske, Yoshi Goto, Bruce Houghton, Emily Johnson, Martin Jutzeler, Kazuhiko Kano, Andrea Di Mauro, Michael Poland, Jorge Polvář, Carlos Rosa, Mike Rosenberg, Yoshi Tamura, Kenichiro Tan, Janis Thal, Olga Vasyukova, Paul Wallace, James White

This project concentrates on volatiles and metals in felsic magmas, using a combination of melt inclusion research and physical volcanology. One of the aims is to explore how degassing of felsic magmas affects eruption styles and products, and the influences of magmatic volatiles on related hydrothermal systems.

In a Journal of Petrology paper (Johnson et al. 2013), a detailed assessment was presented of the crystallisation and degassing histories of rhyolites in the Taupo Volcanic Zone (TVZ), New Zealand, and the behaviour of metals during differentiation. None of the analysed metals appear to partition into the vapour during ascent and degassing, as indicated by the overlap in metal concentrations in the most evolved melt inclusions and pumice glasses. These results imply that, given the remaining metal and chlorine concentrations in the rhyolites upon eruption, the voluminous rhyolites emplaced in the upper crust of the TVZ could be a viable source of some metals, chlorine, and other species to the hydrothermal systems via leaching of the rocks by heated, meteoric waters.

Papers in the American Mineralogist (Vasyukova et al. 2013) and Contributions to Mineralogy and Petrology (Vasyukova et al. 2013) reveal significant diversity in cathodoluminescence (CL) patterns in quartz from six porphyry deposits. In these papers, it is proposed that quartz in porphyry stocks primarily crystallises in-situ after magma emplacement and, thereafter, prolonged crystallisation, involving at least two more stages of crystallisation under continuous cooling, produces additional CL textures. This interpretation is consistent with all CL features observed, and is also in agreement with the existing model for the formation of porphyry-style deposits.

Internationally renowned volcanologist, Professor Stephen Self, visited CODES and IMAS in January, funded by a UTAS Visiting Fellow Grant. During the visit, two manuscripts were advanced to publication stage, a workshop on the dynamics of explosive eruptions was convened, and two public lectures were presented on flood basalts and explosive super-eruptions – both to full houses. Dr Andrea Agangi, University of Johannesburg, also visited CODES, funded by a UTAS Visiting Scholar Grant. CODES is collaborating with Dr Agangi in research on the Proterozoic Rooiberg Felsite in South Africa, a voluminous felsic unit comparable to the Gawler Range Volcanics in South Australia.

Over the past decade, a unique set of submarine silicic pumice samples has been collected from the modern seafloor and young, formerly submarine, successes. This has been accomplished with the support and collaboration of Yoshi Tamura (JAMSTEC), Kazuhiko Kano (Kagoshima University), and other international scientists. Sharon Allen and Rebecca Carey have analysed microtextural and compositional data that reveal the details of submarine eruption dynamics, and have been able to demonstrate that pumice vesulcularity can be used as a proxy for eruption intensity. Their results were presented at the IAVCEI Scientific Assembly in Kagoshima and are the subject of two manuscripts in preparation.

Former PhD student, Martin Jutzeler, has had a paper accepted by the Geological Society of America Bulletin on the Ohanapecosh Formation, Washington, USA, demonstrating how the facies characteristics relate to submarine explosive eruptions. Martin has another manuscript on a similar topic in review with the Bulletin of Volcanology.

Three new PhD projects commenced in 2013. Jodi Fox began research on the volcanic evolution of Heard Island, and will participate in a research cruise in 2014. Sam Holt is studying the dynamics of high fountain events in recent eruptions of Kilauea, Hawaii, and Daniele Vergani is investigating the 2007 eruption of Piton de la Fournaise, Reunion Island, focussing on a comprehensive eruption chronicle using multiple datasets.

OLYMPIC DAM PROJECT

Research on the supergiant Olympic Dam Cu-Au-U-Ag deposit is conducted in collaboration with Kathy Ehrl, BHP Billiton, and Roland Maas, from the University of Melbourne Node. A comprehensive review of the geology, mineralogy, composition and textures of the deposit (Ehrl et al. 2013) was published in a Special Publication of the Society of Economic Geologists. PhD students, Qiuyue Huang and Olga Apukhtina, have collected substantial new data. Qiuyue has been studying the compositions, ages, relationships and affinities of mafic dykes, and Olga has been analysing a complicated assemblage of carbonate minerals. New PhD student, Irma Vejelyte, joined the project and began research on the Wirnda Well prospect, southeast of Olympic Dam.

P1B38 MELT-MELT IMMOBILITY AND THE ORIGIN OF MAGNETITE-APATITE DEPOSITS

LEADER Paul Davidson
TEAM MEMBER Vadim Kamenetsky
COLLABORATORS Mark Dudley, Mirsaileh Mirmohammadi, John Nold, Rainer Thomas, Yuling Xie

The Fanshan study is continuing, and additional samples have been obtained. Extensive melt inclusion studies on these and previous samples have provided considerable evidence of melt/melt immiscibility with silicate, carbonate, sulfide, and Fe-Ti oxide components observed in various combinations in a range of melt inclusions. Three co-authored papers were published this year, in Geology, Ore Geology Reviews, and the Journal of Geosciences.

Opposite: Lake Kilauea within Kilauea caldera, Hawaii.
are identical to those in average global MORB. The observed melting, crystallisation or degassing of CO₂ from these melts. Cl, Br and K were not statistically fractionated during partial source and were not influenced by seawater contamination. The halogens in the Macquarie Island glasses had a mantle between Cl and other trace elements, demonstrate that fractionation of chemical elements in both the mantle source and mantle-derived melts. Measurement of Br/Cl, I/Cl and K/Cl, together with correlations and mantle-derived melts.

The measured δD and δ18O of the Macquarie Island glasses lack of variation is consistent with a bulk melting model in which water is rapidly scavenged into the first partial melt. The narrow ranges of δD and δ18O in normal mantle are mostly due to the buffering effect of clin- and orthopyroxenes in the residual assemblage.

These results have been published in three papers in Chemical Geology and Geochimica et Cosmochimica Acta.

The narrow ranges of δD and δ18O in normal mantle are mostly due to the buffering effect of clin- and orthopyroxenes in the residual assemblage. This is a continuation of the magnetite-apatite deposits and pegmatite research. Four manuscripts related to the felsic magmas project. Two manuscripts on magnetite-apatite deposits and pegmatite research. Four manuscripts related to research on melt immiscibility, kimberlite parental magmas, carbonatites and large igneous provinces. Finally, microprobe studies will be conducted on the new Fanshan samples. This is an extension of the magnetite-apatite deposits and pegmatite research, covered by two of the manuscripts mentioned above.
PROGRAM TWO

FORMATION

OBJECTIVE
To develop practical, process-based models for the formation of hydrothermal and magmatic ore deposits that will help increase discovery rates for Australia’s deep earth resources.

INTRODUCTION
Ore deposits form when chemical and physical processes cause dramatic changes in metal solubilities in hydrothermal fluids or magmas. These processes vary between deposit classes, and also between individual deposits. Evaluating the relative and absolute effectiveness of different ore-forming processes is essential for the development of new, process-based exploration models.

The Formation Program has two major research themes. Ore-Forming Processes investigates fundamental problems in ore genesis, taking advantage of CODES’ unparalleled access to world-class ore deposits, well-constrained sample suites and data sets, and cutting-edge technologies. These technologies are accessed via Program 5, the nodes, and international collaborators. This theme aims to generate high profile publications, targeting high impact journals such as Science, Nature, GCA, EPSL and Geology.

The second research theme is Ore Deposit Characterisation. In order to understand how ore deposits form, it is essential that alteration and mineralisation features are carefully documented, both in the field and in the laboratory. This applied research activity generates essential data for understanding deposit formation and refining mineral exploration models, which makes this theme strongly linked to Program 3. One of the aims is to publish key papers and special issues describing and interpreting world-class ore deposits in Economic Geology and Mineralium Deposita.

HIGHLIGHTS
- Successful implementation of a fully coupled hydro-mechanical modelling approach that is being used to explore permeability enhancement and fluid pathways in intrusion-related hydrothermal systems.
- Huge variations in boron isotopes identified in tourmalines from western Tasmanian Sn granites, implying major physicochemical changes during phase separation.
- Publication of a synthesis of CODES-Newcrest collaborative research outcomes from Australia, PNG and Fiji in SEG Special Publication 17.
- Paper on ‘High-precision U-Pb zircon chronostratigraphy of the Mount Read Volcanic Belt in western Tasmania, Australia: implications for VHMS formation’ has been accepted for publication in Economic Geology.
- Collaboration between CODES and Hefei University leads to new five-year collaborative research project funded by the Chinese Government.
- New PhD studies initiated at Merlin Mo-Re deposit, Cloncurry, and La Productura IOCG deposit, Chile.
ORE DEPOSIT CHARACTERISATION
THEME 2B

P2B1A Exploring the porphyry environment
LEADER Stephen Cox
STUDENT Andrew Clarke
COLLABORATORS David Beck, Arnd Flatten, Pamela Naidoo

Fully coupled hydro-mechanical modelling techniques are being used to explore generation of fluid pathways associated with fracture growth in intrusion-related hydrothermal systems. The 3D simulations explore controls on fluid migration from source cupolas into initially low permeability host rocks. Failure and associated permeability enhancement is driven largely by progressive fluid pressurisation; the orientation of the stress field plays a key role in controlling the geometry and distribution of high permeability host rocks. The most intense fracture damage is localised around the upper parts of cupolas, as seen in many porphyry Cu-Au systems. However, away from the cupula, segments of pre-existing fault networks are re-activated and localised flow. The simulations illustrate progressive migration of permeability enhancement front away from the fluid source via re-activated faults, as well as along segments of lithological contacts. The modelling provides new insights about the dynamics of coupling between fluid pressurisation, deformation and permeability enhancement in intrusion-related ore systems. Ongoing analysis is exploring how fluid production rates, stress states, the intrinsic permeability of host rocks, and the presence of porphyry-related ore systems can impact the generation of giant deposits.

P2B1B Porphyry and skarn mineralisation in China

P2B1C Shallow and deep-level alkalic mineral deposits

P2B2B Genesis of volcanic-hosted copper-lead-silver-gold massive sulphide deposits

P2B3C Hydrothermal event recognition and target vectoring in volcano-sedimentary strata

P2B3D Active base- and precious-metal-rich massive sulphide deposits

P2B4 Iron oxide copper-gold and related deposit types

PROJECT SUMMARIES
was supported by nine industry sponsors. Additional financial support derived from grants from the Natural Sciences and Engineering Research Council of Canada (NSERC) and Geoscience BC. Research results from the Lihir PhD study by Jacqueline Blackwell were published in Harris et al. (2013). The alkalic special issue of Economic Geology will be published in issue 4, 2014, which will conclude this project.

P2B3B GENESIS OF VOLCANIC-HOSTED COPPER-LEAD-ZINC SILVER-GOLD MASSIVE SULFIDE DEPOSITS
LEADER Bruce Gemmell
TEAM MEMBERS Ross Large, Khin Zaw
STUDENTS Mohd Basri Iswadi Bin Basori, Jo Condon, Margy Hawke, Nathan Steeves, Selina Wu
COLLABORATORS Andrew McNeill, Jim Mortensen
The genesis of volcanic-hosted copper-lead-zinc-silver-gold massive sulfide deposits is being investigated across the spectrum of massive sulfide deposit types, from typical seafloor VHMS (zinc-lead-copper-silver-gold) deposits, through sub-seafloor shallow-water, replacement gold-rich epithermal styles, to deep sub-volcanic intrusion-related copper-gold-rich styles. In 2013, research was undertaken on deposits at Foisey-Hellyer-Que-River-Mt Charter (Tasmania), DeGrussa (Western Australia), Greens Creek (Alaska) and Tasik Chini (Malaysia). Selina Wu is completing her PhD study on the VHMS Deposits in the Que-Hellyer Volcanics, western Tasmania. Selina is investigating the geologic setting and genetic relationships of the Foisey-Hellyer-Que-River-Mt Charter deposits and the distribution of hydrothermal alteration throughout the district. Nathan Steeves began his PhD investigation of the Greens Creek VHMS deposit in southeast Alaska. Nathan is studying the mineralogy, metal distribution and geochemical characteristics of the complex ore bodies. The study is being conducted in collaboration with Mark Hannington from the University of Ottawa.

Mohd Basri Iswadi Bin Basori submitted his PhD thesis on the geochemical, isotopic and genetic aspects of the Tasik Chini and related VHMS hydrothermal systems in Malaysia.

Three styles of massive sulphide mineralisation are distinguished in the Bukit Botol deposit area: a) stratiform sulphide lenses; b) disseminated sulphide; and c) stringer sulphide mineralisation. Banne layers are present locally and overlying the massive sulphide lenses. At Bukit Kataya, massive sulphide forms as stratiform sheets, overlain by a layer of Mn-Fe-rich exhalates and bante. The research was funded by Malaysian Government Scholarships and the Ore Deposits of SE Asia project.

Two student projects continued at Sandfire Resources’ new VHMS discovery at DeGrussa, WA. The first, a PhD project by Margy Hawke, is investigating the geologic, structural and geochronological setting of the deposits. The second is a project by Jo Condon, which is concentrating on the ore and gangue mineralogy, textures, paragenesis, mineral chemistry and sulfur isotopes of the prospects.

The first phase of a project aimed at improving the age, and geochronological, constraints on the development of the Mount Read Volcanic Belt (MRVB) was completed, in collaboration with Jim Mortensen (UBC). Work included U-Pb dating of zircons, which produced many new dates that have helped to constrain the timing of the development of...
OUTLOOK

This is the final year that these activities will be reported under the Formation Program. From next year, this program will merge with the Location and Discovery Programs to form one of the four new Modules: Ore Deposit Characterisation. Notwithstanding this change, all ongoing projects that were reported this year will continue as normal.

Plans for 2014 include a wide variety of activities within Australia and internationally. Close to home in Tasmania, detailed geochronological investigations will be conducted into the magmatic-hydrothermal transition textures from the Tasmanian Sn granites. While on mainland Australia, a major field campaign will be held at the Merlin Mo-Re deposit in Cloncurry, Queensland.

A little further afield, PhD studies will be completed at Wafi-Golpu (PNG) and Namosi (Fiji), while field studies will continue at Gosowong (Indonesia) and Lihir (PNG). In addition, a new field program is to be initiated at Mt Kasi (Fiji), and a PhD project will commence at Myra Falls, Canada.

In China, the five-year research collaboration with Hefei University of Technology in the middle and lower Yangtze metallogenic belt is scheduled to commence, and the PhD study in the Zijin mining district will continue. While in South America, a major field campaign will be conducted at the La Productura IOCG deposit in Chile.

The year’s activities will also include a collaboration with Becker Engineering (Sydney, Berlin) for the completion of modelling to explore the dynamics of fracture-controlled flow relevant to formation of porphyry Cu-Au systems.

A highlight in terms of journal articles will be the publication of the alkalic special issue of Economic Geology. Other notable achievements will be the publication of the first paper outlining the new detailed geochronological data for the Mount Read Volcanics, and the publication of a paper on the Cu isotopes of the Brothers volcano black smoker chimneys.
PROGRAM THREE
DISCOVERY

OBJECTIVE
To develop techniques for the acquisition and interpretation of ore deposit geophysical and geochemical data that will assist in the discovery of Australia’s deep earth resources.

INTRODUCTION
The Discovery Program leverages off CODES’ extensive, broad-based research expertise to enhance the development of geophysical, geochemical and geological models for specific world-class ore deposits. The program is structured around two key themes: innovative techniques for discovery, and integrated exploration models for discovery.

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

HIGHLIGHTS
- In the course of his PhD studies, Jeff Steadman made a highly significant discovery of gold-bearing sedimentary pyrite nodules in the Black Flag Beds, well south of Kalgoorlie, Western Australia. This discovery has major implications for gold ore genesis models in the Yilgarn terrane. A paper on the studies has been published in *Precambrian Research*.
- The VPem3D modelling and inversion program was completed for ground, downhole, or airborne TEM. The program performs 3D inversions of TEM data more than 10 times faster than previously available methods.
- Development of the Rosebery Area (Tasmanian base metal province) 3D geological model.
- A well-attended Leapfrog course was completed as part of the Program’s role in maintaining geochemical software in CODES.
- Article published in *Geophysics* on the use of the ambient seismic tool for determination of the depth of cover in mineralised settings.
- An article on the data inference approach to forcing large diverse data sets to yield incisive information received the ‘Bright Spot’ editor’s highlight in *Geophysics*.
- AMIRA P1060 Sponsors Meeting held in Townsville, Queensland.
- Completion of PhD thesis by Victoria Braniff; and Honours theses by Sam Poker and Vikraman Selvaraja.
- PhD theses corrections were submitted and approved for Mathieu Ageneau and Lindsey Clark.
- Successful completion of the AMIRA P1041 project (Application of new technologies to gold deposits), with sponsors deeming that all objectives had been met. The team has published several papers during the year, including an article in *Economic Geology* on the gold deportment and genesis of the Carbon Leader Reef in the Witwatersrand Basin, South Africa.
LEADER GARRY DAVIDSON

TEAM MEMBERS
Mike Baker, Ron Berry, Daniel Bombardieri, Stuart Bull, David Cooke, Leonid Danyushevsky, Nathan Fox, Bruce Gennett, Sarah Gilbert, David Hutchinson, Nic Jansen, Vadim Kamenetsky, Rozi Large, Elena Leunisova, Sebastien Matte, Anya Reading, Michael Roach, Abhisit Salam, Ralf Schaa, Rob Scott, Jennifer Thompson, Craig Winter, Lejun Zhang

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LAKEHEAD UNIVERSITY, CANADA: Peter Hollings, McArthur River Mining
McARTHUR RIVER MINING: Edward Morris
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MONASH UNIVERSITY: Michael Asten, Chris Wilson
NEWCREST MINING: Anthony Harris
OZ MINERALS: Mark Allen, Jorge Renavides, Hamish Freeman, Charles Funk, Nick Smith, Marcel Van Eck
RUSSIAN ACADEMY OF SCIENCES: Valery Maslenikov, Svetlana Maslenikova
SIRIUS RESOURCES: Jeff Foster
TARBIAT MODARES UNIVERSITY, IRAN: Ali Shoieb
UNIVERSITY OF ALBERTA, CANADA: Robert Creaser, Tim Lyons
UNIVERSITY OF CALIFORNIA RIVERSIDE, USA: Tim Lyons
UNIVERSITY OF JOHANNESBURG, SOUTH AFRICA: Bradley Guy
UNIVERSITY OF OTAGO, NEW ZEALAND: David Craw
UNIVERSITY OF QUEENSLAND: Tony Webster
YUKON GEOLOGICAL SURVEY, CANADA: Patrick Sack

LAKEHEAD UNIVERSITY, CANADA: Peter Hollings, McArthur River Mining
McARTHUR RIVER MINING: Edward Morris
MINERAL RESOURCES TASMANIA: Ralph Bottrell, Mark Duffett, Andrew McNell, Jafar Taheri
MMG: Steve Beresford
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YUKON GEOLOGICAL SURVEY, CANADA: Patrick Sack

PROJECT SUMMARIES

THEME 3A INNOVATIVE TECHNIQUES FOR DISCOVERY
P3A1C (AMIRA P1022) THE RAPID APPROXIMATE INVERSION OF TEM DATA
LEADER Peter Fullagar
TEAM MEMBER Ralf Schaa
STUDENT Myall Hingee
AMIRA P1022 was successfully concluded in August. During the course of the three-year project, capabilities for fast approximate 3D inversion of downhole, ground, or airborne TEM data were developed. The key deliverables were:
• Vpem3D - a 3D modelling and inversion program for ground, downhole, or airborne TEM.
• Vpview - a graphical user interface to expedite Vpem3D modelling and inversion.
• Know-how and interpretational insights were gained from the application of the project software to downhole, ground, and airborne TEM data from sponsors’ exploration sites.
The project met, or even exceeded, expectations in most areas. The new algorithm performs 3D inversion of TEM data more than 10 times faster than other available methods. In one highly impressive demonstration (Figure 1), borehole TEM data from a Rio Tinto site was inverted in just two minutes, while the resulting conductivity model was comparable to using conventional 3D TEM inversion software, which requires a run time of more than a week.
Inversion speed is achieved by transforming dB/dt or B-field decays to ‘resistive limits’, which in effect reduces multi-channel TEM inversion to a single channel magnetic inversion. Each model cell contributes to the resistive limit response as a magnetic dipole. Conductivity-depth imaging and 3D geological constraints are employed to restore as much as possible of the time-depth information that is lost as a result of the conversion to resistive limits. The models can carry lithological attributes as well as conductivity. Incorporation of lithology expedites integrated interpretation. It also permits different inversion options, specifically homogeneous property inversion and geometry inversion, in addition to conventional heterogeneous inversion figure (2).
The research built on the results of Ralf Schaa’s PhD study. The project was conducted in collaboration with Fullagar Geophysics, and sponsored by AngloGold Ashanti, Gold Fields, and Rio Tinto. Mira Geoscience contributed as a commercial partner.

CORE PROJECTS

THEME 3A INNOVATIVE TECHNIQUES FOR DISCOVERY
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TEAM MEMBER Ralf Schaa
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The research built on the results of Ralf Schaa’s PhD study. The project was conducted in collaboration with Fullagar Geophysics, and sponsored by AngloGold Ashanti, Gold Fields, and Rio Tinto. Mira Geoscience contributed as a commercial partner.
four papers were published (or accepted) directly relating to rocks exposure. The new techniques being developed reached exploration targets in regions of difficult terrane and limited machine learning strategies in knowledge discovery using at the 2013 ASEG meeting in Melbourne, with another paper and exploration community, the results were also presented international journal for applied geophysics. In order to raise structure of western Tasmania.

This project commenced in 2013, and has strong collaborative links with Mineral Resources Tasmania (MRT) and its TEAM MEMBERS

Daniel Bombardieri, Michael Roach

STUDENT Sam Poker

COLLABORATORS Andrew McNeill

This project has successfully proven the concept of using machine learning strategies in knowledge discovery using high-dimensional inputs of disparate geoscience data layers. This has resulted in new findings from existing data, including the identification of alteration zones and new exploration targets in regions of difficult terrain and limited rock exposure. The new techniques being developed reached maturity during the year, enabling a high level of attainment: four papers were published (or accepted) directly relating to this work.

P344A WESTERN TASMANIAN GEOPHYSICS

LEADER Anya Reading

TEAM MEMBERS Daniel Bombardieri, Michael Roach

STUDENT Sam Poker

COLLABORATORS Mark Duffett, Andrew McNeill

This project commenced in 2013, and has strong collaborative links with Mineral Resources Tasmania (MRT) and its West Tasmania Geoscience Initiative. Through combining geological and geophysical constraints, the research is developing a new understanding of the deep geological structure of western Tasmania.

Next generation 3D geological modelling being used by the team brings together lithological and structural field observations with gravity and magnetic modelling. In the first instance, the 3D geological models may be refined with the best possible constraints from LA-ICP-MS geochemical analysis. Remaining anomalies are of key importance, as they highlight where facies changes mineralisation or alteration systems have been overlooked, and also provide other new insights into details of regional structure.

This work is being driven by Daniel Bombardieri, who is a joint appointment between CODES and MRT. The research has already led to the development of a 3D model for the Rosebery area, which will potentially assist exploration for tin and other base metals in this mineral province. Further developments will be assisted significantly by recent upgrades to the petrophysics laboratory at UTAS/CODES.

THEM 3B INTEGRATED EXPLORATION MODELS FOR DISCOVERY

P381B (AMIRA P1060) ENHANCED GEOCHEMICAL TARGETING IN MAGMATIC HYDROTHERMAL SYSTEMS

LEADERS David Cooke, Bruce Gemmell, Mike Baker

TEAM MEMBERS Nathan Fox, Elena Lounjejeva, Jennifer Thompson, Lejun Zhang

STUDENTS Ayat Baig, Djohanne Celiz, Carlos Jimenez, Wes Lucch, Adam Pacey, Jose Piquer, Emily Smyk, Francisco Testa

COLLABORATORS Huayong Chen, Peter Hollings, Noel White, Clara Wilkinson

This initiative commenced in June 2011, building on research carried out within AMIRA P176A, which concluded in late 2010. The project is being conducted in collaboration with Lakehead University and Imperial College London, and has the support of 20 industry sponsors, making it the largest exploration-based research project in AMIRA’s history.

The aims are to develop and refine new geochemical and geological tools that will help explorers to determine the locations of porphyry and epithermal deposits, discriminate between different styles of mineralisation, and assess the fertility of individual districts. These techniques will assist explorers to detect the subtle hypogene geochemical dispersion halos that extend for kilometres away from the intrusion centres; thereby enhancing the ability to detect new deposits more quickly and at less cost. An additional aim is to develop cost-effective, field-based methods that can be applied by explorers who do not have access to suitable laboratory facilities for LA-ICP-MS geochemical analysis. The two main environments (lithocap and green rock) that are being explored in porphyry-epithelial districts are being further investigated, with the objective of developing new tools for exploration in these areas through analysis of pre-existing and new sample suites. Blind site testing is being used to validate the findings.

Tools developed by the P365A team have proven to work effectively in volcanic terrains, but have not been tested effectively in other environments. Therefore, an important component of the research is to investigate the effects on various protoliths (limestones, sandstones, granite, etc.).

Since project commencement, field campaigns have been conducted in the USA, Canada, Indonesia, Chile, Peru, Panama, Colombia, the Philippines and Argentina. Sponsor meetings in 2011 were held in Townsville, Queensland in May and at CODES in November. The project is scheduled to conclude in June 2014.

P381C LOW- AND HIGH-SULFIDATION EPITHERMAL MINERAL DEPOSITS

LEADERS Bruce Gemmell, David Cooke

TEAM MEMBER Nic Jansen

STUDENTS Mathieu Agenau, Lindsey Clark, Hugo Galvan, Erin Lawlis, Vikraman Selvaraja, Bronte Sutopo

COLLABORATORS Anthony Harris, David Huston, Ali Shohez

The geology and genetic model of low- and high-sulfidation epithermal deposits are being investigated in Australia and in the southwest Pacific region. Research has concentrated on determining the geological and geochemical constraints on the formation of these deposits, which will lead to improved genetic and exploration models.

LOW SULFIDATION DEPOSITS

• Research continued on the Newcrest’s Goowong Goldfield deposit, Malaharaha Island, Indonesia via an Honour’s study by Vikraman Selvaraja. Vikraman’s project was focused on the mineralogy and geochemistry of the advanced argillic alteration in the goldfield.

• PhD student Erin Lawlis continued her thesis on the modern greenground system associated with the low-sulfidation Ladalom Au deposit in PNG. This research is also supported by Newcrest.

• A manuscript is in preparation for submission to Economic Geology, based on the PhD research of Ali Shohez (Tarkwa gold mine, Fekola Resources, Ghana). A highly significant discovery of gold-bearing pyrite nodules in Black Flag Beds, well south of Kalgoorlie, was made by Jeff Steadman in the course of his PhD studies. This work, which was published in the Precambrian Research, has major implications for gold ore genesis models in the Yilgarn terrane in Western Australia.

P382A SEDIMENT-HOSTED GOLD–ARSENIC–TELLURIUM DEPOSITS: GENESIS & EXPLORATION MODELS

LEADERS Ross Large, Sebastien Meffre

TEAM MEMBERS Leonid Danyushhevsky, Garry Davidson, Sarah Gilbert, David Hutchison, Elena Lounjejeva, Abhiset Salam, Rob Scott

STUDENTS Dan Gregory, Jeff Steadman

COLLABORATORS Rob Burnett, Dave Crow, Mark Doyle, Bradley Guy, Peter Haines, Arthur Hickman, Tim Lyons, Valery Masevnikov, Svetlana Maslennikova, Patrick Sack, Peter Sorjonen-Ward

The AMIRA-funded aspects of this project (P1041) were completed during the year.

The aims of the AMIRA project were to test the following:

• The application of new LA-ICP-MS technologies to the resolution of gold deportment and exploration trace element signatures in a range of gold deposits.

• The use of pyrite chemistry as a vector tool in the halo of several gold deposits.

Nine case study sites were provided by the sponsor companies for evaluation, utilising the new LA-ICP-MS technologies developed in the project to determine gold deportment and trace element signatures.

• Wall epithermal gold deposit, PNG (Newcrest)

• Mt Olympus sediment-hosted gold deposit, WA (Sipa)

• Witwatersrand Carbon Leader Reef (CLR), South Africa (AngloGold Ashanti)

• McPhilemmy volcanic-hosted gold deposit, NSW (Newmount)

• Golpu porphyry copper-gold deposit, PNG (Newcrest)

• Hope Bay greenstone-hosted gold deposit, Canada (Newmont)

• Chatree epithermal gold deposit, Thailand (Issara)

• Matarpe epithermal gold deposit, Indonesia (G Resources)

• Geita Hill, BIF-hosted gold deposit, Tanzania (AngloGold Ashanti)

The case studies provided an excellent test for the capabilities of the LA-ICP-MS technology and, in each case, the primary questions relating to gold deportment and exploration trace element signatures were successfully answered. These results have subsequently been combined with petrographic studies of overprinting mineral deposits.

The CODES laboratory team has made very significant progress in developing new interpretation techniques, refining computer reduction processes and reducing the costs of analysis for end-users. A new analytical package has been developed that provides cost-effective gold deportment, exploration signatures and vector testing procedures. This package is now available to the project sponsor companies and other end-users.

Several publications from the team have appeared during the year, including a paper in Economic Geology on gold deportment and the genesis of the Carbon Leader Reef in the Witwatersrand Basin, South Africa.

A highly significant discovery of gold-bearing pyrite nodules in Black Flag Beds, well south of Kalgoorlie, was made by Jeff Steadman in the course of his PhD studies. This work, which was published in the Precambrian Research, has major implications for gold ore genesis models in the Yilgarn terrane in Western Australia.
P385C THE GEOLOGY AND GENESIS OF THE AVEBURY Ni DEPOSIT—IMPLICATIONS FOR EXPLORATION

LEADER Vadim Kamenetsky

STUDENT Alexey Lygin

COLLABORATORS Steve Beresford, Jeff Foster, Andrew McNeill

The serpentinite-hosted Avebury nickel sulfide deposit in Tasmania is the world’s largest known hydrothermal deposit, and provides an unprecedented opportunity to understand sources of metals and fluids responsible for this style of economic mineralisation.

It has been found that a rare type of hydrothermal nickel sulfide mineralisation relates to post-magmatic and post-metamorphic modification of peridotites, rather than to magmatic differentiation processes. This study shows that serpentinisation of the Ni-rich olivine in the Cambrian peridotites of the McVicor Hill Complex, followed by metamorphic transformation related to the Devonian granite intrusion, were instrumental in the economic accumulation of nickel sulfides. This model has implications for exploration for similar deposits in the region.

P386A STRUCTURE AND FORMATION OF THE SAVAGE RIVER MAGNETITE DEPOSIT

LEADERS Ron Berry, Rob Scott

STUDENT Victoria Braniff

COLLABORATORS Ralph Bottrell, Roger Hill, Edward Morris, Jafar Taheri, Tony Webster, Chris Wilson

The Savage River magnetite deposit is hosted by strongly deformed Neoproterozoic meta-sedimentary and metavolcanic rocks (schists) of the Arthur Metamorphic Complex, in NW Tasmania. Grange Resources has owned and operated the mine since 2009. The purpose of its research collaboration with CODES was to develop a structural model for the magnetite ore bodies and their immediate host rocks, and to improve prediction of geotechnical performance of the planned and future pit designs. The study combined principles and techniques of geotechnical engineering and field-based structural geology. A key component of the study was to investigate links between the distribution of unfavourably-oriented brittle feature fabrics (controlling pit wall stability) and ductile feature fabrics formed during the Cambian (Yennan) and Devonian (Tabberabberan) orogenies. This project was completed in 2013, with the submission (and subsequent awarding) of Victoria Braniff’s PhD thesis, entitled ‘Integration of geotechnical and structural data from Savage River Mine, Tasmania’.

Victoria’s study identified unfavourably-oriented hematite-filled joints as the release surfaces for the majority of recent failures at the mine. These joints were found to be concentrated within a 10–60 m wide damage zone along, and to the east of, the subvertical, N-S striking Eastern Contact Fault (ECF), which bounds the highest-grade magnetite ores (to the west). Similar problematic damage zones were identified west of the Magnesite Fault, which locally forms ores (to the west). Similar problematic damage zones were found to be associated with a series of open-space fractures that are locally undeformed, and provide pathways for fluid migration.

Similar zones of mylonitic fabric development are widespread throughout the immediate host rocks at Savage River. U-Pb dating of monazite suggests these mylonites are of Devonian age. Similarily oriented Cambrian mylonite zones record strike-slip displacement, contain biotite, and locally preserve hornblende and higher pressure amphiboles, such as ferrowenchite.

P387A IRON OXIDE COPPER-GOLD AND RELATED DEPOSIT TYPES

LEADER Garry Davidson

TEAM MEMBERS Stuart Bull, Sebastien Meffre

COLLABORATORS Mark Allen, Jorge Benavides, Robert Creaser, Hamish Freeman, Marcus Tomkinson, Marcel Van Eck, Pat Williams

This project has been predominantly based on the Prominent Hill IOCG deposit, South Australia. The main project concluded in 2012, and no further funding was forthcoming. However, funding had been set aside for a Nd isotope study of Prominent Hill, co-ordinated by Pat Williams from Clump Mountain Geoscience, with analytical work being undertaken at the University of Alberta by Robert Creaser. This sub-project used well characterised samples from this and previous CODES-based projects. All major lithologies were analysed in 2013. The next phase of the work is to integrate these results with other findings of this confidential project, during the write-up for refereed journals.

P388 APPLICATION OF CARBONATE C-O ISOTOPES TO GOLD EXPLORATION: SUNRISE DAM, YILGARN CRATON

LEADER Garry Davidson

TEAM MEMBER Craig Winter

COLLABORATORS James Cleverley, June Hill, Michael Nugus, Nick Oliver

This new project developed out of a smaller halo-focused project in 2011, involving components of lithogeochemistry, hyperspectral analysis, stable isotope geochemistry and integration with drilcore features such as vein density, intensity of alteration, and gold grade. From an isotopic perspective, the aims are to determine the usefulness of C-O isotopes for detecting ore halos, while identifying barren from mineralised systems, and constraining the genetic model of ore formation.

There have been significant advances in understanding of C-O variation in Archean orogenic gold systems, with an appreciation that this variation is very much larger than known from earlier studies around the world, which predominantly involved very limited sample populations. The work at Sunrise Dam has been focused on determining the scale of variability in and around individual lodes, and subsequently using this information to establish an appropriate sample density to extend outwards into the rock mass. In 2013, the project produced ~100 analyses of two drill holes that transected deeper lodes. These holes have been analysed at close scale using a large number of geochemical techniques. Work also commenced on evaluating the use of carbonate-staining to cheaply identify carbonate generations, which may help optimise selection of samples for C-O work.

The project, which is solely funded by AngloGold Ashanti, will continue until July 2014.

OUTLOOK

In 2014, the Discovery Program will fall under the domain of the Ore Characterisation Module (see Research Framework starting on page 8 for further details). However, all current and active projects in this program will continue. A highlight of the coming year will be the completion of the geophysical modelling work in the base metal and tin province in western Tasmania, and subsequent preparation of material for publication. Also in the geophysics area, the P3A3A team plan to investigate the viability of a potential new AMIRA project that will build on the success of the machine learning approach to large data sets. In spite of the downturn in exploration activities, this proposal has some chance of success because existing data may be used and no ‘on-site’ logistical support is necessarily required.

In June 2014, the highly successful AMIRA P1060 project will draw to a close, marked by a final Sponsors Review Meeting at CODES. However, the team plan to seek support for a further extension project to enable this valuable research to continue. Also in the exploration models theme, a paper will be finalised on the collaborative Nd-isotope studies at Prominent Hill in South Australia, with the aim of it being published in a top refereed journal later in the year.

There were a number of positive outcomes for students in past year, and it is pleasing to note that a new PhD study is soon to commence on the Don Nicholas low to intermediate sulphidation deposit in Patagonia, Argentina.

Negotiations will also commence with Mexican-based exploration companies with a view to gaining support for further Au-Ag epithermal deposit research. And several spin-off projects from AMIRA P1041 are expected to get underway during what looks to be a very full year of activities.
OBJECTIVE
To create and develop a series of small-scale, low-cost, practical geometallurgical tools, protocols, proxies and processing indices for the purpose of ore-body domaining and mine planning.

INTRODUCTION
Over the past decade, the extent of research conducted within the field of geometallurgy has significantly increased. Industry recognition of this growing discipline, and the subsequent need for new large-scale, integrated geometallurgical research, resulted in the development of the AMIRA P843 (Geometallurgical Mapping and Mine Modelling) project, which has commonly become known as GeM III. The project commenced in July 2005, in collaboration with the University of Queensland (UQ), with a vision to establish a collaborative, cross-discipline research platform to support the emerging role of geometallurgy in providing predictive inputs into mine planning, economic optimisation and sustainability. During its initial four-year period, GeM III became the fastest growing and largest foundation project in AMIRA’s 50-year history, which led to an extension of the project (AMIRA P843A) in 2009. Over the project’s full lifespan, it has been highly successful in developing an array of geometallurgical methods and protocols in areas of comminution and flotation. It has incorporated aspects of mining, liberation, recovery (flotation and leaching) and environmental impact, and carried out important larger-scale, site-specific case studies aimed at evaluating these methods in active mines – paying careful attention to the potential for integration of the findings into resource models, mine planning and optimisation studies.

AMIRA P843A, which was completed in 2013, has made a significant contribution to the testing and application of geometallurgy protocols that define mine variability in processing performance. The measurement of comminution behaviour has reached a mature stage and is now migrating to the companies that provide specialised services to the mining industry, including the project’s five supplier sponsors.

Although this project came to a conclusion in mid-2013, planning is underway for an AMIRA continuation project – see the Outlook section at the end of this Program report for further details.

HIGHLIGHTS

GENERAL
• Final meeting held for AMIRA P843A.
• Eight years’ research compiled into a ‘compendium of results’ and presented to sponsors.
• Protocols for photographic recording of core have been taken up by several sponsors and are in practice at mine sites.
• Site based protocols for measuring proxies for core hardness are being applied at several sites and are receiving wider recognition.
• In line with the GeM III project’s ongoing commitment to technology transfer, the team led, and helped present, the Geometallurgy unit of the Master of Economic Geology Program, held towards the end of the year.
• Program Leader Associate Professor Ron Berry retired.

• Dr Will Goodall from UQ/JKMRC appointed to define and lead the extension to the AMIRA P843A project, which will be called AMIRA P843B (see Outlook section).

THEME 2 (P4A2)
Integrated Blast Modelling
• Release of iFragX blast fragmentation modelling software to sponsors.

THEME 3 (P4A3)
Deterministic Comminution Modelling
• Interactive CD on comminution testing released.

THEME 4 (P4A4)
Texture-based Liberation and Recovery Modelling
• Conducted a major review of texture relevant to liberation, including a review of proxies for gold grain size.
• Protocol established for combined Bond Mill Work Index, and batch flotation test conducted on small samples.

THEME 5 (P4A5)
Predictive Leaching Indices
• Selective leaching tests validated.
• Standard operating procedures released for diagnostic and selective leaching, agglomeration and rheology tests.

THEME 6 (P4A6)
Specialist Analytical and Support Software
• Large-scale trial conducted of STORC (structure from core) and SupLCore (support for core logging) software.

(P4A7) Case Studies and Technology Transfer
• Case studies of Chuquicamata, Escondida, Andina and Los Bronces completed and reports submitted to sponsors.
PROJECT SUMMARIES

THEME 1 (P4A1) PREDICTIVE ENVIRONMENTAL INDICES

As reported in the 2012 Annual Report, this theme has been transferred to CRC ORE, with involvement via UTAS Earth Sciences.

THEME 2 (P4A2) INTEGRATED BLAST MODELLING

LEADER Alan Cocker
TEAM MEMBERS Ron Berry, Toni Kojovic, Angus McFarlane, Simon Michaux, Khoi Nguyen, Italo Onederra
STUDENT Hector Parra Galvez
This theme is divided into three parts. In the first part of the theme, the IfragX software, which integrates high-resolution bulk rock properties into advanced blast models, has been extended to interact with both the DomAin software and data relating to measurements taken while drilling. IfragX was released to the sponsors in March and distributed in the final compendium of results.

In the second part of the theme, blast induced fragment conditioning for leach performance was tested on an artificial rock analogue blasted in barrels. Samples at various positions with respect to the blast centre were tested for comminution strength and leaching behaviour. The blast condition had a detectable effect on crushing strength but not on grinding behaviour. The leaching response to blast intensity was too weak to detect against the experimental noise. Other features of the rock were more important than the blast induced fracturing in the leaching experiments. No additional tests are planned in this area.

In the third part of the theme, a final version of the STORC (structure from oriented core) software program was released, complete with a manual. A large-scale trial, based on 500 metres of sponsor core, demonstrated that this software can produce orientation data on fracture patterns suitable for mine planning.
There have been continual discussions on how to collect and make optimal use of good quality photographs of drill core. The latest recommendations for taking good quality core photographs were covered in the core photography manual, which formed part of the final report. The STORC, SupCore and TextureLets software modules were also developed to highlight applications based on good quality photographs.

Various projects on texture related to mineral processing were nucleated within this Theme, including one covering grain size determination and the use of sampling statistics to generate proxies for gold grain size. As they matured, all these results migrated to Theme 4.

Throughout the life of the extension project, researchers were often posed with the conundrum of what was the optimum number of samples to collect for analysis. While there is no right answer to this question, a discussion of the logic that can inform this process was included in a paper on sampling strategies.

### (P4A7) CASE STUDIES AND TECHNOLOGY TRANSFER

**LEADER** Steve Walters

**TEAM MEMBERS** Ron Berry, Dee Bradshaw, Julie Hunt, Luke Keeney, Toni Kojovic, Pat Walters

Site-based case studies are a feature of the AMIRA P843A project carried out within Theme 4. The aim of these studies is large-scale validation and comparative benchmarking, mainly of tools and methodologies developed in AMIRA P843. The studies are designed to support technology transfer through validation, enhancement and demonstration of outcomes.

Twelve sites were nominated by sponsors for case study scoping. This process entailed close consultation between researchers and nominated sites to identify specific high-impact areas of interest, and the potential benefit that could be used to validate tools and methodologies.

After scoping, nine site-based case studies were undertaken, encompassing large testing programs designed to develop and validate GeM® testing methods and modelling concepts. Outcomes have involved proof of concept for individual site application, technology transfer to sponsor companies, and establishing pre-commercial support for emerging GeM® testing methodologies. The last four case studies, at Escondida, Andina, Chuquicamata and Los Bronces, were completed in 2013.

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**OUTLOOK**

**EXTENSION PROJECT**

With significant support from CODES' collaborating team members at UQ and CSIRO, the GeM® AMIRA P843A project has successfully delivered a number of key benefits to industry partners, including improved forecasting, reduced technical risk, enhanced economic optimisation of mineral production, and more efficient use of the resource.

As a result of these and other successes, there is strong support from the minerals industry to build on this platform. Therefore, various meetings and discussions were completed during 2013 aimed at identifying a forward program for the GeM® project in the form of the AMIRA extension project P843B.

To facilitate the project’s development, Will Goodall from UQ – JKMRC has been appointed to lead this project, supported by Julie Hunt, Wayne Stange, Bruce Gemmill, Steve Pooley and John Jackson. Dr Goodall has extensive experience in gold mineralogy, mineral process development, gold ore characterisation, and geometallurgy.

The main aim of the extension project will be to continue to generate significant value for sponsors via the use of geometallurgical information in a production capacity. The project will provide a consolidation of tools developed in GeM® to date, with a focus on their implementation and the achievement of reliable production forecasting for sponsor companies.

**FINAL ACTIVITIES FOR AMIRA P843A**

- Report results from AMIRA P843A at international conferences.
- Publish results, as confidentiality allows.
- Further develop Theme 1 – Predictive Environmental Indices through CRC ORE.

![Left: Toni Kojovic at the final meeting of AMIRA P843A. Middle: drill core pellets. Right: Ron Berry (right) at the final meeting of AMIRA P843A.](image-url)
PROGRAM FIVE
TECHNOLOGY

OBJECTIVE
Research activities within the Program are aimed at developing new analytical techniques, ensuring that research in the Centre is driven by innovative technology, and that the Centre is at the cutting edge of analytical developments of relevance to ore deposit research.

The program also aims to provide CODES research staff and students with access to state-of-the-art micro-analytical equipment within Australia and overseas, and maintain their awareness of new analytical developments.

INTRODUCTION
The Technology Program explores and develops novel analytical and data interpretation techniques based on the latest technological developments, such as a number of high spatial resolution microprobes. This helps in the understanding, exploration and exploitation of deep earth resources.

Current research projects focus mainly on expanding the capabilities of in-situ multi-element analysis by laser ablation (LA), inductively-coupled plasma mass-spectrometry (ICP-MS), in-situ isotope analysis by LA multi-collector (MC) ICP-MS, non-destructive multi-element analysis using nuclear (PIXE) and synchrotron-based X-ray microprobes (XFMI), and development of new stable-isotope solution-based analytical techniques. Research activities also develop data interpretation tools, such as new algorithms and new user-friendly scientific software packages. These are used primarily for modelling the deep earth processes that lead to ore formation, and for processing of analytical data. Many of the projects have included close collaborations with Node partners, such as the University of Melbourne, CSIRO and the Australian National University.

HIGHLIGHTS
The major highlight of the year was the commissioning and launch of the Newcrest LA-ICP-MS Laboratory at CODES. This state-of-the-art facility is equipped with a Resonetics RESOlution S-155 laser probe coupled to an Agilent 7700s quadrupole mass spectrometer. The high throughput laser ablation system enhances the Centre’s capabilities in terms of ore deposit characterisation, which plays such a vital role in helping mining companies better understand their ore deposits, and subsequently enhance extraction and recovery outcomes. The facility was made possible via funding from Newcrest Mining.

Other highlights include:

• Commissioning of the new CSIRO NMP target chamber and control system, as well as software engineering of beam transport. The system is now complete and awaiting the arrival of the Maia array.
• The new revision B Maia detector achieved greatly improved energy resolution.
• Better understanding of ablation characteristics of pyrite led to improved analytical protocols for quantitative sulfide trace element analysis.
• Improvements in the LBIC on the CSIRO NMP system are expected to result in orders of magnitude improvement in both the sensitivity of the method and speed of analysis.
• Hydrothermal mineral replacement of calcite with As-bearing apatite reveals that complex mineral zoning patterns can form in hours and be destroyed by consequent reactions within days.

Top: Close-up of XRD equipment in the new laboratory.
Bottom: Paul Olin operating the new laser ablation system in the Newcrest laboratory.
using a 193 nm Excimer laser.

and mass-spectrometers. The main focus during the year was on improving the laser ablation cell and ICP-MS to improve washout of the plasma by better understanding ion kinetic energy during laser ablation ICP-MS. These results will be presented at the 2013 Winter Plasma Conference in Florida.

for Laser Ablation.

into the element fractionation between Fe and S during the ablation process for the three different types of lasers at CODES, as well as fractionation during ablated particle transport. This investigation was also part of Sarah Gilbert’s PhD project.

improved protocols were established for uraninite geochronology (smaller spot sizes and better targeting by using SEM / EMPA).

for Laser Ablation.

a 193 nm Excimer laser.

Additional developments during the year involved:

• Decreasing element fractionation for trace element and U-Pb geochronology by modifying He flow in the S-155 cell.

• Modifications to the design of the interface between the laser ablation cell and ICP-MS to improve washout of signal after ablation, which is particularly relevant for the quantification of LA-ICP-MS images.

• Improving sample cleaning procedures and lowering effective detection levels to obtain more accurate low-level concentrations.

• Comprehending processes within the mass spectrometer plasma by better understanding ion kinetic energy during laser ablation ICP-MS. These results will be presented at the 2014 Winter Plasma Conference in Florida.

• Optimising and standardising plasma physical parameters for Laser Ablation.

• Testing new designs of smoothing devices between the laser and ICP-MS.

• Introduction of nitrogen for flushing the beam path to improve energy stability.

These results were presented at the 2013 Winter Plasma Conference in Poland.
The development of laser analyses of rock powders for trace element analyses continued.

Data reduction software for LA-ICP-MS continued to be developed and improved.

In collaboration with ETH Zurich, work has started on the development of new calibration standards for LA-ICP-MS analysis of sulfide minerals.

Work has continued on utilising lithium borate fusion as a means of improving on the formulation of calibration standards for sulfide analysis.

### P5A3 NEW LA-MC-ICP-MS APPLICATIONS

**LEADERS** Bence Paul, Janet Hergt  
**TEAM MEMBERS** Leonid Danyushevsky, Sebastien Meffre  
**STUDENT** Ross Aston  
**COLLABORATORS** Ashley Norris, Jon Woodhead

The aim of this project is to develop new analytical techniques for quantitative, in-situ analysis and the imaging of isotopic compositions of key elements in a range of geological materials. These techniques will lead to new spatially resolved information being available, which will help provide a better understanding of the processes involved in ore formation.

In 2013, the team developed an innovative approach to measuring samples containing multiple minerals ("MinMapper"), which combines principal component analysis with advanced image analysis to allow analysts to process their data on a mineral-by-mineral basis. Each phase can be reduced using a separate reference material and standards for sulfide analysis.

### P5A4 NEW STABLE ISOTOPE MS APPLICATIONS

**LEADERS** Bence Paul, Janet Hergt  
**TEAM MEMBERS** Leonid Danyushevsky, Sebastien Meffre  
**STUDENT** Ross Aston  
**COLLABORATORS** Ashley Norris, Jon Woodhead

The aim of this project is to develop new analytical protocols for the measurement of non-conventional stable isotope compositions (e.g., Cu, Mo) that can be used to explore ore forming processes.

A detailed study of Cu isotopes in a range of ore minerals from the Brothers volcano in the Kermadec Arc was conducted by Heidi Berkenbosch and Bence Paul. This study examines Cu isotope variation between and within black smokers, which makes it one of the most rigorous and detailed studies of its type. The research was presented at the International Applied Geochemistry Symposium in November and a manuscript is being prepared for publication.

Additionally, a paper describing the team’s advanced approach to double-spike deconvolution, which is fundamental to precise molybdenum isotope measurement, has been accepted for publication and will be published in 2014.

This is a key step in providing accurate and reliable Mo isotopic information from Mo-bearing ore minerals.

### P5A5 PYRITE METALLURGY

**LEADERS** Sebastien Meffre, Ross Large, Leonid Danyushevsky  
**TEAM MEMBERS** Ron Berry, Aleksandr Stepanov, Helen Thomas  
**COLLABORATOR** Kathryn Stewart

This project, funded by Newcrest Mining, aims to develop techniques to characterise differences in pyrite chemistry by comparing metallurgical composites from various grade ores. Ultimately, the project will provide a set of techniques (either petrographic, SEM or LA-ICP-MS-based) that can be used to produce metallurgic, ore processing, indices for different types of ore.

This year, the project has focused on improving the LA-ICP-MS-based techniques used to investigate gold deportment for metallurgy.

The following activities were completed:

- Laser ICP-MS analytical procedures for the analysis of gold in pyrite at the Lihir Mine were optimised.
- New etching techniques were tested and developed to highlight the internal growth zones in pyrite, including the quantification of the etching response using automated optical microscopy.
- The relationship between ore grade and pyrite chemistry at the Lihir Mine was investigated, revealing that parts of the deposit with similar ore grades have different pyrite chemistry.

The project has proven that a combination of techniques (etching, MLA, LA-ICP-MS mapping) can provide trace element deportment information at a range of scales, both on intact and composite samples.

### P5A6 ADVANCING APPLICATIONS IN THE FIELD OF ORE DEPOSIT RESEARCH

**LEADER** Leonid Danyushevsky  
**STUDENT** Jamie Laird  
**COLLABORATORS** Robin Kirkham, Jeff McCallum, David Parry, Roland Szymanski

This project focuses on methods for mapping electrical properties, such as the electric field in complex minerals, in order to gain a better understanding of the role of metal sulfide semiconductivity on the genesis of precious metals. During the past year, the work was focused on developing a temperature capability for the LBIC measurement system, which is used to map the electric field distribution in minerals. This has required the use of galvo laser scanners, which has led to a more complicated design of the microscope. When complete, the sensitivity of the LBIC method is expected to be orders of magnitude better.

### P5B1 ION BEAM ANALYSIS DEVELOPMENT

**LEADER** Jamie Laird  
**TEAM MEMBER** Chris Ryan  
**STUDENT** Lloyd Grills  
**COLLABORATORS** Robin Kirkham, Jeff McCallum, David Parry, Roland Szymanski

This year, the project has focused on methods for mapping electrical properties, such as the electric field in complex minerals, in order to gain a better understanding of the role of metal sulfide semiconductivity on the genesis of precious metals. During the past year, the work was focused on developing a temperature capability for the LBIC measurement system, which is used to map the electric field distribution in minerals. This has required the use of galvo laser scanners, which has led to a more complicated design of the microscope. When complete, the sensitivity of the LBIC method is expected to be orders of magnitude better.

### P5B2 NEW ION BEAM APPLICATIONS

**LEADER** Jamie Laird  
**TEAM MEMBER** Chris Ryan  
**STUDENT** Lloyd Grills  
**COLLABORATORS** Robin Kirkham, Jeff McCallum, David Parry, Roland Szymanski

This project focuses on methods for mapping electrical properties, such as the electric field in complex minerals, in order to gain a better understanding of the role of metal sulfide semiconductivity on the genesis of precious metals. During the past year, the work was focused on developing a temperature capability for the LBIC measurement system, which is used to map the electric field distribution in minerals. This has required the use of galvo laser scanners, which has led to a more complicated design of the microscope. When complete, the sensitivity of the LBIC method is expected to be orders of magnitude better.

### P5B3 CRACKING THE SULFATE ISOTOPIC COMPOSITION PROBLEM IN ANTEC NOTE ULE IN HYDROTHERMAL SYSTEMS: APPLICATION OF THE CARBONATE-ASSOCIATED SULFATE (CAS) METHOD

**LEADER** Garry Davidson  
**TEAM MEMBER** David Cooke  
**COLLABORATORS** Ariel Pascoe

The sulfate isotope application developed in 2012 was successfully transferred between laser systems, resulting in improved precision with the Resonetics Excimer laser. Further investigation was undertaken into the optimal configuration of the interface tubing between the laser and the ICP-MS to improve precision and reproducibility, reduce the washout time between samples, and increase sample throughput.

Sulfur isotope samples, previously compiled as standards for sulfide analysis, can be reduced using a separate reference material and improve the repeatability before publication of this work is possible.

### P5B4 ADVANCING NON-DESTRUCTIVE FOCUSED-BEAM SPECTROSCOPY

**LEADER** Le Centre de Recherches Pétrographiques et Géochimiques, resulting in a more robust characterisation of these standards. Preliminary results from this project were presented at the European Conference on Plasma Spectrochemistry in February, and are currently being written up for publication.
Major outcomes for 2013 include:

This project is directed towards continued development of new and existing synchrotron techniques for the study of

Progress in 2013 included:

This project targets the development of new experimental equipment for probing samples of geological interest, using synchrotron radiation at the Australian Synchrotron (AS).

The aims of this project are to:

In 2013, work has continued on developing a new model for plagioclase-silicate melt equilibrium under hydrous conditions at variable pressures. In a parallel development, a suite of melt inclusions in olivine phenocrysts has been prepared for analysis. The aim is to measure the diffusion profiles around the inclusions that are to be used in developing models of tracer diffusion in olivine. An updated version of Petrolog3 was made available on the Petrolog home page (http://petrolog.web.ru).

The focus in 2013 was on developing prototype software that is capable of processing the acquired data, using multiple calibration and internal standards. The prototype is scheduled for in-house testing in mid-2014.

NEW SYNCHROTRON-BASED APPLICATIONS

This project is funded by Newcrest Mining as part of their

This project has been successfully recommissioned at Hutch C at the XAS beamline of the Australian Synchrotron, enabling in-situ measurement of metal speciation at high P-T.

In 2013, the mAESTRO system, a high pressure-temperature synchrotron spectroscopy cell for solution studies, has been successfully recommissioned at Hutch C at the XAS beamline of the Australian Synchrotron, enabling in-situ measurement of metal speciation at high P-T.

The aims of this project are to:

The Technology Program has always played a vital role in underpinning all the Centre’s research activities, and the formation of this module will enable the team to place even more focus on developing new geochemical approaches and analytical methods to aid the design of exploration tools.

The Newcrest laser ablation laboratory came on stream in 2013, adding significantly to the Centres’ technological capabilities and services. CODES will continue to develop these services in 2014, closely aligned to the needs of the minerals industry. CODES has built a reputation for being one of the world’s leading centres for ore characterisation, and the aim is to further enhance that standing in the future. Some of the ongoing activities include developing protocols for analysis of trace elements in rock powders by laser ablation ICP-MS and research on understanding the differences between dry and wet plasma conditions.

Although the Node arrangements will fall away with the ending of CODES tenure as an ARC-funded Centre of Excellence, it is anticipated that many of the strong collaborations will continue into 2014, and beyond. The CSIRO node will continue developments at the Australian Synchrotron (AS) and the CSIRO Nuclear Microprobe (NMP), including the installation of a new Maia 384B detector array as an upgrade to the XFM beamline at the AS, and the fitment of a new chamber to the NMP. These enhancements will greatly improve quantitative imaging of geological samples at the AS, and open up new capabilities for high definition PIXE imaging on the NMP. A more systematic study of trace-element zoning during mineral replacement is also planned, plus XAS experiments at the Australian Synchrotron into Ni, Zn and Eu speciation.
CODES continued, and expanded, its program of outreach activities in 2013. The broad range of activities began early in the year when Jacqui Halpin and Rebecca Carey led a workshop for Year 11 students as part of the national Science Experience initiative. This workshop has been a mainstay on the calendar for a number of years now, and remains popular and well attended. Activities included a range of hands-on exercises aimed at fostering an interest in the geosciences amongst the young participants.

In a similar vein to Science Experience, the Centre accommodated a visit by students in years 10 to 12, which was organised via UTAS and the Australia and New Zealand Association for the Advancement of Science (ANZAAS). The visit was again led by Jacqui and Rebecca and included a number of hands-on exercises.

The Centre has always been amenable to requests from individual schools and colleges to visit its facilities, and characteristically the year was interspersed with visits from a variety of institutions, with ages ranging from pre-school through Year 12. The main co-ordinator of these visits was Michael Roach, but a number of other people provided support. Michael also played a key role in activities outside the Centre by leading a series of geological excursions to Waterworks Reserve, in the foothills of Mount Wellington. In total, he took ten classes from the local Oglevie High School to the reserve, via five excursions. He also teamed up with Jocelyn McPhie for a similar type of field exercise for three Year 8 classes from Bridgewater High School, only on that occasion the venue was the traverse coastline of Sandy Bay.

Other activities out and about amongst the community included Ross Large addressing the Royal Society of Tasmania, where he presented a layman’s version of the background and significance of his research into oxidation levels in the oceans, over time. While at the other end of the age spectrum, Sharon Allen visited Waima Heights Primary School, where she delivered a fun and educational talk on the geology of Hobart to preparatory and Year 1 students.

Perhaps the most unusual outside activity of the year was contributed by Garry Davidson. Working in close collaboration with Mineral Resources Tasmania, Garry helped the Tasmanian Museum and Art Gallery create a unique rock wall that depicts the diverse geology of Tasmania, while doubling as an attractive artwork.

Rock Library curator Izzy von Lichtan has long been a consistent contributor to the outreach program, but 2013 was a busy year even by her standards. Activities got off to a particularly interesting start when she played host to a film crew from the Stranger With My Face Film Festival, who used the unusual backdrop of the Rock Library, and adjacent areas, to shoot footage for a short film. The film was screened at the Hobart-based festival in March, and has sparked an increased interest from local groups wishing to visit the Rock Library and associated geological exhibits.

CSIRO’s Scientists in Schools is a national program that creates and supports long-term partnerships between school teachers and scientists. In support of this important initiative, Izzy assisted a teacher and a group of Year 9 and 10 students from the local Calvin Christian School with project work. In addition, she supervised a work experience student from the same school.

Izzy also played an active role in the CSIRO’s Double Helix Science Club, assisting with the labelling of its rock and mineral collection, providing ideas on possible teaching directions to take with the samples, and selecting Tasmanian rock specimens (donated by CODES/UTAS) for its holiday teaching program. The club plays a valuable role in encouraging students to take an interest in science from an early age.

Izzy’s already impressive collection of rock specimens was given a significant boost during the year when relatives of the late Derek Murray donated his substantial mineral collection to the Rock Library. The exceptional specimens provide an added incentive for people to visit the Centre. Mr Murray was a geologist and former UTAS student.

Late in the year, she was filmed by ABC TV for its Open program, which features a series of short documentaries in which individuals share their stories with viewers. The program is expected to be aired in 2014. To round off an eclectic mix of activities for Izzy, she was also interviewed on geological matters for ABC Radio’s Statewide Evenings show. However, these were just two of a host of TV and radio interviews involving CODES’s staff during the year. Other highlights included Rebecca Carey featuring on the ABC TV’s 7:30 Report, and Bruce Gemmell, Ross Large and Rob Scott being interviewed (on separate occasions) for ABC Radio’s Breakfast with Ryk Goddard program.

All activities were conducted in conjunction with the UTAS School of Earth Sciences.
INDUSTRY LINKS AND RESEARCH COLLABORATIONS

OBJECTIVES
- To be a research focus for the national and international minerals industry.
- Strategically collaborate with other top-level national and international research groups in the field of ore deposits, mineral exploration technologies and mineral processing.

CODES is recognised as a world leader in industry-linked, collaborative ore deposit research. Strong relationships have been developed with a range of industry partners and researchers who invest in, support and contribute to research projects. Fostering and growing these national and international collaborations has been a key strategic focus throughout CODES’ tenure as an ARC Centre of Excellence, and will remain so into the future.

INDUSTRY LINKS AND SYNERGIES
CODES has strong, enduring and mutually beneficial links with a large group of major Australian and international mining companies. These links have been critical for funding CODES’ research, and for technology transfer to the mining and mineral exploration community.

In 2013, the group of CODES’ industry partners comprised of eleven Australian and international mining companies: Anglo American, AngloGold Ashanti, Barrick Gold, BHP Billiton, Buenaventura, MMG, Newcrest Mining, Newmont Mining, Rio Tinto, St Barbara and Teck Resources. Each of the partner companies provides support of $15,000 to $75,000 in cash per year to the core research budget of the Centre. Senior representatives of these companies sit on the Science Planning Panel and Advisory Board, along with other government and university researchers. The panel and board meet annually to discuss the results of CODES’ research and the potential directions for new research.

INDUSTRY PARTNERSHIP OPPORTUNITIES BEYOND 2013
At the end of 2013, CODES’ tenure as an ARC (funded) Centre of Excellence (CoE) came to an end, after eight highly successful years. The next phase of CODES’ evolution commences in January 2014, and includes a number of exciting new partnership opportunities that can be tailored to company requirements. Some companies have already signed-up for the new partnership program, and the indications are promising that the number will grow during 2014.

Major benefits of an alliance with CODES include enhanced prospects of discoveries, optimisation of existing reserves, first call on geoscience graduates, and access to a world-class research team and state-of-the-art facilities. For further details of partnership opportunities beyond 2013, contact the Director, Bruce Gemmell: E. bruce.gemmell@utas.edu.au Tel. +61 3 6226 2893.

ROLE OF AMIRA INTERNATIONAL
AMIRA plays a vital role in facilitating the funding of collaborative research involving university research groups and the minerals industry. AMIRA has agreed to fund a series of research projects within the Centre, which will run over a period of three to four years. In 2013, AMIRA funded these major projects for CODES:
- P843A (GeM² project) Geometallurgical mapping and mine modelling.
- P1022 The rapid approximate inversion of TEM data.
- P1041 Application of new technologies to gold deposits.
- P1060 Enhanced geochemical targeting in magmatic-hydrothermal systems.

RESEARCH COLLABORATIONS AND INTERNATIONAL VISITORS PROGRAM
In 2013, CODES further cemented its reputation for cultivating research collaborations with other Australian and international research organisations. Throughout the year, collaborative research was conducted with 94 international and 22 national organisations.

During the tenure as a CoE, collaborative research between international and Australian-based partners was also facilitated via joint research appointments. The table on the next page details each of the collaborating institutions with the joint researchers and their funding source. These researchers were based at collaborating partner institutions and incorporated research visits to CODES throughout the term of their research projects.

<table>
<thead>
<tr>
<th>INSTITUTION</th>
<th>COE ARC GRANT</th>
<th>RODE MATCHING FUNDS</th>
<th>INDUSTRY / AMIRA FUNDS</th>
<th>UNIVERSITY / CSIRO FUNDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Queensland - Sustainable Minerals Institute (incl. Julius Kruttschnitt Mineral Research Centre &amp; WH Bryan Centre)</td>
<td>Doe Bradshaw (20%), Khoi Ke Nguyen (25%), John Jackson (10%), Steven Possley (14%), Malcolm Powell (8%), Emmanuel Manlapig (1%), Patrick Walters (7%), Yicai Wang (9%)</td>
<td>Grant Ballantyne (15%), Doe Bradshaw (8%), Alan Cocker (20%), Janine Lay (7%), Emmanuel Manlapig (9%), Khoi Ke Nguyen (15%), Malcolm Powell (12%), Patrick Walters (21%), Dixon Weatherley (20%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australian National University</td>
<td></td>
<td></td>
<td>Janine Lay (5%), Roland Maas</td>
<td></td>
</tr>
<tr>
<td>CSIRO</td>
<td>Jamie Laird (50%), Stacey Rong (30%)</td>
<td>Jamie Laird (10%), Stacey Rong (50%)</td>
<td>Chris Ryan, Weihua Liu</td>
<td></td>
</tr>
</tbody>
</table>

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TECHNOLOGY TRANSFER

OBJECTIVES

• Involve end-users (exploration and mining companies) in research planning, research evaluation and research adoption.
• Promote technology transfer so that innovative research outcomes are accessible to end-users.
• Comply with the national principles of intellectual property management for publicly funded research.

TECHNOLOGY TRANSFER ACTIVITIES

CODES undertakes strategic and applied research into the formation, location, discovery and recovery of ore deposits, and the development of innovative technologies to support these research endeavours. These initiatives create knowledge, processes, methods and solutions for the minerals industry and ore deposit researchers – locally, nationally and internationally.

Research results and technical developments in the applied research programs are transferred to end-users via regular research meetings, research reports, monographs, books, digital presentations and software packages, where appropriate. In 2013, 84 research reports were presented to industry clients, and meetings were held to present and discuss progress and adoption of research results.

PUBLICATIONS TARGETED AT END-USERS

CODES also delivers knowledge and applications to end-users and the wider scientific community through a selection of special publications that represent the culmination of major research efforts by the Centre’s staff.

• Ore Geology Reviews – Special Issue (April 2007); Mineral deposits of South China. Editors: Khin Zaw, S Peters, N Cook and Z Hou (no copies sold in 2013).
• The geology of the Broken Hill Pb-Zn-Ag deposit, NSW, Australia (2006). Author: A Webster (3 copies sold in 2013).

COMMERCIAL PRODUCTS AND PROCESSES

Geometallurgical research in Program 4, in collaboration with JKMRC at the University of Queensland, has the potential to JKMRC at the University of Queensland, has the potential to...

SHORT COURSES, WORKSHOPS AND CONFERENCES FOR END-USERS

Short courses and workshops continued to play a key role in the Centre’s technology transfer activities. Throughout the year, a total of 17 courses were held at various locations around the world. This included venues in ten countries on six continents, including Chile and Peru in South America; Canada in North America; China, Indonesia and Myanmar in the Asia Pacific region; Europe; Africa; and Middle East.

Total attendance by industry geologists, academic researchers and postgraduate students was 1,047, with 16 different presenters from the CODES Hub involved in delivering the lectures.

<table>
<thead>
<tr>
<th>TITLE</th>
<th>PRESENTERS</th>
<th>NO.</th>
<th>LOCATION</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWIR</td>
<td>Nic Jansen</td>
<td>10</td>
<td>CODES, Hobart</td>
<td>23 January</td>
</tr>
<tr>
<td>Mineral Deposits in SE Asia</td>
<td>Chun-kit Lai, Takayuki Manaka, Kenzo Sanematsu, Khin Zaw</td>
<td>105</td>
<td>Mandalay University, Myanmar</td>
<td>31 January</td>
</tr>
<tr>
<td>Ore Deposits of South America Short Course</td>
<td>David Cooke, Michael Roach</td>
<td>25</td>
<td>Chile and Peru</td>
<td>9–23 March</td>
</tr>
<tr>
<td>Sediment-hosted Gold Short Course</td>
<td>Ross Large</td>
<td>10</td>
<td>James Cook University, Townsville</td>
<td>1–2 June</td>
</tr>
<tr>
<td>Melt Inclusions Short Course</td>
<td>Leonid Dampushovsky</td>
<td>50</td>
<td>Antalya, Turkey</td>
<td>6 June</td>
</tr>
<tr>
<td>Geochemistry, Hydrology and Geochronology Short Course</td>
<td>David Cooke (Leader), Shawn Barker, Ron Berry, Phil Basson, Graham Cars, Tony Crawford, Leonid Dampushovsky, Garry Davidson, Bruce Gemmell, Scott Halley, Ross Large, Sebastian Meffre, Nick Oliver, Ana Robertson, Lesley Wyborn, Khin Zaw</td>
<td>62</td>
<td>CODES, Hobart</td>
<td>24 June–5 July</td>
</tr>
<tr>
<td>Stable Isotope Geochemistry</td>
<td>Garry Davidson</td>
<td>60</td>
<td>CODES, Hobart</td>
<td>2–3 July</td>
</tr>
<tr>
<td>Geometallurgical Mapping and Mine Modelling Annual Review</td>
<td>Ron Berry, Dave Bradshaw, Alan Bye, Nicky Chapman, Miles Chapman, Alan Cooke, Joe Coruzzi, Julie Hunt, Dave Hutchinson, John Jackson, Timi Kopjar, Vanessa Lindequist, Paul Linton, Angus McFarlane, Khoi Nguyen, Aima Pariotshu-Fox, Hector Parija, Wayne Stange, Steve Walters</td>
<td>40</td>
<td>Boulevard Gardens, Brisbane</td>
<td>10–12 July</td>
</tr>
<tr>
<td>Volcanics and Their Products Short Course</td>
<td>Jocelyn McPhie</td>
<td>15</td>
<td>Bisha, Ethiopia</td>
<td>16–18 August</td>
</tr>
<tr>
<td>Isotile Workshop</td>
<td>Bence Paul</td>
<td>25</td>
<td>Florence, Italy</td>
<td>24–25 August</td>
</tr>
<tr>
<td>Understanding Alterations: Use in Exploration and Development</td>
<td>Andrew Davies, Melissa Gregory, Bruce Gemmell, James Lang, Anne Thompsoon, John Thompson</td>
<td>60</td>
<td>Whistler, BC, Canada</td>
<td>23–24 September</td>
</tr>
<tr>
<td>Mineral Exploration Applications of Stable Isotopes</td>
<td>Shaun Barker, Larry Cathles, David Cooke, Kurt Kyser, Ryan Mathur</td>
<td>25</td>
<td>Whistler, BC, Canada</td>
<td>27 September</td>
</tr>
<tr>
<td>Fluids in the Earth Short Course</td>
<td>Leonid Dampushovsky</td>
<td>30</td>
<td>Naples, Italy</td>
<td>14–18 October</td>
</tr>
<tr>
<td>Tectonic and Mineral Deposit Types in SE Asia</td>
<td>Khin Zaw</td>
<td>40</td>
<td>Naypyidaw, Myanmar</td>
<td>26 November</td>
</tr>
<tr>
<td>Gold (Copper) Workshop: New Development for Discovery</td>
<td>David Cooke, Noel White</td>
<td>70</td>
<td>Bumi, Indonesia</td>
<td>30 November–1 December</td>
</tr>
<tr>
<td>Ore Deposit Models and Exploration</td>
<td>Zhoushan Chang, Huayong Chen, Yanjia Chen, David Cooke, Rich Goldsby, Zengqian Hou, Baishong Hu, Shanyong Jiang, David Leach, Chou Li, Jianwei Li, Jingwen Mao, Pei Ni, Steve Scott, Xiyan Song, Weidong Sun, Noel White, Yuling Zie, Tafda Zhou</td>
<td>270</td>
<td>Hefei, China</td>
<td>9–12 December</td>
</tr>
</tbody>
</table>

**Drying clay sample for geochemical analysis.**
PERFORMANCE INDICATORS

PERFORMANCE MEASURE | TARGET | 2013
---|---|---
RESEARCH FINDINGS
Publications in international journals | 50pa | 69
Percentage of publications in A*/A journals | 70% | 68%
Reports to industry collaborators | 80pa | 84
Special issues and/or research monographs | 1 per 2 years | 1
Invitations to give keynote conference presentations | 10pa | 7
Papers at national/international meetings | 70pa | 80

PERFORMANCE MEASURE | TARGET | 2013
---|---|---
INVESTIGATORS
Average percentage of CIs research in Centre | 70% | 80%
Average percentage of PIs research in Centre | 15% | 35%
Percentage of team-based projects | 80% | 85%
Percentage of Australian cross institutional projects | 30% | 45%

RESEARCH TRAINING AND PROFESSIONAL EDUCATION
Percentage of RHD students attracted from interstate | 45% | 15%
Percentage of RHD students attracted from overseas | 40% | 75%
Honours students in Centre programs | 10 | 14
RHD students in Centre programs | 45 | 49 PhD, 4 MSc
Percentage of students in projects linked with industry | 50% | 70%
Professional short courses/workshops for industry | 5pa | 17

INTERNATIONAL, NATIONAL AND REGIONAL LINKS AND NETWORKS
Centre national or international conferences/workshops | 1 per 2 years | 1 in 2012, 0 in 2013
Registrants at Centre’s conferences/workshops | 100pa | 1,047
International and national visitors per year | 50pa | 90
Collaborative projects with other global centres/groups | 10pa | 15
External collaborators using Centre’s equipment | 10pa | 22

END-USER LINKS
Frequency of meetings with industry representatives | 15pa | 20
End-user representatives to Science Planning Panel and Advisory Board | 20% / 50% | 71% / 63%
Frequency of meetings with AMIRA Research Co-ordinator | 10pa | 12
Number of industry visitors to Centre | 80pa | 46

ORGANISATIONAL SUPPORT
Annual cash contributions from UTAS | $1,800,000 | $1,626,301
Annual cash support from other collaborating universities & CSIRO | $205,000 | $590,284
Annual cash support from industry | $2,000,000 | $3,701,670
Number of new organisations recruited to or involved in the Centre | 1pa | 1

GOVERNANCE
Joint post-doctoral appointments between collaborating institutions/organisations | 5 | 6 (2 CSIRO, 1 UMelb, 3 UQ)
Balance and experience of Advisory Board members | Excellent balance
Annual review of strategic and business plans | Yes
Effectiveness of Centre Research Committee | High
Effectiveness of Science Planning Panel | High
Public profile of Centre | High

NATIONAL BENEFIT
Centre research has input into a major mineral discovery | 1 per 5 years | 0
Employment of Centre’s graduates by minerals industry | >60% | 80%

Participants in the Ore Deposit Models workshop, Hefei University of Technology, China.
FINANCES

ARC CONTRACT AND GOVERNANCE

CODES became the Australian Research Council (ARC) Centre of Excellence (CoE) in one deposit on 1 July, 2005. It was formerly an ARC Special Research Centre. The CoE contract with the Australian Government covered five years, funding from 2005 to 2010. At the mid-term review in November 2008, the ARC awarded an extension of funding for the period 2010 to 2013. The Centre’s financial affairs are conducted within the established procedures, controls and delegations of the University of Tasmania (UTAS) and the CoE’s node universities and institutions. CODES has a policy of assigning budget responsibility to Node and Program Leaders, which is overseen by the Director.

To ensure the ARC’s CoE requirements are met, an inter-institutional agreement was established by the UTAS Research Office, formally binding all participating institutions to the ARC CoE agreement, including funding allocations from the CoE to its nodes and agreed matching contributions made by those nodes. The tables and figures presented in the following pages demonstrate the CoE has met the income and expenditure requirements of the current agreement.

2013 INCOME

Total CODES income was $10.5 million (see Table 1). This was derived principally from industry (35%), the ARC (29%) and UTAS (16%) (see Figure 1). The main income streams over time are compared in Figure 2, demonstrating that ARC funding was exceeded beyond the original CoE agreement of 1:1 in every year of the CoE. The most growth was recorded in the industry stream, which on its own often equalled or exceeded the ARC income in any given year.

THE COE COLLABORATOR/CONTRIBUTOR CASH INCOME AGREEMENT

The CoE funding agreement with the ARC requires that approximately $3 million (pa) be matched, dollar for dollar, with agreed core funding from collaborators/contributors. In 2013, a total of $3 million was matched. Matching contributions made by those nodes are compared in Figure 2, demonstrating that ARC funding from UTAS (16%) and the CoE’s node universities and institutions. Expenditure of both portions of node funding has been reported annually to CODES.

2014 INCOME ESTIMATES

With the completion of the CoE Grant at the end of 2013, overall income to CODES is expected to decrease accordingly in 2014. While new industry projects are being negotiated, and ARC Grants, such as Discoveries, are being applied for, the size of these new projects will not immediately counteract the loss of ARC Centre funding. CODES is pursuing various avenues to ensure this decrease in income is short-lived, and does not negatively impact research and training outcomes.
Table 1
Cash income financial statement 2005–2013

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC - Centre of Excellence Grant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CoE agreed core funding* - 2005 grant indexation (not received until 2006)</td>
<td>0</td>
<td>31,500</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CoE agreed core funding* - ARC grant</td>
<td>1,500,000</td>
<td>3,213,198</td>
<td>3,184,402</td>
<td>3,248,088</td>
<td>3,313,864</td>
<td>3,097,230</td>
<td>2,856,123</td>
<td>2,966,012</td>
<td>3,080,126</td>
</tr>
<tr>
<td>CoE nodes matching funds (agreed matching funds held at node institutions)</td>
<td>0</td>
<td>295,000</td>
<td>255,000</td>
<td>250,000</td>
<td>237,500</td>
<td>242,500</td>
<td>190,000</td>
<td>292,500</td>
<td>590,284</td>
</tr>
<tr>
<td>Additional funding (pre-existing or new)</td>
<td>4,348</td>
<td>60,006</td>
<td>53,000</td>
<td>131,585</td>
<td>25,147</td>
<td>84,795</td>
<td>22,726</td>
<td>20,113</td>
<td>40,200</td>
</tr>
<tr>
<td>Total annual income</td>
<td>4,292,926</td>
<td>8,917,056</td>
<td>8,900,226</td>
<td>9,783,674</td>
<td>10,838,635</td>
<td>9,450,368</td>
<td>9,338,352</td>
<td>13,219,037</td>
<td>10,489,144</td>
</tr>
<tr>
<td>Grand total of all income to date</td>
<td>85,229,418</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Core funding listed in the CoE agreement and matched to the ARC funds

Figure 1
Total Cash Income 2013

Figure 2
Comparison of CODES main income streams 2000–2013

- ARC CoE Grant: 29%
- University of Tasmania: 16%
- Other ARC grants: 0.9%
- Other Commonwealth Government: 2%
- Node matching funds: 0.9%
- Industry/private: 35%
- Other income sources/interest: 6%
- Contracts/consultancies/revenue raising: 11%

Table 1
Cash income financial statement 2005–2013

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
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<tr>
<td>ARC - Centre of Excellence Grant</td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2013 EXPENDITURE OF ARC COE GRANT

Summaries are provided in Table 2 and Figure 3 to show how CODES and its nodes have expended the ARC CoE Grant funds to date. As in past years, the major areas of expenditure in 2013 were salaries, student scholarships, laboratory analyses, and research and field travel. Most areas had similar or lower levels of expenditure when compared to 2012. However, salaries rose again due to an increase in CoE-paid research and development projects.

The 2013 combined ARC CoE income and carry-forward of $3.8 million was offset by expenditure of $3.7 million. This reflects a carry-forward surplus of $184k into 2014. A request has been made to the ARC for these funds to be used for final Centre wind-up costs, such as production of the 2013 CoE Annual Report and the final stages of scholarships. All node ARC CoE Grant funds were reconciled to zero at the end of 2013.

2013 EXPENDITURE ESTIMATES

The ARC CoE carry-forward amount is expected to be spent by the end of June 2014 in line with final reporting and Centre wind-up costs.

NOTES TO, AND FORMING PART OF, THE FINANCIAL STATEMENTS FOR 2013

The financial pages of this Annual Report were prepared by Helen Scott (Senior Finance Officer–SET Hub). Data for the financial statements was extracted from the UTAS TechOne Financial Systems and CODES’ financial databases. All Financial Statements shown here have been reviewed and audited by UTAS.

INCOME STATEMENT EXPLANATIONS

The income figures in Table 1 represent actual income recorded in the University’s finance system or transferred internally from UTAS to CODES during 2013, with the following exceptions:

- The CoE node matching funds are listed as cash income in the income statement (Table 1), but are not actually received as cash by the Centre. These matching funds, contributed by the nodes, are held and expended at the node institutions and reported annually to the CoE. They are listed as cash income in Table 1 to demonstrate that the nodes are providing their agreed annual contribution to the CoE.
- $552k of AMIRA funds, related to the P843A, P1022 and P1060 projects, were deposited into UTAS accounts, but were later transferred to research collaborators for the joint research projects. These funds will be listed as AMIRA income to those collaborators, and can therefore not listed as income to CODES.

In Table 1, sub-categories labelled ‘CoE agreed core funding’ are used to isolate core funding from other general funds. This is in accordance with the ARC requirement that the Centre demonstrates that these agreed core funds have been received each year.

Because of the six-month delay to the establishment of CODES as a CoE, very few agreed cash payments between the CoE and its node/collaborators were contributed in 2005. As a result, the payments for this six-month delay period were made during 2006. This has artificially inflated 2006 income figures by approx $400,000 (i.e. node income +$50,000, UTAS +$200,000, Industry Partners +$130,000). Therefore, any comparison between 2006 and 2007 income figures needs to take this into account.

In 2008, there was a minor retrospective amendment made to the 2005 industry/private income figure, which has increased the 2005 income total by $20,000. This relates to $20,000 of CoE agreed 2005 income, which was paid in advance by Teck Cominco (now Teck Resources) in 2004. It has already been counted in the 2004 income statement of the SRC, but it is now listed again in the CoE’s 2005 data (in the year that it was due) to clearly demonstrate to the ARC that Teck Cominco has met its CoE funding obligations within the five-year CoE agreement period.

EXPENDITURE STATEMENT EXPLANATIONS

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

The expenditure financial statement and pie chart (Table 2 and Figure 3) include the following:

- CODES expenditure of ARC CoE Grant funds (administered by UTAS)
- The nodes’ expenditure of ARC CoE Grant funds (administered by the node institutions and reported annually to UTAS).

Figure 3

Expenditure of ARC Centre of Excellence Grant 2013

Table 2

Expenditure of ARC Centre of Excellence Grant 2005–2013 (CODES plus its nodes)

<table>
<thead>
<tr>
<th>(half-year)</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balance brought forward from previous year</td>
<td>0</td>
<td>954,886</td>
<td>1,345,188</td>
<td>711,979</td>
<td>55,741</td>
<td>(145,268)</td>
<td>372,323</td>
<td>652,363</td>
<td>755,586</td>
</tr>
<tr>
<td>Miscellaneous income (refund of expenses)</td>
<td>0</td>
<td>8,497</td>
<td>28,589</td>
<td>43,155</td>
<td>18,704</td>
<td>1,271</td>
<td>9,641</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ARC income</td>
<td>1,500,000</td>
<td>3,152,698</td>
<td>3,184,402</td>
<td>3,246,088</td>
<td>3,311,864</td>
<td>3,097,230</td>
<td>2,856,123</td>
<td>2,966,012</td>
<td>3,080,126</td>
</tr>
</tbody>
</table>

Expenditure

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Salaries</td>
<td>(348,511)</td>
<td>(1,237,351)</td>
<td>(1,833,309)</td>
<td>(2,135,312)</td>
<td>(1,705,835)</td>
<td>(1,332,826)</td>
<td>(1,251,890)</td>
<td>(1,920,621)</td>
<td>(2,314,316)</td>
</tr>
<tr>
<td>Equipment purchases</td>
<td>(890)</td>
<td>(83,645)</td>
<td>(305,991)</td>
<td>(70,624)</td>
<td>(85,292)</td>
<td>(35,352)</td>
<td>(87,855)</td>
<td>(66,310)</td>
<td>(73,200)</td>
</tr>
<tr>
<td>Equipment leased/rented</td>
<td>(352)</td>
<td>(22,535)</td>
<td>(6,684)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>(280)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Travel and accommodation (research)</td>
<td>(52,453)</td>
<td>(354,309)</td>
<td>(314,206)</td>
<td>(282,161)</td>
<td>(364,065)</td>
<td>(231,763)</td>
<td>(267,358)</td>
<td>(141,511)</td>
<td>(189,354)</td>
</tr>
<tr>
<td>IT and lab maintenance</td>
<td>(1,666)</td>
<td>(91,292)</td>
<td>(208,688)</td>
<td>(145,441)</td>
<td>(82,620)</td>
<td>(16,134)</td>
<td>(33,876)</td>
<td>(57,278)</td>
<td>(20,621)</td>
</tr>
<tr>
<td>Student scholarships</td>
<td>(31,856)</td>
<td>(297,768)</td>
<td>(349,671)</td>
<td>(146,311)</td>
<td>(384,341)</td>
<td>(401,617)</td>
<td>(387,684)</td>
<td>(281,100)</td>
<td>(266,118)</td>
</tr>
<tr>
<td>Public relations and advertising</td>
<td>(5,289)</td>
<td>(105,169)</td>
<td>(77,346)</td>
<td>(57,404)</td>
<td>(66,299)</td>
<td>(36,156)</td>
<td>(8,954)</td>
<td>(74,958)</td>
<td>(158,782)</td>
</tr>
<tr>
<td>Laboratory analyses</td>
<td>(20,900)</td>
<td>(212,256)</td>
<td>(387,735)</td>
<td>(288,411)</td>
<td>(369,447)</td>
<td>(247,563)</td>
<td>(189,524)</td>
<td>(179,152)</td>
<td>(309,972)</td>
</tr>
<tr>
<td>Consultants</td>
<td>(929)</td>
<td>(90,130)</td>
<td>(104,070)</td>
<td>(68,962)</td>
<td>(62,186)</td>
<td>(117,263)</td>
<td>(98,457)</td>
<td>(31,164)</td>
<td>(345,891)</td>
</tr>
<tr>
<td>Visiting academics</td>
<td>(9,002)</td>
<td>(9,900)</td>
<td>(41,645)</td>
<td>(83,221)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>New appointment expenses</td>
<td>0</td>
<td>(9,267)</td>
<td>(10,381)</td>
<td>(22,523)</td>
<td>(3,564)</td>
<td>(14,105)</td>
<td>(624)</td>
<td>(2,086)</td>
<td>0</td>
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<tr>
<td>Miscellaneous</td>
<td>(2,561)</td>
<td>0</td>
<td>0</td>
<td>(2,323)</td>
<td>(906)</td>
<td>0</td>
<td>(6,017)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Balance remaining at end of year</td>
<td>(545,114)</td>
<td>(2,770,883)</td>
<td>(3,847,200)</td>
<td>(3,147,481)</td>
<td>(3,514,872)</td>
<td>(2,989,343)</td>
<td>(2,577,354)</td>
<td>(2,872,430)</td>
<td>(3,651,828)</td>
</tr>
</tbody>
</table>

* From 2010 onwards, visiting academic expenditure is no longer itemised separately.

Opposite: Qiuyue Huang examining gold mineralisation at the Zolotaya Gora gold deposit, Southern Urals, Russia.


CONFERENCES, ABSTRACTS, PAPERS, AND PRESENTATIONS (80)


Kiseeva, E.S., Yaxley, G.M, Litasov, K.D., Ohtani, E., and Kamenetsky, V.S., 2013, High-pressure experimental constraints on the Li-Na carbonate in altered oceanic crust during subduction to the Transition Zone and Lower Mantle: Rocks, reef and rainforest (RI), Biennial conference of the Specialist Group in Geochemistry, Mineralogy and Petrology (SSGMP), Geological Society of Australia, Mission Beach, Queensland, 14–19 July, p. 42.


INVITED KEYNOTE ADDRESSES (7)


Cox, S.F., 2013, Injection-driven swarm seismicity and permeability enhancement: Implications for the dynamics of hydrothermal ore systems in high fluid flux, overpressured faulting regimes: SEG Special Session, 26th International Applied Geochemistry Symposium, Rotorua, New Zealand, 18–21 November.


Kamenetsky, V.S., and Maas, R., 2013, Liquid immobility in mafic melts derived from the continental lithosphere: a clue to the origin of ore deposits: Rocks, reef and rainforest (RI), Biennial conference of the Specialist Group in Geochemistry, Mineralogy and Petrology (SSGMP), Geological Society of Australia, Mission Beach, Queensland, 14–19 July.

McGoldrick, P., 2013, Biological and geochemical features of ~1.6 Ga sea floor vents from northern Australia: Russian Academy of Sciences International Conference on Ore Genesis, Messa, Austria.


Berry, R., 2013, P843A Geometallurgical case study: Codelco Andina Division, Chile Part B: Predicting the Work Index, 39 p.


APPENDICES

NB. Please note that as this was CODES’ last year as a funded Centre of Excellence (CoE), an Activity Plan for future CoE activities is not included in this report. However, key activities for 2014 can be found in the Outlook section of each Program.

CODES POSTGRADUATE STUDENTS 2013

GRADUATE DIPLOMA OF SCIENCE (3)

<table>
<thead>
<tr>
<th>STUDENT</th>
<th>SUPERVISORS</th>
<th>PROJECT</th>
<th>SUPPORT</th>
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<tbody>
<tr>
<td>Wayne Baker</td>
<td>McNeill (MRT), McPhie</td>
<td>The correlations and exploration significance of the Naotone Volcanics, Rosebery Group, western Tasmania</td>
<td>MMG</td>
</tr>
<tr>
<td>John Davidson</td>
<td>Whitaker (IMAS)</td>
<td>Magnetic anomalies in continent ocean transition zones</td>
<td>CRC ORE</td>
</tr>
<tr>
<td>Lydia Wells</td>
<td>Noble</td>
<td>Long-term assessment of the weathering characteristics of sulphide materials</td>
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BACHELOR OF SCIENCE (HONOURS) (18)

<table>
<thead>
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<th>STUDENT</th>
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<th>PROJECT</th>
<th>SUPPORT</th>
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<tbody>
<tr>
<td>Vikraman Selvaraja</td>
<td>Jansen, Cooke</td>
<td>Determining the nature and zonation of advanced argillic alteration</td>
<td></td>
</tr>
<tr>
<td>Jacqueline Rush</td>
<td>Cooke, Jansen</td>
<td>Geology of the Marsden Cu-Au porphyry, NSW</td>
<td>Newcrest Mining</td>
</tr>
<tr>
<td>Will Rowlands</td>
<td>Roach, Reading</td>
<td>Petrophysical properties and geophysical response of the Benambra Complex, western Tasmania</td>
<td></td>
</tr>
<tr>
<td>Sam Poker</td>
<td>Roach, Reading</td>
<td>A geophysical investigation of the northern extent of the Meredith Grant, southwestern Tasmania</td>
<td></td>
</tr>
<tr>
<td>Daniel Phythian</td>
<td>McPhie</td>
<td>Geochemistry and metamorphism of the magmatic Ni-Cu-Ni deposit, Albany-Fraser Range, Western Australia</td>
<td></td>
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<tr>
<td>Matthew Ferguson</td>
<td>Crawford, Large</td>
<td>Mineral paragenesis and geometallurgical characteristics of the Pavinapita deposit, Western Australia</td>
<td>Independence Group</td>
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<tr>
<td>Craig Liddell</td>
<td>Berry, Scott</td>
<td>The structure and metamorphism of the Cox-Bright-Red Point Area, southwestern Tasmania</td>
<td>CODES, SLS, MRT</td>
</tr>
<tr>
<td>Caitlin Officer</td>
<td>G. Davidon, Bull</td>
<td>Geochemistry and metamorphism of the Cox-Bright-Red Point Area, southwestern Tasmania</td>
<td></td>
</tr>
<tr>
<td>Supitchaya Paipana</td>
<td>Zaw, Salam</td>
<td>Geochemistry and mineralisation characteristics of the Mococ gold deposit, Myanmar</td>
<td>One Deposits of SE Asia Project, National Prosperity Company</td>
</tr>
<tr>
<td>Matthew Ferguson</td>
<td>Crawford, Large</td>
<td>Stratigraphy, structure and correlations of the Rosebery Group west of the Rosebery Fault, Rosebery district, western Tasmania</td>
<td>MMG</td>
</tr>
<tr>
<td>Michael McGuire-Febry</td>
<td>McNeill (MRT), McPhie</td>
<td>Stratigraphy, structure and volcanology between the Mount Black Fault and the Rosebery Fault in the north end of Rosebery Mine, western Tasmania</td>
<td></td>
</tr>
<tr>
<td>Tobias Eriksen</td>
<td>Zaw, Manaka</td>
<td>Geology, structure and mineralisation characteristics of the Mutu Taung gold deposit, Myanmar</td>
<td>One Deposits of SE Asia Project, National Prosperity Company</td>
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<tr>
<td>Michael Rileson</td>
<td>Yungu Lim</td>
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Kane Maxwell coursework only Peabody Energy Australia
Rebecca McRae Scott Readton Goldfield, New Zealand Oceanic Gold
Johne Morrison Cooke TBA Newcrest Mining
Michael Musakka Scott Controls on gold mineralisation at Matala and Donribone, Zambia Copperbelt University
Saranaya Zaw Pangengkap, pyrite-geochimistry and ore fluids at Htongyi gold deposit, Myanmar Onge Deposits of SE Asia Project, National Prosperity Company
Joanne Morrison Zaw Neomet Mining
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Erin Lewis Cooke, Jensen Au-bearing porphyry ore of Lithium, Papua New Guinea: Its physicochemical character and nature of the caustic fluids

Alexey Lygin V-Kennedy, McPhie (MRT) The geology, geochemistry and genesis of the Avbury Ni deposit, Tasmania

Charles Makoudi Zaw, Large Trace element variation in Phanerozoic shale sequences in Malaysia: Implications for gold metallurgy of Sedimentary uranum

Takeshi Matsuki* Zaw, Meffre Geology and mineralisation characteristics of the Phuoc Son goldfield, central Vietnam

Claire McMahon G.Danielson Distribution of, and controls upon, pyrite trace element content of hydrothermal alteration zones at Hercules VHMS ore deposit, Tasmania and NED KIUL ore deposit, Northwest Territories, Canada

Peter MORSE Reading, Luong (Computing) Combined computational and human interaction strategies in knowledge generation from spatial and spatiotemporal information

Evan Ovran Cooke, Harris Geology, geochemistry and genesis of the Nambo pyrophyllite-Cu-Ag deposits, Fiji

Richelle Pasquali V-Kennedy, Noble, Geomechanics The characteristics and role of colloidal silica fluids in the formation of the Graves Ridge Zn-Pb project, western Tasmania

Pedro Pedroza de Fonseca McPhee, McNeill (MRT), Relias (GeofCali) Facies analysis and correlations in complex mineralised submarine volcanic successions: Mount Read Volcanics, western Tasmania

Jose Mueden Piçker Cooke, Berry, Scott Rimo Structural geology of the Andes of Central Chile: Evolution, controls on magmatism and the emplacement of giant ore deposits and implications for exploration

Daniele Redi Danyushevsky, De Vries (SRNRA), Lima (SRNRA) A contribution to the understanding of the eruptive behaviour of Somma-Vesuvius; A chemical mineral perspective

Marc Bonne Cooke, Jensen Geology and genesis of the contrasting Wafi-Guyporpyrro-porphry-epithermal deposit, Papua New Guinea

Abhish Salam* Zaw, Meffre, McPhee A geothermal, geochemical and metallogenic study of the Chatree epithermal deposit, Phetchabun Province, central Thailand

Lina Seranno V-Kennedy, McPhee The magmatic province of Patagonia and sills from Mauritania and Mali: Examples of silicic and basaltic large igneous provinces

Subba Sharma G.D. Cooke, Danyushevsky Evaluation of links between mantle-style Nb-Ri mineralisation and magmatism in the Clunclough fold belt, Queensland: Implications for exploration

Jeffrey Steadman Large, Bull, G.Diamond BFe, black shales, and gold deposits: A re-evaluation

Nathan Stevens Gemmell One gene of the Greenes Creek VMS deposit, Alaska: Implications for mining, milling and exploration

Bruno Sudworth* G.D. Cooke, Gemmell, McPhee The Montana Au-Ag high-sulphidation epithermal mineralisation in the Tapanuli Selatan district, North Sumatra Province, Indonesia: Implications for ore genesis and exploration

Francisco Tosta Cooke, Baker Tourmaline breccia pipes: San Francisco de los Andes, Argentina and Chilean Govt, Codelco, AMIRA P1060

Iwa Suyatge V-Kennedy, McPhee, Etting (BHPBilliton) The Mogok Cu-Au high-sulphidation epithermal mineralisation: A re-evaluation

Daniele Vargani McPhee, Carey The 2007 explosive activity at Piton de la Fournaise volcano (Réunion): Constraints on the eruptive processes by the volcanological study of the erupted deposits

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Evan Falloon Danyushevsky, James (MRT), Christie (GNS Science) Implications for ore genesis and exploration

Carlos Andres Jimenez Torres Cooke, White, Baker Baring lithocap, Negro Island, Philippines: Mineralogy, textures, and chemistry

Abhish Salam* Zaw, Meffre, McPhee Evaluation of links between mantle-style Nb-Ri mineralisation and magmatism in the Clunclough fold belt, Queensland: Implications for exploration

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**Note:** The above table highlights key collaborations and research focuses related to mineral deposits, magmatism, and geological processes in various regions, including Southeast Asia and China, focusing on both academic and international collaborations as of 2013.
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<td>Institute of Geochemistry, Russia</td>
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<td>University of Lisbon, Portugal</td>
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Opposite: Karin Orth demonstrating to student Aukje Benedichau during the Master of Economic Geology Geometallurgy short course.
**MAJOR EXTERNALLY FUNDED RESEARCH PROJECTS**

**AMIRA-ARC CENTRE OF EXCELLENCE PROJECTS 2013†**

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<th>MISC FUNDING FOR 2013</th>
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<td>Roach, Schau, Fulagar (Fulagar Geophysics)</td>
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**INDUSTRY AND OTHER EXTERNALLY FUNDED RESEARCH GRANTS 2013**

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<td>McPhie, V.Kamenetsky,</td>
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**APPENDICES**

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### VISITORS TO CODES 2013

#### INDUSTRY VISITORS

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#### NATIONAL ACADEMIC AND GOVERNMENT VISITORS

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<tr>
<td>Mark Kendrick</td>
<td>University of Melbourne</td>
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</tbody>
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#### INTERNATIONAL ACADEMIC AND GOVERNMENT VISITORS

<table>
<thead>
<tr>
<th>NAME</th>
<th>INSTITUTION</th>
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</thead>
<tbody>
<tr>
<td>Andrea Agangi</td>
<td>University of Johannesburg, South Africa</td>
</tr>
<tr>
<td>Shaun Baker</td>
<td>University of Waikato, New Zealand</td>
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<tr>
<td>Marc Campany</td>
<td>University of Barcelona, Spain</td>
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<td>Amaia Castellano</td>
<td>University of Barcelona, Spain</td>
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<tr>
<td>Julien Collot</td>
<td>Geological Survey of New Caledonia</td>
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<tr>
<td>Rosario Esposito</td>
<td>University of Naples, Italy</td>
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<td>Fang Feng Hu</td>
<td>Chinese Academy of Sciences</td>
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<td>Martin Jutzieler</td>
<td>University of Otago, New Zealand</td>
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<tr>
<td>Kate Kesewa</td>
<td>University of Oxford, UK</td>
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<tr>
<td>Chengbiao Leng</td>
<td>Chinese Academy of Sciences</td>
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<tr>
<td>Zhanke Li</td>
<td>China University of Geosciences</td>
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Rosario Esposito from the University of Naples delivering a talk entitled ‘Studies of volatile evolution in magmatic systems using melt inclusions’.