ANNUAL REPORT 2023

CODES

UNIVERSITY of TASMANIA

CODES

VISION

To be the premier international research centre in ore deposit geology.

MISSION

Significantly advance collaborative and innovative ore deposit research for Australian and international researchers and the minerals industry.

GOALS

- Undertake and publish high-quality research.
- Lead the global minerals industry in research on the exploration and recovery of new mineral resources.
- Equip the Australian minerals industry with world-class graduates.
- Communicate the Centre's research to the wider research, industry and general communities.

ABOVE: CODES Honours student Issi Port undertaking fieldwork in western Tasmania during 2023.

FRONT COVER: Participants of the 'Ores in Magmatic Arcs' Masters short course to Chile and Peru pictured in late October 2023 on the Rio Maipo transect through the Central Chilean Andes, learning about the geological setting and structural controls on the world's largest porphyry Cu-Mo deposits at Rio Blanco–Los Bronces and El Teniente (Photo: David Cooke).

BACK COVER: (Clockwise from top left): CODES PhD student Nelao Natukondje Naimbale giving a presentation in Burnie, Tasmania, during the UTAS/CODES RRC Mining Roadshow, held in June; CODES researcher Dr Lejun Zhang (right) with MSc student Chase Turner from Lakehead University and Robin Tolbert from NorthIsle Copper and Gold Inc (centre) examining drill core from the Northwest Expo prospect at Vancouver Island in Canada for the Amira P1249 project; the South America 'Ores in Magmatic Arcs' Masters short course participants pictured in front of CODELCO's El Teniente mine office during a tour of the facility; Hot Chili geologists explaining the geology of the Cortadera area to participants on the South America Masters course.

OPPOSITE: Pyrite-chalcopyrite-bornite mineralization (or cement?) in magmatic-hydrothermal breccia at Antakori, northern Peru. (Photo: David Portocarrero)

Contents

Director's report 2023

2023 was a year of contrasts for staff and students at CODES. There were some great achievements, including our Regional Research Collaboration project's highly successful first full year of research activities, and the appointments of Dr Lejun Zhang to the role of Senior Lecturer in Economic Geology, Dr Owen Missen to the role of Environmental Geology Lecturer and Dr Paul Olin to the role of Leader of CODES Analytical Laboratories. There were also significant outcomes from the field campaigns, cruises and laboratory research conducted by our team of volcanologists and sedimentologists, and from the strong research performances across the entire PhD cohort, which included several PhD completions and many PhD commencements.

We are proud that the CODES team, including both our research staff and professional staff in CODES Analytical Laboratories, achieved our highest level of income since 2016, securing almost $8 million in funding for the year through the financial contributions of UTAS, our industry partners, Government grants and fee-for-service work by CODES Analytical Laboratories. This achievement is testament to the collective hard work and commitment to excellence by all our team members.

The year also proved tumultuous at times, particularly with the tragic and unexpected passing of much-loved PhD candidate Jo Morrison, which shocked and saddened us all. Our thoughts and best wishes go out to Jo's young family. In 2023, we also experienced some significant internal issues at UTAS that proved challenging, exacerbated by the departure of several key CODES staff members in late 2022 and during 2023. Despite the challenges that the year presented, our team can be proud that they achieved an excellent quality of student experience for our PhD, Masters, Honours and undergraduate student cohort, provided significant opportunities for growth to our early- and mid-career researchers, and conducted impactful research across our team-based and individual research projects. Our strong commitment to teaching excellence was also maintained through the successful delivery of our Master of Economic Geology and Graduate Certificate in Economic Geology programs, with highlights including the return of our Ores in Magmatic Arcs field excursions to Indonesia (March) and South America (October–November), both of which were very well-received by the students and industry participants. Our staff and students continued to innovate in their ever-growing community outreach and engagement activities throughout 2023, with significant efforts being directed across the Tasmanian school system to help address the declining enrolments in STEM subjects across the Australian education system.

Our successes during 2023 could not have been achieved without the strong contributions and support of our collaborators, research partners and industry sponsors…

Our successes during 2023 could not have been achieved without the strong contributions and support of our collaborators, research partners and industry sponsors, which are as always hugely appreciated. This Annual Report highlights the successes of our team and our collaborators across the full spectrum of CODES' activities for the past year.

Amira P1249 fieldwork in South America (L–R): CODES Director Professor David Cooke, PhD student Isaac Evinemi, researcher Dr Yamila Cajal and lecturer Dr Matthew Cracknell are pictured at the town of El Salvador in northern Chile.

Research highlights

Our largest collaborative research project, Amira P1249, saw significant contributions to achieving its objectives made by the 14 UTAS staff and research fellows, 14 CODES PhD students, four external research collaborators, and three MSc students from Lakehead University and two Honours students from Universidad Austral de Chile who worked on the project during 2023. The P1249 project is providing its 15 industry sponsors with new tools for recognising proximity to high-grade ore, and new tools, methods, and workflows for translating and upscaling mineralogical, geochemical, and hyperspectral data into quantitative mineralogy for complex orebodies of Cu, Au and other metals. Several of the P1249 students joined the team in 2023 and conducted their initial field research at diverse locations across five continents, including Australia, Canada, Chile, Ghana and Indonesia.

The P1249 team conducted field campaigns, and ran two successful sponsors' meetings and workshops at CODES in June and December 2023, with team members also participating in the Amira Exploration Managers Conference and Society of Economic Geologists Conference in London (August), and the SGA meeting in Zurich (August). The project is delivering significant new insights, tools and workflows for mineral exploration and orebody characterisation.

The Australian Government Department of Education is funding a three-year Regional Research Collaboration (RRC) project at UTAS entitled 'Building Capacity in Regional Australia to enhance Australia's Economy through Research, Training, and Environmentally Sustainable Production of Critical Metals'. CODES is the lead research group on this project, which aims to facilitate the creation and growth of a sustainable critical metals industry in regional Tasmania, through detailed geological and mineral characterisation to identify and evaluate critical metal occurrences and pathways to critical metals production in active mine sites and advanced exploration projects. The project started in late 2022, and so 2023 was the first full year of project activities, with 11 PhD students and five postdoctoral fellows recruited to the project. They are working on critical metals characterisation and pathways to critical metals production across a range of critical and strategic commodities, including tungsten, magnesium, nickel, indium, cobalt, vanadium, tin and copper.

Education researchers are collaborating with our geoscientists, geometallurgists and mineral processing engineers at CODES to devise innovative solutions to community-based barriers that affect engagement in STEM and limit growth of the STEM-capable workforce needed by regional industries for critical metals production. It was a very successful year of research and engagement activities for the RRC team, culminating in a one-day public workshop at Tullah, western Tasmania, with over 50 participants from the local mining and exploration community, and with visiting national collaborators from Geoscience Australia and CSIRO.

Dr Martin Jutzeler led a team of 17 scientists on a 38-day voyage of the CSIRO research vessel RV *Investigator* in March–April 2023. The primary aim of the survey was to map and sample an enormous submarine landslide deposit (> 100 km^3) that had been discovered off the SW coast of Tasmania, in conjunction with biological surveys and an assessment of an unidentified shipwreck, which the team determined to be the 1973 shipwreck of the *Blythe Star*. The survey was conducted with minimal disruptions, with geophysical data, visual imaging and dredging providing a wealth of new information and materials for the team to process and interpret. The shipwreck discovery was widely promoted on local and national media outlets.

Dr Michael Roach and former CODES staff member Professor Bernd Lottermoser at RWTH Aachen

CODES PhD student Hannah Moore (in green dress) was part of the TWICS podcast team that won the 2023 Department of Industry, Science and Resources Eureka Prize for STEM Inclusion.

'Look what I've got!': Dr Tristan Wells holding his two A.B. Edwards Medals and the D.I. Groves Award following an awards presentation ceremony at the Australian Earth Sciences Convention in Perth held in June 2023.

University were successful in securing a two-year research grant from Erasmus+, the EU program for education, training, youth and sport, in late 2023 entitled 'Immersive Virtual Excursions on Critical Minerals for Clean Energy Transitions'. This project commenced at the end of 2023 and aims to generate new virtual teaching resources about critical minerals and their importance for clean energy transitions. Resources are being created for undergraduate and postgraduate education and the efficacy of these new approaches will be evaluated and assessed during the project through student surveys and interviews.

Awards and accolades

We were extremely proud of former PhD student Tristan Wells, who was presented with three top awards at the 2023 Australian Earth Sciences Convention in Perth. Tristan was awarded the A.B. Edwards Medal for the best papers on aspects of Economic Geology in the *Australian Journal of Earth Sciences* that were published in 2020 and 2021. He also received the D.I. Groves Award for 2021 for the best paper published in the *Australian Journal of Earth Sciences* by a young author, who must be the leading author. Congratulations and well done Tristan!

PhD student Hannah Moore was a member of the 'That's what I call Science!' (TWICS) podcast team who were awarded the 2023 Eureka Prize for STEM Inclusion from the Australian Government Department of Industry, Science and Resources. TWICS is connecting with over 10,000 people weekly as it promotes diverse voices in STEM and provides engaging and accessible content for its listeners. It's fantastic to see Hannah and her colleagues recognised for their unwavering commitment to promoting engagement with STEM.

Several of the 2023 cohort of Honours and third-year students from CODES and Earth Sciences were invited to participate in the AusIMM New Leaders Summit in Adelaide, with two students (Harrison Keeble and Sophie Minter) invited to give presentations. Harrison won the best submitted abstract award at the forum – well done to Harrison, Sophie and all other summit participants. Harrison and fellow Honours student Issi Port also both received Australian Institute of Geoscience bursaries in 2023 for their ability to effectively communicate their Honours projects and their implications for the broader geoscience community – well done Issi and Harrison! Former PhD student Tobias Stål was also honoured when he received the 2023 Royal Society of Tasmania Doctoral Award.

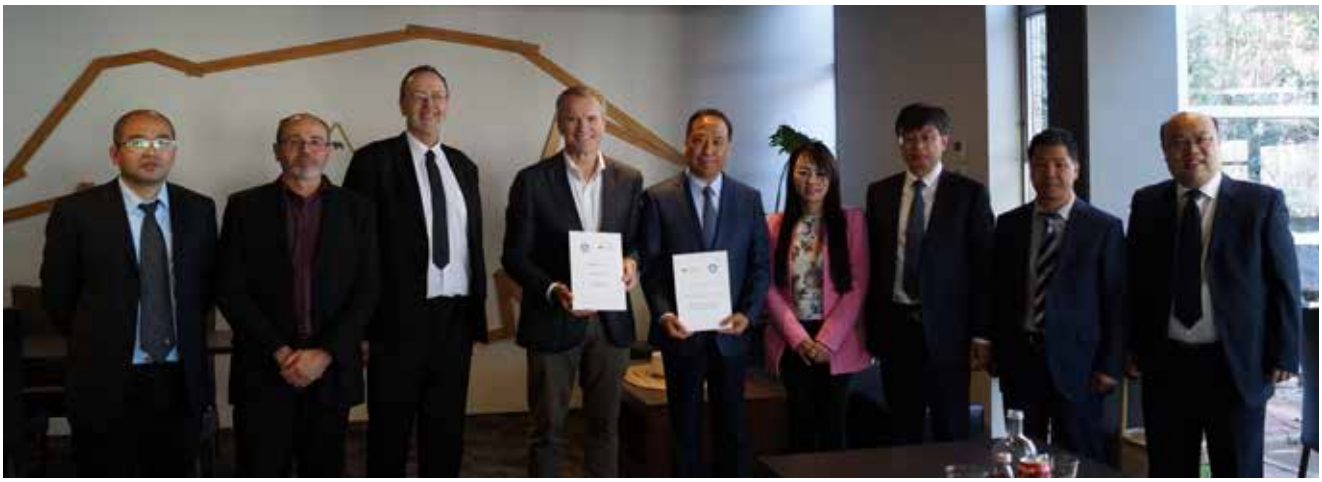
Masters courses

CODES had its busiest year ever in terms of delivery of Master of Economic Geology units in 2023. We delivered six units over the course of the year, with one unit (KEA707) offered twice (once in Indonesia, and once in South America). Course delivery varied from field-based to online, blended and face-to-face, in order to cater for the diverse interests of our student cohort:

- KEA718: Advanced Field Skills in Economic Geology (February)
- KEA707: Ores in Magmatic Arcs (Indonesia) (March)
- KEA716: Fundamentals of Economic Geology (April–May)
- KEA709: Ore Deposit Geochemistry, Hydrology and Geochronology (May–June)
- KEA713: Geodata Analytics (August–October)
- KEA711: Geometallurgy (October)
- KEA707: Ores in Magmatic Arcs (South America) (October–November)

For the first time, we also had students enrol in KEA724 (Thesis unit part A), which was co-taught with the South American version of KEA707. Our student numbers in the Master of Economic Geology program continue to grow, with the Graduate Certificate

Spreading the word: Publicity material for the ProExplo Conference held in Lima, Peru, in May 2023, showing Professor David Cooke as one of the keynote speakers.



In June 2023 a Chinese delegation from the China University of Geosciences, Beijing, visited CODES to discuss high-level cooperation and exchanges between the two institutions. Here Executive Dean of the SNS Terry Bailey and Professor Zhao Zhidan, Vice President CUGB, hold the memorandum of agreement that was signed during the visit.

in Economic Geology proving to be an increasing popular entry pathway to the Masters program.

Conferences and trips

Our staff and students once again embraced the opportunities to promote their major research findings at numerous national and international conferences, including IAVCEI 2023 (New Zealand), European Geosciences Union General Assembly (Austria), ProExplo 2023 (Peru), CRITCON2023 (Adelaide), Australian Earth Sciences Convention 2023 (Perth), Goldschmidt 2023 (France), SEG 2023 (UK), 17th Biennial SGA meeting (Switzerland), Chilean Congresso (Chile) and NewGenGold (Perth). A major highlight was the return of the 'CODES booth' at SEG London, where our team were run off their feet with inquiries from prospective students and potential industry research collaborators.

Visits from overseas

It was with great pleasure that we welcomed a delegation from China University of Geosciences, Beijing (CUGB) in June 2023 that was led by CUGB Vice-President Professor Zhao Zhidan to sign a Memorandum of Understanding with the University of Tasmania. This MOU will lead to greater collaboration and student exchanges between our institutions, with the first cohort of CUGB undergraduate students planning to participate in a two-week field excursion to Tasmania in early 2024. We were also honoured to welcome His Excellency, Mr Johan Pontus Melander, the Swedish Ambassador to Australia, who visited UTAS to discuss opportunities to cooperate in mining, critical minerals and rare earths, including a brief tour of CODES Analytical Laboratories in September 2023.

Staff changes

After 34 years of dedicated service, Dr Michael Roach retired from CODES and Earth Sciences in December 2023. Mike has been a huge part of our team – he was one of the first students recruited into the CODES PhD program in the early 1990s. After the completion of his PhD, Mike

Dr Michael Roach, here pictured gathering data on King Island in 2020, retired at the end of 2023 after 34 years at CODES/Earth Sciences and a 'profoundly impactful career as lecturer, supervisor and researcher'.

progressed directly to his profoundly impactful academic career as a lecturer, supervisor and researcher. Mike carried a huge teaching and supervision load for many years and inspired many students with his passion and dedication to geophysics and geology. He shaped the careers of a significant proportion of our student cohort, who've benefited enormously from his outstanding supervisory skills – Mike always excelled at bringing the best out of his students to help them on their pathway to long and impactful professional careers. Mike was single-handedly responsible for all the CODES and Earth Sciences teaching staff being able to flip to online teaching in 2020 through his amazing 3D visualisations – this proved to be a huge boon for us throughout the pandemic. Mike is a well-loved and deeply respected member of our team, and we have all benefited from having had the pleasure of working with him. While we are all saddened by Mike's resignation, we are pleased that he's chosen to stay connected by taking on an adjunct role, and we all hope that he stays actively involved with us for many years to come. Mike was an inspiration to us all and we wish him the very best for the future.

Dr Jonathan Cloutier left CODES after securing a permanent role at Geoscience Australia (GA) in 2023, after working for two years as an embedded research fellow based at GA in Canberra. We look forward to continued and enhanced collaborations with Jonathan and his colleagues at GA for many years to come. Dr Clare Miller also departed UTAS in early 2023 – we wish her well in her role with the Environmental Protection Agency. Sadly, Dr Paul Olin announced his resignation from CODES Analytical Laboratories at the end of 2023, and so additional changes to the lab staff personnel will occur throughout 2024. Paul has been one of our most popular team members over the past decade, as well as being a great analyst and lab manager. He will depart CODES in February 2024 for a new opportunity at the University of Adelaide.

We were very pleased to welcome several staff to our team in 2023, including research fellows Dr Yamila Cajal, Dr Mohammad Fathi, and Dr Paula Montoya, and professional staff members Jonathon Traynor, and Max Hohl. Thanks to all our new staff who joined the team in 2023 – your contributions have enriched our diverse cohort of staff and students, and your efforts have helped enormously as we continue to strive for excellence across all spheres of academic endeavour.

Publications

CODES continued its outstanding track record of industry impact and engagement through 2023 with the delivery of 287 reports to industry by our research staff, students and the CODES Analytical Laboratories team. There were 12 domestic and 27 international conference presentations by CODES team members, including four keynote addresses. A total of 41 international journal articles written or co-authored by our staff and students were published in 2023.

The year ahead

2024 is CODES' 35th anniversary, and we have many exciting initiatives and activities planned for the year. A three-day Critical and Strategic Metals Symposium will be convened as part of our biannual 'Ore Deposit Models and Exploration Strategies' Masters short course, along with an Exploration Strategies forum, which should see significant domestic and international participation both in-person and online. We will once again deliver our popular field-based biannual Masters short

A BBQ held in the CODES Rock Garden during the Amira P1245 Sponsors' Meeting in December 2023 doubled as a Christmas get together for CODES staff, students and sponsors.

course 'Volcanology and Mineralisation in Volcanic Terrains'. Several of our staff and students will participate in the Society of Economic Geologists (SEG) annual conference, in Namibia, with numerous other domestic and international conferences also on the radar for our team members. Our SEG student chapter is planning a two-week field excursion to visit some of Japan's premier VHMS and epithermal deposits. CODES is looking to initiate a new collaborative research project into sediment-hosted Cu systems, and new research projects in volcanology, geological hazards, Earth evolution, geometallurgy and geoenvironment are in development. The Regional Research Collaboration project should be hitting full capacity in terms of data acquisition and research outputs as it passes its midway point, and the Amira P1249 team should have its full cohort of students recruited and underway by late 2024.

Professor David Cooke
Director of CODES

STATISTICS AT A GLANCE 2023

Academic research staff	43
Postgraduate students	140
Major research projects	45
Countries involved	35
Publications in refereed journals	41
Research reports to industry	287
Workshops and short courses	
Number	23
Countries	5 plus online delivery
Attendees	~600
Funding	
Industry	$1.40 million
UTAS	$2.22 million
Worldwide collaborations	
Industry	63
Institutes and universities	89

Profile and research structure

An overview

CODES commenced operations in 1989, evolving over two and a half decades from an Australian Research Council-funded Key Centre to a Special Research Centre and then a Centre of Excellence. Now in its fourth decade of operations, CODES is known as the Centre for Ore Deposit and Earth Sciences. Based at the University of Tasmania, CODES has grown substantially over the years and is regarded widely by industry and academia as a global leader in ore deposit research and postgraduate training. With 43 highly qualified research staff and 140 postgraduate students, CODES is one of the largest university-based teams of ore deposit researchers in the world.

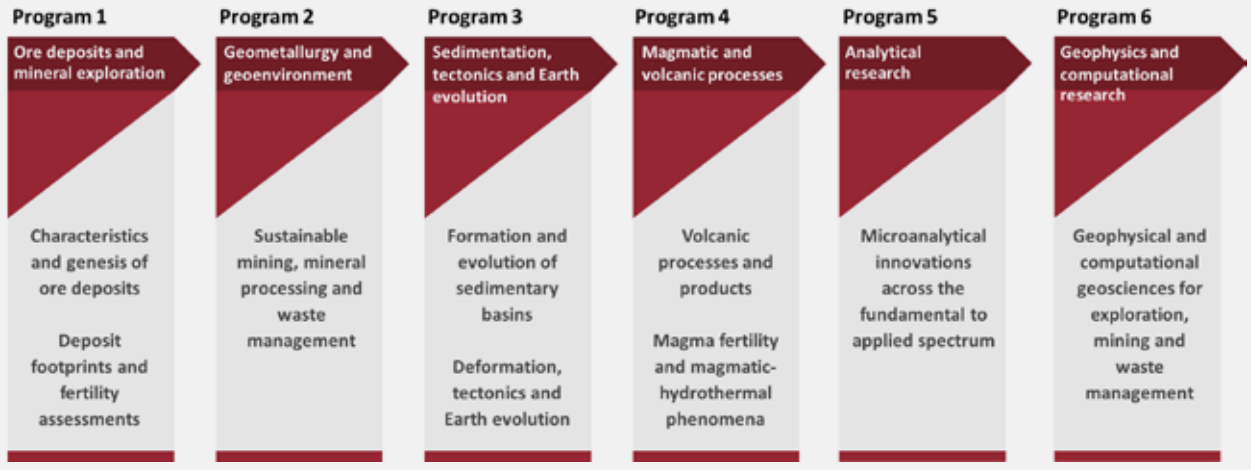
Highly productive worldwide collaborations have been developed with over 63 industry companies, plus a host of joint research initiatives with 89 institutions and universities – 20 in Australia and 69 overseas. It currently has 45 major research projects spanning 35 countries, across six continents. It is also a leading academic group to publish in *Economic Geology*. In the past year, CODES has maintained its reputation for delivering excellence in technology transfer by producing 287 reports to industry and conducting 23 short courses, workshops, conferences and field trips. With the COVID pandemic fading into memory, face-to-face courses were allowed once more. However, the online learning format continued to prove popular as it allowed participants from remote locations, who would not otherwise have been able to attend, to join these courses and workshops.

Industry-focussed research

CODES' research is conducted within and across six research programs (see CODES Research Program Structure graphic below). Our research spans a range of fundamental and applied activities, and our industry-focussed

Codes Research Program Structure

The CODES program structure covers the full spectrum of research from fundamental to applied:



The CODES booth at the SEG 2023 Conference in London during August was a hive of activity. Here CODES staff (L–R) Dr Mike Baker, Professor David Cooke and Dr Wei Hong are joined by Sam Scher, a geochemist and director at LKI Consulting, at the booth.

research aims to develop new exploration techniques for mineral discoveries, and new practices for sustainable mining, mineral processing and waste management. Our research across this spectrum of activities allows CODES to provide the minerals industry with a constant supply of world-class geoscience graduates and creates the platform for our training and upskilling of minerals industry professionals through our highly regarded Master of Economic Geology and Graduate Certificate in Economic Geology programs.

Training and education

Training and education at CODES provides an ongoing supply of highly sought-after geoscience graduates, and delivers a range of professional development short courses and workshops tailored to meet the needs of the minerals industry in terms of upskilling its workforce. The schedule for these courses varies in line with demand. Postgraduate courses are offered at the following levels:

Honours

A one-year degree that will significantly increase employment options or can be used as a stepping-stone to a PhD. Courses are available in Economic Geology, Geophysics, Geochemistry and Environmental Geology.

Graduate Certificate in Economic Geology

This postgraduate offering, introduced in 2021, is designed for professional geoscientists keen to gain a stronger understanding of ore deposits, either for professional development, or as a foundation for further postgraduate training. This one-year degree requires completion of the unit 'Fundamentals of Economic Geology' and one other unit from the Master of Economic Geology coursework offering. Students who complete the GCert can attain the Master of Economic Geology by completing a further six units from the Masters program.

Master of Economic Geology

Industry geologists can participate in a series of intensive, predominately two-week courses aimed at the working geologist in order to upgrade their skills; the MEconGeol is available in coursework only (8 units) and coursework (6 units) plus research

CODES…is regarded widely by industry and academia as a global leader in ore deposit research and postgraduate training.

thesis options. The degree is part of the national Minerals Geoscience Masters (MGM) program. In 2023 a total of seven MEconGeol units were offered: 'Advanced Field Skills in Economic Geology', 'Ores in Magmatic Arcs – Indonesia', 'Fundamentals of Economic Geology', 'Ore Deposit Geochemistry, Hydrology and Geochronology', 'Geodata Analytics', 'Geometallurgy', and 'Ores in Magmatic Arcs – South America'.

PhD and MSc

These higher degree by research (HDR) programs enable students to complete their theses in an environment that provides access to state-of-the-art technology, exceptional links with industry, and supervisors who are international leaders in their respective fields.

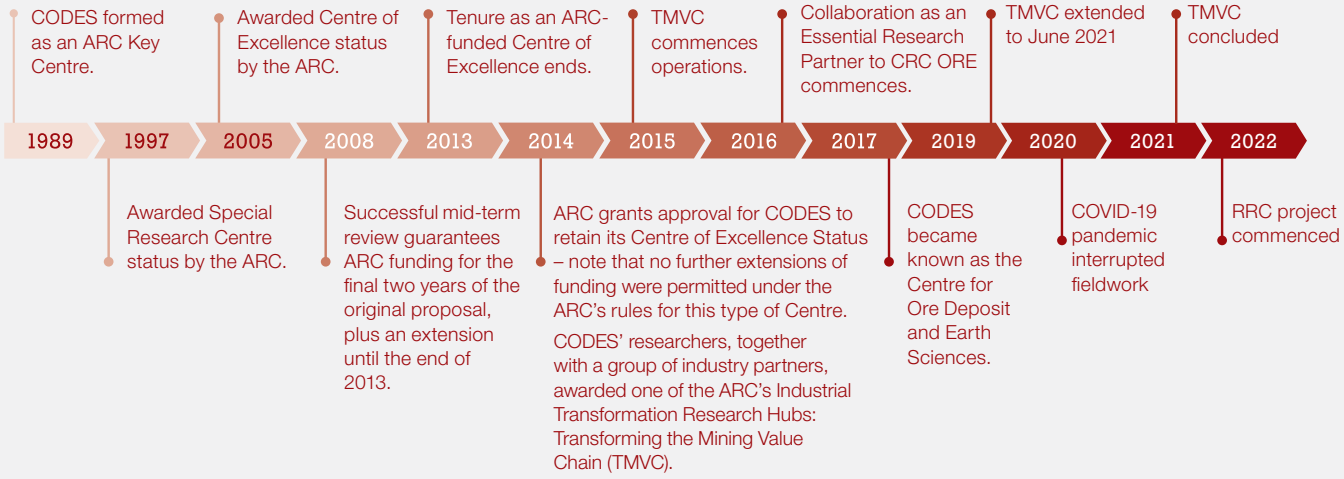
Dr Lejun Zhang (left) undertaking fieldwork in Canada in 2023 with researchers from Lakehead University for the Amira P1249 project.

Research facilities

CODES Analytical Laboratories contain state-of-the-art analytical facilities for a wide range of geological analyses, encompassing the routine multielement analysis of sulphide and oxide minerals, including the full range of platinum group elements; U/Pb dating of a wide range of minerals including zircon, monazite, apatite, rutile and titanite; multielement analysis of silicates; Lu/Hf dating of garnet and apatite; and elemental imaging of minerals and rocks. These facilities include four laser ablation ICP-MS laboratories specialising in ore deposit applications, an XRF laboratory, a solution ICP-MS laboratory and clean room, a fluid/melt inclusion laboratory, a lapidary department and sample preparation facilities. In addition, portable analytical techniques are provided, including shortwave infrared (SWIR) and portable XRF.

CODES has reciprocal access arrangements with the UTAS Central Science Laboratory, which has an extensive suite of complementary equipment, particularly in the areas of electron microscopy and mineral liberation analysis (MLA), X-ray microanalysis, laser Raman and FTIR spectroscopy, and ICP-MS. CODES has established its position at the leading edge in mineral chemistry research for exploration through the development of unique analytical techniques, data processing and screening methods, and calibration standards, combined with employing staff who have extensive expertise in analytical protocols and the interpretation of results.

Timeline



Staff and management 2023

Group photo of all CODES and Earth Sciences staff and students taken in March 2023 in the CODES Rock Garden.

Centre Director

Professor David Cooke has been the Centre Director since mid-2017; he is responsible for the scientific leadership and operational management of the Centre. Also providing support to these roles are 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 from the Department for Energy and Mining, South Australia, who has extensive experience in the minerals industry and the public service. Paul Agnew from Rio Tinto is Deputy Chair. In 2023 there was no Advisory Board meeting due to UTAS undergoing an internal review of its future strategies.

Executive Committee

The Executive Committee consists of the Centre Director, Deputy Director (vacant), Head of the Discipline of Earth Sciences, and representatives from the areas of applied research, fundamental research, education and administration. It meets approximately six times a year, working closely with the Director to develop the Centre's goals, strategies and research directions.

Annual Review

The Annual Review is an annual one-day forum of presentations relating to the Centre's research. The membership is wider than that of the Advisory Board and includes representatives from partner companies, research collaborators and other geoscience stakeholders. The Annual Review is designed to provide stakeholders and interested parties with an opportunity to see the breadth of the research conducted at CODES and to influence future research directions. In 2023 to mitigate ongoing workload issues no Annual Review was held.

Staff movements

Appointments

Academic/research staff

Dr Mohammad Fathi gained a PhD in Mining Engineering-Mineral Processing from Amirkabir University of Technology, Tehran, Iran, and has five years' industrial experience. He took on the role of Research Fellow in Geometallurgy/Engineering Geology at CODES in January 2023.

Dr Yamila Cajal did her PhD at the Research School of Earth Sciences of the ANU. She joined CODES in February 2023 and is working as a Research Fellow in Critical Minerals Characterisation as part of the RRC program and the Amira P1249 project.

Dr Paula Montoya joined CODES in early October 2023 to take up the role of Postdoctoral Research Fellow in Economic Geology. Paula was previously an assistant professor at Universidad del Norte in Colombia.

Professional/ technical staff

Jonathon Traynor began his role as a part-time Senior Technical Officer in March working for both CODES and Earth Sciences.

Dr Max Hohl finished his PhD at CODES in 2023 and then went on to work in the CODES Analytical Laboratories as a Laboratory Analyst from mid-2023.

CODES PhD staff and students at the Amira P1249 BBQ in December 2023. They are (L–R): Dr Yamila Cajal; PhD students Hannah Moore, Acacia Clark, Isaac Brown and Giovana Oliveira Pimentel; Honorary Professor Khin Zaw; Dr Max Hohl; PhD student Bridie Le'Gallais; and professional staff Caroline Mordaunt and Karen Huizing. In the background are former CODES director Professor Bruce Gemmell and Honorary Associate Professor Ron Berry.

Departures/role changes

Academic/research staff

Lecturer in Geoenvironment and Geometallurgy Dr Clare Miller left CODES in early March 2023 and went to work for the Environment Protection Agency as a Scientific Officer based in Hobart.

Postdoctoral Research Fellow Dr Jonathan Cloutier, who joined CODES in February 2019, had latterly been working as a CODES researcher embedded with Geoscience Australia. He left CODES in December 2023, and took up a separate post in Canberra at Geoscience Australia.

Dr Michael Roach retired at the end of December after 35 years' service at Earth Sciences and CODES during which time his contributions to geology at UTAS were profoundly impactful. He will continue to contribute to Earth Sciences/CODES as an honorary staff member and will continue to evolve his 3D geology visualisations technology.

TOP LEFT: Dr Francisco Testa, Lecturer in Earth Sciences, pictured during a morning tea for those working on the Amira P1249 project. TOP RIGHT: Dr Paula Montoya (left), who was appointed as a Postdoctoral Research Fellow in Economic Geology in October, talks with Newmont geologist Sarah Rice at the December Amira P1249 Sponsors' Meeting.

BOTTOM LEFT: CODES staff members Dr Sheree Armistead and Dr Matthew Cracknell taking time out during a morning tea for the Amira Sponsors' Meeting in June 2023 at CODES. BOTTOM RIGHT: Staff members Dr Lejun Zhang and Associate Professor Rebecca Carey listen intently at a CODES welcome morning tea held in March.

STAFF AND MANAGEMENT

NAME	SPECIALISATION	%*
Director, Professor David Cooke, BSc Hons (Latrobe), PhD (Monash)	Porphyry Cu-Au, fluid-rock geochemistry	50

ACADEMIC/RESEARCH STAFF AT UTAS

NAME	SPECIALISATION	%
Dr Sharon Allen, BSc (Massey), MSc (Auckland), PhD (Monash)	Volcanic facies analysis	Hon
Dr Sheree Armistead, BSc Hons (Monash), PhD (UAdelaide)	Plate tectonics, isotope geochemistry, structural geology	70
Dr Mike Baker, BSc Hons (Sydney), PhD (UTAS)	Igneous petrology, mineral chemistry	100
Dr Ivan Belousov, BSc, MSc (Moscow), PhD (Vernadsky)	Igneous petrology, geochemistry, volcanology, LA-ICP-MS analysis	100
Dr Stuart Bull, BSc Hons, PhD (Monash)	Clastic and carbonate sedimentology and volcanology	Hon
Dr Yamila Cajal, BSc Hons (UdeC), PhD (ANU)	Geochemistry, petrology and economic geology	100
Associate Professor Rebecca Carey, BSc Hons (UTAS), PhD (U Hawaii)	Volcanology	50
Dr Matthew Cracknell, BSc Hons, PhD (UTAS)	Geophysics, machine learning and data mining	50
Dr Paul Davidson, BSc Hons, PhD (UTAS)	Melt and fluid inclusions	Hon
Dr Angela Escolme, MEarthSci Hons (Manchester), PhD (UTAS)	Geometallurgy, geochemistry, mineralogy	50
Dr Mohammad Fathi, BSc (SUT), MSc (TMU), PhD (AUT)	Mineral processing, hydrometallurgy	100
Professor J Bruce Gemmell, BSc (UBC), MA, PhD (Dartmouth)	VHMS deposits and epithermal Au-Ag	Hon
Professor David Green, BSc Hons, MSc, DSc, DLitt Hon (UTAS), PhD (Cambridge)	Experimental petrology	Hon
Dr Wei Hong, BSc (CUG), MSc (CAGS), PhD (UTAS)	Economic geology and mineral characterisation	100
Dr Julie Hunt, MSc (UBC), PhD (JCU)	Geometallurgy, economic geology	50
Dr Martin Jutzeler, MSc (U Lausanne), PhD (UTAS)	Volcanology and clastic sedimentology	30
Dr Maya Kamenetsky, PhD (UTAS)	MLA-SEM, geometallurgy, petrology	60
Professor Khin Zaw, BSc (Rangoon), MSc (Queen's), PhD (UTAS)	Fluid inclusions, SE Asian metallogenesis	Hon
Professor Ross Large, BSc Hons (UTAS), PhD (UNE)	Volcanic-hosted and sediment-hosted base metal and gold ores	Hon
Dr Charles Makoundi, MSc, PhD (UTAS)	Geochemistry (incl exploration and isotope geochemsitry), geochronology, clastic sedimentology	Hon
Professor Sebastien Meffre, BSc Hons, PhD (Sydney)	Petrology and tectonics of the SW Pacific	50
Dr Owen Missen, BSc, MSc (UMelb), PhD (Monash)	Environmental geology, mineralogy and biogeochemical cycling	50
Dr Paula Montoya, BSc, MSc (UTAS), PhD Hons (UNAM)	Orebody characterisation, economic geology, geometallurgy	100
Dr Michael Roach, BSc Hons (Newcastle), PhD (UTAS)	Geophysical responses of ore deposits	20
Dr Robert Scott, BSc Hons, PhD (Monash)	Structural geology, gold deposits/Masters Program Coordinator	65
Dr David Selley, BSc Hons (Adelaide), PhD (UTAS)	Structural geology, basin analysis, ore deposit modelling	Hon
Dr Jeff Steadman, BSc (Central Missouri), MSc (Iowa), PhD (UTAS)	Ore and sedimentary pyrite geochemistry; seawater composition through geologic time	77
Dr Francisco Testa, MSc (UNS, Argentina), PhD (UTAS)	Magmatic-hydrothermal breccias, porphyry and epithermal deposits, geochemistry	50
Dr Tony Webster, BSc Hons (Latrobe), BA (UNE), BAVE, BEd Hons (UTAS), GDipMinEng (UNSW), MSc (JCU), PhD (UTAS)	Mining structural geology, complexly deformed deposits	Hon
Dr Lejun Zhang, BSc, PhD (HFUT)	Porphyry Cu-Au and HS epithermal	50

*Research percentage

ACADEMIC/RESEARCH STAFF BASED AT COLLABORATIVE INSTITUTIONS/INDUSTRY

NAME	INSTITUTION	%*
Dr Shaun Barker	MDRU, University of British Columbia	Hon
Dr Ana Liza Cuison	Emmerson Resources	Hon
Dr Kathy Ehrig	BHP	Hon
Dr Anthony Harris	Newmont Corporation	Hon
Professor Peter Hollings	Lakehead University	Hon
Mr Terry Hoschke	Consultant	Hon
Dr David Huston	Geoscience Australia	Hon
Mr Adi Maryono	J Resources	Hon
Dr Gerrit Olivier	Fleet Space Technologies	Hon
Dr John Walshe	Independent	Hon
Dr Tristan Wells	Inflection Resources	Hon
Professor Noel White	Independent	Hon

TECHNICAL/ADMINISTRATIVE STAFF

NAME	JOB TITLE	%*
Mrs Michele Chapple-Smith, GDipAppSci (UTAS)	Lapidary Technician	80
Mr Alex Cuison, BSCE (SLU, Philippines)	Lapidary Manager	100
Ms Fanghua Dai, MSc (CUGW)	Laboratory Analyst	80
Mr Max Hohl, MSc (FAU, Germany)	Laboratory Analyst	50
Ms Karen Huizing	Executive Officer	100
Ms Elena Lounejeva, MSc (UNAM)	Laboratory Analyst	60
Mrs Michelle Makoundi, B Acc (U Marien Ngouabi)	Technical Officer	100
Ms Caroline Mordaunt, BA Hons (King's College London)	Editor and Administrative Officer	70
Mr Maxwell Morissette, BSc (McGill)	Laboratory Analyst in LA-ICP-MS	100
Ms Claire Newland, BBus (Acc) (RMIT)	Administrative Support Officer	70
Dr Jeffrey Oalmann, BSc (Kansas State), MSc (Texas Tech), PhD (KU)	Laboratory Analyst in LA-ICP-MS	100
Dr Paul Olin, BA (SOU), MSc, PhD (WSU)	Manager – CODES Analytical Laboratories	100
Ms Helen Scott, BSc Hons (UTAS), BEd (QUT)	Project Administration Manager | Project Manager – Critical Metals RRC	100
Ms Isabella von Lichtan, BSc Hons (UTAS)	Curator	25

*Research support percentage

ADVISORY BOARD

NAME	INSTITUTION
Chair: Paul Heithersay	Department for Energy and Mining, South Australia
Deputy Chair: Paul Agnew	Rio Tinto Exploration
Terry Bailey	College of Sciences and Engineering, UTAS
Rufus Black	University of Tasmania
Dave Braxton	Anglo American
Mike Christie	First Quantum Minerals
David Cooke	CODES, UTAS
Mark Doyle	AngloGold Ashanti
Simon Ellingsen	School of Natural Sciences, UTAS
Anthony Harris	Newcrest Mining
Anthony Koutoulis	Research, UTAS
Trevor Shaw	Mt Isa Mines (Glencore)
Noel White	Independent
Andrew Wurst	Barrick

EXECUTIVE COMMITTEE

NAME	ROLE
Chair: David Cooke	Director, CODES
vacant position	Applied Research
Rebecca Carey	Fundamental Research
vacant position	Deputy Director, CODES
Sebastien Meffre	Head, Discipline of Earth Sciences
Helen Scott	Administration
Robert Scott	Education

Program one: Ore deposits and mineral exploration

OBJECTIVE

This program aims to use newly developed geological, geochemical, mineral chemical and geophysical features of ore-forming systems and terrains in order to devise better means of discovering mineral resources at surface and under cover.

Introduction

Program 1: Ore deposits and mineral exploration provides industry-focussed process-based models for the formation of base and precious metal ore deposits. It also seeks to develop innovative new tools for determining the most prospective regions for minerals exploration (fertility), and for targeting of buried ore deposits (vectoring). The projects that form Program 1 reflect the range of expertise and level of diversity in the field of hard-rock geology at CODES.

Highlights

CODES Program 1 has continued to produce quality applied research across a number of multi-year projects that have provided significant outputs to both the academic and professional community, both locally and around the world.

The multi-year Amira Global P1249 project 'Exploring, characterising, and optimising exploring complex orebodies – Upscaling orebody knowledge to add value across the mining value chain' continued in 2023. This five-year project seeks to build upon the significant contributions made by the succession of Amira Footprints research projects over the past 19 years whilst also forging new ground in the fields of data analytics and classification. In 2023, three PhD theses from prior Amira Footprints research projects that continued into the P1249 project were completed: Xin Ni Seow's thesis on the genesis, geochemistry and spectral characteristics of alunite supergroup minerals; Yi Sun's thesis on the geology of the quartz – pyrite – gold (QPG) mineralisation and a new model for the genesis of the Mankayan district, Northern Luzon, Philippines; and Rhiannon Jones' thesis on the significance of phyllic alteration at the E26 porphyry Cu-Au deposit in Northparkes, NSW.

The multi-year project on the Loei and Troung Son fold belts in SE Asia has continued producing numerous research outputs, including a paper in the *Journal of Asian Earth Sciences* on 'Using compositions of zircon to reveal fertile magmas for the formation of porphyry deposits in the Loei and Truong Son fold belts, northern Laos' authored by Peerapong Sritangsirikul, and a paper in *Earth-Science Reviews* on 'A review of new detrital zircon U-Pb ages from the Mogok area of Myanmar: Implications for the

Dr Mike Baker (right) and Dr Wei Hong explore the Rio Escalada area near the Magdalena volcanic-hosted massive sulfide deposit, a newly discovered world-class copper-zinc-lead-silver deposit in southwest Spain. Mike and Wei were collecting samples for the Amira P1249 project during September 2023.

stratigraphy and early tectonic evolution of the Mogok Metamorphic Belt (MMB)' co-authored by Khin Zaw, Ivan Belousov and Karsten Goemann (CSL). A final report on the 'Ore deposit geochronology, zircon trace element composition, pyrite chemistry of ore deposits in Laos' project sponsored by Naga Minerals was also submitted in 2023.

The Porphyry research project has been driven by the continuation of Victor Torres' PhD project on the Soledad tourmaline breccia complex in central Peru and David Portocarrero's Master of Economic Geology project on the Antakori deposit in northern Peru. The National Mineral Potential Mapping project has also generated significant outputs in 2023, including Australia-wide mineral potential models for sediment-hosted Cu, clastic-dominated siliciclastic-carbonate (McArthur-type), clastic-dominated siliciclastic-mafic (Selwyn-type), Mississippi Valley-type and Irish-type mineralisation.

CODES Program 1 has continued to produce quality applied research across a number of multi-year projects that have provided significant outputs to both the academic and professional community, both locally and around the world.

The program team

LEADER MIKE BAKER
DEPUTY LEADER LEJUN ZHANG

TEAM MEMBERS:

Ivan Belousov, Ron Berry, Stuart Bull, Yamila Cajal, Jonathan Cloutier, David Cooke, Matthew Cracknell, Angela Escolme, Wei Hong, Julie Hunt, Ross Large, Charles Makoundi, Adi Maryono, Sebastien Meffre, Michael Roach, Thomas Rodemann (CSL), Robert Scott, David Selley, Jeff Steadman, Francisco Testa, Khin Zaw

PHD STUDENTS:

Fuseini Atanga, Jose Barillas Diaz, Billy Beas, Isaac Brown, Axel Cima, Takeshy Coaquira, Stephen Cooke, Vinicius da Cruz, Rob Davidson, Isaac Evinemi, Alex Farrar, Javier Gil Rodriguez, Rhiannon Jones, Joseph Knight, Nelao Natukondje Naimbale, Jaime Osorio, Giovana Pimentel, Olive Ponyalou, Arka Sahu, Angela Santos Costa, Xin Ni Seow, Emily Smyk, Peerapong Sritangsirikul, Markus Staubmann, Yi Sun, Victor Torres, Emrecan Yurdakul, Zebedee Zivkovic

MASTERS STUDENTS:

CODES: Lieth de Selincourt, Joshua Greene, Brendan Hardwick, Ashleigh Job, Ben Johnson, David Portocarrero, Henry Schaumburg

LAKEHEAD U: Jason Dyer, Patrick Hamilton, Mitch Marcelissen, Nafiu Sulyman, Chase Turner

HONOURS STUDENTS:

CODES: Harrison Keeble, Sarah Purdom, Millie Young

AUSTRAL: Reinaldo Gonzalez, Solange Munoz, Ricardo Navarro, Ivania Rojas, Francisco Torres

COLLABORATORS:

ANGLO AMERICAN
David Braxton, Iain Dalrymple

ANGLOGOLD ASHANTI
Ben Hames, Andrew Jenkins, Luke Swift

AKITA UNIVERSITY, JAPAN
June J. Born, Yasushi Watanabe

BHP
Natalie Caciagli, Simon Gatehouse

BOLIDEN
David Drejing-Carroll, Tobias Hermansson, Helen Thomas

CHAKANA COPPER CORP
David Kelley

CHENGDU RESEARCH CENTRE, CHINA GEOLOGICAL SURVEY, CHINA
Linnan Guo, Meifeng Shi

CHIANG MAI UNIVERSITY, THAILAND
Phisit Limtrakun

CHULALONGKORN UNIVERSITY, THAILAND
Arkar Moe Myint, Pitsanupong Kanjanapayont, Kobkul Khiaosanuan (Neam), Abhisit Salam

CMOC/NORTHPARKES
Jon Hoye

CODELCO
Martin Kock, Sergio Pichott, Carolina Rodriguez

CONSULTANT
Mike Crow, Noel White

DEPARTMENT OF GEOLOGY, POLYTECHNIC COLLEGE, LAOS
Patthana Bounliyong

DEPARTMENT OF MINERAL RESOURCES, THAILAND
Punya Charusiri

DGO GOLD
Eduard Eshuys

EVOLUTION MINING
Ned Howard

FIRST QUANTUM MINERALS
David Arribasplata, James Banyard, Federico Cernuschi, Tim Ireland

FORTESCUE METALS GROUP
Cam Quinn, Dana Olafson

GEOLOGICAL SURVEY OF SOUTH AUSTRALIA
Adrian Fabris, Anthony Reid

GEOSCIENCE AUSTRALIA
Karol Czarnota, Michael Doublier, Arianne Ford, David Huston, Anthony Schofield

GLENCORE/MT ISA MINES
Ben Andrew, Alex Brown, Trevor Shaw

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY, MUMBAI, INDIA
Sakthi Saravanan Chinnasamy

INSTITUTE OF TECHNOLOGY OF CAMBODIA, CAMBODIA
Seang Sirisokha

KYAING TONG UNIVERSITY, MYANMAR
Aung Min Oo

KYUSHU UNIVERSITY, JAPAN
Akira Imai

LAKEHEAD UNIVERSITY, CANADA
Peter Hollings

MAHASARAKHAM UNIVERSITY, THAILAND
Clive Burrett

MAHIDOL UNIVERSITY, THAILAND
Patchawee Meow, Pyrinya Putthapiban

MATSA MINING
David Le Madec, James Royall

MAWLAMYINE UNIVERSITY, MYANMAR
Zin Mar Oo

MDRU, CANADA
Shaun Barker

MINERAL MAPPING
Scott Halley

MINERAL RESOURCES TASMANIA
Ralph Bottrill, Clive Calver, Grace Cumming, John Everard, Andrew McNeill

MONASH UNIVERSITY
Laurent Aillères, Ray Cas

MYINGYAN UNIVERSITY, MYANMAR
Htet Sandar Aung

NAGA MINERALS LAOS CO LTD, THAILAND
David Meade

NEWCREST MINING
Rizal Fraval, Karyn Gardner, Anthony Harris, Hana Lee

NEWMONT
Jeff Bigelow, Simon Marshall

NO.2 MINING ENTERPRISE, MINISTRY OF NATURAL RESOURCES AND ENVIRONMENTAL CONSERVATION, MYANMAR
Kyaw Thu Htun

REGULUS RESOURCES
Kevin Heather

RIO TINTO
Paul Agnew, Debora Araujo, Adam Pacey, Mike Whitbread

SANDFIRE RESOURCES
Kristyn Adamczyk, Joel Kitto, Paull Parker, Peter Willems, Jerry Zieg

SOUTH32
Renato Bobis

UNIVERSIDAD AUSTRAL DE CHILE, CHILE
José Piquer

UNIVERSITI KEBANGSAAN, MALAYSIA
Mohd Basril Iswadi Bin Basori, Mazlinfalina Mohd Zin

UNIVERSITY OF MELBOURNE
Roland Maas

UNIVERSITI SAINS MALAYSIA, PENANG, MALAYSIA
Zakaria Endut

UNIVERSITY OF NEW SOUTH WALES
Ian Graham

UNIVERSITY OF TECHNOLOGY PETRONAS, MALAYSIA
Nor Syazwani Zainal Abidin

US GEOLOGICAL SURVEY, USA
Jay Thompson

Projects

Tectonic-magmatic processes and mineral deposits in SE Asia

Amira P1249: Exploring, characterising, and optimising complex orebodies – upscaling orebody knowledge to add value across the mining value chain

Porphyry research

National mineral potential mapping

Project summaries

TECTONIC-MAGMATIC PROCESSES AND MINERAL DEPOSITS IN SE ASIA

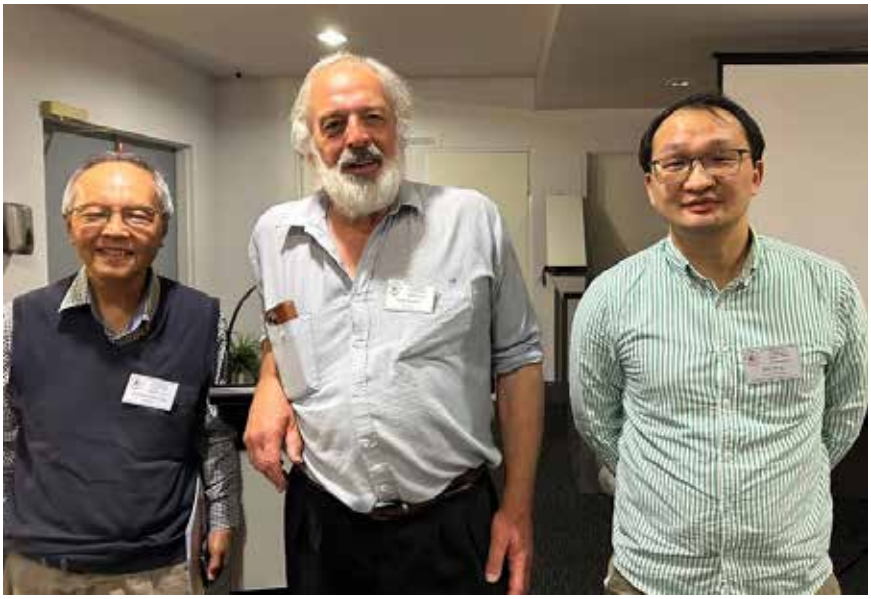
Leaders: Khin Zaw, Sebastien Meffre

Team members: David Cooke, Charles Makoundi, Lejun Zhang

Student: Peerapong Sritangsirikul

Collaborators: Pitsanupong Kanjanapayont, Kobkul Khiaosanuan (Neam), Arkar Moe Myint, Mohd Basril Iswadi Bin Basori, Clive Burrett, Mike Crow, Punya Charusiri, Pyrinya Putthapiban, David Meade, Patchawee Meow, Seang (Sokha) Sirisokha, Ian Graham, Patthana Bounliyong, June J. Born, Zakaria Endut, Linnan Guo, Sakthi Saravanan Chinnasamy, Aung Min Oo, Htet Sandar Aung, Akira Imai, Kyaw Thu Htun, Zin Mar Oo, Abhisit Salam, Phisit Limtrakun, Meifeng Shi, Yasushi Watanabe, Mazlinfalina Mohd Zin, Nor Syazwani Zainal Abidin

Several fold belts in SE Asia contain abundant mineral reserves, including copper, gold, silver, base metals, REE, gemstones, tin and tungsten. These resources are found in a variety of deposit types, such as Cu-Au porphyry-skarn, epithermal gold, tin-tungsten veins, and orogenic gold. Substantial achievements and advancements have been made in the study of the geodynamic setting, magmatic history and mineral deposits in SE Asia. The objectives of this project are to understand the metallogenic processes, and the geochemical and geochronological aspects of ore genesis and mineral formation across different deposit types within these fold belts. The investigation uses zircon geochronology alongside trace elements, whole-rock geochemistry, and Hf isotopes to assess magma fertility and differentiate the geochemical characteristics of mineral-rich and non-productive intrusions. Peerapong Sritangsirikul's recent work in northern Laos for his PhD recognised three magmatic and mineralised events occurred between 434–411 Ma, 299–277 Ma, and 253–243 Ma. Zircon εHf values gave both mantle-derived and crustal contamination signatures. Zircon



Honorary Professor Khin Zaw (left) and postdoctoral researcher Dr Wei Hong (right) both gave presentations at the 45th Seminar of the Joint Mineralogical Societies of Australasia, held in northern Tasmania in October. Mineralogist Ralph Bottrill (centre) from Mineral Resources Tasmania, who works closely with many CODES researchers, also attended.

compositions provided potential porphyry-related fertile magmas. A research paper entitled 'Geochronology and geochemistry of zircons from Loei and Truong Son fold belts, northern Laos region: Implication for porphyry deposits fertility' has been accepted for publication in the *Journal of Asian Earth Sciences*.

This project is linked with several others in the region, including the 'Geochronology of ore deposits in Cambodia', led by Dr Seang (Sokha) Sirisokha from the Institute of Technology, Cambodia. This project is supported by the Japan International Cooperation Agency (JICA), focussing on U-Pb zircon geochronology on mineralised porphyry intrusions in Cambodia along the Loei fold belt. A paper, 'Geochemistry and geochronology of magmatic rocks in southwestern and northeastern Cambodia: Implications for the tectonic evolution of the Loei Fold Belt', was submitted to *Geological Journal*.

The other linked collaborative projects are: 'Tectonic and metallogeny along the Loei Belt in Thailand,' led by Professor Punya Charusiri and funded by Chulalongkorn University and the Department of Mineral Resources; and 'Ore deposit geochronology, zircon trace element composition, pyrite chemistry of ore deposits in Laos' led by Professor Khin Zaw, Dr Charles Makoundi and Professor Sebastien Meffre funded by Naga Minerals Laos Co Ltd. The aim of this project is to determine the genesis of the ore deposits in Laos to develop an exploration model and the selection of drill targets focussing on orogenic gold deposits and copper-gold porphyry/skarn deposits and Ni deposits. Samples were provided by David Meade of Naga Minerals Laos Co Ltd. Studies have investigated the PhuPhu, Namphok, Kenethao and Huayna deposits in the Loei belt, and Vangtat and Dakcheung in the Troungson belt in Laos. A final report was submitted in 2023 and further work is in progress.

The Sukhothai belt lies to the west of the Loei belt and extends from northern Laos through western Thailand and eastern Myanmar; it remains relatively obscure despite hosting substantial mineral wealth. Its diverse ore deposits range from intrusion-related to epithermal-porphyry and orogenic Cu-Au deposits. Recent collaboration between Professor Aung Min Oo (Kyaing Tong University, eastern Myanmar), Professor Sakthi Saravanan Chinnasamy (Indian Institute of Technology Bombay, Mumbai) and Professor Khin Zaw on the Sanparami ore system in Tachileik (eastern Myanmar) produced fruitful results on ore paragenesis, alteration assemblages, petrological and U-Pb geochemistry and a research paper is planned.

In collaboration with the University of Technology Petronas (Malaysia), Dr Charles Makoundi is working on 'Characterisation of the Pulai Gold Prospect in the Central Gold Belt of Peninsular Malaysia: Implications for gold metallogeny'. The objective of the project is to ascertain the timing of gold mineralisation and source of alluvial gold. The project uses Pb isotope, Laser Raman, microthermometry, EPMA and LA-ICP-MS, and results are currently being evaluated. Additionally, this research will explore the genetic connections between the Pulai gold potential and other orogenic gold deposits in the district, as well as develop an ore deposit model using LeapFrog software. A second project on the diagenetic history of carbonate samples from selected study areas was completed in 2023. Dr Charles Makoundi also continued collaboration with Dr Zakaria Endut (Universiti Sains Malaysia) on 'Pyrite geochemistry, isotopes, ore fluids and U-Pb geochronology of orogenic gold deposits in Central Malaysia' supported by the Malaysian Government, and the project results were published in five papers in 2023.

The Southeast Asia region holds significant potential for discovering world-class deposits of porphyry copper-gold-molybdenum, along with granite-related lithium and other essential battery minerals. However, the absence of thorough information and large-scale studies on critical minerals and metal systems poses a challenge to the region's aspirations for green energy, low-carbon development, and the advancement of modern technologies like communication, computing and transportation. Ongoing collaborative research endeavours aim to explore factors governing the tectonic–magmatic history, ore formation, exploration strategies, and environmentally sustainable ore extraction methods crucial for transitioning from fossil fuels to clean energy. A collaborative project with Professor Pyrinya Putthapiban and Dr Patchawee Meow (Mahidol University), Professor Zin Mar Oo (Mawlamyine University, southern Myanmar) and PhD student Peerapong Sritangsirikul on W-Sn-REE-Li mineralisation and

Research fellow Yamila Cajal conducting sampling in collaboration with CODELCO staff at the Porfido Norte porphyry copper deposit, northern Chile for the Amira P1249 project.

related granitoid host rock along the Thai–Myanmar border is well advanced, and a paper was recently published in *Geosystems and Geoenvironment*.

The Mogok Metamorphic Belt in Myanmar is renowned for its rich gemstone deposits, including rubies, sapphires and spinels. Spanning over 600 km from north to south, it is a geological marvel, attracting gem enthusiasts and researchers working on gemstones and tectonics and metamorphism. Although fieldwork was not feasible due to Covid over the past few years, work on previously collected samples from Mogok, in collaboration with Myanmar geologists and the British Geological Survey, produced a paper: 'A review of new detrital zircon U-Pb ages from the Mogok area of Myanmar'. The outcome of this research was presented at the 45th Annual Seminar of the Joint Mineralogical Societies of Australasia held in northern Tasmania, in November. Further work on the precise timing of sapphire formation and host syenite petrogenesis is in progress with Dr Ian Graham (University of New South Wales), and Professor Pitsanupong Kanjanapayont and Arkar Moe Myint from Chulalongkorn University.

AMIRA P1249: EXPLORING, CHARACTERISING, AND OPTIMISING COMPLEX OREBODIES – UPSCALING OREBODY KNOWLEDGE TO ADD VALUE ACROSS THE MINING VALUE CHAIN

Leader: David Cooke

Team members: Mike Baker, Ivan Belousov, Yamila Cajal, Matthew Cracknell, Wei Hong, Julie Hunt, Thomas Rodemann (CSL), Lejun Zhang

Students: Fuseini Atanga, Billy Beas, Axel Cima, Takeshy Coaquira, Stephen Cooke, Jason Dyer (Lakehead U), Isaac Evinemi, Reinaldo Gonzalez (U Austral), Patrick Hamilton (Lakehead U), Rhiannon Jones, Mitch Marcelissen (Lakehead U), Solange Muñoz (U Austral), Ricardo Navarro (U Austral), Jaime Osorio, Giovana Pimentel, Ivania Rojas (U Austral), Arka Sahu, Xin Ni Seow, Emily Smyk, Markus Staubmann, Nafiu Sulyman (Lakehead U), Yi Sun, Francisco Torres (U Austral), Chase Turner (Lakehead U), Jenson Uribe (U Austral)

Collaborators: Paul Agnew, Laurent Aillères, Ben Andrew, Debora Araujo, Jeff Bigelow, Renato Bobis, David Braxton, Alex Brown, Natalie Caciagli, Ferderico Cernuschi, Iain Dalrymple, David Drejing-Carroll, Rizal Fraval, Simon Gatehouse, Scott Halley, Ben Hames, Anthony Harris, Tobias Hermansson, Peter Hollings, Ned Howard, Jon Hoye, Tim Ireland, Andrew Jenkins, Martin Kock, David Le Madec, Hana Lee, Simon Marshall, Dana Olafson, Adam Pacey, Paull Parker, Sergio Pichott, José Piquer, Cam Quinn, Carolina Rodriguez, James Royall, Luke Swift, Helen Thomas, Mike Whitbread, Noel White, Peter Willems

The five-year Amira Global P1249 project 'Exploring, characterising, and optimising exploring complex orebodies – Upscaling orebody knowledge to add value across the mining value chain' entered its second year in 2023. This project provides its sponsors with new tools for recognising proximity to high-grade ore, and new tools, methods and workflows for translating and upscaling mineralogical, geochemical and

Research in Canada for the Amira P1249 project (L–R): Here Robin Tolbert from Northisle Copper and Gold Inc discusses fieldwork progress with Chase Turner, Dr Lejun Zhang and Patrick Hamilton while they were carrying out sampling at the Northwest Expo lithocap at Vancouver Island, British Columbia.

hyperspectral data into quantitative mineralogy for complex orebodies of copper, gold, critical and other metals. The project team will aim to optimise orebody knowledge and provide the information required for mineralogical domaining and resource definition at the mine scale. P1249 is focussed on transition zones – the alteration domains that extend from the orebody into the surrounding unmineralised rocks. Although the primary focus of the project is on porphyry, epithermal, carbonate replacement and skarn deposits, the project also has active sub-projects studying Mt Isa-style Cu, IOCG, orogenic Au, Ni-Cu-PGE and VHMS deposits.

By delivering new and more effective methods and workflows for mineralogical characterisation in the transition zone, P1249 will deliver better exploration models, facilitate informed decision making at all stages of the mining value chain, and identify value opportunities in waste streams that may help reduce waste volumes, thereby providing new orebody knowledge essential for optimising ore extraction and recovery from complex orebodies. The research team will provide new and refined geochemical and geological tools for fertility assessments to establish whether there is a significant mineral resource nearby (i.e., how large is the resource?) and to ensure that deposits are discovered more quickly and at less cost by reducing the amount of drilling required for discovery (vectoring – how far, how deep and in what direction?). These tools will be designed to ensure cost-effective exploration through implementation early in an exploration program, allowing opportunities to be recognised from near-miss drilling, and to allow the presence, location, and potential size of porphyry, epithermal, skarn, carbonate replacement and other resources to be determined rapidly.

Amira P1249 is being conducted by a large team of researchers including 12 UTAS staff, six collaborators and 22 students (PhD, Masters and Honours) from four academic institutions (UTAS, Monash University, Lakehead University and Universidad Austral de Chile). Several sub-projects within P1249 involve postgraduate students. Continuing PhD students and their projects include: Billy Beas (halogen chemistry in the Northparkes E44 deposit), Axel Cima (influence of mineral micro-inclusions on porphyry prospectivity), Takeshy Coaquira (Resolution porphyry Cu-Mo deposit, USA), Stephen Cooke (computer-based modelling of geochemical data), Rhiannon Jones (Northparkes E26 porphyry Cu-Au deposit, New South Wales), Jaime Osorio (Rincones de Araya prospect, Argentina and Valeriano porphyry Cu-Au deposit, Chile), Xin Ni Seow (alunite and APS group mineral chemistry), Emily Smyk (Christmas porphyry Cu-Mo deposit, USA), Markus Staubmann (Cowal GRE46 gold deposit, New South Wales) and Yi Sun (Lepanto district, Philippines). Xin Ni, Yi and Rhiannon each completed and submitted their

theses in late 2023. Patrick Hamilton (Lakehead University) is continuing his MSc study of the Pemberton Hills deposit lithocap (Canada). The Honours projects of Reinaldo Gonzalez (Santa Marta lithocap, Chile) and Francisco Torres (Tibetano prospect, Chile) were also completed at Universidad Austral de Chile this year. Four new P1249 PhD sub-projects commenced in 2023: Fuseini Atanga will study the Akyem orogenic Au deposit in Ghana; Giovana Pimentel will study mineralogical characterisation of the Platreef Ni-Cu-PGE deposit, South Africa; Isaac Evinemi will study the development of deep learning driven ore deposit models for exploration of porphyry deposits; and Arka Sahu will study the capabilities of data mining multi-scale hyperspectral and mineral chemistry data sets. Three new Masters projects based out of Lakehead University, Canada, also commenced in mid-2023: Chase Turner will study Northisle's NW Expo lithocap on Vancouver Island, Canada; Jason Dyer will study sulfide chemistry from the McFinley Au deposit, Canada; and Nafiu Sulyman will study sulfide chemistry from the Red Lake orogenic Au belt of central Canada.

The total cost of the Amira P1249 project over the five years will be AU$16.1 million including research organisation and in-kind contributions of AU$6.8 million and Amira Global development and oversight fees. The total industry and government investment required to fully fund the project is approximately AU$9.31 million over five years. As of December 2023, 14 companies sponsor P1249, including Anglo American, AngloGold Ashanti, BHP, Boliden, CMOCNorthparkes, CODELCO, Evolution Mining, First Quantum Minerals, Fortescue Metals Group, Glencore (Mt Isa Mines), Newmont, Rio Tinto, Sandfire Resources, and South32.

PORPHYRY RESEARCH

Leader: David Cooke

Students: Lieth de Selincourt, David Portacarrero, Victor Torres

Collaborators: Kevin Heather, David Kelley, Joel Kitto

In 2023, Victor Torres continued his PhD study of Cu-Au mineralisation of the Soledad tourmaline breccia complex, central Peru, supported by Chakana Copper Corp. This integrated geological, geochemical and geometallurgical investigation is designed to provide comprehensive orebody knowledge of the Soledad breccia pipes, including their geological setting, age, alteration and mineralisation features, controls on mineralisation and mineral processing characteristics. Victor made significant strides on his research in 2023, mostly finalising his data acquisition, which has allowed him to develop comprehensive geological, mineralogical and geometallurgical 3D models for three of the Cu-Au mineralised breccia pipes at Soledad. His research results were shared through an oral presentation at ProExplo (Lima) and a poster presentation at the SEG (London) conferences. In 2024 he will focus primarily on compiling and writing up research results as the thesis progresses towards completion.

Multi-stage intrusion, brecciation and mineralization at the Antakori Cu-Au-Ag project, northern Peru Cu-Au-Mo

Leaders: David Cooke, Lejun Zhang

Student: David Portocarrero

Collaborator: Kevin Heather

David Portocarrero continued work on his Master of Economic Geology research project, supported by

CODES PhD student Fuseini Atanga examines drill core in the Newmont Africa Akyem core shed in southern Ghana, while doing fieldwork there with Dr Mike Baker as part of the Amira P1249 project.

Regulus Resources, that is investigating the characteristics and origins of epithermal, porphyry and skarn mineralisation in the Antakori Cu-Au deposit, northern Peru. Antakori is a complex magmatic hydrothermal system, with volcanic-hosted high sulfidation Cu-Au ores hosted in Tertiary volcanics, which unconformably overlie deformed sedimentary basement rocks (quartz sandstones and limestones) that host porphyry Cu-Au and skarn mineralisation.

Intermediate sulfidation epithermal veins also cut the district. Highlights of 2023 included new U-Pb and Re-Os dating results that have revealed a complex magmatic-hydrothermal history responsible for porphyry, epithermal and skarn mineralisation and alteration at Antakori. Most of the research results are now complete and work is underway on finalising the thesis.

NATIONAL MINERAL POTENTIAL MAPPING

Leader: Jonathan Cloutier

Collaborators: Karol Czarnota, Michael Doublier, Arianne Ford, David Huston, Anthony Schofield

Dr Jonathan Cloutier began a new collaborative project with Geoscience Australia focussing on the national prospectivity assessment of several mineral systems. This is a three-year project and involves the creation of Cu and Zn-Pb sediment-hosted and IOCG mineral potential assessments of Australia using a mineral systems approach to support the discovery of new resources needed for the transition to net zero. It involves identifying, understanding and utilising relationships between the spatial and temporal distributions of mineral deposits and diverse datasets, including geological, geochemical, isotopic and geophysical datasets.

In 2023, we completed several milestones for the project with the release of national mineral potential models for sediment-hosted Cu, clastic-dominated siliciclastic-carbonate (McArthur-type), clastic-dominated siliciclastic-mafic (Selwyn-type), Mississippi Valley-type and Irish-type. These maps are available to visualise and to download on the Geoscience Australia portal (https://portal.ga.gov.au/). The sediment-hosted models were released by Resources Minister Madeleine King (https://www.minister.industry.gov.au/ministers/king/media-releases/unlocking-mineral-potential-australia) through a media release entitled 'Unlocking the mineral potential of Australia' on 16 March 2023, highlighting the importance of the models to Geoscience Australia and the government. Two extended

Happy in his work: Dr Mike Baker examining outcropping Iberian Pyrite Belt host rocks near the Magdalena VHMS deposit in southwest Spain for the Amira P1249 project.

CODES PhD student Victor Torres in Lima speaking about his Soledad, Peru, project at the ProExplo 2023 conference in May 2023. His work falls within the 'Porphyry Research' project.

abstracts on the Zn-Pb and Cu sediment-hosted models were published and are available for download on the Extended for the Future website (https://www.eftf.ga.gov.au/). In 2023, a national prospectivity model for carbonatite-related rare earth element was also delivered. The model was led by Arianne Ford and is available to visualise and to download on the Geoscience Australia portal (https://portal.ga.gov.au/). Arianne also led a publication in which Jonathan is a co-author (https://doi.org/10.1016/j.oregeorev.2023.105658).

Lastly, 2023 saw the initiation of the IOCG national prospectivity map deliverable. For this model, we will be using a hybrid knowledge- and data-driven approach where the correlation between mappable features and the location of IOCG deposits and occurrences will be evaluated. The statistical approach will enable the assessment of the relevance of each mappable criteria and provide insights into the performance of the model. At the end of 2023, the assessment table which includes all the mappable criteria was completed and the statistical assessment is underway. The IOCG model will be released in July 2024 by the Resources Minister as a media release.

▶ LOOKING FORWARD

The Amira Global P1249 project is continuing through to 2026 and will provide longer-term contributions to the excellent applied research into magmatic-hydrothermal systems by the research team and collaborating institutions. In 2024, two additional PhD student sub-projects are expected to commence, continuing to build upon the quality research capacity at CODES and our collaborator institutions. The SE Asian tectonic processes and mineral deposits project is also expected to continue producing quality research in 2024, with several sub-projects well underway and leading to the submission and publication of research. In mid-2024, the National Mineral Potential Mapping project also plans to deliver and release an IOCG national prospectivity map.

The graduate student cohort of Program 1 continue to generate high-quality research outcomes including theses, peer-reviewed publications, and models for the development of mineralised systems in a diverse range of environments. Program 1 postgraduate research projects continuing into 2024 include eleven CODES PhD sub-projects within Amira P1249 (students: Fuseini Atanga, Billy Beas, Axel Cima, Takeshy Coaquira, Stephen Cooke, Isaac Evinemi, Jaime Osorio, Giovana Pimentel, Arka Sahu, Emily Smyk, Markus Staubmann) with another two expected to commence during the year.

Victor Torres' PhD project on the Soledad tourmaline breccia complex in central Peru; Peerapong Sritangsirikul's PhD project on the geochemistry of fertile magmas in SE Asia; Lieth de Selincourt's MSc project on porphyry Cu-Au prospects in the Temora district of central NSW; and David Portocarrero's MSc project on the Antakori Cu-Au deposit in northern Peru.

Program two: Geometallurgy and geoenvironment

OBJECTIVES

To facilitate sustainable mining, mineral processing and waste management practices in the minerals industry. Our goals are to minimise the impacts and maximise the benefits of metallic mining in diverse environments, at all stages of the production chain, to assist with remediation of legacy issues and to develop innovative solutions for production of commodities from mining waste streams.

Introduction

Program 2: Geometallurgy and geoenvironment addresses some of the challenges the minerals industry faces in the accurate prediction of processing performance and variability in performance due to the limited number of samples that can be tested for metallurgical parameters. Significant technical and operational risks exist where orebodies are poorly characterised. Work within geometallurgy at CODES/UTAS seeks to efficiently integrate and use tools that help characterise geological parameters, particularly mineralogical and geochemical attributes, to undertake deposit-wide characterisation in order to maximise orebody knowledge.

Through a holistic approach, geometallurgy activities identify attributes that contribute to the realised value of a resource, and enable ore variability to be factored into the flowsheets, infrastructure design, and the production and quality forecasts over the life-of-mine. This includes variability in traditional attributes, such as grade, as well as less traditional factors, such as hardness (crushability, grindability), mineral species and abundance, mineral liberation, metallurgical recovery, concentration of deleterious elements, acid generating potential, neutralising potential and smelter enabling characteristics.

In 2023 Program 2 research was increasingly focussed on critical metals as the new Regional Research

Work within geometallurgy at CODES/UTAS seeks to efficiently integrate and use tools that help characterise geological parameters…to undertake deposit-wide characterisation in order to maximise orebody knowledge.

The inaugural Critical Australian Metals Conference (CRITCON2023) was held in Adelaide in May. Dr Owen Missen is pictured chatting with conference attendees; he presented a paper on tellurium biogeochemistry at the conference. (Photo: Jarred Lloyd)

Collaboration project 'Building capacity in regional Australia to enhance Australia's economy through research, training and environmentally sustainable production of critical metals', more simply known as the RRC, got underway. As part of the RRC, two new postdoctoral fellows have joined CODES: one focussed on geoenvironment research, Dr Owen Missen, who joined in late 2022; and one focussed on metallurgy, Dr Mohammad Fathi, who joined in January 2023. At the end of 2023 Dr Missen accepted a Lecturer in Environmental Geology position with UTAS Earth Sciences, where he will continue his geoenvironmental research and RRC participation. Three geometallurgy-focussed PhD students also joined the RRC project under the 'Pathways to Production' element and began their doctoral studies in 2023. Geometallurgy-focussed research also continued as part of the Amira P1249 project and the continuation of a CSIRO Futures project.

Highlights

- Dr Mohammad Fathi, a metallurgical engineer, commenced postdoctoral work with CODES as part of the RRC project (see RRC project section on page 66 for more details)
- Completion of Honours thesis by Daniel Fisher (supported by MSIIP), entitled 'Lithological, geochemical and mineralogical drivers of water quality at the legacy Scotia Mine, northeast Tasmania'.
- Commencement of three PhD projects as part of the RRC: Alfredtina Appiah: 'Pathways to production: Magnesite deposits at Prospect Ridge, northwestern Tasmania'; Emmanuel Dogara Musa 'Pathways to production for critical metals: Kara W deposit, Western Tasmania' and Pratichee Mondal 'Mineral and geoenvironmental characterisation of, and pathways to production for, critical metals from Western Tasmania' focussed on the Savage River deposit.
- Sibele Nascimento submitted her PhD thesis in January 2023 titled 'Geoenvironmental characterisation of historic mine tailings: evaluating opportunities for reprocessing'.
- Yi Sun submitted his PhD thesis in July 2023 titled 'Geology of the quartz-pyrite-gold (QPG) mineralization and the new model of the Mankayan district, northern Luzon, Philippines'.
- Rhiannon Jones submitted her PhD thesis in August 2023 titled 'The significance of phyllic alteration at the E26 porphyry Cu-Au deposit, NSW, Australia'.
- The Master of Economic Geology short course in Geometallurgy (KEA711) ran in-person in 2023, at CODES, from 16–27 October.

Technology transfer

- A 3D visualisation for the Kara mine was assembled and shown for the first time at the RRC sponsors' meeting in July 2023.
- The 'Tasmanian Critical Metals Workshop' was held in western Tasmania on 29 November.
- A report was delivered to CSIRO for the CSIRO Futures project, titled 'Characterisation methodology to predict the particle size at which gangue minerals liberate during selective breakage processes'.

Research Fellow in Geometallurgy/Engineering Geology Dr Mohammad Fathi delivering a talk on the sustainable production of critical minerals at the Australian Earth Sciences Convention (AESC), which was held in Perth in June 2023.

Conferences

In 2023 research outcomes were presented by staff and students at several conferences and geological society meetings, including:

- Dr Missen delivered a talk at the inaugural CRITCON2023 Conference in Adelaide, titled 'Recent insights into tellurium biogeochemical cycling from nano- to macro-scale'.
- PhD student Alfredtina Appiah delivered a poster at CRITCON2023, titled 'Production pathways: Magnesite deposit at Prospect Ridge, northwestern Tasmania'.
- Dr Missen delivered a talk titled 'Comparing cobalt biogeochemistry across cobaltiferous Australian mineral deposits in semi-arid environments' and a poster 'Unlocking Tasmania's critical metal potential from tailings and waste rock storage facilities' at the Australian Earth Sciences Convention (AESC) in Perth.
- Dr Fathi delivered a talk at the AESC titled 'Environmentally sustainable production of critical metals: a mineralogical approach to tungsten recovery'.
- Dr Hunt presented a poster at the SGA Conference in Zurich, titled 'Environmentally sustainable production of critical metals: a Tasmanian approach'.
- Dr Hunt gave an invited oral presentation at the Tasmania Geoscience Forum, titled 'Environmentally sustainable production of critical metals'.

CODES staff and students working across several research programs attended the SGA 2023 conference in Zurich. They included Program 2 Leader Dr Julie Hunt (left), who presented a poster titled 'Environmentally sustainable production of critical metals: a Tasmanian approach'. She is with CODES PhD students Max Hohl, Peerapong Sritangsirikul and Alex Farrar; and CODES staff member Dr Yamila Cajal.

Program 2 Leader Dr Julie Hunt presenting on Element 2: Pathways to Production of the RRC project at the Tasmania Geoscience Forum in Tullah, western Tasmania, in late November 2023.

The program team

LEADER JULIE HUNT
DEPUTY LEADER OWEN MISSEN*

TEAM MEMBERS:

Ron Berry, Jonathan Cloutier, David Cooke, Matthew Cracknell, Mohammad Fathi, Sebastien Meffre, Clare Miller, Paul Olin, Michael Roach

PHD STUDENTS:

Christopher Allen, Alfredtina Appiah, Takeshy Coaquira, Rhiannon Jones, Javier Merrill, Pratichee Mondal, Joanne Morrison, Annah Moyo, Emmanuel Dogara Musa, Sibele Nascimento, Markus Staubmann, Yi Sun, Victor Torres

MASTERS STUDENT:

Lucy Jones

HONOURS STUDENT:

Daniel Fisher

COLLABORATORS:

ALS GLOBAL
Shengli Zhao, Drew Redpath

ANGLOGOLD ASHANTI
Vaughan Chamberlain

BHP
Kathy Ehrig

BLUESTONE MINES TASMANIA
Colin Carter, Kate Cheesman, Brian Dalton, Esther Little, Bill Oats, Derek Sutton

BOLIDEN
Tobias Hermansson

CENTRAL SCIENCE LABORATORY (UTAS)
Sandrin Feig, Karsten Goemann, Thomas Rodemann

COPPER MINES OF TASMANIA
Geoff Cordery

CORESCAN Powered by Epiroc
Lionel Forteneau

CSIRO
Vladimir Jokovic, Paul Revell

DIAMONDBACKS PTY LTD
Greg Wilkie

EVOLUTION MINING
Karyn Gardner, Ned Howard

GeologicAI
Adam MacInnes

GRANGE RESOURCES
Roger Hill

GWR GROUP
Mick Wilson, Teck Wong

MINERAL MAPPING PTY LTD
Scott Halley

MINERAL RESOURCES TASMANIA
Ralph Bottrill, Simon Enman, David Green, Verity Kameniar-Sandery, Andrew McNeill, Jake Moltzen, Jessica Renaud, Carol Steyn, Lia Unwin

MMG
Steve Scott, Corey Jago, Don Macansh

NAGROM
Rain Lewis

NORTHERN STAR RESOURES
Natalee Bonnici

OKANE CONSULTANTS
Mike Okane

SIMSAGE
Toni Kojovic

TASMANIA MINES PTY LTD
Greg Doherty, Marcus Mollison

VOCONIQ
Sefton Derby

*Angela Escolme is on extended maternity leave.

PhD student Alfredtina Appiah stands next to the Mineral Resources Tasmania Hylogger. Alfredtina uses the Hylogger to gain valuable mineralogical information about the types of carbonate and gangue silicate minerals found in Prospect Ridge ore. Pieces of drillcore she selected for this analysis are shown to her left.

Projects

Amira P1249: Exploring, characterising, and optimising complex orebodies – upscaling orebody knowledge to add value across the mining value chain

CSIRO Futures project: A methodology for measuring and modelling gangue liberation using geological analysis and particle grade distributions

RRC project: Environmentally sustainable production of critical metals: Element 2: Pathways to production

Geoenvironment

Dr Owen Missen (right) carrying out environmental geology in western Tasmania on the banks of the King River.

Project summaries

AMIRA P1249: EXPLORING, CHARACTERISING, AND OPTIMISING COMPLEX OREBODIES – UPSCALING OREBODY KNOWLEDGE TO ADD VALUE ACROSS THE MINING VALUE CHAIN

(See Program 1 on page 16 for full details about this project including all collaborators).

Student: Markus Staubmann

The Amira project P1249 includes geometallurgy and geoenvironmental research within Program 2.

Markus Staubmann continued work on his PhD project entitled 'Integrated ore deposit knowledge: optimising mineralogical characterisation through the mining value chain'. He is developing workflows, methods and tools for mineralogical characterisation that allow effective upscaling from the microscopic to the deposit-scale, and aid opportunity recognition and decision-making through all stages of the mining value chain.

CSIRO FUTURES PROJECT: A METHODOLOGY FOR MEASURING AND MODELLING GANGUE LIBERATION USING GEOLOGICAL ANALYSIS AND PARTICLE GRADE DISTRIBUTIONS

Leader: Julie Hunt

Collaborators: Vladimir Jokovic, Paul Revell, Greg Wilkie

The CSIRO Futures project continues the work developed in CRC ORE on pre-concentration, i.e., exploitation of the natural heterogeneity of an orebody to divert gangue or low-value material out of the mining value chain at relatively coarse particle sizes prior to fine crushing and milling.

The extension project is a collaboration between Diamondbacks, CSIRO Mineral Resources and CODES, and is focussed on the liberation of gangue material and the inherent particle grade distributions present in these coarse particle size ranges. The objective of the project is to combine geological characterisation with different analytical techniques (chemical analysis, X-ray tomography) to characterise coarse ore feeds that cannot be analysed by traditional automated mineralogy methods due to the large size of the particles. Particle grade distributions are being examined to determine the particle size where liberation of gangue occurs. Results from this approach can be used to model gangue liberation and predict mass and value flows going to accept and reject streams.

Program 2 Leader Dr Julie Hunt spent time in Belgium and Germany during the Australian winter carrying out lab work. This Selfrag equipment at the GeMMe, University of Liège (Belgium), uses electric pulse fragmentation to determine if liberated scheelite ($CaWO_4$) can be produced using this size reduction methodology.

CODES PhD student Christopher Allen speaking at the first RRC Sponsors' Meeting in July 2023. His research is focussed on geoenvironmental and geometallurgical characterisation of weathered polymetallic wastes, and falls within the 'Geoenvironment' project in Program 2.

RRC PROJECT: ENVIRONMENTALLY SUSTAINALBLE PRODUCTION OF CRITICAL METALS: ELEMENT 2: PATHWAYS TO PRODUCTION

(See the RRC project section on page 66 for full details of this project including all collaborators.)

The first year of geometallurgy work within Element 2 of the RRC project focussed on two critical metal commodities: magnesite and tungsten.

Student: Alfredtina Appiah

PhD student Alfredtina Appiah joined CODES in January 2023. She is conducting metallurgical test work on magnesite ore, as well as logging and sampling core from historic and recent drill core from the Prospect Ridge area in her project entitled 'Pathways to production: Magnesite deposits at Prospect Ridge, northwestern Tasmania'.

Student: Emmanuel Dogara Musa

PhD student Emmanuel joined CODES in March 2023. He is conducting test work on coarse scheelite flotation at Kara Mine, using both existing and new combinations of reagents to optimise conditions in his project entitled 'Pathways to production for critical metals: Kara W deposit, Western Tasmania'.

Student: Pratichee Mondal

Pratichee Mondal joined CODES late in 2023 to embark upon her research at Savage River. Fieldwork for her project will begin early in 2024. Her research project is entitled 'Mineral and geoenvironmental characterisation of, and pathways to, production for critical metals from Western Tasmania'.

Postdoctoral researcher Mohammad Fathi focussed on reviewing and researching methods of comminution for selectively separating scheelite and fluorite in 2023. Dr Julie Hunt carried out electric pulse fragmentation testing of W-bearing ores. See RRC section for details.

GEOENVIRONMENT

Dr Missen collected sediment cores from a number of tailings dams and waste rock dumps and performed initial characterisation work on samples from several industrial and impacted sites across western Tasmania. He is also working closely with the RRC project.

Student: Christopher Allen

Christopher Allen continued work on his PhD focussed on 'Geoenvironmental and geometallurgical characterization of weathered polymetallic wastes: Implications for mine closure, western Tasmania' and is jointly supported by MRT, Bluestone Mines Tasmania Joint Venture, Copper Mines of Tasmania, and Okane Consultants. In 2023 his work focussed on interpretation of geophysics results and running kinetic weathering columns, comparing different conditions and lithologies from weathering waste rocks from a northwest Tasmanian site. He is working closely with the RRC team.

LOOKING FORWARD

Program 2 RRC staff have submitted abstracts and plans to present their research at the following conferences in 2024:

- MetFest!, Burnie, Tasmania (Alfredtina, Emmanuel, Mohammad)
- Australian Mine Waste Symposium, Brisbane, Queensland (Owen)
- AusIMM Critical Metals, Brisbane Queensland (Alfredtina, Emmanuel, Mohammad)
- ICARD, Halifax, Nova Scotia, Canada (Chris)
- Responsible Raw Materials, online (Owen)
- European Mineralogical Conference, online (Owen)
- IAGS, Adelaide, South Australia (Owen).

A project funded by Mineral Resources Tasmania will be completed in 2024, focussing on the drivers of alkaline drainage at a rehabilitated coal mining site in northeast Tasmania.

The following papers have been submitted and are expected to be published in 2024:

- Krebbers et al., 2024, Computed tomography of scheelite ore, Kara Australia: Morphological characterisation and modal mineralogy. *Minerals*, 14, 345, 20 p.
- Fathi et al. – A novel adsorbent for selective separation of rhenium from an industrial environment. *Materials.* Submitted.

Program three: Sedimentation, tectonics and Earth evolution

OBJECTIVE

This program aims to understand the formation and evolution of sedimentary basins, including their ore deposits and metamorphic and deformation histories, within the broader context of geodynamic processes and Earth evolution. This program also includes the study of catastrophic submarine mass-wasting events, which pose a substantial risk to coastal infrastructure and populations. Our goal is ultimately to develop new and refined geological and tectonic models to enhance exploration success for diverse sediment-hosted mineral systems formed throughout Earth history.

Introduction

Program 3: Sedimentation, tectonics and Earth evolution encompasses all aspects of tectonic and sedimentary basin evolution and how these influence the spatial and temporal distributions of sediment-hosted ore deposits. This has a direct impact on the search for, and understanding of, a vast array of ore types, including sedimentary exhalative (SEDEX) Zn-Pb-Ag, Broken Hill-type Ag-Pb-Zn, sediment-hosted orogenic Au, and sediment-hosted Cu-Co-Au. Fundamental research in this program aims to understand the development of life on Earth, including how cycles revealed in marine geochemistry profiles and craton amalgamation may influence the location and timing of sediment-hosted mineral systems.

Catastrophic events occur intermittently through the geological record, and these occasional but extreme events may affect and modify entire basins and coastlines. Further, modern submarine landslides are substantial risks to coastal populations and underwater structures, and studying their deposits will allow us to refine tsunami models for the Australian coast.

Highlights

- Dr Martin Jutzeler was the lead researcher of research voyage IN2023_V02 offshore SW Tasmania on the CSIRO research vessel RV *Investigator* in April–May 2023.
- Four PhD students working within Program 3 submitted their theses for examination during the year:
  - Alex Farrar: 'Tectonic and structural controls on the spatio-temporal distribution of giant porphyry copper deposits in the central Andes'
  - Max Hohl: 'Defining the mineral chemistry footprints of the Starra iron oxide-copper gold deposits in northwest Queensland'
  - Colin Jones: 'Petrogenesis of northeast Tasmanian granites'
  - Elena Lounejeva: 'Geochemical signature of syngenetic and diagenetic pyrite from marine sediments as a paleo-environmental tool'.

Setting sail on the CSIRO research vessel RV Investigator *to the Southern Ocean: Dr Martin Jutzeler, Chief Scientist on the IN2023_V02 voyage (fourth from left in middle row), and PhD student Shannon Frey (standing behind him with red/black top) look forward to the adventures ahead of them.*

- Two Honours students working within Program 3 completed their studies and submitted their theses: Issi Port's thesis was titled 'The structural and metamorphic history of the Eastern Tyennan Region, Lake Pedder, Tasmania' and Madison Mulder's was titled 'The Louisiade Ophiolite Obduction and its implications on the tectonic evolution of the Southwest Pacific'.
- Fieldwork was completed at several study sites including South Australia (Jeff Steadman) and western Tasmania (Sheree Armistead) for the IOCG[3] project.

Publications

Team members published five papers and three reports. Dr Sheree Armistead contributed to an article on the Neoarchean to Paleoproterozoic Betsiboka Suite of Madagascar in a Geological Society of London Special Publication. Dr Sheree Armistead was lead author on 'Pblso: an R package and web app for calculating and plotting Pb isotope data' (*Canadian Journal of Earth Sciences*); and PhD candidate Elena Lounejeva was lead author along with co-authors Dr Jeff Steadman, Professor Ross Large, Dr Paul Olin and Dr Ivan Belousov, on a paper looking at lithogeochemical and sulfide trace-element systematics across the Permian-Triassic boundary, Perth Basin, Western Australia (*Australian Journal of Earth Sciences*). The reports included the CSIRO V02 voyage report by Dr Martin Jutzeler, and IOCG[3] project reports to project sponsors by Dr Jeff Steadman.

Fundamental research in this program aims to understand the development of life on Earth, including how cycles revealed in marine geochemistry profiles and craton amalgamation may influence the location and timing of sediment-hosted mineral systems.

Conferences

Team members went to four conferences, including two international conferences and one invited keynote.

- Dr Sheree Armistead attended the European Geosciences Union General Assembly in Vienna in April and gave an invited keynote presentation.
- Dr Jeff Steadman attended the SEG 2023 Conference in London and gave a talk, as did Professor David Cooke.
- Dr Sheree Armistead attended the AESC Conference in Perth, and gave a presentation.
- Dr Jeff Steadman attended the AGES Conference in Alice Springs, and gave a talk.

The program team

LEADER ROBERT SCOTT
DEPUTY LEADER JEFF STEADMAN

TEAM MEMBERS:

Sheree Armistead, Ron Berry, Stuart Bull, Jonathan Cloutier, David Cooke, Matthew Cracknell, Julie Hunt, Martin Jutzeler, Ross Large, Peter McGoldrick, Sebastien Meffre, Indrani Mukherjee, Karin Orth, Michael Roach, David Selley

PHD STUDENTS:

Alex Farrar, Max Hohl, Colin Jones, Elena Lounejeva, Joanne Morrison, Thomas Schaap, Peerapong Sritangsirikul

MASTERS STUDENTS:

Brendan Hardwick, Ben Johnson

HONOURS STUDENTS:

Madison Mulder, Issi Port

COLLABORATORS:

CARNEGIE INSTITUTION, USA
Robert Hazen

CENTRAL SCIENCE LABORATORY (UTAS)
Sandrin Feig, Karsten Goemann

CSIC, UNIVERSITY OF MADRID, SPAIN
Fernando Tornos

GEOLOGICAL SURVEY OF CANADA
Sally Pehrsson

GEOLOGICAL SURVEY OF QUEENSLAND (DEPARTMENT OF RESOURCES)
Elena Belousova, Alkis Kontonikas-Charos, Rhiannon Jones, Vladimir Lisitsin

GEOSCIENCE AUSTRALIA
Antony Burnham, Andrew Cross, Geoff Fraser, David Huston, David Mole, Scott Nichol

INSTITUTE FOR MARINE AND ANTARCTIC STUDIES (UTAS)
Neville Barrett, Jacqui Halpin, Rafael Leon, Vanessa Lucieer, Joanne Whittaker, Simon Williams

INSTITUTO ITALIANO DI PALEONTOLOGIA UMANA, ROME, ITALY
Alan Cannell

MINERAL RESOURCES TASMANIA
Ralph Bottrill, Clive Calver, Grace Cumming, Mark Duffett, John Everard, Claire Kain, Andrew McNeill, Nick Roberts, Mike Vicary

RUSSIAN ACADEMY OF SCIENCE, RUSSIA
Valeriy Maslennikov

TASMANIAN INSTITUTE OF AGRICULTURE (UTAS)
Ross Corkrey

UNIVERSIDADE FEDERAL DE MINAS GERAIS, BRAZIL
Fabricio Caxito

UNIVERSIDADE FEDERAL DE RIO DE JANIERO, BRAZIL
Renata Schmitt

UNIVERSITY OF ADELAIDE
Andrew Merdith, Jacob Mulder

UNIVERSITY OF MELBOURNE
Stephen Gallagher, Roland Maas

UNIVERSITY OF SASKATCHEWAN, CANADA
Bruce Eglington

UNIVERSITY OF SYDNEY
David Airey, Tom Hubble

UNIVERSITY OF UTRECHT, NETHERLANDS
Peter Bijl, Frida Snilstveit Hoem

This photo of a magnificent Aurora Australis was taken onboard the RV Investigator *during the April–May IN2023_V02 research voyage to explore the submarine landslide offshore SW of Tasmania.*

Projects

Iron oxide copper-gold deposits: Geochemistry and geometallurgy (IOCG^3)

Temporal controls on Tasmanian and eastern Australian ore deposits

Stability of the Australian continental shelf

The geological and tectonic evolution of Tasmania

Developing a global Pb isotope compilation: Implications for geodynamics and the evolution of ore-forming regions

Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia

Trace elements in ancient oceans

Dr Sheree Armistead in one of the CODES labs working on the 'Temporal controls on Tasmanian and eastern Australian ore deposits' project.

Project summaries

IRON OXIDE COPPER-GOLD DEPOSITS: GEOCHEMISTRY AND GEOMETALLURGY (IOCG^3)

Leader: Jeff Steadman

Team members: Sheree Armistead, Matthew Cracknell, Karsten Goemann (CSL), Julie Hunt, Sebastien Meffre

Student: Joanne Morrison

Collaborators: Ralph Bottrill, Grace Cumming, Fernando Tornos

The IOCG^3, which began in September 2022 at CODES, continued in 2023. Fieldwork was undertaken at two study sites (Prominent Hill, South Australia; Alpine, Tasmania), and a sponsors' meeting was held at CODES in September.

Jo Morrison, who started working on Ernest Henry in Queensland in 2022 as part of her PhD, passed away in 2023 after a battle with illness. She is very much missed by the team.

Key outcomes of research efforts in 2023 included the collection of new trace element data across multiple hydrothermal minerals at all study sites, as well as radiogenic and stable isotopic data on sulfides from all deposits in the project.

TEMPORAL CONTROLS ON TASMANIAN AND EASTERN AUSTRALIAN ORE DEPOSITS

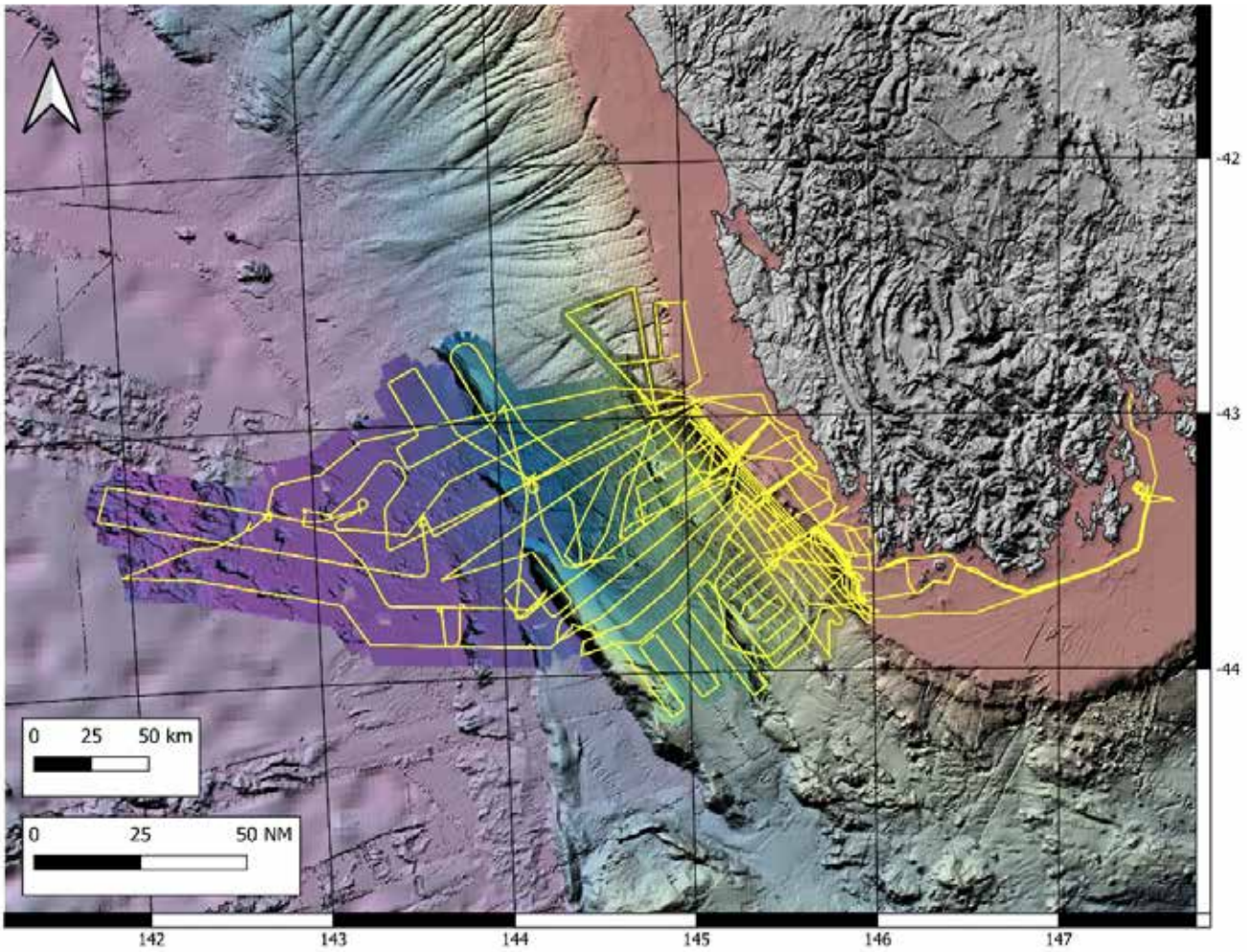
Leaders: Sebastien Meffre, Sheree Armistead

Team member: Jeff Steadman

Collaborators: Ralph Bottrill, Andrew Cross, Grace Cumming, Geoff Fraser, David Huston, Jacob Mulder

This two-year project is part of the Temporal Controls on Mineralisation Module within Geoscience Australia's 'Exploring for the Future' Program, which aims to stimulate mineral exploration investment, including critical minerals, and to open new mineral provinces.

In 2023 significant work was made on dating monazite, apatite and xenotime using the LA-ICP-MS U-Pb technique in the Interview River, Strickland and Balfour deposits in western Tasmania. These deposits previously had few temporal constraints on mineralisation and are difficult to characterise in terms of genetic models. Sheree Armistead presented data at the Australian Earth Sciences Convention in Perth showing that mineralisation in the Rocky Cape Group ore deposits is Mesoproterozoic in age.



This graphic shows the route taken by the CSIRO's RV Investigator *during the IN2023_V02 voyage to the seas off SW Tasmania in April–May 2023. The voyage provided important data for the 'Stability of the Australian continental shelf' project within Program 3.*

STABILITY OF THE AUSTRALIAN CONTINENTAL SHELF

Leader: Martin Jutzeler

Collaborators: Neville Barrett, Peter Bijl, Grace Cumming, Stephen Gallagher, Tom Hubble, Claire Kain, Rafael Leon, Vanessa Lucieer, Frida Snilstveit Hoem, Joanne Whittaker

Western Tasmania submarine slide

Dr Martin Jutzeler led an enthusiastic team of 17 collaborators and students on the highly successful IN2023_V02 voyage offshore SW Tasmania aboard the RV *Investigator* to investigate a giant submarine landslide off the continental shelf. This $4.2 million investment from CSIRO included multiple geophysical and hydrographic surveys in addition to coring and dredging over about five weeks in March–April 2023.

The landslide scar runs >50 km along the continental shelf and shows an abrupt headscarp failure associated with a gigantic multi-100 km^3 submarine landslide deposit. The submarine landslide and associated turbidites were deposited 30–120 km downslope and at 2,000–4,500 m water depth. The headscarp is >400 m high in places, attesting to a single (or a few), catastrophic event(s) with minimal post-event sediment remobilisation. The morphology of the submarine landslide deposit suggests it to be relatively recent (Pleistocene–Pliocene). The main submarine landslide is potentially the biggest recent slide offshore Australia. It is more than twice the size of the 1929 Grand Banks slide offshore Newfoundland that created a 3–8 m tsunami 400 km away and damaged seafloor infrastructure.

Scientists aboard the RV Investigator *examining samples dredged from the seafloor offshore of SW Tasmania. This work falls within the 'Stability of the continental shelf' project in Program 3.*

This voyage sampled and surveyed the landslide in its entirety, including the scarp, the main deposit at the base of the continental slope and the turbidites sheets on the abyssal plain. Sediment cores sampled the turbidites. A seismic reflection and sub-bottom profiler provided exceptional insights

CODES Honours student Issi Port gathering data for his Honours research on the shores of Lake Pedder in western Tasmania. His research fell within the Program 3 'Geological and tectonic evolution of Tasmania' project.

on the internal morphology of the continental slope, its failure, and the landslide deposits.

The team dredged cliffs to recover rocks and sediments from the various landslide scarps to gain insights into what material failed and facilitated the slide. Landslides initiating at continental shelves have national and global impacts due to their likelihood of creating tsunamis and damage to submarine and/or coastal infrastructure. This project provides novel data on catastrophic tsunamigenic submarine mass-wasting events to be used by modellers for tsunami mitigation.

THE GEOLOGICAL AND TECTONIC EVOLUTION OF TASMANIA

(This project was formerly known as Building Tasmania: the Cambrian and beyond)

Leaders: Sebastien Meffre, Robert Scott

Team members: Ron Berry, Martin Jutzeler, Karin Orth

Collaborators: Ralph Bottrill, Clive Calver, Grace Cumming, John Everard, Jacqui Halpin, Andrew McNeill, Jacob Mulder, Mike Vicary

Student: Issi Port

This project, focussed on Tasmanian-based geochronology and tectonics, has been running for many years and has provided some major new insights into the tectonic history of the island. In 2023, Honours student Issi Port studied the stratigraphic affinities, deformation and metamorphic history of complexly deformed Precambrian rocks exposed around the northern shore of Lake Pedder. Issi's work more than doubled the number of samples analysed for detrital zircons from the Tyennan region of SW Tasmania. These new results support the previously proposed correlation of highly deformed schists and quartzites of the Tyennan region and less deformed Mesoproterozoic rocks of the Lower – Middle Rocky Cape Group in NW Tasmania.

However, detrital zircons from a quartz-mica schist immediately west of the Twelvetrees Range, yielded an age distribution that most closely resembled the Irby Siltstone of the Upper Rocky Cape Group. Detrital zircon results suggest that the fault-bounded slices of more highly metamorphosed garnet-bearing, amphibolite facies schist (e.g., Strathgordon Metamorphic Complex) have similar provenance to the more

extensive greenschist facies schists and quartzites with which they are tectonically interleaved. Three fabric forming events were recognised in the medium-grade rocks, but only two in the lower-grade sequences. Growth of garnet in medium-grade rocks is constrained to late- to post-D_1 to early syn-D_2. Apart from widespread, but generally minor chlorite development, there is little evidence of new mineral growth during D_3, suggesting it occurred at much lower temperature.

Attempts to constrain the P-T conditions of garnet growth were largely unsuccessful due to a lack of suitable (preserved) mineral assemblages (e.g., no samples with coexisting garnet, biotite and feldspar were found), likely because of later retrogression. Nonetheless, many garnets record two-stage growth, with more Ca and Mn enriched rich cores and more Fe >> Mg enriched rims, suggestive of growth under conditions of increasing pressure and temperature during the early stages of D_2. Issi's project was supervised by Robert Scott and Sebastien Meffre, and partly supported by funding from Mineral Resources Tasmania.

The voyage IN2023_V02 led by Dr Martin Jutzeler on the RV *Investigator* in March–April 2023 (described elswhere in this report) also provided new data allowing key elements of Tasmania's onshore geology to be mapped deep into the offshore realm. This new information improves constraints on the gross geometry of geological boundaries within the Tasmanian continental crust. The voyage carried out high-resolution (1–3 m) bathymetry on the continental shelf and dredged Precambrian to Tertiary formations on the continental slope and shelf. Bathymetry, dredge sampling and seismic reflection survey data have yielded important new insights into the make-up of the submerged continental blocks that flank southwestern Tasmania, and have provided the research team with an unprecedented view of the continental rift architecture formed during Tasmania's initial separation from Antarctica during the Cretaceous.

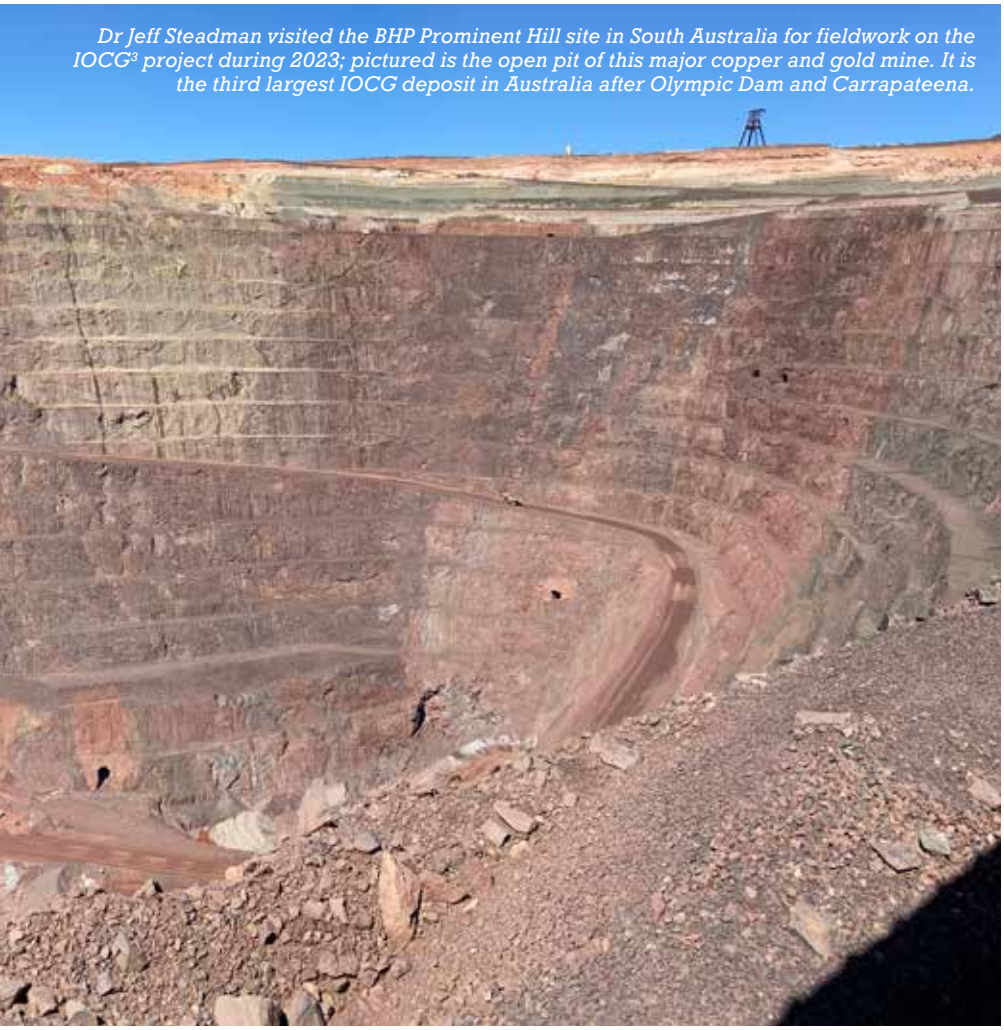
DEVELOPING A GLOBAL PB ISOTOPE COMPILATION: IMPLICATIONS FOR GEODYNAMICS AND THE EVOLUTION OF ORE-FORMING REGIONS

Leader: Sheree Armistead

Collaborators: Bruce Eglington, David Huston, Jacqueline Halpin, Sally Pehrsson

This project builds on Sheree's previous postdoctoral fellowship in Canada, investigating global Pb isotope signatures from ore deposits throughout Earth history. The highlight of this project for 2023 was an invited talk at the European Geosciences Union General Assembly in Vienna, Austria. Sheree presented a talk titled 'Pb isotope heterogeneities in the mantle and links to the supercontinent cycle'.

A new software package was developed to model Pb isotope evolution curves and to calculate



Dr Jeff Steadman visited the BHP Prominent Hill site in South Australia for fieldwork on the IOCG³ project during 2023; pictured is the open pit of this major copper and gold mine. It is the third largest IOCG deposit in Australia after Olympic Dam and Carrapateena.

model ages. This was published as a paper titled 'PbIso: an R package and web app for calculating and plotting Pb isotope data' in the *Canadian Journal of Earth Sciences.*

ORE DEPOSITS AND TECTONIC EVOLUTION OF THE LACHLAN OROGEN, SE AUSTRALIA

Leaders: Sebastien Meffre, David Cooke, Matthew Cracknell

Team members: Ron Berry, Michael Roach, Jeff Steadman

Students: Colin Jones, Thomas Schaap

This ARC Linkage project, aimed at understanding the geology, tectonic evolution and ore deposits of the Lachlan Orogen in southeastern Australia, ran from December 2016 to 2019, but research by two PhD students continued to 2023.

TRACE ELEMENTS IN ANCIENT OCEANS

Leader: Ross Large

Team members: Indrani Mukherjee, Jeff Steadman

Collaborators: Alan Cannell, Fabricio Caxito, Ross Corkrey, Robert Hazen, Valeriy Maslennikov

This project uses the trace element content of sedimentary pyrite through time to interpret changes in the trace element content of past oceans and relationships to atmospheric oxygen. This study combines the results from two totally different methods to estimate atmosphere oxygen concentrations during the Precambrian and Phanerozoic.

This project has been running for several years. In 2023 there was no progress to report, but further progress will be reported for 2024.

LOOKING FORWARD

We are looking forward to renewing our research efforts in sediment-hosted ore deposits in 2024 and beyond. Sheree Armistead is planning a pilot study using geochemistry, geochronology and machine learning techniques to better understand sediment-hosted Cu and critical metal deposits in the Central African Copperbelt and potentially other regions. This work is in collaboration with David Cooke, David Selley, Robert Scott, Matt Cracknell, Jeff Oalmann and Ivan Belousov. The team are aiming to develop a larger research initiative with industry partners in 2024 and beyond.

In the IOCG³ project we are looking forward to recruiting a new PhD student to work on mineral chemistry across multiple Australian deposits, and a Masters student to continue and build on Jo Morrison's excellent work at Ernest Henry. In 2024, the project will continue to work on the Alpine, Prominent Hill, and Hillside deposits, and will add a subproject on mineral chemistry of the Intercept Hill/Con Ryan area of South Australia. Jeff will also conduct fieldwork outside Australia with Dr Fernando Tornos on various Peruvian IOCG systems.

Program four: Magmatic and volcanic processes

▶ OBJECTIVE

This program investigates magmatism, volcanism, volcano-sedimentary processes, and magmatic-hydrothermal mineral systems to unravel the interactions and connections between the mantle, crust and Earth's surface.

Introduction

Program 4: Magmatic and volcanic processes focusses on conducting fundamental research related to magma genesis and ascent, volcanic eruptions and associated volcano-sedimentary processes. This program applies that science to magmatic-volcanic-hydrothermal mineral systems in various tectonic settings, and in both subaerial and submarine environments. The understanding of magmatic and volcanic environments can have implications for natural hazards, and efficient and effective vectoring towards ore deposits.

This program fosters collaboration and maintains a diverse network of partners, including national and international industry stakeholders, research institutions, and geological surveys, marine research centres, and observatories. The contributions and expertise of these partners are highly valued in driving the program's research goals and outcomes.

Highlights

- Start of a three-year Australian Research Council Discovery Project on volcano-sedimentary processes in the Kermadec Arc (Rangitāhua), New Zealand
- Zeb Zivkovic's 2023 publication in *Geochemistry: Expiration, Environment, Analysis*
- Jodi Fox's 2023 publication in *Australian Journal of Earth Sciences*
- Australia and New Zealand International Consortium (ANZIC) funding for a two-year study related to the IODP 379 Expedition offshore Antarctica
- Australia and New Zealand International Consortium (ANZIC) funding for a PhD student to fund post-expedition research related to the IODP 398 Expedition in the Mediterranean
- PhD student Acacia Clark participated in the IODP 398 Expedition
- The team presented four talks and posters at two international conferences
- Honours student Madison Mulder completed her project on SW Pacific tectonics
- Visit of an MSc student (Janne Scheffler) from GEOMAR, Germany.

One of the highlights of 2023 was PhD student Acacia Clark's participation as scientist on board the International Ocean Discovery Program's drilling ship, the RV Joides Resolution*, on a voyage in the Mediterranean Sea. Here Acacia (left) is pictured with Columbia University graduate student Ally Peccia after docking at Heraklion, Greece, at the completion of IODP Expedition 398.*

Program 4 highlights of 2023 include welcoming new postdoctoral researcher Yamila Cajal to CODES, three new PhD students – Vinicius da Cruz, Billy Beas and Axel Cima – and two Honours students: Emily Conn and Madison Mulder.

PhD students Colin Jones and Zeb Zivkovic submitted their theses in 2023, and we wish them all the best with the examination process. Zeb published his first PhD paper titled, 'Comparison of lithium borate fusion and four-acid digestions for the determination of whole-rock chemistry – implications for lithogeochemistry and mineral exploration', in the journal *Geochemistry: Expiration, Environment, Analysis*. This paper demonstrates how the lithogeochemical interpretation can be biased depending on the whole rock geochemical method used for the analysis, and presented a new method that provides unbiased interpretations despite the known biases in the data.

Dr Jodi Fox, together with Professor Jocelyn McPhie and Associate Professor Rebecca Carey, published an article on the revised stratigraphy and first geochronology of the Miocene submarine volcanic succession at Kennaook/Cape Grim, northwestern Tasmania, in the *Australian Journal of Earth Sciences*. This area was a site of submarine intraplate basaltic volcanism during the Miocene (23–25 Ma) in Tasmania.

One of the highlights of 2023 was PhD student Acacia Clark's participation as scientist on board the International Ocean Discovery Program's drilling ship, the RV *Joides Resolutio*n, to the Mediterranean Sea. The aim of this science is to better understand the tectonic and volcanic history of volcanic arcs and volcanoes in the Mediterranean Sea. Look forward to seeing Acacia's publications in 2024.

This program fosters collaboration and maintains a diverse network of partners, including national and international industry stakeholders, research institutions, and geological surveys, marine research centres, and observatories.

The program team

LEADER REBECCA CAREY
DEPUTY LEADER MARTIN JUTZELER

TEAM MEMBERS:

Sharon Allen, Mike Baker, Ivan Belousov, Stuart Bull, Jonathan Cloutier, Yamila Cajal Contreras, Matt Cracknell, Paul Davidson, Trevor Falloon, Jodi Fox, Bruce Gemmell, David H. Green, Maya Kamenetsky, Steffen Kutterolf, Ross Large, Charles Makoundi, Jocelyn McPhie, Sebastien Meffre, Jeff Oalmann, Paul Olin, Gerrit Olivier, Karin Orth, Michael Roach, Jeff Steadman

PHD STUDENTS:

Acacia Clark, Vinicius da Cruz, Shannon Frey, Declan Higgins, Malai Ila'ava, Colin Jones, Bridie Le'Gallais, Hannah Moore, Peerapong Sritangsirikul, Chuang Wang, Zebedee Zivkovic

HONOURS STUDENTS:

Emily Conn, Till Gallagher, Madison Mulder

COLLABORATORS:

AUCKLAND MUSEUM, NZ
Tom Trnski

AUSTRALIAN NATIONAL UNIVERSITY
Richard Arculus

BHP
Kathy Ehrig

CATALYST METALS LTD
Dion Alford, Bruce Kay, Magdaline Kepo

CENTRAL SCIENCE LABORATORY (UTAS)
Christian Dietz, Sandrin Feig, Karsten Goemann, Thomas Rodemann

COLUMBIA UNIVERSITY, USA
Subramanium Ajit

CONSULTANT
Anthony (Tony) Brown, Hartmut Beurlen, Vadim Kamenetsky

DATAROCK
Yasin Dagasan, Liam Webb

DIVERSIFIED MINERALS PTY LTD
Angela Lorrigan

ETH ZURICH, SWITZERLAND
Anders McCarthy

EVOLUTION MINING
Ned Howard

FLEET SPACE TECHNOLOGIES
Gerrit Olivier

GEOLOGICAL SURVEY OF JAPAN, JAPAN
Fumihiko Ikegami

GEOLOGICAL SURVEY OF NEW SOUTH WALES
Chris Folkes

GEOLOGICAL SURVEY OF VICTORIA
Rob Duncan

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Christopher Phillips

GEOMAR, GERMANY
Steffen Kutterolf

GFZ GERMAN RESEARCH CENTRE FOR GEOSCIENCES, GERMANY
Rainer Thomas

GNS SCIENCE, NEW ZEALAND
Cam Asher, Ery Hughes, Paul Jarvis, Geoff Kilgour, Michael Rosenberg

HELMHOLTZ INSTITUTE FREIBERG FOR RESOURCE TECHNOLOGY, GERMANY
Alkiviadis Kontonikas-Charos

GOLD FIELDS, ST IVES GOLD MINE
Gary Sparks, Leon Grimbeek, Matthew Crawford

IFREMER, FRANCE
Martin Patriat

INSTITUT DE PHYSIQUE DU GLOBE DE PARIS, FRANCE
Lisa Retailleau

INSTITUTE OF MARINE AND ANTARCTIC STUDIES (IMAS)
Zanna Chase, Mike Coffin, Jacqui Halpin, Vanessa Lucieer, Taryn Noble, Joanne Whittaker

JAPAN AGENCY FOR MARINE SCIENCE AND TECHNOLOGY
Iona McIntosh

LABORATOIRE DE GEOLOGIE DE LYON: TERRE, PLANETES, ENVIRONNEMENT, FRANCE
Nico Coltice

LOS ALAMOS NATIONAL LABORATORY, USA
Brent Delbridge

MACQUARIE UNIVERSITY
Nathan Daczko

MDRU, CANADA
Shaun Barker

MINERAL MAPPING
Scott Halley

MINERAL RESOURCES TASMANIA
Ralph Bottrill, Grace Cumming, John Everard, Claire Kain, Andrew McNeill

MMG
Corey Jago

MONASH UNIVERSITY
Ray Cas

MURORAN INSTITUTE OF TECHNOLOGY, JAPAN
Yoshi Goto

NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH, NEW ZEALAND
Emily Lane, Erica Spain, Sally Watson, Suzi Woelz, Richard Wysoczanski

NATIONAL MUSEUM OF NATURE AND SCIENCE, JAPAN
Kenichiro Tani

NATIONAL OCEANOGRAPHY CENTRE, UK
Michael Clare, Isobel Yeo

NORTHWEST UNIVERSITY, XI'AN, CHINA
Simon Williams

OCEANAGOLD, NEW ZEALAND
Shannon Richards

OREGON STATE UNIVERSITY, USA
Robert Duncan, Daniel Miggins

PENNSYLVANIA STATE UNIVERSITY, USA
Tushar Mittal

QUEENSLAND UNIVERSITY OF TECHNOLOGY
Patrick Hayman

ROYAL HOLLOWAY COLLEGE LONDON, UK
F. Javier Hernández-Molina

SECOND INSTITUTE OF OCEANOGRAPHY, HANGZHOU, CHINA
Shaoru Yin

UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL, BRAZIL
Everton Bongiolo

UNIVERSITY OF AUCKLAND, NEW ZEALAND
Michael Rowe, Julie Rowland

UNIVERSITY OF CALIFORNIA, BERKELEY, USA
Michael Manga

UNIVERSITY OF CALIFORNIA, DAVIS, USA
Cathy Busby

UNIVERSITY OF CANTERBURY, NEW ZEALAND
Ian Wright

UNIVERSITY OF HAWAII AT MANOA, USA
Bruce Houghton

UNIVERSITY OF HOUSTON, USA
William Sager

UNIVERSITY OF MELBOURNE
Stephen Gallagher

UNIVERSITY OF OTAGO, NEW ZEALAND
James White

UNIVERSITY OF OXFORD, UK
Jane Barling

UNIVERSITY OF RHODE ISLAND, USA
Adam Soule

UNIVERSITY OF STRASBOURG, FRANCE
Michael Heap

UNIVERSITY OF SYDNEY
Maria Seton

UNIVERSITY OF TOKYO, JAPAN
Yusuke Yokoyama

UPPSALA UNIVERSITY, SWEDEN
Abigail Barker

VANDERBILT UNIVERSITY, USA
Ralf Bennartz, Kristen Fauria, Ashok Kumar Gupta, Liam J. Kelly, John Rausch

PhD students Hannah Moore, Meg Harland (IMAS) and Declan Higgins at the summit of Mt Tarawera, New Zealand, after attending the IAVCEI Conference in January.

CODES PhD students Malai Ila'ava and Hannah Moore pictured collecting samples from the Taupo Volcanic Centre, New Zealand, to be used in experiments by PhD student Shannon Frey.

Projects

- Volcanology and geochemistry research related to ore deposits
- Subaerial and submarine volcanology and natural hazards
- Sedimentary volcanology
- Olympic Dam fluid/melt inclusion project
- The tectonic significance of mafic/ultramafic igneous rocks in western Tasmania
- Nature, structure and origin of the St Marys Porphyry, northeastern Tasmania
- Pegmatites and pegmatite-related ores
- VHMS research – ancient

Project summaries

VOLCANOLOGY AND GEOCHEMISTRY RESEARCH RELATED TO ORE DEPOSITS

Leader: Rebecca Carey

Team members: Jonathan Cloutier, Bruce Gemmell, Martin Jutzeler, Ross Large, Jocelyn McPhie, Sebastien Meffre, Paul Olin, Gerrit Olivier, Karin Orth, Michael Roach, Robert Scott, David Selley, Jeff Steadman

Students: Vinicius da Cruz, Malai Ila'ava, Chuang Wang, Zeb Zivkovic

Collaborators: Ray Cas, Matthew Crawford, Yasin Dagasan, Corey Jago, Rob Duncan, Leon Grimbeek, Ned Howard, Andrew McNeill, Gary Sparks, Liam Webb

Detailed analysis of volcanic products and architectures are critical to unravel the mechanisms and timing of mineralisation and the characteristics of ore deposits. Our research group investigates various aspects of volcanic facies architecture in ancient seafloor environments as well as their analogues in modern settings. Our research encompasses conventional fieldwork and endeavours to find and utilise innovative approaches like geophysical techniques and machine learning to tackle questions across fundamental to applied science. In 2023, we integrated a wide range of multidisciplinary tools alongside traditional facies reconstruction for numerous subprojects within our group.

ARC Linkage Project – Exploration targeting from next-generation volcanic facies reconstruction

This Linkage Project represents a comprehensive and multidisciplinary study aimed at enhancing our understanding of the volcanic architecture in mineralised terrains,

and to inform on the relationships between alteration and mineralisation processes with volcanic lithologies. The project seeks to reconstruct volcanic architectures by combining traditional facies analysis and geochemistry, with a novel approach involving modern image analysis and machine learning techniques applied to phenocryst populations in volcanic rocks. The project is based at Cowal gold mine (NSW), Waihi mine (New Zealand) and the Mt Read Volcanics (Tasmania), and is a collaboration with Evolution Mining, OceanaGold, Mineral Resources Tasmania, the University of Auckland, the University of Strasbourg, and Datarock.

The image analysis project aims at improving stratigraphic reconstructions in volcanic terrain by complementing the traditional facies analysis and geochemistry techniques and using the phenocrysts, one of the most common attributes in volcanic rocks. The technique uses simple photographs of volcanic facies in core samples to quantitatively assess shape, abundance and size distribution of feldspar and pyroxene phenocrysts. Statistical analysis is then employed to establish correlations between different volcanic units and fingerprint key markers across fault blocks. This research is led by Dr Martin Jutzeler at CODES, and the machine learning aspect of the project is carried out in collaboration with Datarock. The ultimate goal is to develop and make available a user-friendly tool that can be employed to examine individual volcanic units and aid in accurate stratigraphic reconstructions. Martin is currently finalising the writing of a manuscript for submission to *Geology*, based on dacites in the Mt Read Volcanics.

Malai Ila'ava's PhD project is focussed on reconstructing the basin scale volcanic facies architecture for the oldest known volcanics of the Cowal Igneous Complex (CIC). This project may have regional and tectonic implications as (i) the CIC is one of only a few localities that records the entire Ordovician history of the Macquarie Arc, and (ii) the earliest phase of volcanism is poorly constrained. Malai is currently writing up his thesis comprised of three publication-ready papers. The first paper is currently in print with the *Australian Journal of Earth Sciences* and describes the integration of traditional facies analysis with current 3D modelling techniques based on his experiences at the CIC. The second paper focuses on facies architecture reconstructions for the oldest known volcanics of the CIC. This is integrated with an extensive industry-based four-acid digest whole rock geochemistry dataset along with new zircon U-Pb dates to interpret a new chronostratigraphic framework. These will be the most robust and detailed constraints ever documented for any of the earliest volcanics in the Macquarie Arc. The third paper will be exploratory and expansive and will utilise the early Ordovician chronostratigraphic framework (established in paper two) to extend the stratigraphy and history of deformation at the CIC into Silurian and Devonian times, with implications presented for the Macquarie Arc. This will be done using additional graphic logging, new zircon U-Pb dates, and whole rock major and trace element geochemistry. At a tectonics scale, this project may have implications for reconstructions of Gondwana's eastern margin, which are ambiguous and debated due to several uncertainties about the Lachlan Orogen's Ordovician history.

A collaborative research team composed of Associate Professor Rebecca Carey, Dr Shaun Barker,

Associate Professor Rebecca Carey describing geology at the summit of Mt Tarawera on an unofficial post-conference field trip with University of Hawaii students following the IAVCEI 2023 conference in New Zealand.

Shannon Richards and Professor Michael Heap is currently investigating the physical and thermal properties of volcanic rocks and shallow intrusive rocks. One project is investigating the physical properties of intermediate-felsic rocks that favour high-grade mineralisation sourced from OceanaGold's Waihi mine in New Zealand. We have conducted a series of rock properties measurements and stress tests to gain an understanding of how the process of alteration influences the strength and fracture characteristics of rocks, particularly in relation to fluid transport. While alteration clearly leads to a heightened variability in mechanical properties of rocks, the type and degree of alteration is critically important, and less so the original rock porosity and permeability. This information together with the paragenesis of mineralisation will hold some insights into the evolution of fluid flow drivers and timing of mineralisation.

SUBAERIAL AND SUBMARINE VOLCANOLOGY AND NATURAL HAZARDS

Leader: Rebecca Carey

Team members: Sharon Allen, Trevor Falloon, Jodi Fox, Martin Jutzeler, Steffen Kutterolf, Jocelyn McPhie, Paul Olin, Karin Orth

Students: Acacia Clark, Shannon Frey, Hannah Moore, Chuang Wang

Collaborators: Ralf Bennartz, Everton Bongiolo, Ralph Bottrill, Cathy Busby, Ray Cas, Grace Cumming, Nathan Daczko, Brent Delbridge, Robert Duncan, John Everard, Kristen Fauria, Ashok Kumar Gupta, Michael Heap, Bruce Houghton, Fumihiko Ikegami, Liam J. Kelly, Geoff Kilgour, Steffen Kutterolf, Michael Manga, Tushar Mittal, Gerrit Olivier, Christopher Phillips, John Rausch, Lise Retailleau, Michael Rosenberg, Maria Seton, Adam Soule, Kenichiro Tani, James White, Joanne Whittaker, Simon Williams, Richard Wysoczanski

Late Bronze Age eruption of Santorini Volcano

PhD student Acacia Clark was Australia's scientist on board the International Ocean Discovery Program's drilling ship, the RV *Joides Resolution*. The purpose of the voyage (Dec 2022–Feb 2023) was to understand the tectonic and volcanic history of volcanic arcs and volcanoes in the Mediterranean. Acacia was on board for two months, and will conduct a research project together with collaborators Steffen Kutterolf (GEOMAR), Michael Manga (UC Berkeley), and Iona McIntosh (JAMSTEC) on the Late Bronze Age eruption of Santorini Volcano.

Okataina Caldera, New Zealand

In 2023, PhD students conducted a month-long field study of two eruption deposits from the Okataina Caldera in the North Island of New Zealand. This fieldwork was supported by Geological and Nuclear Sciences New Zealand. It was designed to map these field deposits in order to calculate eruption parameters and understand activity as a proxy for future eruptive behaviour.

How do powerful large basaltic eruptions initiate? CODES PhD student Hannah Moore has mapped the initial unit of the historic 1886 eruption of Tarawera volcano, in order to calculate eruption styles and intensities during the start of this eruption. Her data are useful for understanding the risk associated with mafic volcanoes not just in Australia, but globally. We look forward to reading that publication in 2024!

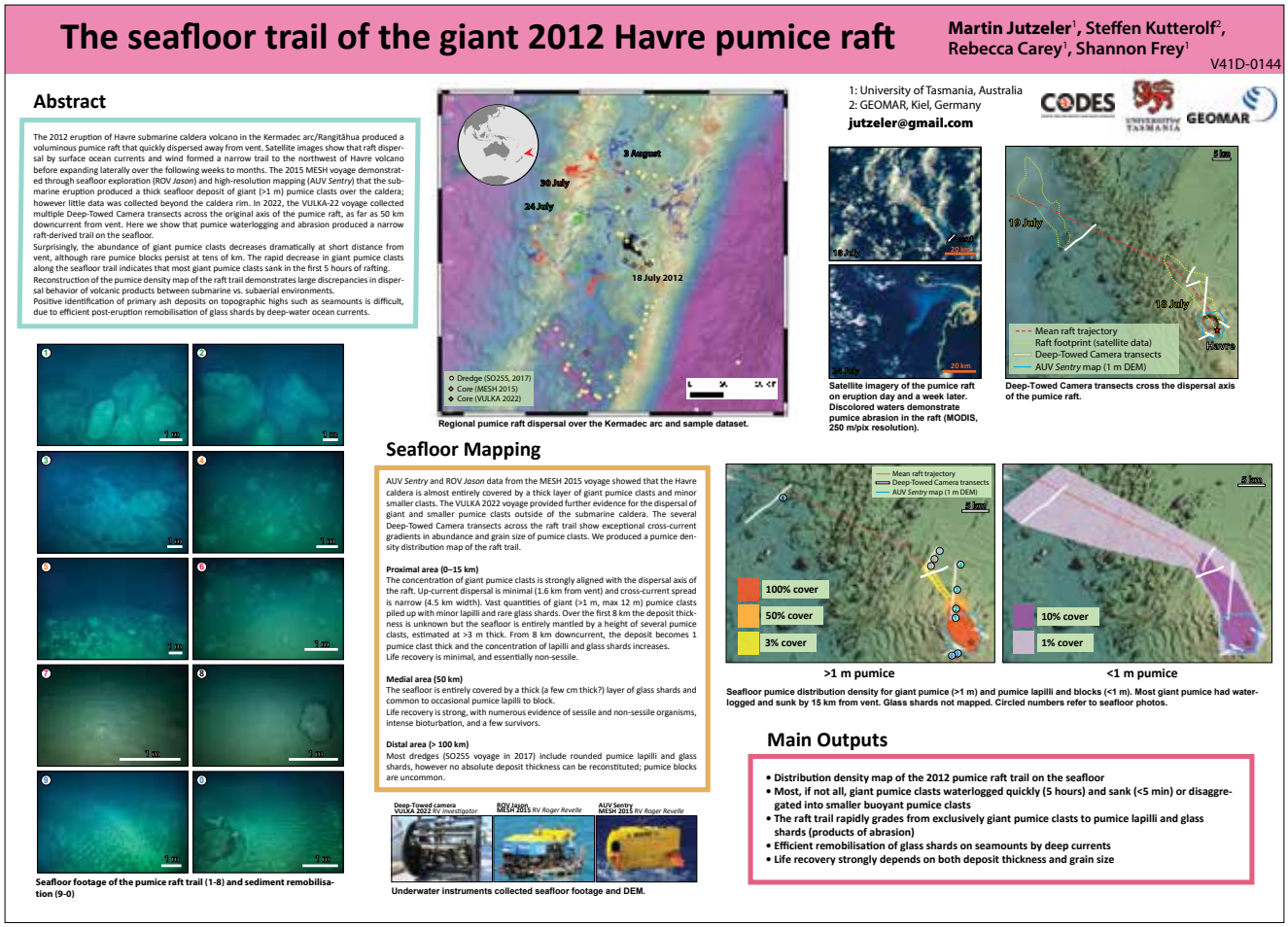
How do large silicic volcanic eruptions transition between explosive and effusive behaviour? CODES PhD student Acacia Clark is studying an eruption unit that represents exactly that. This 'Unit M' of the 1315 CE eruption of Tarawera volcano likely hosts the globally best exposed proximal succession of explosive and effusive eruption deposits. Acacia has mapped these deposits and demonstrated a long-lived (months?) highly complex eruptive phase that likely took place over months. Understanding of the underlying magmatic and environmental factors that influenced the transition from explosive to effusive volcanism during the 1315 CE eruption links directly to a key challenge in the National Academies Report on volcanic eruptions published in 2017. Acacia's research will form a framework for future researchers to provide insights into the mechanisms and triggers that facilitate such transitions, contributing to assessing volcanic hazards at silicic volcanoes globally.

Cenozoic volcanism in Tasmania

In a collaborative effort with Mineral Resources Tasmania (MRT), CODES PhD student Chuang Wang is engaged in a research project centred around passive seismic analysis in western Tasmania. The primary focus of this study is to utilise field data obtained from a dense network of seismometers located north of Hellyer mine. By leveraging this comprehensive dataset, Chuang has successfully reconstructed the depth of Tertiary basalts that overlay the mineralised Mt Read Volcanics. The findings of this passive seismic survey are further supported by a few drill holes in the region. The significance of this research lies in its ability to offer a novel approach for exploration targeting in areas where the mineralised Palaeozoic basement is obscured by significant thicknesses of younger successions, ranging from tens to hundreds of metres. By integrating passive seismic analysis into the exploration process, Chuang's work has the potential to revolutionise the identification of promising exploration targets, facilitating the discovery of mineral deposits that are concealed beneath younger geological formations.

Cenozoic SW Pacific volcanism and tectonics

In 2023, Honours student Madison Mulder began a project focussed on an aspect of Cenozoic SW Pacific tectonics. Her project was to understand the genesis of igneous, volcanic and sedimentary succession of rocks dredged on a submerged fragment of Australia's crust (Louisiade Plateau) immediately south of the Solomon Islands. Her research has demonstrated a complex history of subduction reversals, basin opening



A poster presented at the International Conference on Volcanology and Geophysical Signal Processing ICVGSP, 27–28 September, San Francisco, by Dr Martin Jutzeler.

and ophiolite emplacement sometime between 55 and 35 Ma. The research is still ongoing, and we look forward to reading this paper in 2024!

Heard Island, Kerguelen Plateau, Australian Antarctic Territory

Under the leadership of former CODES PhD student Dr Jodi Fox, a team of researchers consisting of Associate Professor Rebecca Carey and Dr Trevor Falloon (UTAS), Professor Bob Duncan (Oregon State University) and Dr Jane Barling (Oxford), is actively involved in investigating the volcanic history of Heard Island. Their primary focus revolves around understanding the characteristics and origins of the most recent volcanic rocks formed as a consequence of the Kerguelen Mantle Plume. Together, this team will publish whole-rock, mineral and isotope geochemistry data together with 40Ar/39Ar geochronology of rocks and IODP samples that will provide the first evidence for zonation of a Kerguelen Mantle Plume.

Balleny volcanic chain, offshore Tasmania

Beneath the Tasman Sea and Southern Ocean lies an intriguing volcanic chain believed to be linked to the Balleny Mantle Plume. This seamount chain provides a remarkable record of continental breakup events between Australia, Zealandia and Antarctica approximately 90–35 million years ago. This breakup eventually led to the opening of the Southern Ocean around 50–30 million years ago, giving rise to the powerful Antarctic Circumpolar Current. Preliminary investigations involving whole-rock geochemistry and argon geochronology have provided compelling support for the Balleny Mantle Plume hypothesis. The data obtained exhibit an age-progressive trend, and HIMU mantle source geochemistry, strengthening the link between the seamount chain and the Balleny Mantle Plume. The age ranges of these seamounts overlap with ages of Tasmanian volcanic centres at the time that the plume should be immediately east of Tasmania, raising the question of whether it can be invoked as the driver for this magmatism. This is an active area of research being conducted together with Dr John Everard from Mineral Resources Tasmania.

Fukutoku-oka-no-ba eruption, 2021

Together with a USA-led team, Dr Martin Jutzeler has published an article in *Earth and Planetary Science Letters* on the rapid response of the 2021 pumice-raft forming eruption of Fukutoku-oka-no-ba in the Izu-Bonin Arc, south of Japan. The research team used a combination of satellites to describe the formation of a pumice raft co-jointly with a stratospheric vapour plume and phreatomagmatic jets from a shallow-water vent. The use of commercial satellites with ultra-high resolution (1 m) proved to be critical to identify critical processes in the formation of pumice rafts. Together with lower resolution satellite images, such datasets provide exceptional information that revolutionises our understanding of shallow marine volcanism.

SEDIMENTARY VOLCANOLOGY

Leader: Martin Jutzeler

Team members: Rebecca Carey, Steffen Kutterolf, Jocelyn McPhie, Karin Orth

Students: Emily Conn, Shannon Frey

Collaborators: Abigail Barker, Cathy Busby, Kristen Fauria, Stephen Gallagher, F. Javier Hernández-Molina, Steffen Kutterolf, Emily Lane, Michael Manga, Tushar Mittal, John Rausch, Tom Trnski, Sally Watson, Suzi Woelz, Ian Wright, Richard Wysoczanski, Shaoru Yin, Yusuke Yokoyama, James White

The Sedimentary Volcanology project encompasses research on eruption, transport and deposition dynamics in modern and ancient volcanic successions. Sub-projects include:

Eruption and volcano-sedimentary processes during submarine caldera-forming events

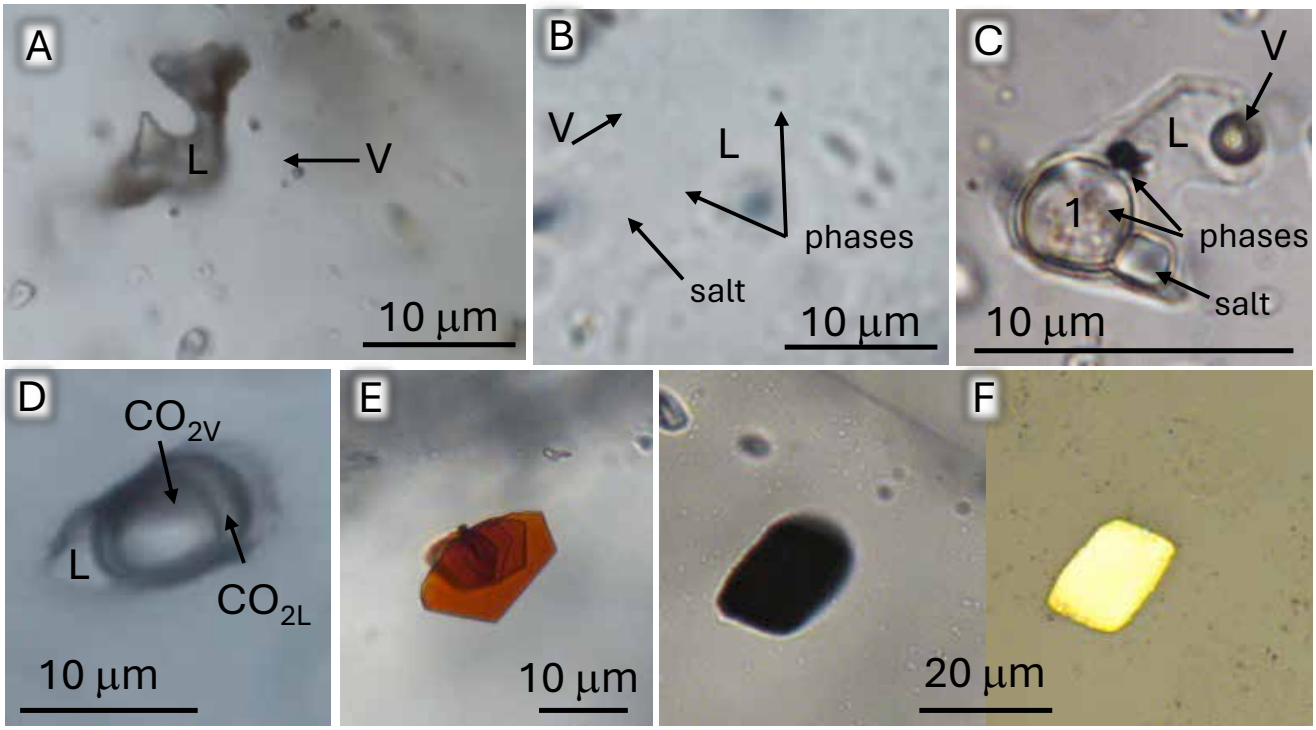
An ARC Discovery project to study submarine volcanism and its tsunamigenic effects began late in 2023. This multidisciplinary project is led by Dr Martin Jutzeler together with chief investigators Associate Professor Rebecca Carey and Professor Stephen Gallagher (University of Melbourne) and partner investigators Dr Steffen Kutterolf, Professor Yusuke Yokoyama, Professor Michael Manga and Dr Emily Lane. Targeting Macauley volcano in the Kermadec Arc (Rangitāhua) and its 5.7 ka caldera, this project aims to assess the ability of explosive submarine volcanism to create trans-ocean tsunami. The team will combine the multiple datasets collected during the 2022 voyage, conduct ^{14}C dating on Foraminifera for chronostratigraphy reconstruction and collect near-vent samples on Macauley Island to numerically model eruption and sediment transport processes. These models will then be used to model tsunami generation and assess their potential impact on coastal populations and infrastructure. This project is very timely, as it targets volcanic processes very similar to those that occurred during the January 2022 eruption of Hunga Tonga, although being an order of magnitude more voluminous. Expected outcomes include an unprecedented reconstruction of the architecture of submarine caldera volcanoes that has direct application for mineral exploration on the Australian continent, and new innovative models applicable globally for a richer understanding of volcanic tsunami and eruptions that shape the seafloor.

PhD student Shannon Frey is conducting research on two sediment cores collected on the submarine sediment waves on the slope of the submarine Macauley caldera. These cores recovered exceptional stratigraphy, consisting in a complex succession of planar- and cross-bedded pumiceous units. Together with seismic reflection transects across the sediment waves, these cores allowed Shannon to interpret these pumiceous units as being eruption-fed. Their sedimentary patterns point towards deposition from high-flux subaqueous density currents fed from a large-magnitude eruption at Macauley volcano. This research project is at the forefront of research on caldera-forming submarine volcanism, and has direct relevance to the Hunga Tonga 2022 eruption that had global significance for volcanology and geohazards.

Janne Scheffler, Master of Science student at GEOMAR, Germany, visited CODES for six months from late 2022 to April 2023. Janne was supervised by Martin and Rebecca, together with Dr Steffen Kutterolf, who has recently become a CODES' adjunct. Janne's research was focussed on a complex 40-cm volcaniclastic unit cored at ca. 150 km from the active volcanic arc during IN2022_V02 voyage. Geochemical fingerprinting on glass shards points towards Macauley as source volcano, 150 km away. Based on high-resolution sampling, Janne interpreted the complex planar- and cross-bedding and grading in components in the stratigraphy as evidence for multi-stage transport processes involving pyroclastic flows travelling over water followed by rapid settling of the pyroclasts through the water column. Janne is currently working on a manuscript on this project, while starting her PhD at GEOMAR.

Emily Conn started an Honours project with Dr Martin Jutzeler and Associate Professor Rebecca Carey on stratigraphic reconstruction of three sediment cores collected nearby submarine caldera volcano Havre during the IN2022_V02 voyage. Emily was part of the voyage as an invited external student in 2022, and joined CODES for her Honours studies this year. Using sediment componentry and geochemical analyses Emily will unravel the source volcanoes and style of eruptions that produced the multiple volcanic units that mantle the deep seafloor.

This piston core is central to PhD student Shannon Frey's work. It is an epoxy sediment peel of core IN2022_V02_08PC/4 collected from the 2022 voyage to the Kermadec arc, led by Martin Jutzeler. This core was sampled from a sediment wave on the volcanic flanks, thought to be deposited by subaqueous eruption-fed density currents travelling under supercritical flow conditions.



Dr Maya Kamenetsky is researching quartz- and carbonate-hosted fluid inclusions at Olympic Dam. This image shows different types of inclusions in Olympic Dam quartz: A. type I - two-phases liquid (L) and vapor (V) bubble, B, C. type II - multi-phase liquid- vapor bubble ± salt crystal ±hematite and other solid minerals (Phase 1 on C identified as florencite with tiny bits of hematite), D. type III – liquid (L) and/or vapor (V) CO2 ± liquid (L) phase, E, F. type IV - mineral inclusions: hematite flake (E) and chalcopyrite (F)

Impact of ocean currents on volcanic seamounts

PhD student Shannon Frey is working on the interactions between ocean currents and seamounts. Based on imagery from the IN2022_V02 voyage in the Kermadec Arc (Rangitāhua), a sediment core collected in 2015 and ARGO floats data, Shannon identified that long-lasting and transient mid-water ocean currents strongly remodel seafloor sediment down to >1,000 mbsl, creating complex dune and scour fields on Havre volcano. This study has strong implications for identification of syn- vs. post-eruption sedimentation and paleocurrent directions in the rock record.

OLYMPIC DAM FLUID/MELT INCLUSION PROJECT

Leader: Maya Kamenetsky

Collaborators: Kathy Ehrig, Vadim Kamenetsky, Alkis Kontonikas

The project is focussed on identifying the generations of quartz- and carbonate-hosted fluid inclusions in relationship to their use (temperature and composition) as representative of the alteration fluids and their involvement in the evolution of Olympic Dam.

The Olympic Dam deposit is recognised as magmatic-hydrothermal, formed at the brink of solidification of the host Roxby Downs (RD) granite and largely assisted by near-contemporaneous intrusion of mafic and felsic magmas of the Gawler Range volcanic series. It is also speculated that the initial (at ~1600 Ma) mineralisation was modified and/or upgraded by several tectonic, sedimentary and magmatic events in the late Mezoproterozoic and throughout the Neoproterozoic. The chemical and mineralogical modifications (alterations) at Olympic Dam are largely hydrothermal, i.e., caused by circulating aqueous and carbonic fluids of intratelluric, deuteric and surficial origins.

The mineralised lithologies, such as granite breccia, are rich in quartz supplied by the Roxby Downs granite. Although quartz veining is rare at Olympic Dam, the sulphide mineralisation is believed to have a hydrothermal origin and to have come from granite-related deuteric and external fluids. The ore-forming potential of granite-derived (i.e., deuteric) and granite-equilibrated (distal) fluids is particularly interesting in the case of the multi-element Olympic Dam deposit (C, Fe, F, U, REE, Cu, Au, etc).

Our extensive petrographic study of quartz in RD granite within the Olympic Dam orebody has shown multiple generations of quartz (broadly magmatic, hydrothermal and secondary) and a mix of fluid inclusion types and compositions in each grain of quartz and a given granite sample. To get 'background' information on fluids accompanying 'magmatic' stage of the RD granite, or deuteric fluids, we selected the samples from the distal drill hole RD2488, i.e., ~5 km away from weakly altered (< 5% Fe) granite, enveloping the mineralised granite breccia. This drill hole contains relatively fresh Roxby Down granite that shows at least three generations of quartz: broadly magmatic (granitic), hydrothermal ('clear') and secondary 'turbid' quartz according to petrographic and cathodoluminescence (CL) examinations.

Fluid inclusions are present in all generations of quartz, although their quantity varies among different zones or grains of quartz. The majority of

Deputy Leader of Program 4, Dr Martin Jutzeler, is seen here presenting his research on the Kermadec Arc/Rangitāhua at the IAVCEI 2023 conference in Rotorua, New Zealand, which took place in January.

these inclusions are typically small, measuring less than 5 microns, and are often arranged in trails that may follow various or subparallel directions along growth plates or healed fractures. Many of these inclusions exhibit signs of decrepitation. Most of the inclusions are considered to be secondary or pseudo-secondary in nature. While these inclusions are common in certain samples, it is rare to come across individual distinct inclusions larger than 10 microns without any noticeable necking down features.

Our study identified four types of fluid/melt inclusions hosted in Olympic Dam quartz: two-phases liquid and vapour bubble, multi-phase liquid-vapour bubble ±salt crystal ±hematite and other solid minerals, liquid and/or vapour CO_2 ±melt/liquid phase, and mineral inclusions.

Minerals assemblage of inclusions, hosted by quartz, were identified using optic microscope, RAMAN spectroscopy, electron microscope SEM on exposed inclusions and LA-ICP-MS analyses of different types of quartz in inclusion-rich zones. The most abundant phases identified in inclusions are water, salt (commonly NaCl with a lesser amount of KCl or mixture), hematite, magnetite, and Ce-La minerals (florencite-like ($CeAl_3(PO_4)_2(OH)_6$)), carbonates (siderite-dolomite/ankerite-calcite in order of decreasing occurrences, different carbonates can be present in one inclusion), rutile, phlogopite, sulphates (K, Mg and Ca bearing), fluorite, apatite, barite, and sulphides (pyrite and chalcopyrite). Moreover, in LA-ICP-MS analyses many inclusions display high Pb concentrations, along with less common high U compositions.

The findings from our analysis of fluid inclusions suggest that the crystallisation/recrystallisation of Roxby Downs granite may have led to the development of deuteric aqueous fluids containing high concentrations of fluorine, chlorine and sulphur. Interactions between these fluids and the original granitic rocks could have resulted in the creation of oxidised compounds (such as hematite, carbonates and sulphates) as well as reduced mineral species (including sulphides and uraninite).

THE TECTONIC SIGNIFICANCE OF MAFIC/ULTRAMAFIC IGNEOUS ROCKS IN WESTERN TASMANIA

Leader: Ivan Belousov

Team members: Trevor Falloon, Rebecca Carey

Student: Bridie Le'Gallais

Collaborators: Ralph Bottrill, Anthony Brown, Grace Cumming, John Everard, Roland Maas, Andrew McNeill

This project aims at constraining the number and geographical spread of different magmatic series that exist within western Tasmanian mafic/ultramafic complexes, the nature of parental magma compositions of these complexes, and the possible tectonic settings at which these Tasmanian mafic/ultramafic complexes have formed prior to emplacement into their current position.

Bridie was away for most of 2023; however, some progress was made on the project. Results of Rb/Sr, Sm/Nd, Lu/Hf and Pb isotopes measurement using multi collector ICP-MS at the University of Melbourne for three metabasalt samples were received. The Sm/Nd, Lu/Hf and U/Th/Pb isotope results show complexity, but are usable, while Rb/Sr isotope results seem to be completely overprinted by alteration. Also, a search has started in the Mineral Resources Tasmania and University of Tasmania rock collections for historical regional samples to acquire new whole rock, glass, spinel, olivine and clinopyroxene compositions for a comparison study.

NATURE, STRUCTURE AND ORIGIN OF THE ST MARYS PORPHYRY, NORTHEASTERN TASMANIA

Leader: Karin Orth

Team members: Rebecca Carey, Sebastien Meffre

Student: Till Gallagher

Collaborators: Ralph Bottrill, Grace Cumming

In February 2023 Till Gallagher presented his Honours research on the St Marys Porphyry at the IAVCEI conference in Rotorua. Till has re-appraised the volcanic architecture of the St Marys Porphyry, the only example of extrusive activity during the Devonian magmatism in northeastern Tasmania. He examined one drillhole and 17 kms of coastal outcrop between Falmouth and Chain of Lagoons as well as other outcrops between Falmouth and St Marys in the west. Till has unpicked the seemingly monotonous St Marys Porphyry into distinct ignimbrite flow units. He conducted U-Pb zircon dating of the St Marys Porphyry and some of the surrounding sedimentary and igneous units. These dates confirm the Devonian age of the magmatism. They show that the southern Piccaninny Granite is time equivalent to the St Marys Porphyry and raises questions about the relationship between the St Marys Porphyry and the supposed feeder dyke to the northwest, the Catos Creek Dyke. The dates also show that this outflow succession formed at a different time to voluminous eruption units in Victoria which are both older (Snowy River Volcanics) and younger (Acheron, Cerberean successions). The new dates suggest a slightly older age for the Tabberabberan Orogeny in eastern Tasmania making it older than the orogenic event in Victoria. We look forward to publishing this detailed dataset in 2024.

PEGMATITES AND PEGMATITE-RELATED ORES

Leader: Paul Davidson

Collaborators: Rainer Thomas, Hartmut Beurlen

This initiative examines melt-melt immiscibility in felsic silicate melts, in the formation of pegmatites and pegmatite-related ore deposits. Pegmatites are noted for the presence of giant crystals, sometimes including rare minerals and gems, and are prime sources of several rare elements, even though their major element chemistry differs little from the standard haplogranitic melts, which are generally accepted to be their parental magmas. Therefore, it can be inferred that something in their origin favours extremely efficient partitioning, which would explain the high rare element concentrations (up to ore grade). Moreover, such processes need not be restricted to pegmatites, or even terrestrial processes.

More recently, the discovery in pegmatitic rocks of micro-diamond inclusions, some in minerals that only form at much greater depths than they were found, has important implications for the origin of pegmatite-forming melts. Such high- and ultra-high-pressure minerals and mineral inclusions imply extremely rapid transport from at least lower crustal depths. Published experimental work by various authors suggests that aluminosilicate melts formed at such depths has extraordinary abilities to dissolve fluids and metals, suggesting a new transport mechanism that may have wider implications in ore genesis. Such fluids may also contribute elements to some magma bodies, thus selectively enriching some in economically valuable elements, and may provide a mean to distinguish potentially productive from unproductive magma bodies.

In 2023, as a consequence of our research, we published 'The First Finding of Water-Free Copper Iodide and Iodate in a Chrysoberyl-Sillimanite Association from the Roncadeira Pegmatite, Borborema Province, NE-Brazil' by Rainer Thomas, Hartmut Beurlen and Paul Davidson in the journal *Aspects in Mining and Mineral Science*.

Other papers from this project are listed in the Publications section of this report.

VHMS RESEARCH – ANCIENT

Leader: Mike Baker

Team members: Jonathan Cloutier, Matt Cracknell, Charles Makoundi

Student: Zebedee Zivkovic

Collaborators: Shaun Barker, David Green, Scott Halley, Andrew McNeill

Tasmania

Dr Mike Baker, Dr Matt Cracknell and Dr Shaun Barker (MDRU) are leading a project initially entitled 'Lithogeochemical fertility indicators for VHMS deposits' initiated in June 2019 as a Masters by Research, which was expanded in scope and transferred to a PhD project in 2020, undertaken by candidate Zebedee Zivkovic. The expanded project titled, 'Whole rock lithogeochemical methods in magmatic-hydrothermal environments: applications to mineral exploration', takes advantage of recent improvements in geochemical assay methods to produce whole rock lithogeochemical interpretations based on geochemical methods commonly used in industry for exploration (i.e., four-acid digests and alkali fusions). The first part of the project was to

quantify the bias in the data between the four-acid digestion and alkali fusion methods and how this was translated in the resultant lithogeochemical interpretations. The study found significant loss in recovery for Zr, Hf, Nb, Ta, Ti and Eu in the acid digestion; however, certain ratios including Nb(Ta)/Ti and Eu/Eu* preserved their lithogeochemical information despite significant under-reporting in individual elements. Lithogeochemical interpretation using only acid digestion data produced more mafic and more alkaline rock compositions compared to the fusion data. This study has been published in *Geochemistry: Exploration, Environment, Analysis* (GEEA) and highlights the importance of using fit-for-purpose geochemical methods when undertaking lithogeochemical analysis.

The second part of the study was to develop a lithogeochemical method that was impartial to the analytical method and demonstrate different applications in a variety of geological settings. The first case study uses data gathered from the Cambrian Mount Read Volcanics (MRV) of western Tasmania and applies the method to identify prospective mineralised horizons across the MRV by comparing the lithogeochemistry of known mineralised horizons at the Rosebery deposit with MRV samples collected more regionally across the province. A second case study applies the method to samples of Paleoproterozoic intrusions from the western Wunaamin Miliwundi Orogen of the western Kimberley. Lithogeochemical analysis of these rocks identified an intrusion unusually depleted in V which was correlated with similarly V depleted rocks in the east Kimberley where they are associated with a large Ti-V resource. Subsequent petrographic and geochronological data confirmed these intrusions to be part of the same Large Igneous Province, thereby, significantly extending the exploration search space for similar Ti-V deposits in the west Kimberley.

Dr Charles Makoundi (CODES/MRT) is continuing his work on downhole hyperspectral mineralogy and multielement analysis to characterise the different types of alteration minerals downhole and their connections to the distribution of precious and base metals for the Mount Julia (Henty) deposit in the Mount Read Volcanic Belt. Drill holes MJ021 and Z15182 were selected for this study. Two mining companies, Catalyst Metals Limited (the new owner) and Diversified Minerals Pty Ltd (the previous owner), are supporting this project. To ascertain compositional variation and fluid evolution, a portion of the project has investigated the chemistry of pyrite. A research paper is in preparation for this project.

▶ LOOKING FORWARD

In 2024 Catherine Lit will begin their PhD at CODES under the supervision of Dr Martin Jutzeler, Associate Professor Rebecca Carey and Dr Ivan Belousov. This PhD is funded by an ARC Discovery Project and Catherine will carry out tephrostratigraphic reconstructions in the Kermadec Arc (Rangitāhua) to reconstruct the volcanic history of this region. The study will be invaluable to constrain volcanic recurrence and submarine and subaerial sediment transport at the scale of a volcanic intra-oceanic arc. Catherine is expected to arrive at CODES in late 2024. Martin and Catherine will participate in fieldwork on the very remote Macauley Island in the Kermadec Arc (Rangitāhua), pending permits. This exciting opportunity will provide exceptional stratigraphic reconstruction and sampling of a major proximal deposit from the 5.7 ka caldera-forming eruption of the now-submarine Macauley caldera. This research is part of Martin's ARC Discovery Project.

Poliana Vida Salgado will begin her PhD in the Iberian Pyrite Belt on the Magdelena VHMS deposit as a part of the Amira P1249 project and we look forward to seeing some of those rocks and research outcomes.

Rebecca has secured >$7M in funding for a voyage to Tonga using Australia's research vessel, the RV *Investigator*. Rebecca submitted an Australian Research Council Future Fellowship application to bring a team together to conduct research on the 2022 powerful explosive eruption of Hunga Tonga volcano. The research will elucidate the drivers of large explosive eruptions, and will use numerical modelling approaches to examine deep explosive magma-water interactions that trigger breccia pipe formation associated with porphyry-style mineralisation.

2024 will be a busy year for Program 4 with two students – Hannah Moore and Malai Ila'ava – due to submit their theses. We are also looking forward to more fieldwork by land, sea and air in 2024.

View of Mt Taranaki taken by Dr Karin Orth; it is the second highest peak in the North Island of New Zealand at 2,518 m. Understanding this volcano's periodicity from the ring plain deposits was the focus of a pre-IAVCEI2023 conference field trip in late January.

Program five: Analytical research

OBJECTIVES

- Analytical research underpins much of our most innovative research across the fundamental to applied spectrum.
- New developments in analytical research generated by CODES Analytical Laboratories provide the basis for CODES' global leadership in micro-analytical techniques specifically applied to mineral exploration, U/Pb and Lu/Hf geochronology, critical mineral characterisation, mineral processing, ore genesis and waste management, igneous geochemistry and volcanology.
- CODES Analytical Laboratories also provides analytical services to government, academia and industry.

Introduction

Program 5: Analytical research explores and develops novel analytical and data interpretation techniques based on the latest technological and algorithmic developments, such as maintaining a number of high spatial resolution microprobes, developing and testing advanced data-reduction algorithms and applying new techniques to natural samples. This helps in the understanding, exploration and exploitation of deep Earth resources.

Current research projects focus predominantly on expanding the capabilities of laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) for geological applications, analytical data reduction, and the development of new, user-friendly software packages. In 2023, a significant proportion of research activities was focussed on the development of critical mineral characterisation workflows, Lu/Hf dating of garnet and other minerals as well as using ICP-Tof imaging for acquiring rapid mineral maps.

The analytical projects using LA-ICP-MS include in-situ multielement analysis and imaging of element distribution within minerals; in-situ isotope analysis, focussing on a range of U/Pb and Lu/Hf dating applications; development of calibration standards; and technological developments aimed at improving the capabilities of the laser microprobes.

Highlights

Research

A paper on the development and characterisation of reference material (STDGL3) for sulphide analysis by LA-ICP-MS and a paper on a method for U/Pb dating of rutile and garnet

Current research projects focus predominantly on expanding the capabilities of laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) for geological applications, analytical data reduction, and the development of new, user-friendly software packages.

Dr Paul Olin (left) from the CODES Analytical Laboratories team talks with Associate Professor Thomas Rodemann from UTAS Central Science Laboratory during an Amira Sponsors' Meeting in December 2023.

were published in 2023. Both of these papers were published in *Geostandards & Geoanalytical Research* (see Publications section at the back of this report for details).

Papers on the development of a standard for garnet Lu/Hf dating, methods for epidote U/Pb dating and trace element analyses of alunite are being prepared for publication.

Equipment

No new instruments were installed during 2023.

Staff

The team welcomed Max Hohl as a Laboratory Analyst. He will be helping with programming spots for U/Pb geochronology, doing CL imaging and performing analytical data reduction.

Conferences

- Dr Jeffrey Oalmann presented at the North American Workshop on Laser Ablation (NAWLA) on ICP-Tof imaging and garnet Lu/Hf dating. This was held at the University of Notre Dame, Indiana, USA.
- Dr Ivan Belousov presented at the Goldschmidt 2023 conference on PGE analyses in sulphides from mantle rocks; this took place in Lyon, France.

CODES Program 5 leader, Dr Ivan Belousov, at the Goldschmidt 2023 conference in Lyon, France, with Associate Professor Irina Zhukova from the China University of Geosciences. Irina formerly worked in the CODES Analytical Laboratories.

The program team

LEADER IVAN BELOUSOV
DEPUTY LEADER JEFFREY OALMANN

TEAM MEMBERS:

Sheree Armistead, Matthew Cracknell, Fanghua Dai, Kate Jenkins, Sebastien Meffre, Maxwell Morissette, Paul Olin

PHD STUDENTS:

Axel Cima, Xin Ni Seow

COLLABORATORS:

CENTRAL SCIENCE LABORATORY (UTAS)
Karsten Goemann

CURTIN UNIVERSITY
Bruno Vieira Ribeiro

ETH ZURICH, SWITZERLAND
Marcel Guillong and Andrea Giuliani

LAURIN TECHNIC
Michael Shelley

MDRU, CANADA
Shaun Barker

NORRIS SCIENTIFIC
Ashley Norris

UNIVERSITY OF ADELAIDE
Sarah Gilbert

UNIVERSITY OF KIEL, GERMANY
Dieter Garbe-Schönberg

UNIVERSITY OF MELBOURNE
Roland Maas

US GEOLOGICAL SURVEY, USA
Jay Thompson

Projects

- Fundamentals of ICP-MS
- Fundamentals of laser ablation
- Calibration standards for LA-ICP-MS
- LA-ICP-MS instrumentation development
- U/Pb dating
- Lu/Hf dating
- LA-ICP-MS data reduction software
- Interpretation of LA-ICP-MS time-resolved signals

Project summaries

FUNDAMENTALS OF ICP-MS

Leader: Ivan Belousov

Team members: Maxwell Morissette, Jeffrey Oalmann, Paul Olin

Student: Xin Ni Seow

This project is aimed at better understanding the physical processes that occur in ICP-MS, in order to improve its performance and the range of applications for laser ablation.

The main focus in 2023 continued to be on improving our understanding of the influence of plasma conditions on quantification of analyses of different minerals. Development of methods for quantitative analyses of trace elements in minerals without using matrix matched reference materials was continued. A paper describing the method for alunite is being prepared for publication. A study of rates of doubly charged species production for different elements has been continued.

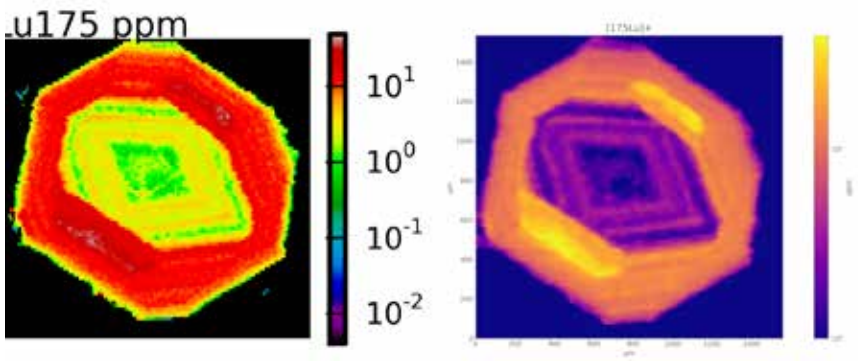
FUNDAMENTALS OF LASER ABLATION

Leader: Ivan Belousov

Team members: Maxwell Morissette, Jeffrey Oalmann, Paul Olin

Collaborators: Karsten Goemann, Ashley Norris, Michael Shelley

This project aims to gain a better understanding of laser ablation processes, leading to improved analysis of geological materials, especially sulphide minerals. A publication describing the relationship between matrix composition, ablation rate and elemental fractionation is in preparation with submission planned for 2024.



This photo shows a comparison of imaging results generated by LA-ICP-MS and ICP-Tof showing Lu zonation in garnet grain. Acquisition of ICP-Tof maps took ~10 times less time, but LA-ICP-MS are more quantitative. This comparison is a collaborative work with Curtin University and will be published in 2024 in Geostandards & Geoanalytical Research.

CALIBRATION STANDARDS FOR LA-ICP-MS

Leader: Ivan Belousov

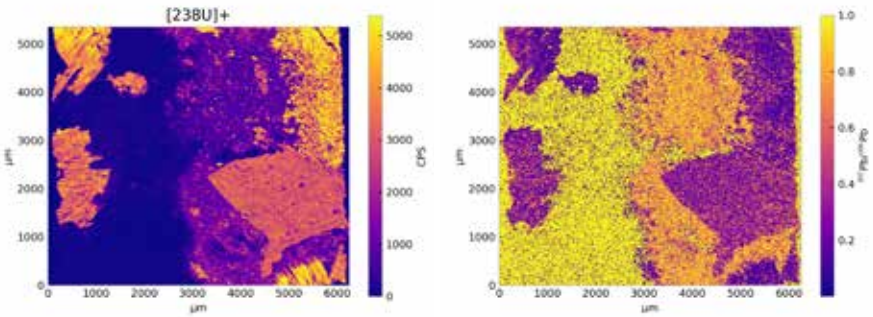
Team members: Maxwell Morissette, Jeffrey Oalmann, Paul Olin

Collaborators: Dieter Garbe-Schönberg, Karsten Goemann, Bruno Vieira Ribeiro, Marcel Guillong, Andrea Giuliani

This project is aimed at the development and characterisation of new calibration reference materials for LA-ICP-MS analysis of various geological materials.

Calibration standard STDGL3 for sulphide analysis has been distributed to several more analytical laboratories worldwide. A manuscript describing this new reference material has been published in *Geostandards & Geoanalytical Research.*

Collaboration with Curtin University has commenced to develop a new calibration standard for Lu/Hf dating of garnet. Publication is being prepared for inclusion in the journal *Geostandards & Geoanalytical Research*. Collaboration with ETH Zurich has also commenced on standards for U/Pb dating of calcite and Rb/Sr dating of mica.



ICP-ToF images of the distribution of uranium and $^{207}Pb/^{206}Pb$ in RA138 calcite reference material (Guillong et al., 2024). Images of this size (~6x6mm) would take ~24 hours to acquire with 12 um spot size using a regular LA-ICP-MS approach; however they took only ~4 hours using ICP-ToF. High U and low $^{207}Pb/^{206}Pb$ parts of the calcite could be used for calibration of U/Pb dating in calcite, while other parts have potential to be used for Lu/Hf dating.

LA-ICP-MS INSTRUMENTATION DEVELOPMENT

Leader: Ivan Belousov

Team members: Jeffrey Oalmann, Paul Olin

Collaborators: Ashley Norris, Michael Shelley

This project tests, designs and develops new instrumentation to ensure continuing advances in geological LA-ICP-MS applications. Example developments include ablation cells, the interface between the laser and the mass-spectrometer and testing new types of laser microprobes and mass-spectrometers. In 2023 we continued to test the fast washout funnel for fast imaging using ICP-ToF.

U/PB DATING

Leaders: Jeffrey Oalmann, Ivan Belousov

Team members: Maxwell Morissette, Kate Jenkins

Collaborator: Roland Maas

This project investigates the causes of limitations to U/Pb dating of minerals by LA-ICP-MS, with the aim of enhancing laboratory practices and instrumentation parameters to lower systematic errors and improve precision. Ongoing investigations for zircon, apatite, garnet, rutile, epidote and titanite are currently underway. Preliminary method development for U/Pb dating of wolframite and scheelite began in 2023.

CODES PhD student Axel Cima examining a laser mount and searching for mineral microinclusions in alteration minerals from porphyry rocks to drive new LA-ICP-MS sessions. Axel is working within the 'Interpretation of LA-ICP-MS time-resolved signals' project.

A paper on understanding the ablation behaviour of garnet and rutile and its impact on the accuracy and precision of U/Pb dating of these minerals has been published in *Geostandards & Geoanalytical Research*.

LU/HF DATING

Leaders: Jeffrey Oalmann, Paul Olin

Team members: Sheree Armistead, Ivan Belousov, Maxwell Morissette

Collaborators: Sarah Gilbert, Jay Thompson

This project is aimed at method development for Lu/Hf dating of minerals using Agilent 8900 QQQ MS. Currently we are working on methods for garnet, apatite, calcite and monazite.

LA-ICP-MS DATA REDUCTION SOFTWARE

Leader: Jeffrey Oalmann

Team members: Ivan Belousov, Paul Olin

Collaborator: Ashley Norris

This project aims to develop comprehensive, user-friendly LA-ICP-MS data processing software, capable of:

- quantification of trace element and U/Pb dating data acquired using multiple calibration standards and a range of internal standard elements;
- quantification of images depicting distribution of major and trace element concentrations in fine-grained multi-mineral aggregates of sulphides, silicates, phosphates and carbonates;
- identification of mineral phases in, and sizes of, micro inclusions in minerals.

Activities in 2023 were directed towards imaging elemental distributions in minerals. A software version capable of processing images of elemental distributions is being tested. A Python script for processing of ICP-Tof images is being developed.

INTERPRETATION OF LA-ICP-MS TIME-RESOLVED SIGNALS

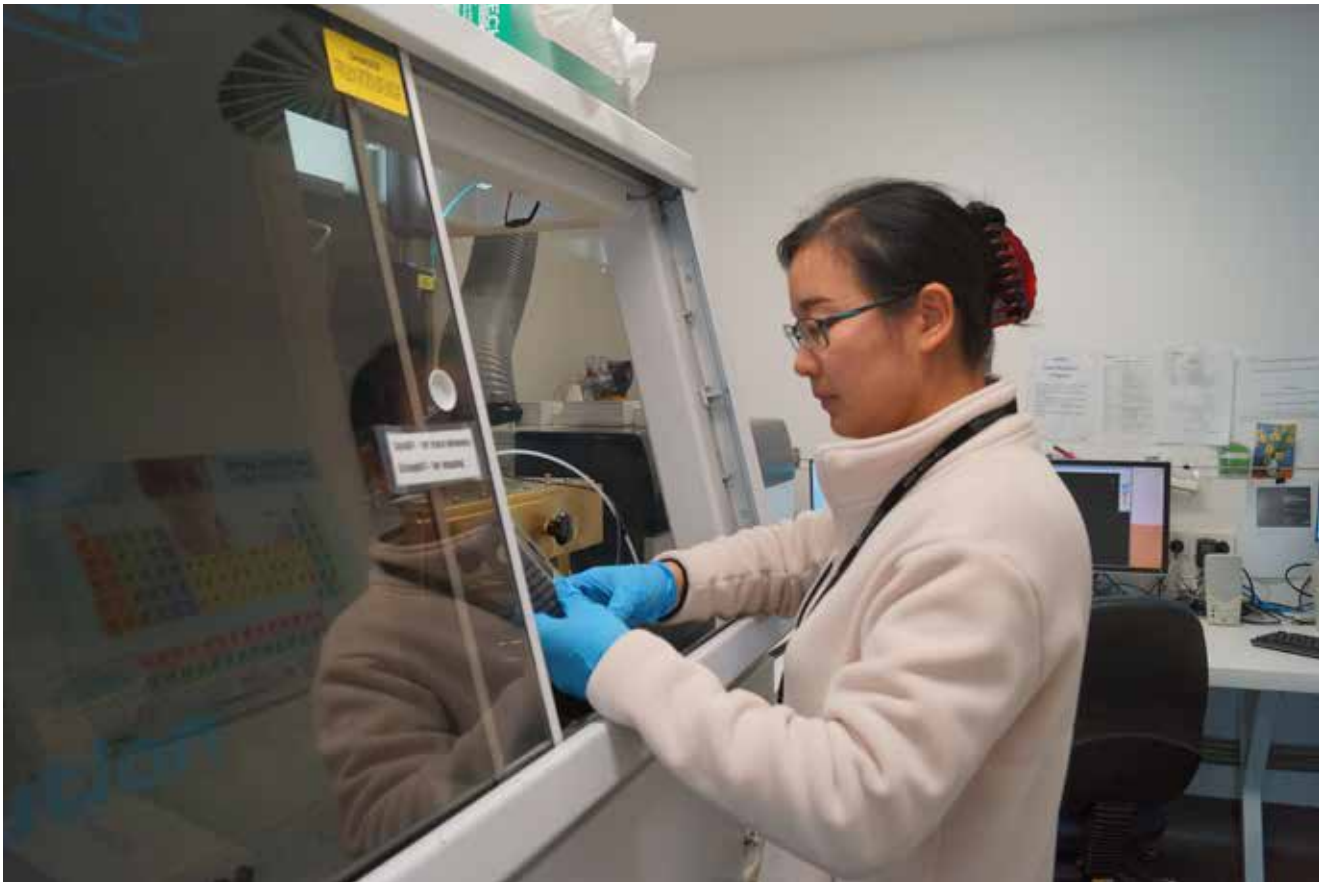
Leader: Ivan Belousov

Team members: Matthew Cracknell, Sebastien Meffre

Student: Axel Cima

Collaborator: Shaun Barker

This project aims at developing algorithms for correct identification of mineral inclusion populations in LA-ICP-MS analyses. Such inclusions carry significant information about processes during the formation of hydrothermal and magmatic minerals and their use could significantly



Laboratory Analyst Fanghua Dai is pictured in CODES Lab D. She is testing the energy of the RESOlution 193 nm excimer laser ablation system coupled with an Agilent 8900 ICP-MS, which is used to analyse trace elements for CODES Analytical Laboratories industry customers.

improve our understanding of ore deposit formation and could be used in vectoring and fertility studies for a range of deposit styles.

During 2023 we have continued to improve algorithms for identification of micro-inclusions in time-resolved LA-ICP-MS signals from a range of minerals. Work has been started on deconvolution of mixed LA-ICP-MS signals and their use for quantification of micro inclusions in minerals.

▶ LOOKING FORWARD

The team will further develop its analytical research in 2024. Developments using Agilent 8900 QQQ, the LA-LIBS tandem system and ICP-ToF are expected to include:

- Use of Agilent 8900 QQQ MS for Re/Os dating of molybdenite, Rb/Sr dating of micas and S isotopic measurements for sulphides and sulphates.
- Investigating applicability of LA-LIBS systems for quantitative analysis of halogens and light elements in different minerals.
- Continued development of the application of ICP-ToF for imaging elemental distributions in minerals by LA-ICP-MS.

Program six: Geophysics and computational geosciences

OBJECTIVE

This program addresses the challenges associated with technological advances in automated data acquisition and imaging methods across all aspects of the geosciences. It seeks solutions to managing, processing, analysing, visualising and interpreting minerals industry datasets. This research program contributes to research across all stages of the mining value chain from exploration to mining and mineral processing and to waste management.

Introduction

Program 6: Geophysics and computational geosciences focusses on the applications of novel methods for data collection, data analysis, data integration, data-driven decision making and visualisation. It includes a diverse range of projects researching three-dimensional geophysical interpretation, near surface and environmental geophysics, geodata analytics, data visualisation, exploration targeting and geoscience education. One of the unique aspects of Program 6 is that it contributes to all of the other CODES research programs, especially Program 2, via method development, data processing and analysis, and the interpretation and visualisation of results.

Modern minerals industry activities are undertaken in data-rich environments characterised by a wide range of quantitative and qualitative information. There have been significant recent advances in areas such as geophysical data acquisition, geophysical data processing and inversion, multielement geochemical analyses, and a range of new optical and infrared imaging techniques. The challenge is to be able to effectively integrate these diverse data streams using new methods and workflows that can effectively transform data into information and knowledge. The ultimate aim of this data synthesis is to facilitate more informed decision making at all stages of the mining value chain, from mineral exploration to extraction, processing and waste management.

Highlights

Thesis submissions

- Sibele Nascimento submitted her PhD thesis on the geoenvironmental characterisation of historical mine tailings (linked to Program 2 and the TMVC).
- Alex Farrar submitted his PhD thesis on the tectonic and structural controls on the spatio-temporal distribution of giant porphyry copper deposits in the central Andes.

Publications

- Sibele Nascimento published the first paper of her thesis in *Mine Water and the Environment* that documents over 20 years of water quality and chemistry data collected along the mine waste-impacted Queen and King river system, western Tasmania.
- Javier Merrill Cifuentes published the second paper from his PhD thesis in *Minerals Engineering* that applies his mineral co-occurrence probability field (MCOPF) algorithm to automatically generate clusters of

mineral texture from drill core imagery to better predict hardness and Cu recovery.

- Alex Farrar published an interpretation of deep-seated and long-lived structural corridors in the central Andes, which was linked to the prevalence of giant porphyry copper deposit clusters, in *Economic Geology*.
- Sibele Nascimento published the second paper of her thesis in *Applied Geochemistry*, which integrated mineralogical and geochemical data with geophysical models to better understand the internal characteristics and structure of the tailings deposited in the King River delta, western Tasmania.
- Matthew Cracknell contributed to a paper by computer science Masters student Laura Sotomayor published in *Computers and Electronics in Agriculture* that employed machine learning to predict plantation forest productivity.

▼

One of the unique aspects of Program 6 is that it contributes to all of the other CODES research programs.

Conferences

- Collaborator Tobias Ståal presented a poster on his research into the geophysical similarities between Antarctic and global continental crust at IUGG XXVII in Berlin, Germany.
- Alex Farrar presented his research methods for establishing temporal correlations between plate motion, orogenesis and giant porphyry Cu metallogeny in the Andes at SGA2023 in Zurich, Switzerland.
- Tobias Ståal presented his work on the use of information entropy for communicating continental-scale tectonic model complexity at EGU23, Vienna, Austria.
- Alex Farrar presented his findings on the cause-and-effect of plate motion and crustal thickening using time-series analysis and data analytics at AEGC2023 in Brisbane, Australia.
- Matthew Cracknell delivered an invited talk on advances in the detection of buried magmatic-hydrothermal systems to the Latin Rocks, ChileExplore2023 industry conference in Santiago, Chile.

Technology transfer opportunities through Amira P1249:

- Calculated mineralogy using Pedras and mineral texture clustering (MCOPF) Python packages, October 2023, Santiago, Chile
- LocatOre version 3.0, December 2023, Hobart, Australia.

Award

Dr Tobias Ståal, who completed his PhD at CODES in the field of sub-ice lithospheric boundaries and a new geothermal heat flow model for Antarctica, was awarded the Royal Society of Tasmania's 2023 Doctoral (PhD) Award. This award recognises recent PhD graduates 'who have made significant advances in the course of their doctoral research'. Tobias is currently collaborating with CODES researchers on various projects.

Other highlights

- In late 2023 Michael Roach (officially) retired. We celebrate Mike's many decades of outstanding research and teaching contributions to the CODES team. Mike will likely continue to ferret away in the background, passionately developing content for his 3D geological visualisation project.
- University of Ghana Geophysics Lecturer Eric Dominic Forson visited CODES supported by a 'Building a New Generation of Academics in Africa' (BaNGA) grant to collaborate with Matthew Cracknell for three months. During his visit, Eric and Matthew worked closely on applying machine learning tools to aid hydrological modelling and mineral exploration across Ghana.

Sunset at the EL Salvador mining town in the Atacama Desert in northern Chile taken by Dr Matthew Cracknell while on a fieldwork trip to South America in late 2023.

The program team

LEADER MATTHEW CRACKNELL

DEPUTY LEADER PAULA MONTOYA LOPERA

TEAM MEMBERS:

Michael Baker, Yamila Cajal, David Cooke, Michael Roach, Rob Scott, Lejun Zhang

PHD STUDENTS:

Axel Cima, Stephen Cooke, Isaac Evinemi, Alex Farrar, Richard Hill, Sibele Nascimento, Giovana Pimental, Arka Sahu, Thomas Schaap

COLLABORATORS:

CENTRAL SCIENCE LABORATORY (UTAS)
Thomas Rodemann

CODELCO
Jimenez Arevalo Felipe, Carolina Rodriguez

FIRST QUANTUM MINERALS
Mike Christie, Tim Ireland

INSTITUTE OF MARINE AND ANTARCTIC STUDIES (IMAS)
Jacqueline Halpin, Joanne Whittaker

MINERAL RESOURCES TASMANIA
Daniel Bombardieri, Mark Duffett, Clint Siggins, Carol Steyn

PHYSICS – SCHOOL OF NATURAL SCIENCES (UTAS)
Anya Reading, Tobias Stål

UNIVERSIDAD AUSTRAL DE CHILE, CHILE
José Picquer

UNIVERSITY OF SOUTH AUSTRALIA
David Giles, Tom Raimondo

WESTERN MINING SERVICES
Jon Hronsky

Projects

Pathways to mineral discoveries through computer-based modelling of geochemical data

Integrating geology and geophysics for resources targeting

Geological visualisation and virtual education

Deep learning for mineralogical domaining and predictive modelling of ore deposits

Multi-scale hyperspectral and mineral chemistry data mining

Project summaries

PATHWAYS TO MINERAL DISCOVERIES THROUGH COMPUTER-BASED MODELLING OF GEOCHEMICAL DATA

Leader: Matthew Cracknell

Team members: Michael Baker, Lejun Zhang

Student: Stephen Cooke

Stephen's project is embedded within the Amira P1249 research project and aims to further develop methods and techniques for ore deposit vectoring using geochemical data such as mineral chemistry and whole-rock analyses. His main focus is on the continued experimentation and development of the LocatOre software platform. LocateOre implements both knowledge-driven and data-driven methods for vectoring towards porphyry copper mineralisation and magmatic-hydrothermal heat and fluid sources. The LocatOre knowledge-driven approach uses proximitor equations, first recognised in the Amira P765A research project, to identify the location of intrusive bodies associated with mineralisation. The data-driven approach uses a combined Monte Carlo and regression method to exploit geochemical gradients in mineral chemistry data to highlight the location of intrusive bodies. While both methods are useful for vectoring, Stephen will be addressing problems around communicating model uncertainties resulting from limited numbers of samples and their potentially inadequate spatial distribution.

Stephen has made good progress with the modelling of sample spatial distributions and initiated experiments to test the efficacy of the LocatOre data-driven approach for vectoring. This culminated with the release of LocatOre version 3.0 in mid-2023. In late 2023, Stephen successfully facilitated a LocatOre workshop to the Amira P1249 sponsor group. This workshop provided a summary of the new functions and tools in LocatOre version 3.0. The workshop included updates on model visualisation with new colour ramp options, improvements to knowledge-driven model outputs, use of Ripley's K to report on the degree of spatial clustering of input samples, and a declustering routine that reduces the impact of spatial clustering on output models.

Stephen is heading towards the final 12–18 months of his project and aims to publish papers that summarise and test LocatOre in its current form and investigate the impact of sample spatial distribution on output models, which can be used to report on model robustness. Stephen will be presenting his research at the IGC2024 conference in Korea in 2024.

CODES PhD student Stephen Cooke presenting a workshop on the LocatOre software at the Amira P1249 Sponsors' Review Meeting 4 in December. This workshop provided a summary of the new functions and tools in LocatOre version 3.0.

CODES PhD student Alex Farrar talking about his research methods for establishing temporal correlations between plate motion, orogenesis and giant porphyry Cu metallogeny in the Andes at SGA2023 in Zurich, Switzerland.

INTEGRATING GEOLOGY AND GEOPHYSICS FOR RESOURCES TARGETING

Leader: Matthew Cracknell

Team member: David Cooke

Student: Alex Farrar

Collaborators: Mike Christie, Jon Hronsky, Tim Ireland, José Piquer

CODES PhD student Alex Farrar, generously supported by First Quantum Minerals, is investigating the relationship between geodynamic and structural controls, in particular the intersections of deep-seated structural corridors, on the formation of giant porphyry copper deposits in the central Andes. The central Andes offers an excellent case study region due to its prolific metal production, well-documented geologic evolution and distinct spatial and temporal mineralisation events. Alex will use information that describes the location, timing, grade and structural setting of both economic and non-economic porphyry Cu deposits, combined with detailed structural mapping, GPlates tectonic models and spatio-temporal machine learning approaches to predict the localisation of giant porphyry camps.

In 2023, Alex was able to combine his structural corridor model of the central Andes with tectonic models and orogenic proxies derived from multiple sources to generate a spatio-temporal prospectivity model of giant porphyry copper deposits. This model used supervised machine learning to successfully predict copper mineralisation across the central Andes through time (from 70 ma to the present). This model also highlighted the Maracunga Au-Cu porphyry belt and the Bolivian Sn-W belt despite not receiving training data representing these belts.

The first of many highlights of the year for Alex was the publication of the first paper based on his thesis in *Economic Geology* after a very rigorous review process. This publication has been well received by the economic geology community despite (because of?) its controversial findings. Alex submitted his thesis, titled 'Tectonic and structural controls on the spatio-temporal distribution of giant porphyry copper deposits in the central Andes', for examination around the middle of 2023. We expect his examination and corrections to be finalised by early 2024 … watch this space!

Dr Matthew Cracknell and Dr Yamila Cajal examining orbicular granite near the town of Caldera in northern Chile during a fieldwork trip to South America in late 2023 .

Dr Yamila Cajal Contreras, Dr Matthew Cracknell and CODES PhD student Isaac Evinemi waiting to examine core in the EMSA core shed at the town of El Salvador in northern Chile during a 2023 fieldwork trip. EMSA provides mining exploration services to the Chilean mining company CODELCO.

Screen shot of the Tarawera UAV (#25) interactive virtual tour showing basaltic pyroclastic deposits overlying rhyolite and rhyolitic pyroclastics. Mt Tarawera, North Island, New Zealand (model is ~450 m across). Available from: https://sketchfab.com/3d-models/tarawerauav25-5ef8ff6fe10f40e9a036eebfba13dd1e

GEOLOGICAL VISUALISATION AND VIRTUAL EDUCATION

Leader: Michael Roach

In 2023 the focus of geological visualisation and virtual education was motivated by the generation of learning materials for use in undergraduate and postgraduate teaching programs and also professional education. During 2023, we continued to digitise rock samples from our teaching and research collections and these virtual objects have been made freely available through the online Sketchfab portal: https://sketchfab.com/search?q=ausgeol&sort_by=-publishedAt&type=models

DEEP LEARNING FOR MINERALOGICAL DOMAINING AND PREDICTIVE MODELLING OF ORE DEPOSITS

Leader: Matthew Cracknell

Team members: Michael Baker, Yamila Cajal, Lejun Zhang

Student: Isaac Evinemi

Collaborator: Carolina Rodriguez

This project contributes to the Amira P1249 research project and aims to better understand the applicability of deep learning methods to the modelling of ore deposits. New PhD student, Isaac Evinemi, started work on this project in mid-2023. In October, Isaac and fellow researchers visited the CODELCO-owned Porfido Norte deposit in northern Chile, which is the focus of his research project. In the field, Isaac was able to gain familiarity with the rocks and get an impression of the structural complexity of the deposit and see first-hand how some of the data he will be using in his models is collected. We thank CODELCO for supporting us during our field visit.

Isaac aims to bring together all of the data provided by CODELCO and integrate these data with some of the techniques developed at CODES over the past few years for adding value to drill core data sets, such as mineral texture clustering and calculated mineralogy. This integrated database will then be used to generate domains, or regions with similar properties, for exploration and geometallurgical applications, using the latest deep learning architectures. Isaac will explore the best approaches for data integration and if robust deep learning models can be generated from these data.

We look forward to the insights gained from this project, which will aid CODELCO mine planning and inform the future use of Artificial Intelligence (AI) for ore deposit modelling.

Dr Matthew Cracknell, leader of Program 6, expands on the topic of locating buried porphyry targets at the Chile Explore – Latin Rocks 2023 conference in Santiago, Chile, which was held in mid-October.

Geologists and geophysicists from UTAS were based at Bunger Hills, East Antarctica, for two months over the summer in 2023 to study the geology and glaciology of the Denman Glacier region. UTAS Research Fellow in Computational Physics (Geophysics) Oceans and Cryosphere Dr Tobias Stål, who took this photo while doing fieldwork, is collaborating with Dr Matthew Cracknell on a number of topics within Program 6.

MULTI-SCALE HYPERSPECTRAL AND MINERAL CHEMISTRY DATA MINING

Leader: Lejun Zhang

Team member: Matthew Cracknell

Student: Arka Sahu

Collaborator: Thomas Rodemann

Lejun Zhang and Matthew Cracknell, along with CSL director Thomas Rodemann, are supporting new Amira P1249 PhD student Arka Sahu to development workflows and protocols for predicting mineral chemistry from spectral observations. Arka has completed preliminary models for epidote and chlorite from the Batu Hijau Cu-Au porphyry deposit in Indonesia. While it is early days yet, he has produced promising results. Nevertheless, the methodology being developed will need to account for mineral heterogeneity in order to fully realise the potential for field-based spectral observations to act as a proxy for variations in mineral chemistry.

OTHER COLLABORATIONS

As always, the Program 6 research group provides technical advice and knowledge across most of the other research themes:

- Matthew Cracknell is working closely with Axel Cima and the CODES labs in Program 5 to develop methods for detecting and identifying microincisions.
- Paula Montoya Lopera and Matthew Cracknell are providing advice and technical support to the Regional Research Collaboration (RRC) for Critical Metals in Tasmania project embedded within Programs 1 and 2.
- Matthew Cracknell and David Cooke guided Sibele Nascimento through the last stages of her PhD project, aligned with Program 2, on the environmental characterisation and reprocessing potential of the tailings deposited in the King River delta, western Tasmania.
- Mike Baker and Matthew Cracknell, with support from Pete Hollings at Lakehead University, Canada, are supervising new Amira P1249 PhD student Giovana Pimental's project, which is aligned with Programs 1 and 2. Her project aims to gain insights into ore deposit characterisation that can be gained from a large suite of drill core data at one of Anglo American's Ni-PGE deposits in the Platreef region of South Africa.

▶ LOOKING FORWARD

In 2024, we will officially welcome Dr Paula Montoya Lopera to fill the deputy leader position of Program 6, following Michael Roach's retirement. Paula started with CODES in late November 2023 and will bring with her a wealth of experience with ore deposit characterisation through advanced data analysis. Matthew and Paula will be involved with many CODES research projects, such as Amira P1249 Module 2 and the Regional Research Collaboration (RRC) for Critical Metals project.

Program 6 researchers plan to revive the CODES internal workshop series that offers training and support for widely used software applications (e.g., LeapFrog, GIS, Python etc.). They also aim to familiarise staff and students with emerging tools such as the Python implementations of calculated mineralogy (Pedras) and mineral texture clustering (MCOPF).

In a new initiative, the Program 6 working group will meet on a regular basis to discuss emerging technologies to aid geoscience research, such as Artificial Intelligence (AI), database management and security, and new advances in geochemical modelling and analysis.

We look forward to 2024, which will bring more opportunities to collaborate with the great staff and students within the diverse family that is CODES, and to celebrate our collective achievements.

CODES | RRC
CENTRE FOR ORE DEPOSIT AND EARTH SCIENCES
REGIONAL RESEARCH COLLABORATION CRITICAL METALS

Regional Research Collaboration

Project title: 'Building capacity in regional Australia to enhance Australia's economy through research, training, and environmentally sustainable production of critical metals'

▶ OBJECTIVES

The main aims of the Regional Research Collaboration (RRC) project are to:

- Facilitate environmentally sustainable critical metals production in Tasmania.
- Grow UTAS' research capacity and capability through skills development.
- Improve student retention rates and grow the pool of job-ready graduates for the regions.
- Create sustainable long-term research partnerships.

Introduction

In May 2022 UTAS was granted $3.5 million from the Australian Government's RRC Program to fund a novel three-year collaborative partnership between researchers from CODES and the School of Education at the University of Tasmania and the Tasmanian minerals industry. The partnership enables UTAS to work with industry and government to investigate environmentally sustainable critical metals production and improve educational outcomes and regional job opportunities for communities in Tasmania's West Coast region. Tasmanian industry partners supported the funding application, along with the Tasmanian Minerals, Manufacturing and Energy Council (TMEC) and Mineral Resources Tasmania (MRT). The research project is known by its short title as 'Environmentally sustainable production of critical metals'.

Critical metals (including tungsten, cobalt, nickel, rare earth elements, indium and magnesium) are vital but scarce resources that society requires for modern technology, infrastructure and the transition to a renewable energy future. This project aims to provide new methods and approaches to critical metal processing from existing mines, and from legacy mine wastes leading to improved environmental outcomes. The collaboration includes two partner academic institutions – the University of Queensland and the GeMMe research group at the Université de Liège (Belgium). The ten industry partners are: Group 6 Metals (Dolphin mine on King Island), ABx Group (Deep Leads exploration project), Bluestone Mines Tasmania Joint Venture (Renison mine), Tasmania Mines (Kara mine), Mallee Resources (Avebury mine), GWR – Tasmanian Magnesium (Prospect Ridge), Copper Mines of Tasmania (Mt Lyell mine), Grange Resources (Savage River mine), MMG (Rosebery mine) and (Stellar Resources).

The critical metals project is led by four Chief Investigators – three from CODES (Professor David Cooke, Dr Julie Hunt and Dr Lejun Zhang) and one from the UTAS School of Education (Professor Sharon Fraser). Together they are

West Coast fieldwork for Element 1 of the RRC project: (L–R) CODES PhD student Emrecan Yurdakul, and postdoctoral researchers Dr Owen Missen and Dr Mohammad Fathi standing in front of the Prince Lyell Open Pit at the Mt Lyell mine.

leading a team of early- to mid-career academic and technical staff, and project-funded postdoctoral researchers in the three elements of the project.

Methodology

Students and postdoctoral researchers spend several months on-site with the industry partners to collect samples, characterise critical metal occurrences, test new processes and workflows and help to address the objectives of the project. They are conducting laboratory research at CODES and, where appropriate, at the partner academic institutions. Funding for this project has enabled CODES to take on four new postdocs, and eleven PhDs have joined the project.

The deposits that our researchers are examining in Tasmania for their critical metals potential include Devonian granite-related mineral systems at Renison Bell, Mt Bischoff and Severn; nickel at Avebury; tungsten at Dolphin and Kara; magnesium at Prospect Ridge, REE at Deep Leads, and by-product critical metals potential at the Cambrian polymetallic VHMS deposit at Rosebery; and the copper gold deposit at Mt Lyell. Extractable levels of critical metals such as antimony, bismuth, cobalt, gallium, germanium and indium may be found in these tailings and waste – and in new orebodies as well. Research is focussing first on unearthing western Tasmania's considerable critical metals potential that lies in its existing mines, mine tailings and waste rocks. Understanding the deportment and reserves of critical metals in existing tailings and waste rock is key to unearthing new finds and helping Australia to become more self-sufficient in these resources, which will be vital for the future as the world transitions to a sustainable green energy future.

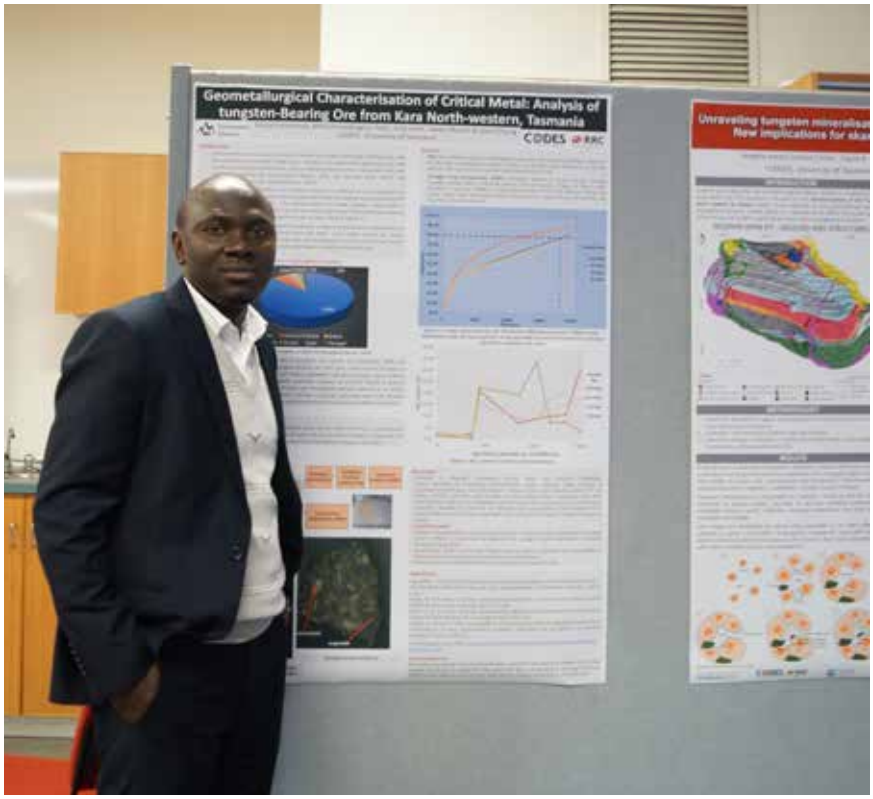
Highlights

During 2023 PhD students Alfredtina Appiah, Vinicius da Cruz, Jose Barillas Diaz, Emmanuel Dogara Musa, Jane Hall-Dadson (School of Education), Nelao Natukondje Naimbale and Pratichee Mondal joined the project, bringing the total number of students involved up to eleven.

One of the great opportunities being provided by the RRC is the wealth of new geological data being made available through our new PhD studies. This is a major renewal of CODES' research into the geology and mineral resources of Tasmania, and we are excited to see the commencement of these PhD studies that will reveal the critical metals potential of many of Tasmania's most significant mineral resources.

In early June 2023, staff and students from all three Elements of the project, together with representatives from the mining industry, and community residents, held a Mining Roadshow in northwest Tasmania as part of the RRC commitment to outreach and engagement. The Roadshow held community forum events in Zeehan and Burnie. Both events included presentations by eight RRC PhD students and an industry panel, with around 50 participants at each event.

Understanding the deportment and reserves of critical metals in existing tailings and waste rock is key to unearthing new finds and helping Australia to become more self-sufficient in these resources, which will be vital for the future as the world transitions to a sustainable green energy future.



The first Regional Research Collaboration Sponsors' Meeting in July 2023 was an opportunity for researchers and sponsors to network and discuss progress. Here CODES PhD student Emmanuel Dogara Musa stands next to his poster depicting his work on the Kara mine in northwestern Tasmania.

Key topics discussed included the job opportunities in mining, and how mining is adapting to be more environmentally sustainable. The community were keen to learn why international students had chosen to study in Tasmania and to help Tasmania develop its critical metal potential. There was strong engagement from local community and industry members who collectively discussed the global challenges facing society, and how mining of copper and critical metals is an essential part of tackling those challenges, and how students and community members could participate in meeting this global challenge. Element 3 researchers used the community forums to initiate engagement with community members as part of their initial research into community awareness of STEM education and employment opportunities, with presentations that elicited passionate engagement from community members. A news article highlighting the Zeehan community meeting was published in the *Western Echo* in June 2023.

Key achievements from the three Elements of the project in 2023 were:

Element 1: Unlocking critical metal resources

Initiation of Element 1's work programs by students and staff at our industry partners' mine sites in 2023 focussed primarily on characterisation of sample ore, gangue and waste materials. A significant part of the work program was the collection and characterisation of sample material for laboratory analyses of critical metal contents. Over the course of 2023, students and staff spent considerable time (weeks to months individually) at each of the partners' industrial sites in regional Tasmania to undertake field characterisation of the ores and host rocks as the basis for laboratory work on critical metal deportment. Later in 2023, the project's laboratory work demonstrated that specific critical metals are present in ores, gangue minerals and mine wastes at all study sites (Renison Bell, Rosebery, Avebury, Mt Lyell, Heemskirk, Dolphin, Deep Leads, Aberfoyle).

Work is ongoing to establish the distribution of critical metals throughout each orebody, and to develop tools for effective characterisation to aid mineral processing and exploration.

Element 2: Pathways to Production

Element 2 is addressing industry's barriers to cost-effective critical metal production that include issues with crushing and grinding, separation of critical metals from gangue, and efficient energy use. Substantial progress was made in 2023 with regards to characterisation of critical metal ores and gangue, with initial trials on tungsten processing options at Kara mine delivering sample test results, preliminary workflows for separating critical metals, and testing regimes for workflow implementation.

Progress was also made at the Prospect Ridge magnesite deposit regarding developing the workflow for carbonate-hosted critical metal characterisation and processing. All these activities have contributed significantly with regards to progress towards achieving Element 2's planned outcome of cost-effective critical metal production.

Element 3: Education and engagement

Element 3 has the objective of devising innovative solutions to community-based barriers that affect engagement in STEM and limit growth of the STEM-capable workforce needed by regional industries for critical metals production. Community engagement/outreach activities (e.g., presentations at forums; museum open days; school visits to the West Coast Study Hub) have formed the basis of our data generation activities with stakeholders responding to survey, interview and/or interactive activities communicating their perceptions of the mining industry and their understandings and experiences with the education system. These activities were informed by the Element 3 sub-committee which included the project team, and members of the West Coast community and industry representatives. From the data generated from these activities, the project has identified key community-based barriers and/or concerns that affect their engagement with mining industries.

The program team

LEADERS DAVID COOKE, JULIE HUNT, LEJUN ZHANG, SHARON FRASER (SCHOOL OF EDUCATION)




PROJECT MANAGER:

Helen Scott

TEAM MEMBERS:

CODES: Sheree Armistead, Mike Baker, Ivan Belousov, Yamila Cajal, Rebecca Carey, Matthew Cracknell, Mohammad Fathi, Wei Hong, Sebastien Meffre, Clare Miller, Owen Missen, Rob Scott, Jeff Steadman

CENTRAL SCIENCE LABORATORY:
Thomas Rodemann

SCHOOL OF EDUCATION:
Kim Beasy, Connie Cirkony

PHD STUDENTS:

CODES: Chris Allen, Alfredtina Appiah, Angela Costa, Vinicius da Cruz, Jose Barillas Diaz, Emmanuel Dogara Musa, Javier Gil Rodriguez, Pratichee Mondal, Nelao Natukondje Naimbale, Emrecan Yurdakul

SCHOOL OF EDUCATION:
Jane Hall-Dadson

COLLABORATORS:

ABx GROUP LTD
Mark Cooksey

BLUESTONE MINES TASMANIA JOINT VENTURE PTY LTD
Mark Aheimer, Colin Carter, Brian Dalton, Esther Little

COPPER MINES OF TASMANIA PTY LTD
Geoff Cordery

GRANGE RESOURCES
Roger Hill, Ben Maynard, Nicholas van der Hout

GROUP 6 METALS LTD
Tim Callaghan, Keith McKnight, Rowena Murcott

GWR GROUP LTD (TASMANIAN MAGNESIUM PTY LTD)
Mick Wilson

MALLEE RESOURCES LTD
Tony Chisnall, Josh Denholm

MINERAL RESOURCES TASMANIA
Mark Duffett, David Green, Andrew McNeill, Clint Siggins, Carol Steyn

MMG AUSTRALIA LTD
Corey Jago, Don Macansh, Kevin Robinson

STELLAR RESOURCES LTD
Gary Fietz, Adam Frankcombe, Rebecca Lockley

TASMANIA MINES PTY LTD
Greg Doherty, Marcus Mollison

TASMANIAN MINERALS, MANUFACTURING AND ENERGY COUNCIL (TMEC)
Ray Mostogl, Vanessa Skipworth

UNIVERSITÉ DE LIÈGE, BELGIUM
Eric Pirard

UNIVERSITY OF QUEENSLAND
Rick Valenta

The project comprises three elements:

ELEMENT 1:

Unlocking critical metal resources – developing characterisation and deportment toolboxes and workflows for effective resource evaluation and improvements to waste management.

ELEMENT 2:

Pathways to production – address barriers to cost-effective critical metal production including issues with crushing and grinding, separation of critical metals from gangue, and efficient energy use.

ELEMENT 3:

Education and engagement – devise innovative solutions to community-based barriers that affect engagement in STEM and limit the growth of the STEM-capable workforce needed for critical metals production in regional areas.

CODES PhD student Angela Costa walking across the turbidite sequence near Currie on King Island in 2023; Angela is working on characterisation of tungsten deposits at Grassy.

Project summaries

ELEMENT 1: UNLOCKING CRITICAL METAL RESOURCES – DEVELOPING CHARACTERISATION AND DEPORTMENT TOOLBOXES AND WORKFLOWS FOR EFFECTIVE RESOURCE EVALUATION AND IMPROVEMENTS TO WASTE MANAGEMENT

CHARACTERISATION OF W MINERALISATION AT GRASSY, KING ISLAND, TASMANIA – IMPLICATIONS FOR ORE GENESIS, EXPLORATION, AND PATHWAYS TO PRODUCTION

Leader: David Cooke

Team members: Julie Hunt, Lejun Zhang, Yamila Cajal

PhD student: Angela Costa

Collaborators: Keith McKnight, Tim Callaghan, Rowena Murcott (Group 6 Metals Ltd)

This PhD study investigates the geology, alteration, and mineralisation of the Dolphin W deposit in Grassy, King Island. Key objectives include determining mineralogy using petrographic, SWIR, SEM, and MLA analyses, and assessing critical and valuable metal deportment with LA-ICP-MS to optimise mineral processing. The study will also propose a refined genetic and exploration model for W mineralisation on King Island.

In the first year of her candidature, Angela Costa completed field mapping, sampling, and drill core logging. Advanced analytical work has been conducted, including UV imagery, SEM, microprobe, LA-ICP-MS, TerraSpec, HyLogger, and uXRF. Different generations of scheelite mineralisation have been identified and integrated with the alteration paragenetic sequences. Initial results from epidote chemistry showed potential for developing vectors proximal to the ore and discriminators for different types of skarn alteration. Angela successfully completed her confirmation of candidature. In year 2, she will continue microanalytical work to constrain the paragenetic sequences of alteration and mineralisation and conduct U-Pb dating on different hydrothermal gangue and ore minerals to determine the age of the deposits.

CHARACTERISATION OF COMPLEX OREBODIES IN THE SOUTHERN PART OF THE ROSEBERY–HERCULES DISTRICT, WESTERN TASMANIA

Leader: David Cooke

Team members: Ivan Belousov, Yamila Cajal, Rebecca Carey, Wei Hong, Lejun Zhang

PhD student: Vinicius da Cruz

Collaborators: Don Macansh, Corey Jago, Kevin Robinson (MMG Australia Ltd)

This PhD project aims to characterise the complex orebodies and volcano-sedimentary succession at the southern end of the Rosebery mine, focussing on the potential for critical metals exploration. The specific goals are to understand the stratigraphy and alteration of the Cambrian primary mineralisation and Devonian overprint mineralisation, characterise the Devonian mineralisation in terms of ore and gangue minerals, develop geological and geochemical constraints and vectors for the orebodies at southern Rosebery mine, and assess the potential for critical metals in these complex orebodies.

Vinicius completed the majority of his fieldwork, created a draft geological cross-section, and conducted initial SEM and LA-ICP-MS analyses in 2023. Preliminary results indicate that Devonian granite-related hydrothermal events overprinted primary Cambrian VHMS massive sulfide mineralisation. Critical elements indium and germanium were been identified in high concentrations within sphalerite and chalcopyrite. Vinicius will complete his confirmation of candidature in early 2024, and will then conduct additional fieldwork and focus on micro-analytical work on sulfides to evaluate the critical metal potential across the ore lenses in the southern part of Rosebery.

CHARACTERISATION OF THE HEEMSKIRK TIN PROJECT, ZEEHAN, WESTERN TASMANIA

Leader: David Cooke

Team members: Wei Hong, Robert Scott

PhD student: Nelao Natukondje Naimbale

Collaborators: Gary Fietz, Adam Frankcombe, Rebecca Lockley (Stellar Resources Ltd)

The Heemskirk tin project in Zeehan, western Tasmania, hosts Australia's largest undeveloped tin resource, owned by Stellar Resources Ltd. This PhD project focusses on characterising the stratigraphy and structure of the Heemskirk project to aid near-mine exploration and improve orebody knowledge. The objectives include conducting detailed core logging to understand stratigraphy and structurally controlled Sn mineralisation, mapping alteration assemblages during field core logging and using hyperspectral techniques, and using LA-ICP-MS to determine critical metal deportment in sulfides and cassiterite for optimising mineral processing. Additionally, the project will test LA-ICP-MS trace element analyses of accessory sulfides and gangue minerals to aid mineral exploration.

Nelao completed her initial fieldwork and collected more than two hundred samples for detailed characterisation in 2023. A preliminary paragenetic scheme and cross-section were built based on detailed graphic logging and initial microanalytical work. In 2024, Nelao will complete her confirmation of candidature and conduct additional fieldwork to enhance and refine the cross-section and paragenetic sequences. Selected gangue and ore minerals will be analysed using SEM and LA-ICP-MS to investigate the occurrences and deportment of critical metals in the Heemskirk tin project.

CHARACTERISATION OF THE AVEBURY NICKEL DEPOSITS, ZEEHAN, WESTERN TASMANIA

Leader: David Cooke

Team members: Ivan Belousov, Yamila Cajal, Wei Hong, Lejun Zhang

PhD student: Jose Barillas Diaz

Collaborators: Tony Chisnall, Josh Denholm (Mallee Resources Ltd)

This PhD research project aims to characterise the geology, alteration, mineralisation, paragenesis, geochemistry and geochronology of the Avebury Ni deposit in western Tasmania. This will be achieved through drill core logging, surface and underground mapping, and advanced analytical laboratory techniques.

In 2023, Jose completed a significant component of fieldwork, and conducted initial analytical work using TerraSpec, HyLogger, pXRF, SEM, and LA-ICP-MS techniques. His preliminary results revealed the complexity of Ni sulfide minerals at Avebury. A detailed geological cross-section is being built based on detailed graphic logging. Initial results on the deportment of PGEs have been presented at the project review meetings.

In 2024, Jose will completed his confirmation of candidature and field work, and will then focus on petrographic and SEM work to unlock the paragenetic sequence of the alteration and mineralisation at Avebury. Detailed LA-ICP-MS work will be conducted to investigate the concentration and deportment of critical metals at Avebury.

CODES PhD student Nalao Natukondje Naimbale examining drill core at Stellar Resources' Severn deposit near Zeehan on Tasmania's West Coast. This is Australia's largest undeveloped tin resource.

Core principles: CODES PhD student Javier Gil Rodriguez in the Renison core shed. Javier is working on the characterisation of the Renison Bell tin deposit.

CHARACTERISATION OF RENISON BELL TIN DEPOSIT, WESTERN TASMANIA

Leader: David Cooke

Team members: Ivan Belousov, Wei Hong, Owen Missen

PhD student: Javier Gil Rodriguez

Collaborators: Colin Carter, Mark Aheimer, Esther Little (Bluestone Mines Tasmania Joint Venture Pty Ltd.)

Renison Bell in western Tasmania is Australia's largest Sn producer, with potential for by-product Cu production. However, the potential for recovery of other critical metals such as In, Co, or Ni from ores, gangue, and/or waste, or the discovery of other granite-related critical metal resources such as W, Nb, or Ta in the district, has yet to be explored. This characterisation-based PhD research project aims to aid near-mine exploration and improve orebody knowledge at Renison, assisting in the discovery of additional Sn resources and evaluating the potential for the discovery and/or recovery of critical metals.

Javier completed several fieldwork seasons and created his first detailed geological cross-section in 2023 based on graphic logging and some initial petrographic and microanalytic work. Preliminary results showed the existence of critical metal-bearing minerals such as scheelite, monazite, and native bismuth. Other critical metals such as Co, Ni, Sb, Bi, In, Sc, Te, and V have been identified as trace elements in sulfides and oxides. Javier successfully completed his confirmation of candidature in late 2023. In 2024, Javier will continue with fieldwork to complete two more cross-sections and will continue petrographic and geochemical analyses of critical metal deportment at Renison.

OREBODY KNOWLEDGE OF THE WESTERN THARSIS CU-AU DEPOSIT, TASMANIA

Leader: Lejun Zhang

Team members: Mike Baker, Rob Scott

PhD student: Emrecan Yurdakul

Collaborator: Geoff Cordery (Copper Mines of Tasmania Pty Ltd)

The Western Tharsis Cu-Au deposit (12.4 Mt indicated and inferred resource, averaging 1.3% Cu and 0.3 g/t Au) is one of the major unmined deposits in the Mount Lyell district, hosted by the Central Volcanic Complex of the Mount Read Volcanics. The main research objectives of this PhD study are to characterise the paragenesis, timing, style of mineralisation, and associated alteration at Western Tharsis, and to provide a detailed geological, exploration and geometallurgical model of the deposit. This will help optimise mine planning, develop deposit-specific exploration tools, and understand the relationships between Western Tharsis and regional tectonic and magmatic evolution processes.

Emrecan conducted several field campaigns and completed 2.5 km^2 of anaconda-style bench mapping, 5 km^2 of regional structural and geological surface mapping, and more than 3,000 metres of graphic drill core logging and reinterpretation of previous logs in 2023. A total of 519 outcrop and drill core samples were collected for detailed analysis, including whole geochemistry, SWIR, FT-NIR, FTIR, SEM, and LA-ICP-MS. Preliminary results were presented at project review meetings and Emrecan successfully completed his

confirmation of candidature in late 2023. In 2024, he will focus on the geological and geochemical characterisation of alteration and mineralisation, and a detailed investigation of the potential of critical metals at Western Tharsis.

ELEMENT 2: PATHWAYS TO PRODUCTION – ADDRESS BARRIERS TO COST-EFFECTIVE CRITICAL METAL PRODUCTION INCLUDING ISSUES WITH CRUSHING AND GRINDING, SEPARATION OF CRITICAL METALS FROM GANGUE, AND EFFICIENT ENERGY USE

▼

Substantial progress was made in 2023 with regards to characterisation of critical metal ores and gangue.

PATHWAYS TO PRODUCTION – MAGNESITE DEPOSITS AT PROSPECT RIDGE, NORTHWEST TASMANIA

Leader: Julie Hunt

Team members: Owen Missen, Mohammad Fathi, Lejun Zhang

PhD student: Alfredtina Appiah

Collaborator: Mick Wilson (GWR Group Ltd (Tasmanian Magnesium Pty Ltd))

The Prospect Ridge exploration tenement encompasses the Arthur River and Lyons River magnesite deposits in the Arthur Lineament of NW Tasmania, a high strain zone that is 5–10 km wide and 110 km long, comprised of Cambrian metamorphosed rocks. The magnesite deposits within the Arthur Lineament are yet to be mined and have not been fully defined. This PhD thesis will evaluate pathways to produce magnesite concentrates from Prospect Ridge, including the Arthur River and Lyons River Mg deposits in the northern part of the Arthur Lineament. The local geology, alteration and mineralisation will be characterised through drill core logging and laboratory investigations. Ore and gangue mineralogy are being determined using petrographic, short-wave infrared (SWIR), SEM-based automated mineralogy, and geochemical analyses. Magnesium deportment will be constrained through detailed LA-ICP-MS to help optimise mineral processing options. Simple field- and/or laboratory-based tools will be tested and applied to assist with domaining high-grade magnesite and discriminating it from visually similar dolomite, calcite and ankerite. Deportment of other metals of value (e.g., Cu, Au, Fe) in the adjacent rocks will also be assessed to evaluate geological controls on their distributions and to determine whether there is potential for by-product metal production in the tenement. Opportunities for blending wastes from Prospect Ridge with other mine wastes in western Tasmania will be evaluated to establish whether there are opportunities to improve environmental management of acid drainage at other mine or legacy sites.

RECOVERY OF CRITICAL METALS FROM TAILINGS STREAMS, LEGACY MINE WASTE AND WATERS: SAVAGE RIVER MAGNETITE DEPOSIT, NORTHWEST TASMANIA

Leader: Owen Missen

Team members: Julie Hunt, Mohammad Fathi

PhD student: Pratichee Mondal

Collaborators: Ben Maynard, Roger Hill, Nicholas van der Hout (Grange Resources)

This PhD research project is focussed on geoenvironmental and geometallurgical characterisation of material that reports to waste streams to aid opportunity recognition for by-product metal recoveries while reducing the volume of potentially deleterious wastes on-site. It aims to assist in recovery of critical metals from wastes at Savage River while, in turn, also reducing the environmental impacts of legacy wastes by improving characterisation to inform mineral processing and waste management. This PhD project commenced in late 2023 and will assess whether critical metals such as V, Co and/or Ti can be recovered from the Savage River ores and/or wastes.

PATHWAYS TO PRODUCTION – KARA W-FE MINE, NW TASMANIA

Leader: Julie Hunt

Team members: Mohammad Fathi, Owen Missen

PhD student: Emmanuel Dogara Musa

Collaborators: Greg Doherty, Marcus Mollison (Tasmania Mines Pty Ltd)

To address global supply issues, growth in critical metal resources and advances in their extraction technologies are required. Kara in northwestern Tasmania has substantial critical metal resources such as scheelite (W) with the potential to contribute significantly to growth in

The UTAS/CODES Mining Roadshow, held in June 2023, was aimed at introducing the RRC project to the West Coast community. Here CODES PhD student Vinicius da Cruz is presenting the outline of his research into the Rosebery mine to an audience in Burnie.

critical metals inventory. Extraction of critical metals from ores and waste materials can be challenging and pose potential barriers to cost-effective recovery that need to be addressed. These include potential issues with crushing and grinding, separation of critical metals from gangue, and efficient energy use. Consequently, it has become imperative to rationalise technological schemes of sustainable mineral processing with due consideration to reducing environmental impact, energy, and cost. The aim of this research is to develop sustainable pathways to scheelite ($CaWO_4$) production for the Fe-W skarn-type deposits at Kara mine. The objectives include: (1) Rock characterisation of representative samples to identify lithology, alteration and mineralisation using drill core logging, geochemistry and X-ray diffraction; (2) Detailed petrographic and geochemical characterisation of ore and gangue minerals focussed on critical metal deportment, liberation and association; (3) Evaluation of processing methods currently used on-site for W-bearing ore, using bench-scale tests to assist optimisation of critical metal recovery for different domains/ore types; (4) Assessment of the feasibility of using other techniques, not currently used on site, to help improve extraction, concentration and saleability of products; and (5) creation of characterisation and testing workflows based on the outcomes of the research to optimise critical metals recovery and sustainable/optimal use of the orebody.

OPTIMISING REMEDIATION OF LEGACY MINES – MINERALOGICAL CONTROLS ON LONG-TERM WASTE ROCK WEATHERING AND MINE DRAINAGE

Leader: Sebastien Meffre

Team members: Matthew Cracknell, Clare Miller, Owen Missen

PhD student: Chris Allen

Collaborators: Mark Duffett, Clint Siggins, Carol Steyn (all MRT); Brian Dalton (Bluestone Mines)

Characterisation of mine wastes through lab- and field-based tests is now standard practice in the initial stages of mine closure. However, there is insufficient knowledge about how exposure and weathering may influence mine wastes in the medium term (i.e., ~10 years). Previous studies have indicated the importance of secondary mineral formation on leachate chemistry. However, most studies typically consider only the weathering of recently extracted rocks or deeply weathered waste rocks rather than investigating both fresh and weathered materials to understand how weathering and exposure affects mineralogy, surface area and texture, grain size, and metal(loid) deportment. The Happy Valley Waste Rock dump at Mount Bischoff has been exposed to the effects of weathering over a 10–12-year period. This provides an excellent opportunity to study the progression of weathering and changes in mineralogy, surface area and texture, grain size and metal deportment on rocks exposed to weathering for a known amount of time without requiring long-term column or barrel tests in addition to having the ability to study relatively fresh materials of the same lithology. This PhD study commenced in early 2022 and is integrating geophysical studies of the waste rock pile with geochemical studies of waste products and benchtop testing to evaluate the evolution of mine wastes at Happy Valley, and to evaluate options for future waste management.

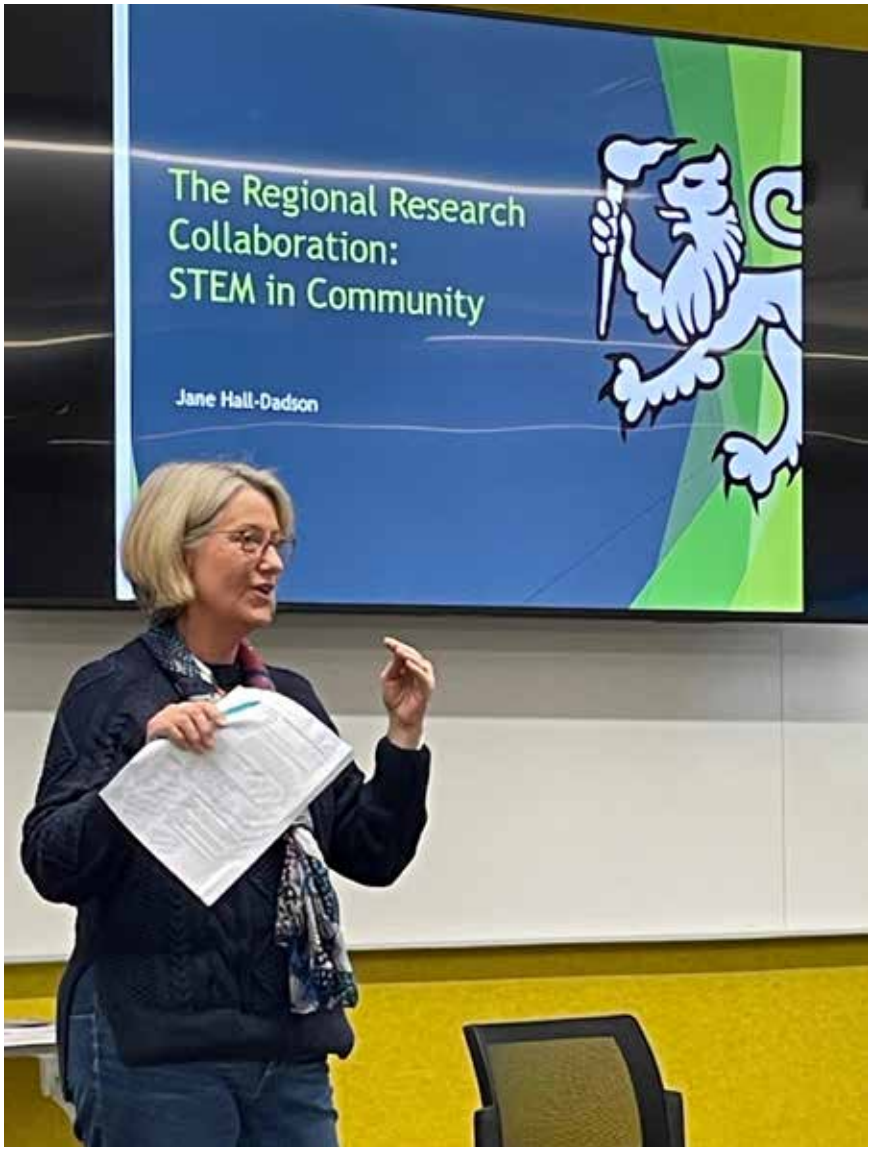
ELEMENT 3: EDUCATION AND ENGAGEMENT – DEVISE INNOVATIVE SOLUTIONS TO COMMUNITY-BASED BARRIERS THAT AFFECT ENGAGEMENT IN STEM AND LIMIT THE GROWTH OF THE STEM-CAPABLE WORKFORCE NEEDED FOR CRITICAL METALS PRODUCTION IN REGIONAL AREAS

ADDRESSING REGIONAL BARRIERS TO ENGAGEMENT IN STEM – EDUCATION AND OUTREACH STRATEGIES RELATING TO CRITICAL METALS PRODUCTION

Leader: Sharon Fraser

Team members: Kim Beasy, Connie Cirkony, David Cooke

PhD student: Jane Hall-Dadson



Jane Hall-Dadson, a PhD student in the School of Education involved with the RRC project's Element 3, is seen here presenting her research aims at the UTAS/CODES Mining Roadshow in Burnie during the winter of 2023.

As Australian society responds to climate and social challenges, we need to continue to develop new technologies and a skilled workforce with more STEM graduates and increasing numbers of STEM-qualified workers. Complicating our technology development is a need for significantly more critical minerals for the energy, transport, telecommunication and medical sectors. Global demand for these metals and minerals is increasing while their supply is potentially unstable. Australia is well-situated to supply a number of these minerals, with the potential for significant economic benefits, but mining sectors are also suffering from workforce supply issues.

Pathways to STEM careers choices are heavily influenced by family interactions, beginning in early childhood and extending to skill recognition during primary and high school and encouragement during tertiary studies. There is a paucity of research, however, that considers how a lack of positive familial STEM experiences might be countered. Research into the familial factors that make STEM careers unimaginable for some Australian children is warranted, particularly in regional settings such as the West Coast of Tasmania. Understanding the factors that influence regional families' attitudes to STEM careers could evoke strategies to raise their interest and increase STEM aspiration in these areas.

This PhD study aims to build understanding of parental influences on STEM aspirations. It will suggest strategies that support ongoing engagement with STEM education and the development of community STEM capital. To achieve these aims, the project will initially survey West Coast community members to establish existing levels of engagement with STEM. The survey will identify community members with lower levels of STEM engagement for in-depth interviews. These interviews will seek understanding of how negative attitudes to STEM education form and how children's participation in STEM education might be encouraged. Finally, the findings from surveys and interviews will be used to inform focus group discussions, including a broad range of community members, with the aim of generating strategies to support increased engagement with STEM education, and participation in STEM careers within the community.

Following a review of relevant literature, community consultation and development of appropriate methodology in 2023, the project's design will allow confirmation of Jane's PhD candidature in March 2024. The granting of Human Research Ethics Approval will follow.

Training and education




LEADERS REBECCA CAREY, MATTHEW CRACKNELL, ROBERT SCOTT AND MARTIN JUTZELER

▶ OBJECTIVES

- Produce world-class PhD, Masters and Honours geoscience graduates
- Deliver a range of professional development short courses and workshops tailored to the needs of the minerals industry

Introduction

CODES has an international reputation for excellence in postgraduate education, which includes providing students with a comprehensive grounding in the Earth sciences. Students come from all over the world to study at CODES, with many graduates progressing to senior roles in the minerals industry, state and federal governments, and academia. Training and education activities also play a vital role in CODES' research across our six research programs. Training and education at CODES includes the Higher Degree by Research (both PhD and Masters by Research), Master of Economic Geology, Graduate Certificate in Economic Geology and Honours programs. CODES also runs a variety of one-off short courses and workshops (online and/or face-to-face). These short courses and workshops provide our students with diverse new skills critical to their research, in addition to those which are aimed at re- and up-skilling minerals industry professionals (see the 'Technology transfer' section in this report for a list of these short courses and workshops held in 2023).

Highlights

First, a big congratulations to the five PhD graduates in 2023. An update on where four of our graduates are now: Rob Davidson is now working for Hecla Mining Company as Director Geology and Exploration in Alaska. Sibele Nascimento is working at UQ. Joe Knight is working as a Contract Geologist for CSA Global, and Javier Merrill-Cifuentes is working as a Data Scientist at Datarock.

AWARDS

In 2023 CODES PhD students won several awards which are absolutely worth mentioning here in Highlights:

Hannah Moore was part of a team that won the Eureka Prize for STEM Inclusion for the regular podcast 'That's what I call Science!' (TWICS). The Australian

CODES Honours, Masters and PhD graduates pictured outside the Hotel Grand Chancellor, Hobart, in December 2023 following their graduation ceremony.

Museum Eureka Prizes are the country's most comprehensive national science awards, honouring excellence across the areas of research and innovation, leadership, science engagement, and school science. These awards are provided annually. Hannah represented the TWICS team at the Prime Minister's Prizes for Science awards dinner in Canberra, held in October.

Tristan Wells was awarded the A. B. Edwards Medal for best paper on aspects of economic geology published in the *Australian Journal of Earth Sciences* (AJES) in both 2020 and 2021, as well as the 2021 David I. Groves Award for the best paper published in the AJES by a young author. He was presented with all three medals at a ceremony in Perth in June 2023.

Alex Farrar won best student presentation at the South Australia Geological Society of Australia meeting for the Specialist Group in Tectonics and Structural Geology.

In 2023 we welcomed eleven new PhD students into CODES, increasing our PhD cohort by a third! These new students are a wonderful addition to CODES and we look forward to hearing about their work in future years. In 2023, seven students graduated from the MEconGeol program and a further three students completed the degree, and will graduate in 2024.

Postgraduate programs

CODES runs a range of postgraduate programs that provide many of the next generation of world-class geoscientists. We have programs at the following levels: PhD, Masters by Research, Master of Economic Geology, Graduate Certificate in Economic Geology and Honours.

PHD AND MASTERS BY RESEARCH PROGRAM

Much of the exciting research conducted at CODES is produced by our PhD and Masters students, who make a major contribution across the breadth of CODES' research activities and outputs. Postgraduate projects at CODES range across the spectrum of our research programs and include sponsorship/collaborations with industry in Tasmania, Australia and globally, and with the Tasmanian State Government, geological surveys and other academic institutes throughout the world. Currently 77% of our HDR students have projects with partners in the minerals industry.

Our PhD and Masters students are high-calibre individuals attracted to CODES by our global reputation for excellence as a research training centre. PhD and Masters students are supported by UTAS-derived scholarships and tuition fee waivers, in addition to industry funding of scholarships and research costs.

In 2023 eleven students enrolled into our PhD program. Most of the new PhD students are involved in the CODES Regional Research Collaboration which began in late 2022. There is incredible diversity and breadth within this PhD cohort which is warmly welcomed and sure to push the PhD students to another win in the Song Contest at the annual Geology Dinner! We wish them all the best with their studies.

▼

In 2023 we welcomed eleven new PhD students into CODES, increasing our PhD cohort by a third!

'Advanced Field Skills in Economic Geology' Masters short course students pictured in February 2023, western Tasmania.

Our new overseas PhD students who joined CODES in 2023: Arka Sahu (India), Vinicius da Cruz (Brazil), Alfredtina Appiah (Ghana), Jose Barillas Diaz (Mexico), Emmanuel Dogara Musa (Nigeria), Nelao Natukondje Naimbale (Namibia), Isaac Evinemi (Nigeria), Giovana Oliveira (Brazil), Fuseini Atanga (Ghana), Pratichee Mondal (India), Olive Lucas Ponyalou (PNG).

MASTER OF ECONOMIC GEOLOGY PROGRAM

The coursework-based Master of Economic Geology degree at CODES forms part of the national Minerals Geoscience Masters (MGM) program – a collaboration between UWA, UTAS and Curtin University.
The MGM remains the course of choice for industry-based geoscientists, attracted by the opportunity of studying for an internationally recognised degree, while still being able to pursue full-time careers in the minerals industry.
Dr Robert Scott is the program coordinator for all Master of Economic Geology short courses at CODES.

2023 was a busy year for the MEconGeol program, with seven coursework units delivered, the most ever in a single year. There were 13 new admissions to the MEconGeol, three re-admissions and seven students commenced the Graduate Certificate in Economic Geology (GCertEconGeol), bringing the total number of students active in the program to 76. The GCertEconGeol is awarded for completing Fundamentals of Economic Geology (KEA716) and one other unit from the MEconGeol coursework offering. Completing the GCert is a new pathway for admission to the MEconGeol, which is awarded following the successful completion of a further six units. David Eddy, Ben Ferguson, Brendan Hardwick, Carl Jackman, Riley Jenkins, David Mallon and Todd McGilvray all graduated in 2023, while Michael Adams, Roseanna Dale and David Portocarrero all completed the degree and will graduate in 2024. Sam Connell was awarded the GCertEconGeol.

Summaries of the seven UTAS-based Masters short courses held during 2023 follow:

ADVANCED FIELD SKILLS IN ECONOMIC GEOLOGY

12–25 FEBRUARY 2023

This unit provides training in fundamental and advanced mapping and field skills for minerals industry geologists. Techniques covered include field-based rock and mineral identification, fact and form surface mapping, Anaconda-style mapping, structural measurement and graphic logging techniques for drill core, and the use of spectral, geochemical and remote sensing data sets in making and interpreting geological maps. The unit was delivered by CODES teaching staff Robert Scott, Lejun Zhang and Francisco Testa, with CODES PhD student Emrecan Yurdakul assisting as demonstrator. The first week of the unit is delivered concurrently with the CODES/Victorian Institute of Earth and Planetary Sciences (VIEPS) Exploration Field Skills mapping camp and involved a total of 22 participants. The first mapping area is located ~20 km north of Queenstown (where participants stay until early in the second week of the intensive delivery), but the first day is spent in Hobart at Mineral Resources Tasmania's core storage facility in Mornington, with participants logging three drill cores from the mapping area. After travelling to Queenstown, and a series of introductory lectures on day two, participants spend four days mapping a ~3 km^2 area centred on the Hall Rivulet Canal. The mapping area is 13 km south (along strike) from the poly-metallic Rosebery volcanic-hosted massive sulfide (VHMS) deposit. Participants use information obtained during the field mapping and core logging exercises to interpret the structure and stratigraphy of the mapping area and based on this, identify untested areas with potential for hosting significant VHMS-style deposits at less than 500 m depth.

The second week of the fieldtrip began with a 2.5-day Anaconda mapping and core logging exercise on the Mt Lyell mine lease in Queenstown. CODES is very grateful to Geoff Cordery and CMT for again facilitating this exercise. Participants then travelled to George Town (northeast Tasmania) for three days of structural mapping exercises in the multiply deformed Lower Palaeozoic turbidites exposed in wave-cut rock platforms on the NE

coast. The fieldtrip concluded with a daytrip to the Freycinet Peninsula on the east coast of Tasmania, where participants examined and mapped magmatic–hydrothermal transition features developed in the granites exposed at Bluestone Bay.

ORES IN MAGMATIC ARCS – INDONESIA

12–24 MARCH 2023

In March 2023, the 'Ores in Magmatic Arcs – Indonesia' short course began in Jakarta on the island of Java, with 11 Master of Economic Geology students and 10 other industry participants. The unit was led by CODES staff Lejun Zhang and David Cooke in partnership with Indonesia-based geologists Adi Maryono and Iryanto Rompo from J-Resources. This highly practical unit focussed on developing participants' field skills and theoretical understanding of the spectrum of ore deposit types that form in magmatic arc settings.

The course kicked off with a two-day CODES-MGEI joint workshop on Porphyry and high sulfidation epithermal deposits in Jakarta. In addition to the CODES Master of Economic Geology students, more than 70 participants from the mineral industry, universities and research institutes attended the workshop. Following the workshop, first up was a visit to Pongkor low sulfidation epithermal Au-Ag deposit in West Java for an operational overview, underground tour, and drill core review.

The next day, the group flew to Banyuwangi in East Java to visit the Tujuh Bukit porphyry – high sulfidation epithermal Au-Cu deposit, outcropping porphyry mineralisation at Pulau Merah, and the Tanjung Jahe diatreme. The group then visited the active volcano and largest crater lake on Earth at Mt Ijen in East Java. Participants hiked to the crater rim before sunrise to view the famous 'blue fire' emanating from the active fumaroles. After sunrise, they inspected vast exposures of advanced argillic altered rock in the crater walls of this active magmatic-hydrothermal system.

In the second week, participants flew to Lombok for visits to Awang, Sundancer, Simba lithocaps, Pengulu breccia, and Brambang porphyry deposit. At the Sundancer, participants walked a transect through a complete lithocap profile from barren to mineralised zones and into an underlying porphyry Cu-Au prospect. After two nights in Lombok participants travelled to Batu Hijau in Sumbawa for an open pit tour, and drill core inspection. This was followed by a visit to the Elang porphyry Cu-Au deposit and the newly discovered Elang South deposit, located 60 km east of Batu Hijau in south-central Sumbawa. The party then returned to Lombok for a day of lectures and presentations by the students. The next day, they flew to Bima in northeast Sumbawa before driving to the south coast to visit the Onto giant porphyry – high sulfidation Au-Cu deposit for the final site visit of the fieldtrip. We were the first international group to visit Onto since its discovery. Everyone involved had a great time visiting and learning about the amazing ore deposits of the Sunda-Banda Arc, as well as enjoying the wonderful hospitality and culture of Indonesia. We would like to extend our sincere thanks to all our hosts and everyone who supported us throughout this incredible journey.

FUNDAMENTALS OF ECONOMIC GEOLOGY

17–22 APRIL 2023
AND 8–12 MAY 2023

This unit introduces the fundamental skills and theory needed by all economic geologists, and covered topics including ore deposit classes, environments of ore formation, mineralogy and textures, paragenesis, zoning, geochemical and geophysical

Dr Owen Missen (left) with CODES PhD student Javier Gil Rodriguez carrying out tailings dam sampling during fieldwork to the west coast of Tasmania in February 2023.

Participants of the 'Ores in Magmatic Arcs – Indonesia' Masters short course that ran in March 2023. The CODES team is viewing drill core from Elang and Elang South giant porphyry – high sulfidation Au-Cu deposit, Sumbawa, Indonesia.

characteristics of ore deposits, supergene features and the economics of economic geology. First delivered in 2021, Fundamentals of Economic Geology is now delivered annually in April/May and is one of two compulsory units in the current structure of the MEconGeol degree. The other compulsory unit in the degree is Ore Deposit Models and Exploration Strategies, which is delivered biennially in even-numbered years. In 2023, Fundamentals was presented by CODES staff David Cooke (unit coordinator), Michael Baker, Francisco Testa, Michael Roach, Robert Scott and Lejun Zhang along with guest presenters Tim Callaghan, Scott Halley, Cassady Harraden, Larry Meinert and Noel White, and was attended by 45 people (19 Masters students, 11 industry participants and 15 others).

A virtual geological tour and sample set for the Dolphin scheelite deposit on King Island forms the centrepiece of this unit. The virtual tour, which was prepared by Michael Roach, Lejun Zhang and Francisco Testa, contains interactive 3D imagery of the entire open pit, with close-ups of key exposures in the pit walls, and high-resolution 3D imagery, mineralogical and geochemical data for a representative suite of ore and host rock samples collected from the pit. Participants use the Dolphin deposit sample set to reinforce many of the key concepts (e.g., paragenesis, mineral and metal zonation) and analytical techniques introduced in this unit. CODES is grateful to King Island Scheelite for enabling the pit access and sampling required to develop this exercise.

ORE DEPOSIT GEOCHEMISTRY, HYDROLOGY AND GEOCHRONOLOGY

29 MAY–3 JUNE 2023 AND 3–7 JULY 2023

In 2023, this unit was delivered in blended mode, with live streaming of the face-to-face classes delivered in Hobart. The unit provides an up-to-date review of the theory and practice of geochemistry, hydrology and geochronology applied to studies of mineral exploration and ore deposit genesis. Fifteen Masters students, four industry participants and 22 other participants attended the 2023 delivery. The first week covered the basic principles of metal transport and deposition in hydrothermal fluids, fluid flow and the localisation of mineralisation in hydrothermal systems, granites and granite metallogeny, the use of magmatic minerals and whole-rock geochemistry in exploration. The first week of the intensive delivery finished with a workshop on the use of pyrite in mineral exploration and studies of ore deposit genesis. Prior to the unit, Masters students send pyrite-bearing rock samples to CODES which are prepared for, and analysed by, laser ablation ICP-MS. Students then analyse and interpret the data generated for their sample during the short course, determining things such as the lead isotope model age and paragenetic history. For ore-related pyrite samples, textural and compositional features of the pyrite can commonly be used to infer the chemistry of the hydrothermal fluid and conditions of pyrite formation. Topics covered in the second week of intensive delivery included the application of radiometric dating and stable isotopic techniques to mineral exploration, mass balance in hydrothermally altered rocks, and mineral chemistry vectoring in porphyry and epithermal environments.

There was also a session on unconventional thinking applied to mineral systems, with guest speakers Scott Halley, John Walshe and CODES PhD student Alex Farrar. Long-time contributors, Phil Blevin (GSNSW), Lesley Wyborn (ANU) and Nick Oliver (Consultant, HCOV Global) were also involved in the 2023 delivery of this unit. CODES presenters were David Cooke (unit coordinator), Sheree Armistead, Mike Baker, Ivan Belousov, Matt Cracknell, Wei Hong, Sebastien

Meffre, Jeff Oalmann, Robert Scott, Jeffery Steadman and Lejun Zhang. On the final day of the short course, the Masters students presented their interpretations of the LA-ICP-MS data obtained for their pyrite samples.

GEODATA ANALYTICS

7 AUGUST–16 SEPTEMBER 2023 AND 18–22 SEPTEMBER 2023 AND 25 SEPTEMBER–15 OCTOBER 2023

Forty-three people (18 Masters students, 13 minerals industry representatives and 12 other participants) attended the 2023 offering of Geodata Analytics. Participants immersed themselves in a diverse range of fundamental data analytics topics applied to geological problems, including data wrangling, machine learning and image processing, all under the guidance of unit coordinator Matt Cracknell. This unit is delivered entirely online and split into three sections. The first section is self-paced, and involves working through a series of pre-recorded lectures, prescribed readings and associated exercises. Participants prepare a video based on an assigned literature review topic. The videos are uploaded to CODES' YouTube channel for others to view and comment on. This exercise is a great way to get students engaging with one another in the online environment and fosters a strong sense of shared learning, which was continued through the remainder of the unit delivery. The second section involves an intensive week of live lectures and practicals led by Matt Cracknell, with guest presenters John Thompson, Shawn Hood, Michael Gazley, June Hill, Isaac Evinemi, Eric Grunsky, Alex Farrar and McLean Trott dialling in from across the world to discuss topics such as geochemical exploratory data analysis, hyperspectral image classification and what the future of geodata analytics might hold. In the third section course participants were split into teams and tackled a geodata analytics problem; the results of these sessions were shared in a series of group presentations.

GEOMETALLURGY

16–27 OCTOBER 2023

Dr Julie Hunt and Dr Rob Scott coordinated the Master of Economic Geology short course in Geometallurgy in October 2023, the seventh time the course has been run at CODES. This year the course had 15 participants: eight Masters students, four industry participants and three other students. The course was held in-person at CODES and presentations were given by UTAS staff and guest presenters. Guest speakers included Toni Kojovic (SimSAGe), Sefton Derby (Voconiq), Bill Staunton (Curtin University), David Green and Verity Kameniar-Sandery (MRT), Laurence Dyer (Curtin University), Scott Halley (Mineral Mapping), Natalee Bonnici (Northern Star Resources), Karyn Gardner (Evolution Mining), Kathy Ehrig (BHP), and Tobias Hermansson (Boliden). The course included a visit to the MRT core library and hyperspectral (Hylogger) equipment plus visits to CSL and CODES laboratories. In the middle of the course a field trip was made to ALS Burnie Labs and processing facilities at Kara Fe-W operation (Tasmania Mines) and Renison Sn operation (Bluestone Mines Tasmania).

Dr Wei Hong (left) and Dr Mike Baker from CODES handling a flow of enquiries from prospective students at the CODES booth during the SEG Conference in London, held during August 2023.

ORES IN MAGMATIC ARCS – SOUTH AMERICA

25 OCTOBER–11 NOVEMBER 2023

The magmatic arcs of the South American Andes are the source of most of the world's copper and molybdenum, and are also major sources of gold and silver. Students enrolled in the Master of Economic Geology program had the unique experience of a 16-day field excursion to Chile and Peru in October – November 2023 to learn first-hand about some of the amazing Andean mineral deposits and the environments that they formed in. Led by David Cooke, Yamila Cajal, Victor Torres and Jaime Osorio, 20 Masters students and industry representatives visited several major porphyry, epithermal, IOCG, VHMS, skarns, and carbonate replacement deposits, including El Teniente, Rio Blanco, Candelaria, Manto Verde, Santo Domingo, Cerro Lindo, Antakori, Tantahuatay, La Zanja, Ucchucchacua, and Yumpug. For the first time, this excursion involved two student cohorts, KEA707 (Ores in Magmatic Arcs) and KEA724 (thesis project part A), so that students who previously completed the Indonesian version of KEA707 could participate.

The Master of Economic Geology program for 2024:

- 4–7 February: Advanced Field Skills in Economic Geology
- 1–14 March: Volcanology and Mineralisation in Volcanic Terrains
- 8–13 April and 6–10 May: Fundamentals of Economic Geology
- 3–8 June and 8–12 July: Ore Deposit Models and Exploration Strategies
- 28 October–2 November and 18–22 November: Exploration in Brownfield Terrains

HONOURS PROGRAM

The Honours degree in Earth Sciences is designed to train our students for both industry and academia. The program is coordinated by Dr Martin Jutzeler and consists of thesis-based research balanced with a literature review and four weeks of short course units that take place in Tasmania or at universities in Victoria. The Honours year also includes in-house one-day workshops to improve the students' writing skills and introduce them to the specific software they will need for their projects. The Honours program has two intakes a year (February and July) and consists of around 38 weeks of study, with graduations in December and August. Our Honours program allows full- or part-time enrolment and has been proven as an efficient segue for our graduate students to access competitive industry employment.

The 2023 academic year saw the graduation of five Honours students. Dan Fisher completed his MRT-funded Honours project on the characterisation of tailings dams at Scotia Mine in NE Tasmania, which was started in 2022. Four February-starters, Harrison Keeble, Madison Mulder, Issi Port and Millicent Young completed their Honours that were generously funded by the ARC, Alkane Resources, Evolution Mining, and MRT. Two July-starters, Emily Conn and Sarah Purdom, will graduate in 2023 and are funded by the ARC and Battery Minerals. Details about the Honours projects can be found in their respective programs. The 2023 cohort produced theses of exceptional quality, with all students getting first-class Honours.

Honours coursework program – VIEPS

In 2023, CODES offered two short courses as part of the Victorian Institute of Earth and Planetary Sciences (VIEPS) Honours coursework program. This program is attended by CODES and Victorian Honours students.

EXPLORATION FIELD SKILLS MAPPING CAMP

Course leaders: Rob Scott, Francisco Testa, Lejun Zhang

Eight Honours students followed this course in 2023, in addition to six MSc and six PhD students, one postdoc and three industry participants. This course provides participants with the opportunity to develop or enhance existing skills in geological mapping, core logging and structural analysis, within a mineral exploration context. Students map and interpret a ca. 5 km^2 area in the mineralised

The 'Ores in Magmatic Arcs – South America' Masters short course ran in late 2023, and once again, was highly popular. Here participants survey the geology while travelling to Uchucchacua in Peru.

Cambrian Mount Read Volcanics. Prior to travelling to Tasmania's West Coast participants spent a day examining drill cores from the mapping area at MRT's core storage facility in Hobart. HyLogger data for the drill cores provides important insights into the nature and extent of hydrothermal alteration affecting the rock sequence exposed in the study area. Insights from drill core coupled with an analysis of data collected during the fieldwork, provides the basis for the students' assessment of the future exploration potential of the study area.

ENVIRONMENTAL GEOLOGY FIELD TECHNIQUES

Course leaders: Matthew Cracknell, Owen Missen

Four Honours students joined the five-day environmental geology field course that ran over a week in August. The course started with 1.5 days of lectures at CODES given by Owen Missen and Matthew Cracknell followed by an afternoon of practising field techniques on the Sandy Bay campus and in the nearby Lambert Rivulet. Students then conducted three days of fieldwork at various sites in western Tasmania in the Queenstown–Strahan area. The trip began with a visit to Mt Lyell mine to discuss the past and current environmental management strategies at the site. The next day, the students braved the elements on a pyritic sediment bank of the King River delta, which has over 20 historic piezometers installed. Hydrogeologic measurements were taken from all accessible holes. Subsequently, the students visited the King River delta and dug trenches to view the oxidation layer occurring above the fresh pyrite layer, exposed by digging into the delta's surface.

On the final day, water samples and in-field water chemistry measurements (pH, conductivity) were taken by the students along the Queen River system across Queenstown to examine the chemistry of water in a system heavily impacted by mine drainage. Once back at CODES, the water samples were analysed by ICP-MS to determine their metal concentrations. Collectively, these data allowed them to geoenvironmentally assess these legacy sites. Students were assessed based on several assignments related to the visits to the mine site, sediment banks, King River delta and water chemistry.

Honours skills workshops

As in previous years Honours students attended a number of workshops covering software programs and communication skills.

Student projects

IN AUSTRALIA

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

1. **Allen, Christopher.** TAS

Optimising remediation of legacy mines – mineralogical controls on long-term waste rock weathering and mine drainage.

2. **Appiah, Alfredtina.** TAS

Pathways to production: Magnesite deposits at Prospect Ridge, northwestern Tasmania.

3. **Barillas Diaz, Jose.** TAS

Atypical nickel mineralization in metasomatic rocks – The Avebury Ni deposit, Western Tasmania.

4. **Beas, Billy.** NSW

Orebody knowledge, halogen deportment and vectoring implications of the E44 Au-Cu deposit, Northparkes District, New South Wales, Australia.

5. **Brown, Isaac.** WA

Geology, geochemistry and genesis of the Havieron gold copper deposit, Paterson Province, Western Australia.

6. **da Cruz, Vinicius.** TAS

Characterisation of the complex orebodies in the Rosebery Middle Mine: implications for ore processing and mineral exploration.

7. **de Selincourt, Lieth.** NSW (Masters)

Application of mineral chemistry to aid exploration for Cu-Au-Mo porphyry mineralisation in the Temora district, New South Wales, Australia.

8. **Fisher, Daniel.** TAS (Honours)

Lithological, geochemical and mineralogical drivers of water quality at the legacy Scotia Mine, northeast Tasmania.

9. **Gil Rodriguez, Javier.** TAS

Characterisation of skarn-type deposits: Renison Bell Sn deposit.

10. **Greene, Joshua.** VIC (Masters)

The geological and geochemical fingerprinting of high-grade gold mineralisation in the Shepherd deposit, Costerfield Victoria.

11. **Hardwick, Brendan.** WA (Masters)

Mineralised textures at the Tropicana gold mine: Implications for the genetic model and deportment of gold.

12. **Hohl, Max.** QLD

Defining the mineral chemistry footprints of the Starra iron oxide-copper gold deposits in northwest Queensland.

13. **Ila'ava, Malai.** NSW

Volcanic architecture of the Cowal Igneous Complex, NSW.

14. **Johnson, Benjamin.** QLD (Masters)

Pyrite textures and trace element chemistry of the Century Deposit – implication for exploration.

15. **Jones, Colin.** TAS

The petrogenesis of the Devonian granites of the East Tasmania Terrane.

16. **Jones, Lucy.** QLD (Masters)

An investigation into the mineral associations and relationship between chalcopyrite and sphalerite at Cannington Mine, North Queensland.

17. **Jones, Rhiannon.** NSW

The significance of phyllic alteration at the E26 porphyry Cu-Au deposit, NSW, Australia.

18. **Keeble, Harrison.** NSW (Honours)

Characterising the regolith profile of the E41 Gold Deposit, Cowal, NSW: implications for ore processing and mineral exploration.

19. **Le'Gallais, Bridie.** TAS

The tectonic significance of mafic /ultra mafic igneous rocks in western Tasmania.

20. **Mondal, Pratichee.** TAS

Recovery of critical metals from legacy mine waste: Savage River magnetite deposit, northwest Tasmania.

21. **Musa, Emmanuel Dogara.** TAS

Pathways to production for critical metals: Kara W deposit, western Tasmania.

22. **Naimbale, Nelao Natukondje.** TAS

Characterisation of the Heemskirk tin project.

23. **Nascimento, Sibele Cristina do.** TAS

Geoenvironmental characterisation of historic mine tailings: A multidisciplinary approach.

24. **Port, Issi.** TAS (Honours)

The structural and metamorphic history of the Eastern Tyennan Region, Lake Pedder, Tasmania.

25. **Purdom, Sarah.** VIC (Honours)

Genesis of a possible IRGS deposit near Stawell, Victoria.

26. **Santos Costa, Angela Isaura.** TAS

Characterisation of tungsten mineralisation at Grassy, King Island, Tasmania – implications for ore genesis, exploration, and pathways to production.

27. **Schaap, Thomas.** TAS, NSW, VIC

Tectonic evolution of the early Palaeozoic Lachlan Orogen.

28. **Schaumburg, Henry.** TAS (Masters)

The Kara Fe-W skarn: A mineral chemistry and age dating study to better determine controls on skarn formation.

29. **Staubmann, Markus.** NSW

Geology, geochemistry, and geometallurgy of the GRE46 epithermal gold deposit, Cowal District NSW.

30. **Young, Millie.**
NSW (Honours)

Geology, alteration, mineralization and geochemistry of the Peak Hill Au-Cu deposit, NSW – Genetic and exploration implications.

31. **Yurdakul, Emrecan.** TAS

Orebody knowledge of the Western Tharsis Cu-Au deposit, Tasmania: implications for ore processing and mineral exploration.

32. **Zivkovic, Zebedee.**
TAS, WA

Trace element systematics in whole rock analysis of magmatic-hydrothermal ore deposits.

OUTSIDE AUSTRALIA

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

1. **Atanga, Fuseini.** Ghana

Deposit characterisation and exploration vectors for the Akyem orogenic gold deposit, Ghana.

2. **Cima, Axel.**
Indonesia, USA

Microinclusions in porphyry Cu deposits.

3. **Clark, Acacia.**
New Zealand, Greece

Dynamics of subaerial silicic explosive volcanism: The 1315 CE Kaharoa eruption and the Late Bronze Age eruption of Santorini.

4. **Coaquira, Takeshy.** USA

Resolving multiple generations of white mica and clay alteration at the Resolution porphyry Cu-Mo deposit, Arizona.

5. **Conn, Emily.**
New Zealand (Honours)

Sediment core stratigraphy at Havre, Kermadec Arc/Rangitāhua.

6. **Davidson, Rob.** Mexico

Geology and genesis of the San Sebastian vein system, Durango, Mexico.

7. **Evinemi, Isaac.** Chile

Mineralogical domaining and predictive modelling of porphyry copper deposits using deep learning approach.

8. **Farrar, Alex.** Peru, Chile, Argentina

Tectonic and structural controls on the spatio-temporal distribution of giant porphyry copper deposits in the Central Andes.

9. **Frey, Shannon.** New Zealand

Behaviour of submarine caldera-forming silicic eruptions in the Kermadec arc, New Zealand.

10. **Higgins, Declan.** New Zealand

Volcanic architectures.

11. **Job, Ashleigh.** Chile (Masters)

Geology, structural control and exploration implications of Au mineralized Fenix gold project, Maricunga Belt, Chile.

12. **Knight, Joseph.** Myanmar

The tectonic and metallogenic setting of Cu-Au mineralisation in Myanmar: Implications for mineral exploration in the Central Magmatic-Volcanic Arc.

13. **Merrill, Javier.** Chile

Quantification of mineral texture for geometallurgical predictive modelling.

14. **Moore, Hannah.** New Zealand

Shallow conduit, vent, and sedimentation processes involved in the 1886 basaltic Plinian eruption at Tarawera Volcano, New Zealand.

15. **Mulder, Madison.** Coral Sea (Honours)

The Louisiade Ophiolite Obduction and implications on the tectonic evolution of the Southwest Pacific.

16. **Osorio, Jaime.** Chile

Anatomy of the porphyry-epithermal transition in the Valeriano Cu-Au deposit, Chile.

17. **Pimentel, Giovana.** South Africa

Rock characterisation of the PlatReef.

18. **Ponyalou, Olive.** PNG

Geology, genesis, and exploration significance of Cu-Au veins and altered rocks in the Kainantu Cu-Au district, PNG.

19. **Seow, Xin Ni.** South Korea, USA

Genesis, geochemistry and spectral characteristics of alunite supergroup minerals: Implications in lithocap and porphyry explorations.

20. **Smyk, Emily.** USA

Geology, geochemistry, geochronology and exploration footprints of the Christmas porphyry Cu-Mo deposit, Arizona.

21. **Sritangsirikul, Peerapong.** Mainland SE Asia

Tectonic evolution and related mineral deposits of mainland SE Asia: Insights from geochemistry and geochronology of zircons.

22. **Sun, Yi.** Philippines

Geology of the Quartz – Pyrite – Gold (QPG) mineralization and the new model of the Mankayan District, Northern Luzon, Philippines.

23. **Torres Pacheco, Victor.** Peru

Geology, genesis, and geometallurgy of Cu-Au-Ag mineralized tourmaline breccia pipes at Soledad, central Peru.

King Island at sunset.

Lab-based projects

Cooke, Stephen.

Pathways to mineral discoveries through computer-based modelling of geochemical data.

Lounejeva, Elena.

Trace element geochemistry of pyrite in sediments across the Permian Triassic boundary.

Moyo, Annah.

Controlling acid and metalliferous drainage at legacy sites in Tasmania using industrial wastes.

Sahu, Arka.

Multi-scale hyperspectral and mineral chemistry data mining.

Participants of the 2023 CODES SEG Student Chapter field trip to South Australia are pictured at the Prominent Hill mine processing plant.

Society of Economic Geologists (SEG) Student Chapter

The CODES SEG Student Chapter at the University of Tasmania is a branch of the Society of Economic Geologists. We are dedicated to fostering an inclusive and collaborative social fabric within the geosciences research community with a focus on engagement between students and industry. We pride ourselves on making significant contributions to the social and professional lives of students from a diverse range of backgrounds and cultures.

In 2023, CODES experienced a large influx of PhD students from across the world including from Brazil, Ghana, Mexico, Peru, Colombia, Türkiye, Nigeria, India and Namibia as well as Australia. Many of these students joined the SEG Student Chapter as a way to integrate into the CODES community and expand their friendship groups.

The Chapter held its AGM in October 2023 and elected a new committee. Newly elected committee members were undergraduate students Bryce de Hahn (Secretary) and Yvette Chan (Treasurer). Axel Cima was re-elected as President and Arka Sahu became Vice President. The outgoing committee members Acacia Clark (Vice President), Alex Farrar (Treasurer) and Max Hohl (Secretary) are thanked for their tremendous efforts over the previous year.

Field trip

The 2023 field trip to South Australia, organised by the CODES SEG Student Chapter in collaboration with the University of Adelaide's Student Chapter, was an incredibly enriching experience that left an indelible mark on our understanding of geology and exploration. The total of 21 participants on this trip included eight students from the University of Adelaide and two industry participants from First Quantum Minerals.

With a primary focus on Gawler's craton geology and iron oxide-copper-gold (IOCG) systems, the trip was an immersive journey into the world of mineral exploration and geological phenomena. One of the highlights of the trip was the opportunity to visit several mines, including the iconic Olympic Dam (Cu-Au-Ag-U), Prominent Hill (Cu-Au) and Kanmantoo (Cu).

These visits allowed us to witness firsthand the geological complexities and mineral deposits associated with IOCG systems. Exploring these mines was not only educational but also awe-inspiring, providing a deep appreciation for the intricate interplay of geological forces that shape our planet's resources.

The group participated in two networking events. The first, sponsored by the Australian Institute of Geoscientists (AIG), connected us with professionals and experts in the field. The second, organised by the SEG, offered a platform for knowledge exchange and forging valuable connections with fellow students from the University of Adelaide.

Among the standout aspects of our trip was the visit to the Fleet Space Technologies facility, where we were introduced to cutting-edge technologies poised to revolutionise exploration practices in Australia. This not only expanded our horizons but also served as an icebreaker, fostering camaraderie and connections among participants.

It is essential to extend our gratitude to the SEG and to First Quantum Minerals, for their unwavering support. Without their generosity, this incredible learning opportunity would not have

been possible. Moreover, we would like to thank all the involved parties including the South Australia SEG Student Chapter, Fleet Space Technologies, AIG, BHP and Hillgrove Resources. We also had the support of Dr Jeffrey Steadman, one of our CODES/UTAS experts on the Gawler Craton and IOCG systems, who joined us during the trip and gave insights to understanding these deposits.

Networking and social events

The Chapter actively co-hosted multiple BBQs, which served a dual purpose of generating funds to support SEG activities, such as regular monthly meetings and social events, as well as providing opportunities to socialise. In addition, the SEG CODES Student Chapter ran two networking events hosting Amira sponsors during the Amira Sponsors' Review Meetings in July and December. These events proved invaluable in facilitating interactions with industry representatives from some of the world's most prominent mining companies. One of these events was exclusively for the RRC – Critical Metals project participants, a group central to the majority of operating mines and prospects in Tasmania.

The Chapter also hosted two welcoming BBQs for UTAS staff and Earth Sciences students. To add a more casual and laid-back touch, a karaoke night allowed students to socialise in a relaxed and informal environment. Other social events held by the Student Chapter included welcome BBQs for Honours and first-year students as well as a Party Bus outing and drinks at a local watering hole.

Lectures and meetings

As in the previous year, the SEG Student Chapter hosted an Evolution Mining recruiting session in March (with Ned Howard), followed by a networking BBQ, as well as a hyperspectral workshop in April (run by Lejun Zhang and Jake Moltzen) and an ioGAS workshop in August (run by former SEG president, Zebedee Zivkovic).

The hyperspectral workshop delved into the world of reflectance spectroscopy and its wide-ranging applications in economic geology. The sessions were not merely theoretical; they included hands-on experience, where students were taught how to effectively utilise tools such as Terraspec, portable FTNIR and TSG software.

CODES SEG Student Chapter President in 2023, Axel Cima (left), with CODES SEG Social Media Officer Angela Costa attending one of the Amira P1249 networking gatherings at the CODES offices in Hobart.

During the ioGAS workshop, students were introduced to the fundamentals of ioGAS software, and exposed to more advanced tools and techniques for handling geochemical data.

These talks and workshops not only enriched our students' knowledge but also equipped them with practical skills and career insights that are invaluable in the field of geology and the mining industry.

Finances and fundraising

The Chapter operated using the accumulated funds from many years of fundraising events within CODES. It was successful in securing a grant from the SEG Stewart R. Wallace Fund in 2023, which helped fund the 2023 field trip to South Australia. And the Chapter continued to sell a variety of geological field equipment, such as hammers, hand lenses etc. in order to raise funds and introduce the Chapter to new incoming students.

Future plans

After the successful 2023 field trip to South Australia and mine visits at Olympic Dam, Prominent Hill and Kanmantoo, the Student Chapter set its main objectives for 2024 at its AGM. One of the most significant ideas is related to a Japan–South Korea fieldtrip in the context of the IGC Korea 2024 conference, where we would potentially have not only support from CODES Director Professor David Cooke and researcher Dr Lejun Zhang but also collaboration with Lakehead University SEG Student Chapter students.

A smaller trip to the crocoite mine at Dundas will also be discussed in order to integrate new members in early 2024, as well as talks and workshops proposed and given by experienced PhD students.

▶ LOOKING FORWARD

With 35 PhD students currently enrolled it looks to be an exciting year ahead for CODES research. Our students are conducting projects in 14 sites within Tasmania, six locations on mainland Australia and 18 international sites.

The CODES SEG Student Chapter is planning a field trip to Japan for interested students in the second half of 2024, and there are several fieldwork trips to international locations planned, including to Spain, South Africa and Santorini in Greece. In addition, many of our PhD students will be attending conferences both in Australia and overseas, including the SEG Conference, which will be held in Namibia in 2024.

Outreach and media

Outreach continues to be an important activity for the team at CODES/Earth Sciences, and 2023 included another busy schedule of visits to schools, community events and visits by students to the geology facilities at the Sandy Bay campus.

Taking into account the larger events attended by CODES/Earth Sciences, outreach activities in 2023 were seen by more than 6,200 students and members of the public. This was a huge effort by the CODES/Earth Sciences staff and students involved – and we extend a big thank you to all of them.

In May there was a huge turnout for Agfest in the north of the state, and Rosie the CODES dinosaur was busy attracting attention to the Earth Sciences/CODES stall.

Agfest

In 2023 Agfest made a return to its autumn slot in the calendar, running from 4–6 May at Quercus Park near Carrick in northern Tasmania. CODES PhD students Axel Cima and Chris Allen, and Honours student Harrison Keeble represented CODES at this event. Around 50,000 people attended Agfest with around 1,000 people visiting the Earth Sciences/CODES stall. Rosie, one of the CODES dinosaurs, made a strong impression as she roamed the grounds under bright blue skies and invited young and old to greet her.

Beaker Street Festival

In 2023 the Beaker Street Festival, which is described as a 'week-long celebration of science in lutruwita/Tasmania' ran in August for the eighth time. CODES PhD student Angela Costa, who is studying the tungsten skarn systems on King Island, took part in the Beaker Street Science Photography Prize, entering her photo of a boulder from the Dolphin open pit at Grassy. It shows the tungsten-molybdenum mineralisation within the rock using ultraviolet light. Her photo was chosen to be featured throughout the festival as she won the category in which it was entered.

EDGE Radio

CODES PhD student Hannah Moore was part of the team that runs Tasmania's Edge Radio podcast *That's*

LEFT: The Beaker Street Festival in August provided an opportunity for CODES PhD student Angela Costa to showcase her work on the tungsten skarn system on King Island; she is pictured here with her entry in the Beaker Street Science Photography Prize competition. RIGHT: CODES PhD student Hannah Moore (far left) was part of the team that runs Tasmania's Edge Radio podcast That's What I Call Science! *The TWICS team was recognised for its achievements in spreading the word about science by winning the 2023 Eureka Prize for STEM Inclusion. The other team members were (L–R): Kate Johnson, Katya Bandow, Georgia Stewart, Anna Abela and Olly Dove.*

What I Call Science! (TWICS), which aims to increase the representation of diverse voices in the sciences. During 2023 she was busy playing an important presenting and organising role for the team. All episodes are released on Edge Radio in Hobart and are available across all major podcast platforms. The TWICS team was recognised for its achievements in spreading the word about science by winning the 2023 Eureka Prize for STEM Inclusion. Well done to Hannah and the rest of the team on this huge achievement!!

It Takes a Spark! STEM conference

On 1 September Professor Sebastien Meffre took part in the large event that is 'It Takes a Spark!' – a gathering of science teachers and students across a wide range of science topics from health to AI and including, of course, rocks and minerals. The event was hosted by Guilford Young College in Hobart.

Sebastien's sessions, aimed at students in Years 8 to 10, were called 'Tasmanian minerals, electric cars and solar panels' in which he talked about Tasmania's complex geology and the relationship between geology and mineral deposits right through to the end use for these minerals in society. Around 100 students were involved in, and inspired by, the sessions that Sebastien ran.

CODES PhD student Emmanuel Dogara Musa gives a presentation about his research into the Kara Fe-W skarn deposits at the UTAS/CODES Mining Roadshow, held in June at Zeehan.

Launceston Gem and Mineral Show

This event took place over two days in November with CODES PhD student Chris Allen hosting the CODES/Earth Sciences stand, and an estimated 1,000 people visiting the exhibit.

Mining Roadshow

UTAS/CODES held a Mining Roadshow on the West Coast of Tasmania as part of the Regional Research Collaboration (RRC) commitment to outreach and engagement. The show travelled to Zeehan and Burnie in early June. Key topics discussed included the job opportunities in mining, and how mining is adapting to be more environmentally sustainable.

Both events included a great mix of presentations by eight CODES RRC PhD students and an industry panel, with fantastic attendance across both events. Dr Owen Missen said that 'Many people commented on the great team we have brought together at CODES'.

Participants and organisers of the UTAS/CODES Mining Roadshow held in early June are pictured in the Gaiety Theatre at Zeehan following the successful evening of presentations by CODES PhD students and ensuing audience discussions.

School visit and trips

In 2023 CODES/Earth Sciences continued its program of educational visits with staff and PhD students travelling to schools and colleges across the state. CODES/Earth Sciences also hosted a number of school groups for tours of the geology facilities on the Sandy Bay campus.

Among the many educational visits that took place were:

- 16 February: Professor Sebastien Meffre visited the Zeehan Primary School and talked to students about rocks and minerals.
- 30 May: PhD student Zeb Zivkovic conducted a volcano learning session at Blinking Billy Point for Year 4 students from Friends School.
- 27 July: Dr Francisco Testa ran a school leavers' master class for Year 9 students at Newstead College in Launceston.
- 3 November: PhD students Alfredtina Appiah and Nelao Natukondje Naimbale, and Professor Sebastien Meffre ran a 'Microscopes, timescale, minerals and mining' session for Year 8 students from Mackillop College on the Sandy Bay campus.

The Royal Society of Tasmania

In September 2023 Dr Michael Roach gave a lecture to the Society entitled 'Making it "Real": Geological Visualisation Methods for Research, Education and Public Outreach'.

Dr Roach is a pioneer in the application of emerging digital visualisation methods for use in geoscience research and education. See the lecture on YouTube at: https://rst.org.au/view-lecture-michael-roach-sep2023/

CODES staff member Dr Francisco Testa talks to a group of Newstead College students during an outreach tour of the geology facilities at the Sandy Bay campus in 2023.

The Rock Library

CODES/Earth Sciences Rock Curator Izzy von Lichtan was pleased to assist the Bass Strait Maritime Centre based in Devonport with an exhibition looking at the history of minerals and their influence in the area of Tasmania adjacent to the Bass Strait. The exhibition, titled 'Strait: Metals, Minerals and Mining Along the Strait' ran from 8 May–8 July 2023.

Izzy provided four large boxes of specimens including rocks, ores and glass flasks filled with Bass Strait oil, together with background information. UTAS was an exhibition sponsor along with Group 6 Metals, which is working with CODES on the current RRC project.

A highlight for the collection was a visit in late February 2023 by Dr Nicolás Campione and Dr Russell Bicknell, both from the Palaeoscience Research Centre, University of New England. They were here on a week-long visit to Tasmania to examine the Triassic vertebrate material, especially the type material, held within the UTAS and TMAG collections. The trip also included field excursions to the type locations and venturing to areas previously not listed to have fossil material, but with rocks of a similar age. Excitingly small fragments of fossil were found.

This trip was a precursor to further research to be done on the type material held in the UTAS collection utilising new preparation and analysis techniques, including use of the Australian Synchrotron.

The West Coast Heritage and Minerals Fair in November attracted a large number of interested locals and potential geology students. Here Dr Owen Missen from CODES engages with one of the many visitors to the event in Zeehan.

UTAS Open Days 2023

The Sandy Bay campus Open Day was held on 17 September; the Inveresk campus Open Day was on 1 October. Here at Sandy Bay, Professor Sebastien Meffre ran tours of the Earth Sciences and CODES buildings and there was a minerals and microscopes session, as well as the usual stall staffed by our PhD students.

UTAS STEPs Program

As part of this ongoing outreach program to the West Coast of Tasmania facilitated by Regional Learning Office (West Coast) Belinda Martin, CODES and Earth Sciences staff and students held an information presentation for then-Deputy Vice Chancellor (Academic) Martin Grimmer at the Study Hub West Coast. In addition, Professor Sebastien Meffre and CODES visiting Masters student Janne Scheffler gave a presentation to Zeehan Primary School students.

West Coast Heritage and Minerals Fair

The weekend of 11–12 November saw CODES postdoctoral researcher Owen Missen head out to Zeehan to run the CODES stall along with UTAS Regional Learning Officer for the West Coast, Belinda Martin.

Professor Sebastien Meffre (right) and Professor Sharon Fraser from the School of Education were kept busy running the Earth Sciences/CODES stall at the Zeehan Careers and Study Expo Pilot in early September.

Apart from the amazing specimens of rock (including large pieces of King Island scheelite ore, sample Cygnet porphyry, high-grade galena specimens and a range of polished pieces from Hellyer mine) visitors to the stall were treated to CODES rock sweets and other giveaways including polished rocks from the 'Gemnasium'.

Zeehan Careers and Study Expo Pilot

This event, held in September at the Study Hub West Coast, was run by Professor Sebastien Meffre and Professor Sharon Fraser (from the School of Education and one of the leads in the CODES Regional Research Collaboration (RRC) critical metals project). It attracted a huge

Friday, 31 March 2023

RENEWABLES TRIPLE TREAT

AVEBURY NICKEL MINES ELECTRIC OPPORTUNITIES

We're aiming to produce as much as we can while keeping to our principles of being clean and low impact

JOHN LAMB

Day 4: Mining for the future

Professor Sebastien Meffre contributed to a story on the future of mining in Tasmania in The Mercury *(March 2023).*

crowd of interested locals and tourists. The RRC project, which is focussed on research into the discovery and processing of critical metals, and how the local community can benefit from this, was showcased.

Media

A selection of media involving CODES/Earth Sciences topics in 2023:

PRINT

Sebastien Meffre: Sebastien quoted in a *Mercury* article on 'Mining for the Future' feature, March 2023.

TV

Sebastien Meffre and Matthew Cracknell: Channel 7 TV Nightly News, November 2023. Sebastien and Matt were filmed in the MRT core facility at Mornington during the announcement of new drilling leases in Tasmania, with Matt talking about the importance of the core facility to CODES' research and teaching work.

RADIO

A selection of radio interviews given by CODES/Earth Sciences staff during the year:

Rebecca Carey:

- ABC Radio with Suzanne Hill (21 July): undersea volcanoes
- ABC Radio Sunshine Coast (5 December): Mount Marapi

CODES was mentioned in November on Channel 7's Nightly News in a story about newly announced drilling grant leases in Tasmania. Professor Sebastien Meffre and Dr Matthew Cracknell were filmed in the MRT core facility at Mornington, with Matt talking about the importance of the core facility to CODES' research and teaching work.

- ABC News Radio (4 December): Mount Marapi
- ABC Radio Sydney (6 December): the Indonesian volcano eruption at Mount Marapi

Owen Missen

- ABC Northern Tasmania, Breakfast (7 June): critical metals in Tasmania
- ABC Radio Hobart (31 October): Young Ologist feature, talking about his work as a mineralogist

Jeff Oalmann:

- ABC Radio Hobart (23 October): Ologist feature, talking about working as a geochronologist

Industry links

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 is a key strategic focus.

Dr Alan Kobussen from Rio Tinto talks with CODES PhD student Isaac Evinemi during a tea break while attending the P1249 Amira Sponsors' Review Meeting held in December 2023.

Industry links and synergies

CODES has strong, enduring and mutually beneficial links with a group of major Australian and international mining companies. These links have been and continue to be critical for funding CODES' research, and for technology transfer to the mining and mineral exploration community. In 2023, the group of CODES' Industry Partners comprised of seven Australian and international mining companies: Anglo American, AngloGold Ashanti, Barrick, First Quantum Minerals, Mount Isa Mines (Glencore), Newcrest Mining and Rio Tinto.

Partner companies have been providing support of up to $60,000 in cash per year to the core research budget of the Centre. Gold and Platinum Partners are also offered a seat on the CODES Advisory Board, which meets at least annually to discuss the strategic direction of the Centre.

Representatives of these companies are invited to the CODES Annual Review, along with other government and university researchers. The Annual Review showcases the breadth of research undertaken at the Centre through a day of oral and poster presentations for our stakeholders, and offers the opportunity to influence future research directions. In 2023 to mitigate ongoing workload issues no Annual Review was held.

Industry partnership opportunities

CODES offers partnership opportunities aligned to the evolving needs of mining companies. The minerals industry is cyclical by nature, and operating conditions can vary greatly from one year to the next, often through unforeseen circumstances.

Dr Anil Subramanya, General Manager Australasia of Amira Global, addresses an audience of CODES researchers and other staff during his visit to CODES in April 2023.

For this reason, our partnership opportunities are offered on an annual basis, giving partners the flexibility to adjust their involvement in line with their current operating conditions and research requirements. Funding levels are tailored to suit all levels of operation, from junior explorers through to the large multinationals. Companies may sign up at the Silver ($20K), Gold ($40K) or Platinum ($60K) level, depending on their planned level of involvement with the Centre. Benefits of a partnership agreement vary depending on the level of investment, but 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.

CODES offers partnership opportunities aligned to the evolving needs of mining companies.

Further details can be found at: https://www.utas.edu.au/codes/about-us/industry-partnership-program

Role of Amira Global

Amira Global plays a vital role in facilitating the funding of collaborative research involving university research groups and the minerals industry. Amira funds projects within the Centre, which run over a period of one to five years. In 2023 it continued to fund the five-year project – Amira P1249 'Exploring, characterising, and optimising complex orebodies – upscaling orebody knowledge to add value across the mining value chain'.

Research collaborations

In 2023, CODES continued its reputation for cultivating research collaborations with other Australian and international research organisations. Throughout the year, collaborative research was conducted with 69 international and 20 national organisations.

CODES Industry Partners 2023

PLATINUM

GOLD

SILVER

Technology transfer

A presentation in progress during the Amira Sponsors' Meeting in December 2023, which was held at CODES.

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 ore deposits (characterisation and context) and geometallurgy, and the development of innovative enabling 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 2023, 287 research reports were presented to industry clients. Meetings were also held to present and discuss progress and adoption of research results.

Projects that delivered significant technology transfer objectives during 2023 included:

- a new software package developed by Dr Sheree Armistead and collaborators to model Pb isotope evolution curves and to calculate model ages. This was published as a paper titled 'PbIso: an R package and web app for calculating and plotting Pb isotope data' in the *Canadian Journal of Earth Sciences*.
- a 3D visualisation for the Kara mine developed by Dr Michael Roach and others was assembled and shown for the first time at the RRC sponsors' meeting in July 2023.

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.

The following publications were sold during 2023:

- *Altered volcanic rocks: A guide to description and interpretation* (2005). Authors: C. Gifkins, W. Herrmann and R. Large (23 copies).
- *Geophysical signatures of copper-gold porphyry and epithermal gold deposits, and implications for exploration* (2011). Author: T. Hoschke (18 copies).
- *The geology of the Broken Hill Pb-Zn-Ag deposit, NSW, Australia* (2006). Author: A. Webster (1 copy).
- *Volcanic textures: A guide to the interpretation of textures in volcanic rocks* (1993). Authors: J. McPhie, M. Doyle and R. Allen (27 copies).
- *24ct Au workshop. CODES Special Publication 5* (2004). Editors: D. Cooke, C. Deyell and J. Pongratz (1 copy).

The Amira Sponsors' Meeting in December 2023 was an important networking opportunity; here Dr Wei Hong points out details on his project poster during a break in proceedings.

CODES-led short courses, workshops, conferences and field trips for end-users

By 2023 all COVID restrictions had been lifted and face-to-face courses, workshops and conferences could be held both here and overseas. They continued to play a key role in the Centre's technology transfer activities. However, one legacy of the COVID pandemic has been the preference for some participants to teach and learn online, meaning that online offerings are now a permanent feature of CODES offerings. During 2023 a total of 23 technology transfer events were held.

Total attendance by industry geologists, academic researchers and postgraduate students was approximately 600 with 47 presenters, including PhD and MSc students, from CODES involved in delivering the courses or leading the conferences or field trips.

2023 SHORT COURSES, WORKSHOPS, CONFERENCES AND FIELD TRIPS LED BY CODES

TITLE	PRESENTERS	NO.	LOCATION	DATE
Advanced Field Skills in Economic Geology (MEconGeol short course)	**Robert Scott, Francisco Testa, Emrecan Yurdakul, Lejun Zhang**	22	Western, eastern and northeastern Tasmania	12–25 February
Exploration Field Skills Mapping Camp (VIEPS)	**Robert Scott, Francisco Testa, Lejun Zhang**	24	Hobart/western Tasmania	13–20 February
Ores in Magmatic Arcs – Indonesia (MEconGeol short course)	**David Cooke,** Adi Maryono, Iryanto Rompo, **Lejun Zhang**	21	Indonesia	12–24 March
Fundamentals of Economic Geology (MEconGeol short course)	**Mike Baker,** Tim Callaghan, **David Cooke,** Scott Halley, Cassady Harraden, Larry Meinert, **Michael Roach, Robert Scott, Francisco Testa, Noel White, Lejun Zhang**	45	Online	17–22 April AND 8–12 May
Ore-forming processes in hydrothermal systems – implications for ore genesis and exploration (proEXPLO 2023 pre-conference workshop)	**David Cooke**	35	Lima	7 May

TITLE	PRESENTERS	NO.	LOCATION	DATE
Antamina–Hilarión Project (proEXPLO 2023 post-conference field excursion)	**David Cooke,** Lisard Torró	13	Peruvian Andes	11–14 May
Ore Deposit Geochemistry, Hydrology and Geochronology (MEconGeol short course)	**Sheree Armistead, Mike Baker, Ivan Belousov,** Phil Blevin, **David Cooke, Matthew Cracknell, Alex Farrar,** Scott Halley, **Wei Hong, Sebastien Meffre, Jeff Oalmann,** Nick Oliver, **Robert Scott, Jeff Steadman,** John Walshe, Lesley Wyborn, **Lejun Zhang**	41	Online and face-to-face, CODES	29 May–3 June AND 3–7 July
RRC Mining Roadshow Workshops	**Alfredtina Appiah, Yamila Cajal, David Cooke, Angela Costa, Vinicius da Cruz, Jose Barillas Diaz, Emmanuel Dogara Musa, Owen Missen, Nelao Natukondje Naimbale Javier Gil Rodriguez, Emrecan Yurdakul**	64	Zeehan, Burnie	7–8 June
Amira P1249 Sponsors' Review Meeting 3	Laurent Aillères, **Mike Baker, Ivan Belousov, David Cooke, Stephen Cooke, Matthew Cracknell, Leonid Danyushevsky,** Mitch Marcelissen, **Javier Merrill,** Angela Rodriguez, **Markus Staubmann,** Olga Verezub, **Lejun Zhang**	25	CODES	13–14 June
Fourier transform-near infrared (FT-NIR) and Fourier transform infrared (FTIR) spectroscopy workshop	Thomas Rodemann	15	CODES	14 June
Geodata Analytics (MEconGeol short course)	**Matthew Cracknell, Isaac Evinemi, Alex Farrar,** Michael Gazley, Eric Grunsky, June Hill, Shawn Hood, John Thompson, McLean Trott	43	Online	7 August–16 September AND 18–22 September AND 25 September–15 October
Environmental Geology Field Techniques (VIEPS)	Matthew Cracknell, Owen Missen	4	CODES, Hobart and western Tasmania	?? August
Amira P1249 Technology Transfer Workshop at SEG Conference	**David Cooke**	8	London	25 August
CODES SEG Student Chapter Field Trip to South Australia	Stephen Barber, Chris Booth, **Isaac Brown, Angela Costa, Vinicius da Cruz,** Rian Dutch, Adrian Fabris, **Alex Farrar,** Jack Fraser, Georgina Gordon, Dale Groom, Graham Heinson, Jose Hernandez, Peter Hill, James Livesey, Cecilia Loyola, Tom Raimondo, Anthony Reid, Caitlin Rowell, **Victor Torres,** Max Verdugo, Claire Wade, Jie Yu, **Zebedee Zivkovic**	21	South Australia	5–11 October
Amira P1249 update workshop for Rio Tinto	**David Cooke**	10	Santiago	11 October
Amira P1249 update workshop for Anglo American	**Yamila Cajal, David Cooke, Jaime Osorio,** José Piquer	10	Santiago	12 October
Amira P1249 update workshop for CODELCO	**Yamila Cajal, David Cooke, Jaime Osorio,** José Piquer	30	Santiago	13 October
Amira P1249 Calculated Mineralogy (Pedras) and Mineral Texture Clustering Workshop	**David Cooke, Matthew Cracknell, Isaac Evinemi**	10	Santiago	16 October
Geometalllurgy (MEconGeol short course)	Natalee Bonnici, Sefton Derby, Laurence Dyer, Kathy Ehrig, Karyn Gardner, David Green, Scott Halley, Tobias Hermansson, **Julie Hunt,** Verity Kameniar-Sandery, Toni Kojovic, **Rob Scott,** Bill Staunton	15	CODES	16–27 October
Ores in Magmatic Arcs – South America (MEconGeol short course)	**Yamila Cajal, David Cooke, Jaime Osorio,** José Piquer, **David Portocarrero, Victor Torres**	24	Chile, Peru	25 October–11 November
Tasmanian Critical Metals Workshop	**Christopher Allen, Alfredtina Appiah, Sheree Armistead, David Cooke, Angela Costa, Vinicius da Cruz, Emmanuel Dogara Musa, Mohammad Fathi,** Sharon Fraser, **Javier Gil,** Jane Hall-Dadson, **Wei Hong, Julie Hunt, Owen Missen, Nelao Natukondje Naimbale,** Thomas Rodemann, **Emrecan Yurdakul, Lejun Zhang**	50	Tullah	30 November
Amira P1249 Sponsors' Review Meeting 4	**Fuseini Atanga, Mike Baker, Billy Beas, Ivan Belousov,** Jeff Bigelow, Alex Brown, **Axel Cima, Takeshy Coaquira, David Cooke, Stephen Cooke, Matthew Cracknell,** Iain Dalrymple, **Jason Dyer, Isaac Evinemi,** Bright Foli, Scott Halley, Peter Hollings, **Wei Hong, Harrison Keeble, Jaime Osorio,** José Piquer, **Xin Ni Seow, Arka Sahu, Markus Staubmann, Jeff Steadman, Nafiu Sulyman, Chase Turner, Lejun Zhang**	29	CODES	6–7 December
LocatOre workshop	**Stephen Cooke**	20	CODES	7 December

Performance indicators

PERFORMANCE MEASURES

	TARGET	2023
Research Findings (CODES and Earth Sciences)		
Publications in international journals	50pa	41
Percentage of publications in high-quality international journals	70%	58%
Reports to industry collaborators	80pa	287
Special issues and/or research monographs	1 per 2 years	0
Invitations to give keynote conference presentations	10pa	4
Papers at national/international meetings	70pa	39
Research Training and Professional Education		
Percentage of HDR students attracted from interstate	25%	15%
Percentage of HDR students attracted from overseas	65%	67%
Number of Honours students in CODES' programs	15	7
Number of HDR students in CODES' programs	50	48
Percentage of students in projects linking with industry	80%	76%
Professional short courses/workshops for industry	4pa	23
International, National and Regional Links and Networks		
CODES' national or international conferences/workshops	1 per 2 years	1
Registrants at CODES' conferences/workshops	600pa	~600
End-user Links		
Frequency of meetings with industry representatives	15pa	50+
National Benefit		
CODES' research has input into a major mineral discovery	1 per 5 years	9 in 31 years

Buenaventura's new Yumpag carbonate-hosted Ag mine on the flanks of a large Miocene intrusion into limestones in the Central Peruvian Andes; CODES ran the 'Ores in Magmatic Arcs' Masters short course to Chile and Peru in late 2023 (Photo: David Cooke).

Finances

2023 income

Total CODES income was $7.8 million (see Table 1). This was derived principally from UTAS (28%), Contracts/Consultancies/Revenue Raising (24%), and the combined income sources of the Regional Research Collaboration Project (22%) (see Figure 1). The main income streams over time are compared in Figure 2, showing an increase in overall income to CODES in 2023 when compared to 2022. This increase occurred with the initiation of funding to the Regional Research Collaboration, as well as an increase in support from UTAS in the scholarships and tuition fee waiver space. All other categories showed small to moderate decreases, partially offsetting the new funding levels related to the Regional Research Collaboration.

Summary of the main income streams to CODES in 2023:

- **Host institution support:** Funding from UTAS in 2023 was $2.2 million, up from $1.8 million in 2022, attributable to a marked increase in PhD scholarship funding (living and tuition fee) from central sources, due to the commencement of PhD candidates working within the Regional Research Collaboration, and other major research projects in CODES. UTAS funding relates primarily to research salaries, PhD scholarships and income earned by the Centre from research output.
- **Contracts/Consultancies/ Revenue Raising:** Combined funding of $1.9 million comprises funding related to Short Courses ($368k), Analytical Services ($1.5 million) and Book Sales ($9k).
- **Regional Research Collaboration Project:** The combined income sources for the RRC amounted to $1.7 million in 2023, comprising of funding from the Department of Education ($1.7 million), and other sources including interest and additional project support ($36k).

TABLE 1: CASH INCOME FINANCIAL STATEMENT 2023

ARC Grants	
Discovery Grants	87,776
	87,776
Regional Research Collaboration – Critical Metals	
Department of Education	1,700,000
Other Project Support	16,875
Miscellaneous (incl interest)	19,097
	1,735,972
Other Commonwealth Government	
Specific Projects	492,338
	492,338
State Government	
Specific Projects	10,000
Student Projects	8,800
	18,800
Industry/private	
Amira Global Projects	794,736
CODES Industry Partners	265,000
Directly Funded Research Projects	219,089
Directly Funded Student Projects	125,200
	1,404,026
Contracts/consultancies/revenue raising	
Short Courses	367,732
Book Sales	9,255
Miscellaneous (incl. Analytical Services)	1,475,783
	1,852,770
University of Tasmania – host institution support	
Operating Grant	838,882
Scholarships and Tuition Fee Waivers	1,381,530
Strategic Projects	4,450
	2,224,862
Other income sources/interest	
Student Support	8,112
Miscellaneous	2,832
	10,944
Total annual income	**7,827,487**

FIGURE 1:

Total Cash Income 2023

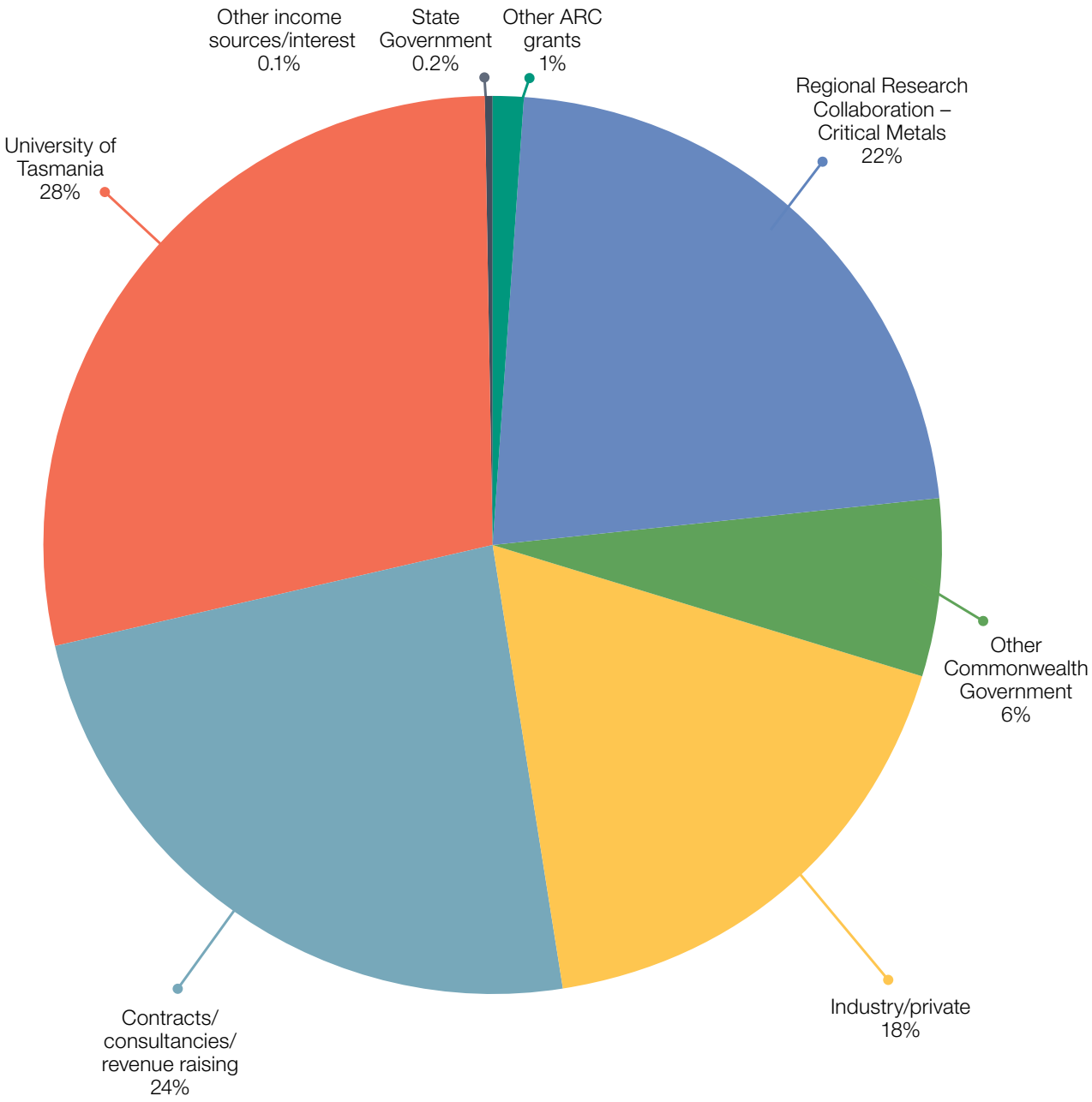
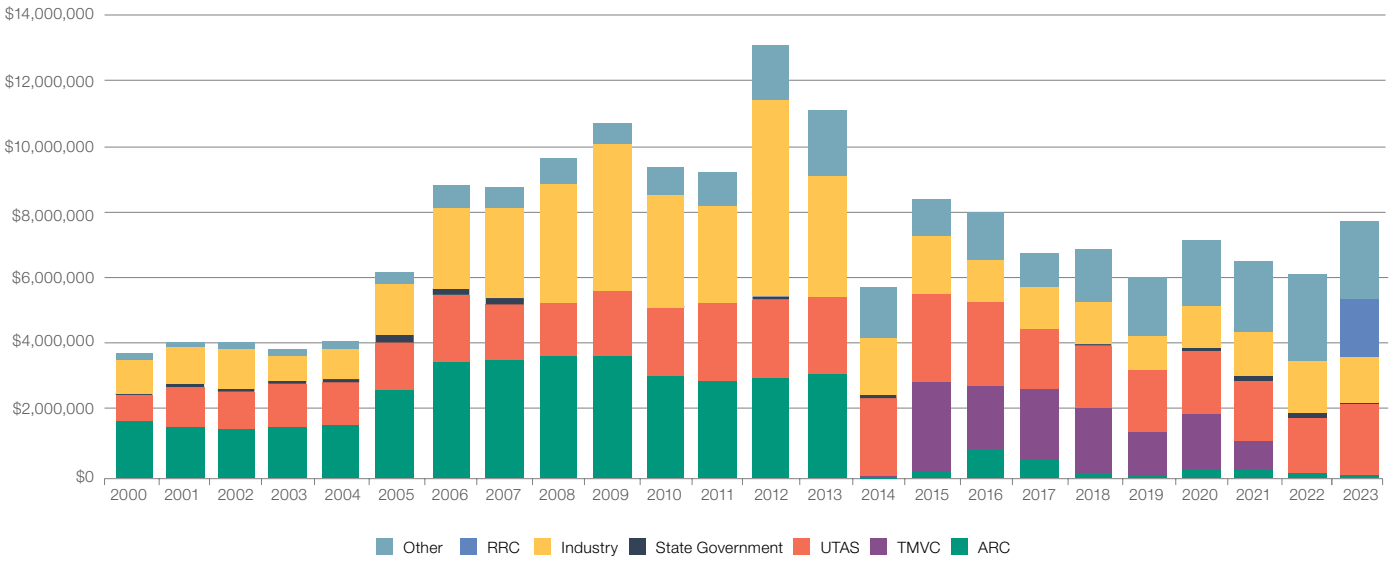


FIGURE 2:

Comparison of CODES main income streams 2000–2023



2024 income estimates

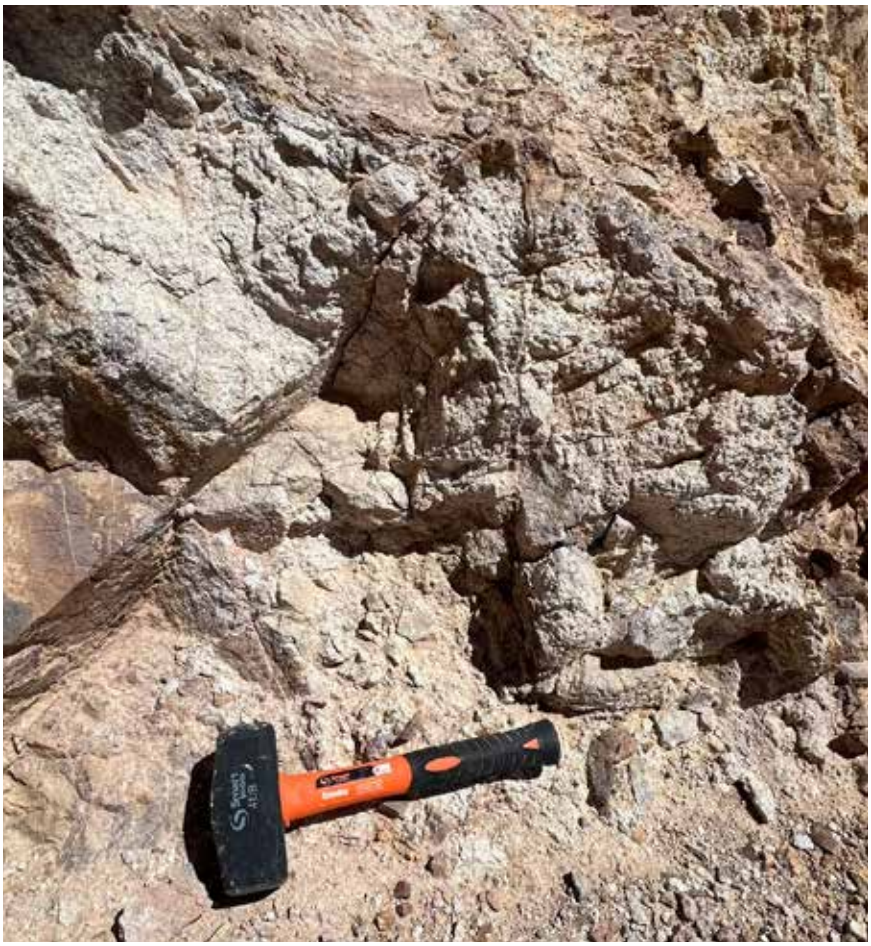
Funding to CODES in 2024 is expected to be at a similar level when compared to 2023. Primary streams will continue to be represented by UTAS, in the form of scholarships and tuition fee waivers, external funding of predominately existing research projects, and sustained external use of the CODES Analytical Laboratories.

Notes to, and forming part of, the financial statements for 2023

The financial pages of this Annual Report were prepared by Helen Scott (Project Administration Manager). Data for the financial statements was extracted from UTAS systems, particularly its Finance System.

Income statement explanations

The income figures in Table 1 represent actual income recorded in the University's finance system, transferred internally from UTAS to CODES during 2023, or centrally administered for CODES RHD students (as in the case of scholarships and tuition fee waivers).



Publications 2023

Refereed journal articles (41)

Archibald, D.B., Collins, A.S., **Armistead, S.E.,** Foden, J.D., Payne, J.L., and Razakamanana, T., 2023, Zircon U–Pb, oxygen and hafnium isotopic characteristics of the Neoarchean–Paleoproterozoic Betsiboka Suite, Madagascar: tracing source to sink pathways in Proterozoic and Phanerozoic provenance studies: Geological Society London Special Publications, v. 531, p. 189-206.

Armistead, S.E., Eglington, B.M., and Pehrsson, S.J., 2023, PbIso: an R package and web app for calculating and plotting Pb isotope data: Canadian Journal of Earth Sciences, doi. org/10.1139/cjes-2023-0029

Belousov, I., Danyushevsky, L., Goemann, K., **Gilbert, S., Olin, P.,** Thompson, J., **Lounejeva, E.,** and Garbe-Schoenberg, D., 2023, STDGL3, a reference material for analysis of sulfide minerals by Laser Ablation ICP-MS: An assessment of matrix effects and the impact of laser wavelengths and pulse widths: Geostandards and Geoanalytical Research, v. 47(3), p. 493-508.

Crow, M., **Khin Zaw,** Kyaw Thu, **Belousov, I.,** and Goemann, K., 2023, A review of new detrital zircon U-Pb ages from the Mogok area of Myanmar: Implications for the stratigraphy and early tectonic evolution of the Mogok Metamorphic Belt (MMB): Earth-Science Reviews, v. 242, Article 104441.

Cui, H., Deng, Y., Zhong, R., Li, W., Yu, C., Danyushevsky, L.V., **Belousov, I.,** Li, Z., and Wang, H., 2023, Determining the ore-forming processes of Dongshengmiao Zn-Pb-Cu deposit: Evidence from the linear discriminant analysis of pyrite geochemistry: Ore Geology Reviews, v. 163, Article 105782.

Cui, H., Zhong, R., Li, W., Yu, C., **Danyushevsky, L.V., Belousov, I.,** Liu, C., and Li, Z., 2023, Revealing the orogenic genesis of Huogeqi Cu-Pb-Zn deposit: Evidence from the machine learning-based data interpretation of pyrite geochemistry: Ore Geology Reviews, v. 154, Article 105350.

Dauad, H., Endut, Z., Ismail, S., Aminuddin, M.I.K.A., and **Makoundi, C.,** 2023, Characterization of polymetallic-gold deposit of eastern Manson's Lode, Ulu Sokor, Kelantan: Malaysian Journal of Microscopy, v. 19(2), p. 196-207.

Del Mouro, L., Becker-Kerber, B., Janasi, V.A., de Araújo Carvalho, M., Waichel, B.L., Lima, E.F., Rossetti, L.M.M., **Cruz, V.,** Souza Silva, M., Famelli, N., and Ortega-Hernández, J., 2023, Organic walled microfossils in wet peperites from the early Cretaceous Paraná-Etendeka volcanism of Brazil: Scientific Reports, v. 13, Article 15362.

Fauria, K.E., **Jutzeler, M.,** Mittal, T., Gupta, A.K., Kelly, L.J., Rausch, J., Bennartz, R., Delbridge, B., and Retailleau, L., 2023, Simultaneous creation of a large vapor plume and pumice raft by the 2021 Fukutoku-Oka-no-Ba shallow submarine eruption: Earth and Planetary Science Letters, v. 609, Article 118076.

Farrar, A.D., Cooke, D.R., Hronsky, J.M.A., Wood, D.G., Benavides, S.B., **Cracknell, M.J.,** Banyard, J.F., Gigola, S., Ireland, T., Jones, S.M., and Piquer, J., 2023, A model for the lithospheric architecture of the Central Andes and the localization of giant porphyry copper deposit clusters: Economic Geology, v. 118(6), p. 1235-1259.

Ford, A., Huston, D., **Cloutier, J.,** Doublier, M., Schofield, A., Cheng, Y., and Beyer, E., 2023, A national-scale mineral potential assessment for carbonatite-related rare earth element mineral systems in Australia: Ore Geology Reviews, v. 161, Article 105658.

Fox, J.M., McPhie, J., Carey, R.J., and Jourdan, F., 2023, Revised stratigraphy and first geochronology of the Miocene submarine volcanic succession at Kennaook/Cape Grim, northwestern Tasmania: Australian Journal of Earth Sciences, v. 70(4), p. 510-534.

Habib, U., Meffre, S., Berry, R., and Belousova, E., 2023, Provenance of lower Paleozoic sedimentary rocks in Tasmania and Waratah Bay, southern Victoria: constraints from detrital zircon hafnium isotopes and trace-element geochemistry: Australian Journal of Earth Sciences, v. 70(2), p. 175-188.

Jenkins, K., Goemann, K., **Belousov, I., Morissette, M.,** and **Danyushevsky, L.,** 2023,

Mine waste meets the harbour: Third-year students and members of the Strahan community stand on the King River delta underneath clearing skies. The delta contains a significant resource of copper and cobalt as it is formed by sediments derived from the Mt Lyell mine.

Investigation of the Ablation Behaviour of Andradite-Grossular Garnets and Rutile with Implications for U-Pb Geochronology: Geostandards and Geoanalytical Research, v. 47(2), p. 267-295.

Kaewpaluk, S., Salam, A., Assawincharoenkij, T., Manaka, T., Poompuang, S., Munsamai, S., and **Khin Zaw,** 2023, Geology, mineralization, and alteration of B Prospect of the epithermal Au-Ag deposit in Central Thailand: A study on Chatree's satellite deposit for future gold exploration: ScienceAsia, v. 49, p. 131-140.

Korneeva, A., Kamenetsky, V.S., Nekrylov, N., Kontonikas-Charos, A., **Kamenetsky, M.,** Savelyev, D., Zelenski, M., and Krasheninnikov, S., 2023, A melt inclusion approach to reconstructing sulfur contents and sulfide saturation of primitive basaltic melts: Lithos, v. 436-437, Article 106596.

Kutyrev, A., Kamenetsky, V.S., Kontonikas-Charos, A., Savelyev, D.P., Yakich, T.Y., **Belousov, I.A.,** Sandimirova, E.I., and Moskaleva, S.V., 2023, Behavior of platinum-group elements during hydrous metamorphism: constraints from Awaruite (Ni3Fe) Mineralization: Lithosphere, doi.org/10.2113/2023/lithosphere_2023_126

Li, X., Zhou, T., Fan, Y., Chen, J., **White, N.C., Zhang, L.,** Tang, M., Lin, X., Du, Y., and Zhang, Y., 2023, Geology and exploration indications of the lithocap in Qianpu area, Luzong Basin, Anhui: Ore Geology Reviews, doi.org/10.1016/j.oregeorev.2023.105811

Lounejeva, E., Steadman, J.A., Large, R.R., Grice, K., **Olin, P.,** and **Belousov, I.,** 2023, Lithogeochemical and sulfide trace-element systematics across the Permian-Triassic boundary, Perth Basin, Western Australia: constraints on the shallow marine environment during the end-Permian mass extinction: Australian Journal of Earth Sciences, v. 70(5), p. 716-730.

Makoundi, C., Endut, Z., and **Khin Zaw,** 2023, Geochemistry of the Devonian and Permo-Triassic black shales in Peninsular Malaysia: Insights into provenance, tectonic setting, and source rock weathering: Minerals, v. 13(7), Article 911.

Makoundi, C., Khin Zaw and Endut, Z., 2023, U-Pb dating, lead isotopes, and trace element composition of Pyrite hosted in Black Shale and Magmatic rocks, Malaysia: implications for Orogenic gold mineralization and exploration: Minerals, v. 13(2), Article 221.

Makoundi, C., Khin Zaw, Endut, Z., and Zabidi, H., 2023, Trace element composition of pyrite from selected black shale and chert exposures in the Central Belt of Peninsular Malaysia: implications for mineral exploration: Minerals, v. 13(6), Article 829.

McNulty, B.A., Gemmell, J.B., Davidson, G., and Fox, N., 2023, Integrated stratigraphy, lithofacies, and U-Pb geochronology of the Myra Falls VHMS deposits, British Columbia, Canada: implications for episodic volcanism and ore deposit formation: Mineralium Deposita, v. 58, p. 307-335.

Merrill-Cifuentes, J., Cracknell, M.J., and **Escolme, A.,** 2023, Rock hardness and copper recovery prediction using textural clustering: Minerals Engineering, v. 193, Article 108005.

Missen, O.P., Mills, S.J., Brugger, J., Birch, W.D., and Elliott, P., 2023, Crystal chemistry of zemannite-type structures: IV. Wortupaite, the first new tellurium oxysalt mineral described from an Australian locality: Mineralogical Magazine, v. 87(6), p. 908-915.

Morishita, T., Hnin Min Soe, Hla Htay, Than Htut Lwin, Guotana, J.M., Tamura, A., Mizukami, T., and **Khin Zaw,** 2023, Origin and Evolution of Ultramafic Rocks along the Sagaing Fault, Myanmar: Journal of Earth Science, v. 34, p. 122-132.

Moyo, A., Parbhakar-Fox, A., Meffre, S., and **Cooke, D.R.,** 2023, Alkaline industrial wastes – Characteristics, environmental risks, and potential for mine waste management: Environmental Pollution, v. 323, Article 121292.

Moyo, A., Parbhakar-Fox, A., Meffre, S., and **Cooke, D.R.**, 2023, Geoenvironmental characterisation of legacy mine wastes from Tasmania – Environmental risks and opportunities for remediation and value recovery: Journal of Hazardous Materials, v. 454, Article 131521.

Nascimento, S.C., Cooke, D.R., Townsend, A.T., **Davidson, G., Parbhakar-Fox, A., Cracknell, M.J.**, and **Miller, C.**, 2023, Long-term impact of historical mining on water quality at Mount Lyell, Western Tasmania, Australia: Mine Water and the Environment, v. 42, p. 399-417.

Nascimento, S.C., Parbhakar-Fox, A., **Cracknell, M.J., Cooke, D.R., Miller, C.,** and **Heng, W.X.**, 2023, Geochemical, mineralogical, and geophysical methods to establish the geoenvironmental characteristics of the King River delta, Queenstown, Western Tasmania: Applied Geochemistry, v. 159, Article 105820.

Rainer, T., Beurlen, H., and **Davidson, P.,** 2023, The first finding of water-free copper iodide and iodate in a chrysoberyl-sillimanite association from the Roncadeira pegmatite, Borborema Province, NE-Brazil: Aspects in Mining and Mineral Science, v. 11(4), p. 1304-1308.

Sinclair, D., Heap, A., Norris, K., **Carey, R.,** Anderson, C., and Lea, E., 2023, End user perspectives on design and conduct of health-related disaster research: International Journal of Disaster Risk Reduction, v. 96, Article 103919.

Sotomayor, L.N., **Cracknell, M.J.,** and Musk, R., 2023, Supervised machine learning for predicting and interpreting dynamic drivers of plantation forest productivity in northern Tasmania, Australia: Computers and Electronics in Agriculture, v. 209, Article 107804.

Thomas, R., **Davidson, P.,** Rericha, A., and Recknagel, U., 2023, Ultrahigh-pressure mineral inclusions in a crustal granite: evidence for a novel transcrustal transport mechanism: Geosciences, v. 13(4), Article 94.

Wei, Y., Yu, S., Guo, Q., **Missen, O.P.,** and Xia, X., 2023, Microbial mechanisms to transform the super-trace element tellurium: a systematic review and discussion of nanoparticulate phases: World Journal of Microbiology & Biotechnology, v. 39, Article 262.

Wind, S.C., Hannington, M.D., Schneider, D.A., Fietzke, J., Kilias, S.P., and **Gemmell, J.B.**, 2023, Origin of hydrothermal barite in polymetallic veins and carbonate-hosted deposits of the Cyclades continental back arc: Economic Geology, v. 118(8), p. 1959-1994.

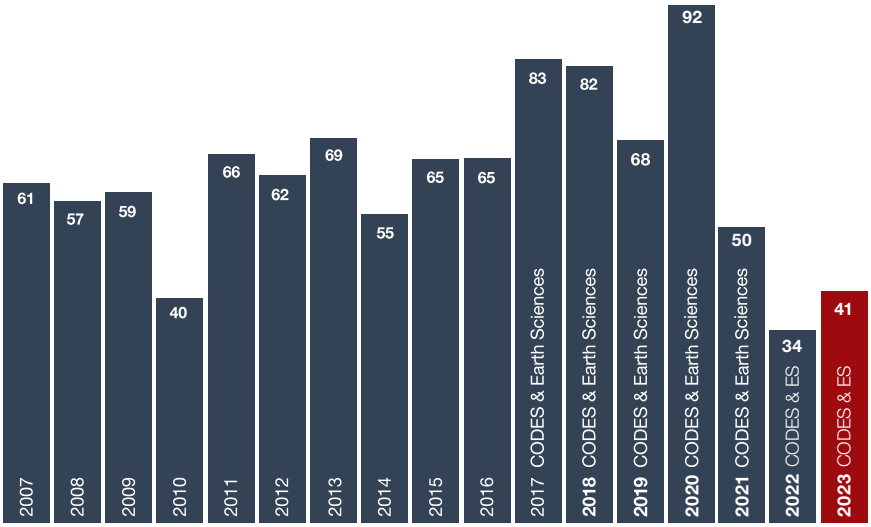
Xiao, X., Zhou, T., Hollings, P., **White, N.C.,** Fan, Y., **Zhang, L.**, and Fu, B., 2023, Pyrite geochemistry in a porphyry-skarn Cu (Au) system and implications for ore formation and prospecting: Perspective from Xinqiao deposit, Eastern China: American Mineralogist, v. 108(6), p. 1132-1148.

Xiao, X., Zhou, T., **White, N.C.,** Fan, Y., **Zhang, L.,** and Chen, X., 2023, Systematic textural and geochemical variations in magnetite from a porphyry-skarn Cu (Au) system and implications for ore formation, perspective from Xinqiao Cu-Fe-Au deposit, eastern China: Ore Geology Reviews, v. 153, Article 105271.

Zamruddin, N.N.S.A., Abidin, N.S.Z., Endut, Z., **Makoundi, C.,** Lok, L.K., and Ismail, M.S., 2023, Trace element analysis of pyrite and arsenopyrite using the LA-ICPMS technique in Pulai, Central Belt of Peninsular Malaysia: Minerals, v. 13(8), Article 1026.

Zin Mar Oo, **Khin Zaw, Belousov, I.,** Putthapiban, P., and **Makoundi, C.,** 2023, Tectonic and metallogenic implications of W-Sn related granitoid rocks in the Kawthaung-Bankachon area, southernmost part of Myanmar: Constraints from petrology, geochemistry, and U-Pb zircon geochronology: Geosystems and Geoenvironment, v. 2(4), Article 100188.

Zivkovic, Z., Danyushevsky, L., Halley, S., **Barker, S.,** and **Baker, M.,** 2023, Comparison of lithium borate fusion and four-acid digestions for the determination of whole-rock chemistry – implications for lithogeochemistry and mineral exploration: Geochemistry: Exploration, Environment, Analysis, doi.org/10.1144/geochem2022-054



REFEREED JOURNAL ARTICLES

Evening falls in northern Chile in the vicinity of the Porfido Norte porphyry Cu deposit. CODES ran a Masters course entitled 'Ores in Magmatic Arcs' in Chile and Peru in late 2023.

Invited keynotes addresses (4)

Armistead, S., Eglington, B., Pehrsson, S., and Huston, D., 2023, Pb isotope heterogeneities in the mantle and links to the supercontinent cycle: EGU General Assembly 2023, Vienna, Austria.

Cooke, D.R., 2023, Gold-rich porphyry provinces of the circum-Pacific – characteristics, origins and exploration criteria: NewGenGold 2023, Perth, Australia.

Cooke, D.R., Cracknell, M., Cooke, S., Smyk, E., Wilkinson, J.J., Belousov, I., Baker, M., Zhang, L., Thompson, J., Hollings, P., White, N., Gemmell, J.B., and Chang, Z., 2023, Tools to aid porphyry exploration in diverse geological environments: ProExplo 2023, Lima, Peru.

Jutzeler, M., and Kutterolf, S., 2023, Silicic explosive submarine volcanism in the Kermadec arc: proximal to distal perspectives: Stronger together Oceanic Volcanism workshop, GEOMAR, Kiel, Germany.

Conference abstracts (39)

Appiah, A.A.A., Hunt, J., Fathi, M., Missen, O.P., and Zhang, L., 2023, Production mineralogy: Magnesite deposit at Prospect Ridge; northwestern Tasmania: CritCon 2023, Adelaide, Australia, Poster.

Armistead, S.E., Meffre, S., Bottrill, R.S., Cross, A., Huston, D., and Steadman, J., 2023, Potential for Proterozoic mineralisation in western Tasmania: Australian Earth Sciences Convention (AESC) 2023, Perth, Australia, Oral presentation.

Baker, M.J., Cracknell, M., Cooke, D.R., Drejing-Carroll, D., and Orovan, E., 2023, Random forest classification of epidote mineral chemistry from the Aitik deposit, northern Sweden: SEG 2023, London, UK, Oral presentation.

Belousov, I., Batanova, V.G., Sobolev, A.V., Olin, P., and Danyushevsky, L.V., 2023, Sulphides from mantle section pyroxenites of Voykar Ophiolite (Polar Urals): Goldschmidt 2023, Lyon, France, Abstract, Oral presentation.

Cajal, Y., Campbell, I.H., and Carrasco-Godoy, C.I., 2023, Magma evolution and fertility of the supergiant porphyry copper deposits from Central Chile: insights from PGE and zircon geochemistry: Chilean Geological Conference, Santiago, Chile, Oral presentation.

Cajal, Y., Campbell, I.H., and Carrasco-Godoy, C.I., 2023, The role of magmatic sulphide saturation in the formation of the supergiant porphyry copper deposits from Central Chile: SGA 2023, Zurich, Switzerland, Oral presentation.

Carrasco-Godoy, C.I., Campbell, I.H., and Cajal, Y., 2023, Zircon geochemistry: insights into porphyry copper deposits fertility from machine learning applications: SGA 2023, Zurich, Switzerland, Oral presentation.

Cheng, R.-L., Michalski, J., and Jutzeler, M., 2023, Subaerial pyroclastic deposits altered in subaqueous environments in the ancestral Cascades arc in Southern Washington State: AGU 2023 Fall Meeting, San Francisco, USA, Poster.

Participants of the 'Ores in Magmatic Arcs – Indonesia' short course, which ran in early 2023, pictured at the Mt Ijen crater, in East Java, Indonesia. The climb to the crater at dawn is one of the highlights of this well-attended Masters unit.

Cooke, D.R., Cracknell, M., Belousov, I., Danyushevsky, L., Barker, S., Baker, M. Cooke, S., Wilkinson, J.J., Chang, Z., Thompson, J., and White, N., 2023, Applications of multielement epidote and chlorite mineral chemistry to locate mineralized centers: A case study from the Batu Hijau porphyry Cu-Au district, Indonesia: SEG 2023, London, UK, Oral presentation.

Cracknell, M.J., Baker, M.J., Cooke, S., Cooke, D.R., Belousov, I., Olin, P., and Kuhn, S., 2023, Targeting buried hydrothermal systems for porphyry copper exploration: Latin Rocks 2023, Chile Explore Congress 2023, Santiago, Chile, Oral presentation.

Edgar, J.O., Barker, A.K., Hamelin, C., Harris, C., and Jutzeler, M., 2023, Subduction zone influence in the Izu rear-arc: Goldschmidt 2023, Lyon, France, Oral presentation.

Farrar, A.D., Cracknell, M.J., Cooke, D.R., and Schaap, T., 2023, Inferring causality between plate motion, orogenesis and giant porphyry Cu metallogeny in the Andes: A data driven analysis: SGA 2023, Zurich, Switzerland, Oral presentation.

Farrar, A.D., Cracknell, M.J., Cooke, D.R., and Schaap, T., 2023, Cause-and-effect of plate motion and crustal thickening using time-series analysis and data analytics: Australian Exploration Geoscience Conference (AEGC), Brisbane, Australia, Oral presentation.

Fathi, M., Hunt, J., and Cooke, D.R.,023, Environmentally sustainable production of critical metals: A mineralogical approach to tungsten recovery: Australian Earth Sciences Convention (AESC) 2023, Perth, Australia, Oral presentation.

Gil-Rodriguez, J., Cooke, D.R., Missen, O.P., Zhang, L., Hong, W., Carter, C., Aheimer, M., and Little, E., 2023, Critical metals in Renison Sn deposit, Western Tasmania: Australian Earth Sciences Convention (AESC) 2023, Perth, Australia, Poster.

Hong, W., 2023, Granite-related critical metal mineralisation in Tasmania: JAMSS Seminar 2023, Launceston, Australia, Oral presentation.

Hong, W., Testa, F., Cooke, D.R., Fox, N., Zhang, L., Baker, M., Orovan, E., Ahmed, A., Hollings, P., Belousov, I., and Harris, A., 2023, Tourmaline: a fertility assessment and vectoring tool for magmatic-hydrothermal systems: SEG 2023, London, UK, Poster.

Hunt, J., Roach, M., Zhang, L., Fraser, S., Cajal, Y., Fathi, M., Hong, W., Missen, O., and Cooke, D., 2023, Environmentally sustainable production of critical metals: a Tasmanian approach: SGA 2023, Zurich, Switzerland, Poster.

Ila'ava, M., Jutzeler, M., Carey, R.J., and Cas, R.A.F., 2023, Multi-disciplinary approach to volcanic architecture reconstruction in the mineralised Macquarie arc, Cowal NSW, Australia: IAVCEI Scientific Assembly, Rotorua, New Zealand, Oral presentation.

Jutzeler, M., Dagasan, Y., Carey, R., and Ila'ava, M., 2023, Volcanic stratigraphy reconstruction based on machine-learning crystal size distribution: AGU 2023 Fall Meeting, San Francisco, USA, Oral presentation.

Jutzeler, M., Kutterolf, S., Carey, R., and Frey, S., 2023, The Seafloor Trail of the Giant 2012 Havre Pumice Raf: AGU 2023 Fall Meeting, San Francisco, USA, Poster.

Jutzeler, M., Kutterolf, S., Frey, S., Orth, K., Clark, A., Conn, E., Fabian, S., Gimonkar, Y., Ila'ava, M., Magri, L., McLatchie, M., Moore, H., Port, I., Wang, C., Wilson, E., Watson, S., Woelz, S., and Wysoczanski, R., 2023, Eruption and sedimentation behaviour at Macauley and Havre submarine caldera volcanoes, Rangitāhua/ Kermadec arc: IAVCEI Scientific Assembly, Rotorua, New Zealand, Oral presentation.

Missen, O.P., Mills, S.J., Clases, D., Gonzalez de Vega, R., Castillo-Michel, H., Villalobos-Portillo, E.E., Cowin, M., and Porteous, H., 2023, Comparing cobalt biogeochemistry across cobaltiferous Australian mineral deposits in semi-arid environments: Australian Earth Sciences Convention (AESC) 2023, Perth, Australia, Oral presentation.

Missen, O.P., Mills, S.J., Etschmann, B., Shuster, J., Rea, M.A.D., Sanyal, S.K. and Brugger, J., 2023, Recent insights into tellurium biogeochemical cycling from nano- to macro-scale: CritCon 2023, Adelaide, Australia, Invited oral presentation.

Missen, O.P., Hunt, J., Zhang, L., and Cooke, D.R., 2023, Unlocking Tasmania's critical metal potential from tailings and waste rock storage facilities: Australian Earth Sciences Convention (AESC) 2023, Perth, Australia, Poster.

Negi, P., Belousov, I., Danyushevsky, L.V., Saikia, A., and Ahmad, M., 2023, Anorthosite and associated gabbronorite plutons of Barabar hills in Chotanagpur granite gneiss complex (CGGC), eastern India: Estimation of parental melt for gabbronorite using equilibrium distribution method (EDM): EGU General Assembly 2023, Vienna, Austria, Abstract, 1p.

Oalmann, J., Olin, P., Belousov, I., and Morissette, M., 2023, Combining Laser Ablation ICP-ToF-MS elemental mapping with ICP-MS/MS Lu-Hf dating of garnet: North American Workshop on Laser Ablation (NAWLA), Notre Dame, USA, Oral presentation.

Osorio, J., Cooke, D., Zhang, L., Belousov, I., Bravo, F., Torres, O., and Jannas, R., 2023, Anatomy of a moderated telescoped porphyry – high sulfidation system: Insights of a 2-km-long vertical profile of alteration at Valeriano Cu-Au Deposit, Chile: Chilean Geological Conference, Santiago, Chile, Oral presentation.

Santos, A.I.C., Cooke. D., Zhang. L., Hunt. J., and Cajal, Y., 2023, Unravelling tungsten mineralisation at Grassy, King Island, Tasmania – New implications for skarn paragenesis and ore genesis: Australian Earth Sciences Convention (AESC) 2023, Perth, Australia, Poster.

Scheffler, J., Jutzeler, M., Kutterolf, S., and Carey, R., 2023, Submarine record from eruption-fed vertical density currents, Kermadec arc/Rangitāhua: INQUA XXI Congress, Roma, Italy, Oral presentation.

Scheffler, J., Kutterolf, S., Jutzeler, M., and Carey, R.J., 2023, Submarine sediment record from eruption-fed vertical density currents, Kermadec arc/Rangitāhua: AGU 2023 Fall Meeting, San Francisco, USA, Poster.

Sritangsirikul, P., Meffre, S., and Khin Zaw, 2024, Porphyry fertility assessment using zircon chemistry, Loei and Truong Son fold belts, Laos region: Mahidol University International Geoscience Conference (MUIGC) 2024, Kanchanaburi, Thailand, Oral presentation.

Sritangsirikul, P., Meffre, S., Khin Zaw, Belousov, I., Lai, Y., Richards, A., and Charusiri, P., 2023, U-Pb ages and trace elements of zircons from Loei and Truong Son fold belts, northern Laos: Implication for porphyry deposit fertility: SGA 2023, Zurich, Switzerland, Poster.

Stål, T., Reading, A.M., Cracknell, M.J., Ebbing, J., Halpin, J.A., Kelly, I.D., MacKie, E.J., Sobh, M., Turner, R.J., and Whittaker, J.M., 2023, Using information entropy to optimise and communicate certainty of continental scale tectonic models: EGU General Assembly 2023, Vienna, Austria, Oral presentation.

Stål T., Reading, A.M., Cracknell, M.J., Ebbing, J., Halpin, J.A., Kelly, I.D., MacKie, E.J., Sobh, M., Turner, R.J., and Whittaker, J.M., 2023, The Antarctic continent mapped by global similarity association: XXVIII General Assembly of the International Union of Geodesy and Geophysics (IUGG), Berlin, Germany, Oral presentation.

Steadman, J.A., Meffre, S., and Cuison, A.L., 2023, Facilitating exploration breakthrough in Tennant Creek: Expanding the geochemical and geochronological toolbox: AGES 2023, Alice Springs, Australia.

Steadman, J.A., Zieg, G.A., Meffre, S., and Large, R.R., 2023, Geochemical constraints on the origin of the Black Butte Cu-Co deposits, Montana: SEG 2023, London, UK.

Ward, S., Fauria, K., and Jutzeler, M., 2023, Distinct pumice flotation mechanisms of the texturally heterogeneous products of the 2019 Unnamed Volcano eruption, Tonga: IAVCEI Scientific Assembly, Rotorua, New Zealand, Poster.

Ward, S., Fauria, K.E., Jutzeler, M., Dasent, J., Wright, V., and McGlynn, N., 2023, Quantifying heterogenous textures in rafted pumice from the 2019 eruption of Volcano F, Tonga: AGU 2023 Fall Meeting, San Francisco, USA, Poster.

Research reports to industry/government agencies (287)

Allen, C.C., Meffre, S., Cracknell, M.J., Missen, O.P., Miller, C.B., and Jamieson, H., 2023, Geoenvironmental & geometallurgical characterisation of weathered polymetallic mine waste: Optimisation of remediation of legacy mine sites in Tasmania: RRC SRM #1, 7 July 2023, p. 161-178.

Allen, C.C., Meffre, S., Cracknell, M.J., Missen, O.P., Miller, C.B., and Jamieson, H., 2023, Geoenvironmental & geometallurgical characterisation of weathered polymetallic mine waste: Optimisation of remediation of legacy mine sites in Tasmania: RRC SRM #2, 29 November 2023, p. 276-287.

AMIRA P1249 research team, 2023, P1249 SRM4 – Poster session introduction: Amira P1249 SRM #4, 6 & 7 December 2023, p. 120-125.

Appiah, A.A.A., Hunt, J., Fathi, M., Missen, O.P., and Hong, W., 2023, Beneficiation of magnesite ore from the Arthur River deposit: RRC SRM #2, 29 November 2023, p. 178-192.

Appiah, A.A.A., Hunt, J., Missen, O.P., Fathi, M., and Zhang, L., 2023, Pathways to production: Magnesite deposits at Prospect Ridge, northwest Tasmania: RRC SRM #1, 7 July 2023, p. 226-237.

Armistead, S., 2023, Critical Metals in Tasmania's Proterozoic: RRC SRM #2, 29 November 2023, p. 11-34.

Armistead, S., 2023, Potential for Proterozoic mineralisation in western Tasmania: temporal controls project update, 27 October 2023, 14p.

Armistead, S., Meffre, S., Bottrill, R., Steadman, J., Cross, A., and Huston, D., 2023, Alpine apatite – fingerprinting IOCG mineralisation in the Arthur Metamorphic Complex: IOCG^3 Annual Sponsors' Meeting 2, September 2023, 25 p.

Atanga, F., and Baker, M., 2023, Akyem orogenic Au deposit, Ghana: Amira P1249 SRM #4, 6 & 7 December 2023, p. 168-189.

Baker, M., and the AMIRA P1249 research team, 2023, Introduction: Amira P1249 SRM #4, 6 & 7 December 2023, p. 1-24.

Baker, M., and the AMIRA P1249 research team, 2023, P1249 Module 3 Technology Transfer - Progress against plan: Amira P1249 SRM #4, 6 & 7 December 2023, p. 398-407.

Baker, M., and Atanga, F., 2023, Akyem orogenic Au deposit, Ghana: Amira P1249 London Tech Transfer Meeting, 24 August 2023, p. 42-44.

Baker, M., Cracknell, M., and Testa, F., 2023, Cowal green rock multivariate analysis: update – June 2023: Amira P1249 SRM #3, 13 & 14 June 2023, p. 392-416.

Baker, M., Halley, S., and Cima, A., 2023, Ventana porphyry Au-Cu prospect, Argentina: Amira P1249 London Tech Transfer Meeting, 24 August 2023, p. 80-96.

Baker, M., Halley, S., Osorio, J., and Cima, A., 2023, Ventana porphyry Au-Cu prospect, Argentina: Progress report – June 2023: Amira P1249 SRM #3, 13 & 14 June 2023, p. 360-391.

Baker, M., and Piquer, J., 2023, P1249 Honours Projects Update: Amira P1249 SRM #3, 13 & 14 June 2023, p. 36-50.

Baker, M., and Steadman, J., 2023, Mount Isa Copper Mine, Australia - P1249 progress report: Amira P1249 SRM #4, 6 & 7 December 2023, p. 90-119.

Barillas-Diaz, J.L., Cooke, D.R., Zhang, L., Hong, W., Cajal, Y., Chisnall, A., and Denholm, J., 2023, Characterisation of the Avebury Ni deposits, Western Tasmania: Genesis and evolution: RRC SRM #1, 7 July 2023, p. 130-145.

Beas, B., Zhang, L., Cooke, D.R., and Hoye, J., 2023, P1249 Modules 1 & 2 – Exploration tools for assessing fertility and vectoring to high-grade ore: E44, Northparkes district: Amira P1249 SRM #3, 13 & 14 June 2023, p. 417-452.

Beas, B., Zhang, L., Cooke, D.R., and Hoye, J., 2023, P1249 Modules 1 and 2 Exploration tools for assessing fertility and vectoring to high-grade ore: E44, Northparkes district: Amira P1249 SRM #4, 6 & 7 December 2023, p. 67-89.

Belousov, I., 2023, Capabilities and limitations of LA-ICP-MS technique for critical metals analyses: RRC SRM #1, 7 July 2023, p. 22-51.

Belousov, I., 2023, P1525 CODELCO fertility and vectoring report: Pastos Largos: Report to CODELCO, 28 p.

Belousov, I., 2023, P1525 CODELCO fertility and vectoring report: San Bartolo: Report to CODELCO, 30 p.

Belousov, I., 2023, P1578 CODELCO vectoring report: Report to CODELCO, 17 p.

Belousov, I., Cima, A., and Olin, P., 2023, P1419. Sulphide compositions in eight samples: Report to First Quantum Minerals, 15 p.

Belousov, I., Cima, A., Olin, P., and Dai, F., 2023, P1419B. Sulphide compositions in 15 samples: Report to First Quantum Minerals, 14 p.

Belousov, I., and Cooke, D., 2023, P1371 CODELCO fertility and vectoring report, Exploradora: Report to CODELCO, 9 p.

Belousov, I., and Cooke, D., 2023, P1371 CODELCO fertility and vectoring report, Porfido Norte: Report to CODELCO, 16 p.

Belousov, I., and Cooke, D., 2023, P1371C CODELCO fertility and vectoring report, Exploradora: Update using alunite compositions: Report to CODELCO, 12 p.

Belousov, I., and Cooke, D., 2023, P1371C CODELCO fertility and vectoring report, Porfido Norte: Update: Report to CODELCO, 13 p.

Belousov, I., and Cooke, D., 2023, P1376 CODELCO fertility and vectoring report, Andina Norte: Report to CODELCO, 52 p.

Belousov, I., and Cooke, D., 2023, P1376 CODELCO fertility and vectoring report, Talisman Project: Report to CODELCO, 13 p.

Belousov, I., and Cooke, D., 2023, P1416 Copperman fertility and vectoring report: Report to Copperman, 12 p.

Belousov, I., and Cooke, D., 2023, P1416B Copperman fertility and vectoring report: Poderosa update: Report to Copperman, 13 p.

Belousov, I., and Cooke, D., 2023, P1416B Copperman fertility and vectoring report: Raiya prospect update: Report to Copperman, 12 p.

View of the Newmont Africa Akyem gold mine in southern Ghana taken by Dr Mike Baker in 2023 while doing fieldwork for the Amira P1249 project.

Belousov, I., and Cooke, D., 2023, P1577 Great Northern Minerals fertility and vectoring report: Report to Great Northern Minerals, 22 p.

Belousov, I., and Dai, F., 2023, P1376. Chlorite and epidote chemistry for 85 samples for CODELCO: Report to CODELCO, 5 p.

Belousov, I., Halley, S., Cracknell, M., Cooke, D., Piquer, J., and Baker, M., 2023, Nolasco/Santa Clara Rio Tinto Blind Test - Overview of results: Amira P1249 Santiago Tech Transfer Meeting, 11 October 2023.

Belousov, I., Halley, S., Cracknell, M., Cooke, D.R., Piquer, J., and Baker, M., 2023, Nolasco/Santa Clara - Rio Tinto Blind Test: Amira P1249 SRM #3, 13 & 14 June 2023, p. 325-352.

Belousov, I., Halley, S., Cracknell, M., Cooke, S., Piquer, J., Baker, M., Gluchowska, J., Agnew, P., Pacey, A., and Powell, W., 2023, Nolasco/Santa Clara Rio Tinto Blind Test: Amira P1249 London Tech Transfer Meeting, 24 August 2023, p. 20-29.

Belousov, I., and Hohl, M., 2023, P1416 part 2. Chlorite and epidote chemistry for 11 additional samples: Report to Copperman Chile, 4 p.

Belousov, I., and Hohl, M., 2023, P1525. Chlorite, epidote, quartz, carbonate, alunite and tourmaline chemistry from 78 samples: Report to CODELCO, 5 p.

Belousov, I., and Hohl, M., 2023, P1529. Chlorite and epidote chemistry for 3 samples: Report to BHP Peru, 3 p.

Belousov, I., and Hohl, M., 2023, P1577. Chlorite and epidote chemistry for 16 samples for Great Northern Minerals: Report to Great Northern Minerals, 4 p.

Belousov, I., and Hohl, M., 2023, P1578. Chlorite and epidote chemistry from 15 samples: Report to CODELCO, 3 p.

Belousov, I., and Hohl, M., 2023, P1589. Chlorite and epidote chemistry for 2 samples: Report to First Quantum Minerals, 3 p.

Belousov, I., and Hohl, M., 2023, P1625. Chlorite and epidote chemistry for 20 samples: Report to Inflection Resources, 5 p.

Belousov, I., and Morissette, M., 2023, P1589: U-Pb apatite and titanite geochronology report: Report to First Quantum Minerals Chile, 7 p.

BHP, 2023, AMIRA P1249 Project Submission – Ocelot: Amira P1249 SRM #3, 13 & 14 June 2023, p. 106-120.

Cajal, Y., 2023, Element 1 Research: Unlocking Critical Metal Resources – Other research opportunities: RRC SRM #1, 7 July 2023, p. 116-129.

Cajal, Y., Campbell, I., and Carrasco-Godoy, C., 2023, Magma fertility in Central Chile: Rio Blanco and El Teniente: Amira P1249 Santiago Tech Transfer Meeting, 13 October 2023.

Cajal, Y., Piquer, J., Hollings, P., and Belousov, I., 2023, Magmatic mineral chemistry in Central Chile: Amira P1249 London Tech Transfer Meeting, 24 August 2023, p. 16-19.

Cima, A., Belousov, I., Cooke, D.R., and Cracknell, J., 2023, Microinclusions in alteration and vein minerals for vectoring and fertility assessment of porphyry Cu ± Au ± Mo

The Central Peruvian Andes, photographed by David Cooke during the 'Ores in Magmatic Arcs' field trip, November 2023.

deposits: Amira P1249 SRM #4, 6 & 7 December 2023, p. 126-147.

Cima, A., Belousov, I., Cooke, D.R., and Cracknell, J., 2023, Microinclusions in porphyry Cu-Mo-Au deposits: Amira P1249 SRM #3, 13 & 14 June 2023, p. 51-70.

Coaquira, T., Zhang, L., Escolme, A., Cooke, D.R., Halley, S., and Belousov, I., 2023, Geological evolution and chemistry of the supergiant high-grade Resolution Cu-Mo porphyry deposit, Arizona: Amira P1249 SRM #4, 6 & 7 December 2023, p. 306-357.

CODELCO, 2023, AMIRA - CODELCO GCEX P1249 Module 2 - Porfido Norte, Potrerillos district: Amira P1249 SRM #3, 13 & 14 June 2023, p. 353-359.

Cooke, D., 2023, Exploring, characterising, and optimising complex orebodies – Integrated deposit knowledge to add value across the Mining Value Chain: Amira P1249 Santiago Tech Transfer Meeting, 12 October 2023.

Cooke, D.R., 2023, Introduction to RRC Critical Metals Project – Sponsors Review meeting #1: RRC SRM #1, 7 July 2023, p. 1-21.

Cooke, D.R., 2023, Ocelot – A module 2 study site: Amira P1249 London Tech Transfer Meeting, 24 August 2023, p. 97-101.

Cooke, D.R., and the AMIRA P1249 research team, 2023, Introduction: Amira P1249 London Tech Transfer Meeting, 24 August 2023, p. 1-15.

Cooke, D.R., and the AMIRA P1249 research team, 2023, P1249 Forward Program 2023 – 2024: Amira P1249 London Tech Transfer Meeting, 24 August 2023, p. 102-104.

Cooke, D.R., and the AMIRA P1249 research team, 2023, P1249 Forward Program - December 2023 to June 2024: Amira P1249 SRM #4, 6 & 7 December 2023, p. 408-413.

Cooke, D.R., and the P1249 team, 2023, P1249 Forward Program - July to November 2023: Amira P1249 SRM #3, 13 & 14 June 2023, p. 531-535.

Cooke, S., Cracknell, M., Baker, M., and Zhang, L., 2023, Pathways to mineral discoveries through computer-based modelling of geochemical data: Amira P1249 SRM #3, 13 & 14 June 2023, p. 121-151.

Cooke, D., Cracknell, M., Belousov, I., Barker, S., Baker, B., Cooke, S., Wilkinson, J., Chang, Z., Thompson, J., and White, N., 2023, Applications of multielement chlorite mineral chemistry to locate mineralized centers: A case study from the Batu Hijau porphyry Cu-Au district, Indonesia: Amira P1249 Santiago Tech Transfer Meeting, 13 October 2023.

Cracknell, M.J., 2023, CODES student poster introductions: Amira P1249 SRM #3, 13 & 14 June 2023, p. 71-105.

Cracknell, M., 2023, New technologies: Amira P1249 Santiago Tech Transfer Meeting, 13 October 2023.

Cracknell, M.J., 2023, P1249 Update - Students, Staff and Activities: Amira P1249 SRM #3, 13 & 14 June 2023, p. 23-35.

Cracknell, M., and the AMIRA P1249 research team, 2023, P1249 Module 2 - Progress update: Amira P1249 SRM #4, 6 & 7 December 2023, p. 389-397.

Cracknell, M., and Evinemi, I., 2023, Calculated Mineralogy / Pedras: Amira P1249 Santiago Tech Transfer Meeting, 16 October 2023.

Cracknell, M., and Evinemi, I., 2023, Mineral texture clustering: Amira P1249 Santiago Tech Transfer Meeting, 16 October 2023.

Cracknell, M., Evinemi, I., Cajal, Y., Baker, M., Cooke, D.R., and Belousov, I., 2023, Porfido Norte: Amira P1249 London Tech Transfer Meeting, 24 August 2023, p. 38-41.

Cracknell, M., Osorio, J., and Brown, A., 2023, Drill core RGB image colour and texture analysis: Amira P1249 SRM #3, 13 & 14 June 2023, p. 504-530.

da Cruz, V.G.P., Cooke, D.R., and Zhang, L., 2023, The Devonian hydrothermal alteration of Rosebery and some implications for critical metals: RRC SRM #2, 29 November 2023, p. 138-161.

Dai, F., Morissette, M., and Oalmann, J., 2023, P1421: Report on quartz trace element contents: Report to Fortescue Mining Group, 19 p.

Dai, F., Morissette, M., and Oalmann, J., 2023, P1503: Report on quartz trace element contents: Report to Fortescue Mining Group, 12 p.

Dogara, E.M., Hunt, J., Fathi, M., and Missen, O.P., 2023, Scheelite processing challenges and opportunities: A case study of coarse flotation: RRC SRM #2, 29 November 2023, p. 193-204.

Dogara, E.M., Hunt, J., Missen, O.P., and Fathi, M., 2023, Pathways to production of Kara Fe-W skarn deposit: RRC SRM #1, 7 July 2023, p. 214-225.

Dyer, J., Hollings, P., and Sulyman, N., 2023, Characterization of the alteration footprint of the McFinley gold deposit, Red Lake, Ontario: Amira P1249 SRM #4, 6 & 7 December 2023, p. 287-305.

Evinemi, I., 2023, Mineralogical domaining and predictive modelling of porphyry copper deposits using deep learning approach: Amira P1249 SRM #4, 6 & 7 December 2023, p. 358-376.

Evinemi, I., 2023, Porfido Norte deep learning: Amira P1249 Santiago Tech Transfer Meeting, 13 October 2023.

Fathi, M., 2023, Addressing challenges in fine particle processing of critical minerals: An exploration of constraints: RRC SRM #2, 29 November 2023, 288-300.

Fathi, M., 2023, Environmentally sustainable production of critical metals: Essential problems in scheelite and magnesite processing: RRC SRM #1, 7 July 2023, p. 238-248.

Fraser, S., 2023, Element 3 in the Regional Research Collaboration: RRC SRM #1, 7 July 2023, p. 265-277.

Fraser, S., and Hall-Dadson, J., 2023, Element 3 Workshop: Education and engagement in the Regional Research Collaboration: RRC SRM #2, 29 November 2023, p. 205-243.

Goemann, K., and Olin, P., 2023, P1498B. EMPA identification of the arsenate phases in one sample: Report to ALS, 1 p.

Gil-Rodriguez, J., Cooke, D.R., Missen, O.P., and Hong, W., 2023, Critical metals in the Renison Bell tin deposit: RRC SRM #2, 29 November 2023, p. 162-177.

Gil-Rodriguez, J., Cooke, D.R., Zhang, L., Missen, O.P., and Hong, W., 2023, Critical metals in the Renison Bell tin deposit, Western Tasmania, RRC SRM #1, 7 July 2023, p. 93-115.

Halley, S., Baker, M., and Belousov, I., 2023, Chlorite Chemistry from LA-ICP-MS and SWIR - Interrogating the data in ioGAS: Amira P1249 SRM #3, 13 & 14 June 2023, p. 219-240.

Hollings, P., Sulyman, N., Dyer, J., Turner, C., and Zhang, L., 2023, Canada based study sites: Amira P1249 London Tech Transfer Meeting, 24 August 2023, p. 65-70.

Hong, W., 2023, Geochemistry of Tasmanian granites and associated critical metal potential: RRC SRM #1, 7 July 2023, p. 146-160.

Hong, W., Zhang, L., Belousov, I., White, N., Cooke, S., Goemann, K., and Jones, R., 2023, Kurpetai-3 update – part two: Mineral chemistry: Fertility assessment and vectoring: Amira P1249 SRM #3, 13 & 14 June 2023, p. 192-218.

Hong, W., Zhang, L., and Cooke, D.R., 2023, Tasmanian granite-associated critical minerals with a focus on control on Sn, W and Li mineralisation: RRC SRM #2, 29 November 2023, p. 54-73.

Hunt, J., 2023. Characterisation methodology to predict the particle size at which gangue minerals liberate during selective breakage processes: CSIRO Futures project report, 34 p.

Hunt, J., 2023, Environmentally sustainable production of critical metals: Pathways to production: RRC SRM #1, 7 July 2023, p. 201-213.

Hunt, J., 2023, Introduction to environmentally sustainable production of critical metals workshop: RRC SRM #2, 29 November 2023, p. 1-10.

Ilaava, M., and Jutzeler, M., 2023, The geology of the Cowal Gold Mine and its regional setting in the Ordovician Macquarie Arc, Lachlan Orogen, New South Wales: University of Tasmania.

Ila'ava, M., Jutzeler, M., Cas, R.A.F., and Carey, R.J., 2023, Stratigraphy, tectonics and volcanic facies analysis and 3D modelling in the Cowal Igneous Complex (CIC), NSW: Industry report, December 2023, 3 p.

Ila'ava, M., Jutzeler, M., Cas, R.A.F., and Carey, R.J., 2023, Tectonic and stratigraphic cross section of the Cowal Igneous Complex, NSW: Industry report, February 2023, 1 p.

Ila'ava, M., Jutzeler, M., Cas, R.A.F., and Carey, R.J., 2023, Update on the regional and local tectonic in the vicinity of the Cowal Igneous Complex, NSW: Industry report, May 2023, 62 p.

Ila'ava, M., Jutzeler, M., Cas, R.A.F., and Carey, R.J., 2023, Volcanic facies analysis and 3D modelling in the Cowal Igneous Complex (CIC), NSW: Industry report, December 2023, 1 p.

Jones, R., Cooke, D.R., Hoye, J., Halley, S., Coaquira, T., Zhang, L., Escolme, A., Belousov, I., and Bozoglu, M., 2023, Phyllic alteration: key findings from the E26 porphyry Cu-Au deposit, Northparkes, NSW, Australia: Amira P1249 SRM #3, 13 & 14 June 2023, p. 453-503.

Jutzeler, M., 2023, Gigantic submarine landslide offshore western Tasmania: risk mitigation for shelf derived tsunami in Australia: Voyage report to CSIRO on IN2023_V02 voyage, 112 p.

Jutzeler, M., 2023, Volcanic facies analysis in the Cowal Igneous Complex: May 2023, 2 p.

Kamenetsky, V., and Kamenetsky, M., 2023, Quartz types from distal to proximal granite hosting the Olympic Dam deposit: Report for BHP, 35 p.

Kamenetsky, V., and Kamenetsky, M., 2023, RD2488 inclusions in granitic and hydrothermal quartz: Report for BHP, 16 p.

Keeble, H., Zhang, L., Cooke, D.R., Rodemann, T., and Howard, N., 2023,

Characterising the Regolith Profile of the E41 deposit, Cowal, NSW: Implications for Ore processing and Mineral Exploration: Amira P1249 SRM #4, 6 & 7 December 2023, p. 51-66.

Lounejeva, E., 2023, P1410. Identification and quantification of mineral phases by X-ray diffraction (XRD) in twenty three samples, 2 p.

Lounejeva, E., 2023, P1433. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five November 2022 samples: Report to BMTJV, 2 p.

Lounejeva, E., 2023, P1456. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five December 2022 samples: Report to BMTJV, 2 p.

Lounejeva, E., 2023, P1477. Identification and quantification of mineral phases by X-ray diffraction (XRD) in eight January 2023 samples: Report to BMTJV, 3 p.

Lounejeva, E., 2023, P1493. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five February 2023 samples: Report to BMTJV, 2 p.

Lounejeva, E., 2023, P1506. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five March 2023 samples: Report to BMTJV, 2 p.

Lounejeva, E., 2023, P1522. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five April 2023 samples: Report to BMTJV, 2 p.

Lounejeva, E., 2023, P1542. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five May 2023 samples: Report to BMTJV, 2 p.

Lounejeva, E., 2023, P1543. Identification and quantification of mineral phases by X-ray diffraction (XRD) in six samples: Report to GRSRM, 4 p.

Lounejeva, E., 2023, P1565. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five June 2023 samples: Report to BMTJV, 2 p.

Lounejeva, E., 2023, P1596. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five July 2023 samples: Report to BMTJV, 2 p.

Lounejeva, E., 2023, P1605. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five August 2023 samples: Report to BMTJV, 2 p.

Lounejeva, E., 2023, P1646. Identification and quantification of mineral phases by X-ray diffraction (XRD) in eleven September and October 2023 samples: Report to BMTJV, 2 p.

Lounejeva, E., 2023, P1674. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five November 2023 samples: Report to BMTJV, 2 p.

Marcelissen, M., Hollings, P., Belousov, I., Maryono, A., and Rompo, I., 2023, Magmatic mineral chemistry of the eastern Sunda arc, Indonesia: Amira P1249 SRM #3, 13 & 14 June 2023, p. 259-297.

Martin, B., 2023, Mining Roadshows Zeehan and Cradle Coast Campus – June 2023: RRC SRM #1, 7 July 2023, p. 278-285.

Missen, O.P., 2023, Critical metals in mine wastes: RRC SRM #2, 29 November 2023, p. 74-93.

Missen, O.P., 2023, Geoenvironmental research in the RRC: State of opportunities: RRC SRM #1, 7 July 2023, p. 249-264.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1376. U-Pb zircon geochronology report 1: Andina project: Report to CODELCO, 23 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1376. U-Pb zircon geochronology report 2: Talísman project: Report to CODELCO, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1451-P1452: U-Pb zircon geochronology report: Report to Anglo American Canada, 14 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1466: U-Pb zircon geochronology report for eight samples: Report to ALS Global, 10 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1467: U-Pb zircon geochronology report for 3 samples: Report to ALS Global, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1468: U-Pb zircon geochronology report for 12 samples: Report to ALS Global, 12 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1482: U-Pb zircon geochronology report on 4 samples: Report to Anglo American Chile, 6 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1486: Zircon U-Pb geochronology and trace elements in twelve samples: Report to BHP Chile, 11 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1504: U-Pb zircon geochronology report: Report to Teck USA, 8 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1507A: U-Pb zircon geochronology report for twelve samples: Report to Anglo American, Chile, 12 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1507B: U-Pb zircon geochronology report for twelve samples: Report to Anglo American Chile, 11 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1509: Zircon U-Pb geochronology and trace elements in five samples: Report to BHP Chile, 8 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1510: U-Pb zircon geochronology report on 4 samples: Report to ALS Global, 8 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1511: U-Pb zircon geochronology report for four samples: Report to ALS Global, 8 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1512: U-Pb zircon geochronology report on one sample: Report to Newmont Australia, 6 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1515: U-Pb zircon geochronology report on 1 sample: Report to Teck Chile, 6 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1516: U-Pb zircon geochronology report on two samples: Report to Teck USA, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1517: U-Pb zircon geochronology report for three samples: Report to ALS Global, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1518A: Zircon U-Pb

Foliated volcaniclastic andesite outcrop in the northern Iberian Pyrite Belt (IPB), Spain, photographed by David Cooke while doing fieldwork in the southwest of Spain during September 2023.

geochronology and trace elements in twelve samples: Report to BHP Chile, 9 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1518B: U-Pb zircon geochronology report on 4 detrital samples: Report to BHP Chile, 10 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1523: U-Pb zircon geochronology report for two samples: Report to First Quantum Chile, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1524: U-Pb zircon geochronology report for four samples: Report to BHP Peru., 8 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1529: U-Pb zircon geochronology report on 7 samples: Report to BHP Peru, 10 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1532: U-Pb zircon geochronology report for five samples: Report to ALS Global, 8 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1533: U-Pb zircon geochronology report for seven samples: Report to ALS Global, 9 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1534: U-Pb zircon geochronology report for three samples: Report to ALS Global, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1537: U-Pb zircon geochronology report for twelve samples: Report to ALS Global, 11 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1538: U-Pb zircon geochronology report on two samples: Report to Anglo American Chile, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1544: U-Pb zircon geochronology report for three samples: Report to First Quantum Chile, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1545: U-Pb zircon geochronology report on 12 samples: Report to Teck Chile, 12 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1546: U-Pb zircon geochronology report on four samples: Report to Teck Turkiye, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1547: U-Pb zircon geochronology report for two samples: Report to ALS Global, 6 p.

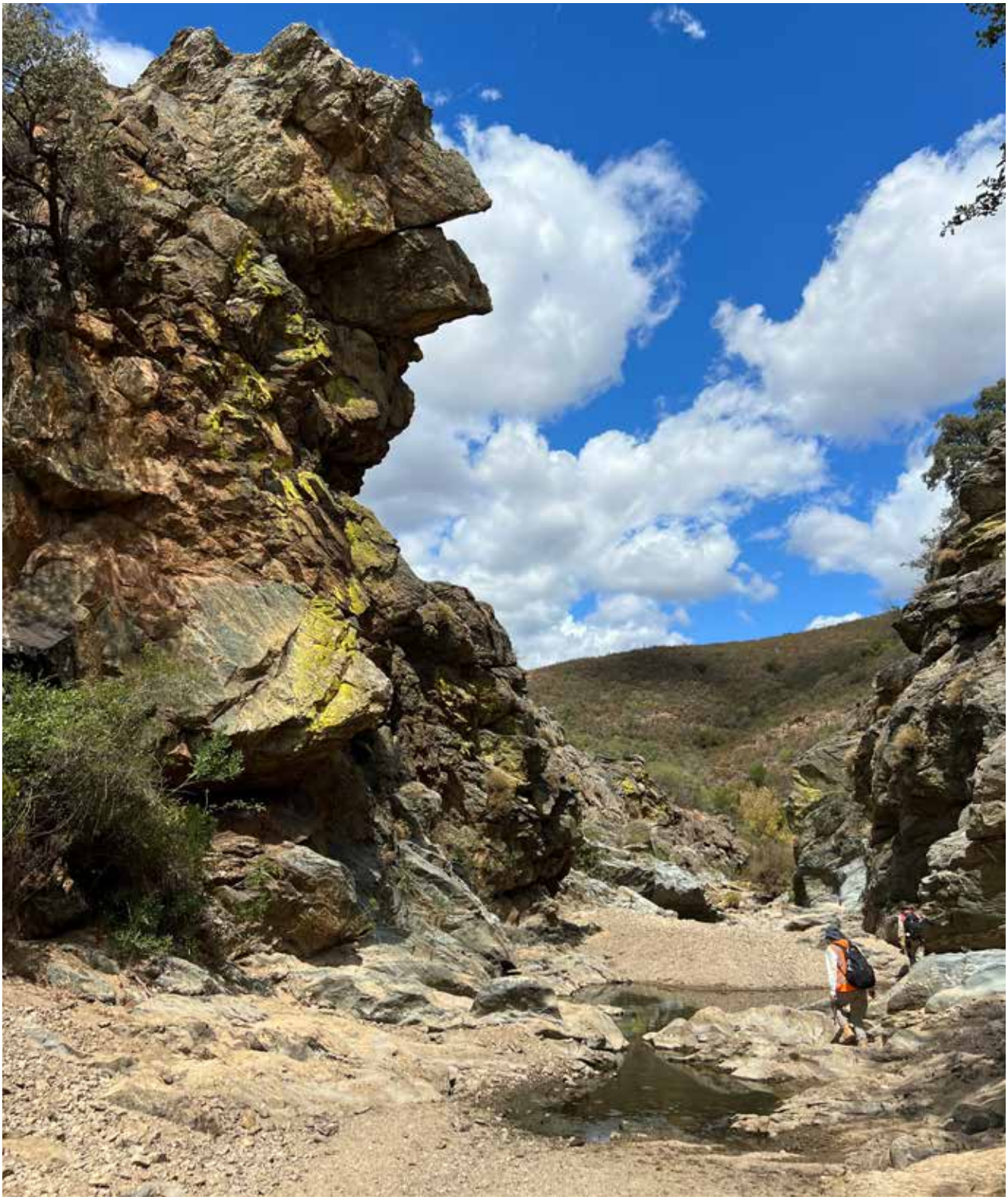
Morissette, M., Oalmann, J., and Olin, P., 2023, P1548: U-Pb zircon geochronology report for one sample: Report to ALS Global, 6 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1549: U-Pb zircon geochronology report for two samples: Report to ALS Global, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1550: U-Pb zircon geochronology report for one sample: Report to ALS Global, 6 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1555: U-Pb zircon geochronology report on three samples: Report to Teck USA, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1559: U-Pb zircon



Outcrops of foliated and folded volcaniclastic andesite in the northern Iberian Pyrite Belt (IPB), southwest Spain. CODES staff Wei Hong and Mike Baker can be seen picking their way through this gorge in this photo taken by David Cooke in September 2023.

geochronology report on 7 detrital samples: Report to BHP Chile, 13 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1566: U-Pb zircon geochronology report on four samples: Report to ALS Global, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1567: U-Pb zircon geochronology report on nine samples: Report to Anglo American Europe, 10 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1568: U-Pb zircon geochronology report for one sample: Report to ALS Global, 6 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1572: Zircon U-Pb geochronology and trace elements in six samples: Report to BHP Chile, 9 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1573: U-Pb zircon geochronology report on 5 samples: Report to BHP Peru, 8 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1575: U-Pb zircon geochronology report on one sample: Report to Anglo American Ecuador, 6 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1581: U-Pb zircon geochronology report for 4 samples: Report to First Quantum Chile, 8 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1582: U-Pb zircon geochronology report for one sample: Report to ALS Global, 6 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1583: U-Pb zircon geochronology report for one sample: Report to ALS Global, 6 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1584: U-Pb zircon geochronology report for one sample: Report to ALS Global, 6 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1585: U-Pb zircon geochronology report on 4 samples: Report to BHP, Peru, 8 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1591: U-Pb zircon geochronology report for four samples: Report to ALS Global, 8 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1599: U-Pb zircon geochronology report for six samples: Report to ALS Global, 9 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1600: U-Pb zircon geochronology report for one sample: Report to ALS Global, 6 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1606: U-Pb zircon geochronology report on 7 samples: Report to Coeur Mining Mexico, 9 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1607: U-Pb zircon geochronology report for one sample: Report to First Quantum Chile, 6 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1608: U-Pb zircon geochronology report on 5 samples: Report to BHP Peru, 8 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1612: U-Pb zircon geochronology report for one sample: Report to Teck Canada, 6 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1617: U-Pb zircon geochronology report for five samples: Report to ALS Global, 8 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1619: Zircon U-Pb geochronology and trace elements in five samples: Report to BHP Chile, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1619b: U-Pb zircon geochronology report on 1 detrital sample: Report to BHP Peru, 6 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1623: U-Pb zircon geochronology report on 5 detrital samples: Report to Teck Peru, 11 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1626: U-Pb zircon geochronology report for three samples: Report to First Quantum Peru, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1630: U-Pb zircon geochronology report on three samples: Report to Anglo American Ecuador, 7 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1631: Zircon U-Pb geochronology and trace elements in five samples: Report to BHP Chile, 8 p.

Morissette, M., Oalmann, J., and Olin, P., 2023, P1634: U-Pb zircon geochronology report on 11 detrital samples: Report to BHP Chile, 17 p.

Naimbale, N.N., Cooke, D.R., Hong, W., and Scott, R., 2023, Characterisation of the Heemskirk tin project – Zeehan, western Tasmania: RRC SRM #2, 29 November 2023, p. 108-137.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1407: U-Pb zircon geochronology: Report to BHP Peru, 14 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1414: U-Pb zircon geochronology report: Report to Teck USA, 5 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1415: U-Pb zircon geochronology report for 3 samples: Report to Servicio Nacional de Geología y Minería, Chile, 6 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1420: Zircon U-Pb geochronology and trace elements for three samples: Report to ALS, 7 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1423: Zircon U-Pb geochronology and trace elements in four samples: Report to BHP Chile, 8 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1424: U-Pb zircon geochronology report: Report to BHP Peru, 11 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1430: U-Pb zircon geochronology report: Report to Anglo American Chile, 8 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1434: U-Pb zircon geochronology report: Report to Teck Turkey, 7 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1435: U-Pb zircon geochronology report: Report to Anglo American Canada, 10 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1437: U-Pb zircon geochronology report: Report to Anglo Gold Ashanti, 7 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1438: U-pb zircon geochronology report for five samples: Report to ALS Global, 8 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1439: U-Pb zircon geochronology report: Report to Anglo American Canada, 9 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1443: U-Pb zircon geochronology report on 13 samples: Report to Anglo American Chile, 17 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1444: U-Pb zircon geochronology report: Report to Anglo American Canada, 9 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1445: U-Pb zircon geochronology report on 20 samples: Report to Teck Chile, 18 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1448: U-Pb zircon geochronology report for three samples: Report to ALS Global, 7 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1449: U-Pb zircon geochronology report for 12 samples: Report to ALS Global, 11 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1450: U-Pb zircon geochronology report for 2 samples: Report to ALS Global, 6 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1454: U-Pb zircon geochronology report on 4 samples: Report to Anglo American Namibia, 6 p.

Oalmann, J., and Belousov, I., 2023, P1457. Chlorite and Epidote Chemistry: Report to BHP Peru, 3 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1457: U-Pb zircon geochronology report on 5 samples: Report to BHP, Peru, 8 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1458: U-Pb zircon geochronology report on 9 samples: Report to Anglo American Chile, 9 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1460: U-Pb zircon geochronology report on 4 samples: Report to First Quantum Zambia, 15 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1461: U-Pb zircon geochronology report: Report to Anglo American Chile, 13 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1462: U-Pb zircon geochronology report: Report to Anglo American Chile, 12 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1469: U-Pb zircon geochronology report for 4 samples: Report to Wiseman Metals, 8 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1470A: U-Pb zircon geochronology report on 16 of 31 samples: Report to Anglo American Chile, 15 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1470B: U-Pb zircon geochronology report on 15 of 31 samples: Report to Anglo American Chile, 15 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1474: U-Pb zircon geochronology report on 6 samples: Report to BHP Chile, 9 p.

Oalmann, J., and Morissette, M., 2023, P1476. U-Pb zircon geochronology report for two samples: Report to ALS Global, 6 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1479: U-Pb geochronology report: Report to Newcrest, 6 p.

Oalmann, J., and Morissette, M., 2023, P1480: U-Pb zircon geochronology report for one sample: Report to ALS Global, 6 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1481: U-Pb zircon geochronology report on 5 samples: Report to ALS Global, 11 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1487: U-Pb zircon geochronology report on 19 igneous samples: Report to Anglo American Zambia, 16 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1487: U-Pb zircon geochronology report on 8 detrital samples: Report to Anglo American Zambia, 14 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1492: U-Pb zircon geochronology report for one sample: Report to ALS Global, 6 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1494: U-Pb zircon geochronology report for one sample: Report to First Quantum Chile, 6 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1495: U-Pb zircon geochronology report on 11 detrital samples: Report to BHP Chile, 17 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1495: Zircon U-Pb geochronology and trace elements in ten igneous samples: Report to BHP Chile, 11 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1525: U-Pb zircon geochronology report on 20 samples: Report to Codelco, 16 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1530: U-Pb zircon geochronology report on 2 detrital samples: Report to Teck, USA, 7 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1539: U-Pb zircon geochronology report on 13 samples: Report to Teck USA, 12 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1551: U-Pb zircon geochronology report on 1 sample: Report to First Quantum Zambia, 6 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1590: U-Pb zircon geochronology report on four samples: Report to ALS Global, 8 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1598: U-Pb detrital zircon geochronology report on 2 samples: Report to First Quantum Zambia, 6 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1601: U-Pb zircon geochronology report on 7 samples: Report to Teck Chile, 9 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1602/P1468: U-Pb detrital zircon geochronology report on 12 samples: Report to ALS, 18 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1611: U-Pb zircon geochronology report on 7 detrital samples: Report to Teck Chile, 13 p.

Oalmann, J., Morissette, M., and Olin, P., 2023, P1627: U-Pb zircon geochronology report on two samples: Report to Anglo Gold Ashanti, 7 p.

Olin, P., 2023, P1436. Gold contents in pyrite, chalcopyrite, and bornite in nine samples: Report to FQM, 6 p.

Olin, P., and Oalmann, J., 2023, P1447. Titanium and vanadium contents in various minerals: Report to ALS, 8 p.

Olin, P., Dai, F., and Oalmann, J., 2023, P1455. Lithium contents in various minerals in two samples: Report to ALS, 5 p.

Olin, P., Dai, F., and Oalmann, J., 2023, P1473. Lithium contents in various minerals in three samples: Report to ALS, 9 p.

Olin, P., 2023, P1498A. Gold contents in arsenate phases in one sample: Report to ALS, 8 p.

Olin, P., 2023, P1499. Gold contents in pyrite and arsenopyrite in one sample: Report to ALS, 7 p.

Olin, P., 2023, P1505. Lithium contents in various minerals in one sample: Report to ALS, 3 p.

Olin, P., 2023, P1508. Lithium contents in various minerals in one sample: Report to ALS, 4 p.

Olin, P., 2023, P1513. Gold contents in pyrite in one sample: Report to ALS, 6 p.

Olin, P., 2023, P1557. Gold contents in pyrite and arsenopyrite in three samples: Report to MODA, 9 p.

Olin, P., 2023, P1558. Gold contents in sulfide minerals in one sample: Report to MODA, 9 p.

Olin, P., 2023, P1561. Gold contents in pyrite and covellite in six samples: Report to ALS Geochemistry, 14 p.

Olin, P., 2023, P1564. Gold contents in sulfide minerals in two samples: Report to MODA, 8 p.

Olin, P., and Dai, F., 2023, P1571. Lithium contents in various minerals in eight samples: Report to ALS, 9 p.

Olin, P., and Dai, F., 2023, P1580. Gold contents in pyrite and arsenopyrite in three samples: Report to ALS, 9 p.

Olin, P., and Dai, F., 2023, P1586. Lithium contents in various minerals in two samples: Report to ALS, 5 p.

Olin, P., and Dai, F., 2023, P1595. Lithium contents in various minerals in three samples: Report to ALS, 5 p.

Olin, P., and Dai, F., 2023, P1614. Lithium contents in various minerals in one sample: Report to ALS, 4 p.

Olin, P., 2023, P1620. Lithium contents in various minerals in one sample: Report to ALS, 4 p.

Olin, P., 2023, P1621. Nickel contents in pyrrhotite in one sample: Report to ALS, 5 p.

Olin, P., and Dai, F., 2023, P1641. Gold contents in pyrite and arsenopyrite in one sample: Report to ALS, 6 p.

Olin, P., and Dai, F., 2023, P1642. Gold, cobalt, and arsenic contents in various minerals in two samples: Report to ALS, 13 p.

Osorio, J., Cooke, D., and Zhang, L., 2023, Valeriano Cu-Au deposit, Chile: A vertical profile of a weakly to moderate overprinted porphyry – high sulfidation system: Amira P1249 Santiago Tech Transfer Meeting, 13 October 2023.

Piquer, J., 2023, Tectonomagmatic controls on the formation of giant porphyry systems: the case of Central Chile: Amira P1249 Santiago Tech Transfer Meeting, 12 October 2023.

Piquer, J., Arcos, C., Cooke, D., Belousov, I., Hollings, P., and Baker, M., 2023, Discrimination of porphyry-related epidote using mineral chemistry in the Andes of central Chile: Amira P1249 Santiago Tech Transfer Meeting, 13 October 2023.

Piquer, J., Cajal, Y., Hollings, P., Muñoz, S., and Belousov, I., 2023, Magma fertility in Central Chile - Whole-rock and mineral chemistry: Amira P1249 SRM #3, 13 & 14 June 2023, p. 298-324.

Piquer, J., González, R., Torres, F., Uribe, J., Baker, M., Belousov, I., and Steadman, J., 2023, Honours project results in Andean study sites: Amira P1249 SRM #4, 6 & 7 December 2023, p. 190-241.

Resta, J., 2023, Rentails: Realise the full potential of Renison: RRC SRM #2, 29 November 2023, p. 268-275.

Rodemann, T., 2023, Introduction to Vibrational Spectroscopy: RRC SRM #2, 29 November 2023, p. 244-267.

Sahu, A., Zhang, L., Rodemann, T., and Cracknell, J., 2023, Exploring spectral signatures of alteration minerals: Amira P1249 SRM #4, 6 & 7 December 2023, p. 148-167.

Santos Costa, A.I., Cooke, D.R., Zhang, L., Hunt, J., and Cajal, Y., 2023, Application of new techniques for orebody knowledge: An example from Grassy W skarn deposits: RRC SRM #2, 29 November 2023, p. 94-107.

Santos Costa, A.I., Cooke, D.R., Zhang, L., Hunt, J., and Cajal, Y., 2023, Characterisation of W mineralisation at Grassy, King Island, Tasmania: RRC SRM #1, 7 July 2023, p. 64-92.

Staubmann, M., 2023, Mineral characterisation for calculated mineralogy - Cowal (GRE46), NSW, Australia: Amira P1249 SRM #4, 6 & 7 December 2023, p. 25-50.

Staubmann, M., Halley, S., Cooke, D.R., and Cracknell, M., 2023, Module 2 – Calculated Mineralogy and Hyperspectral Data; Case study - GRE46, Cowal district, NSW, Australia: Amira P1249 London Tech Transfer Meeting, 24 August 2023, p. 71-79.

Steadman, J., 2023, Pyrite at Mt Isa: Amira P1249 London Tech Transfer Meeting, 24 August 2023, p. 42-64.

Steadman, J., 2023, IOCG^3 Year 1 Overview: IOCG^3 Annual Sponsors' Meeting 2, September 2023, p. 1-12.

Steadman, J., 2023, Alpine Magnetite and Pyrite: IOCG^3 Annual Sponsors' Meeting 2, September 2023, p. 32-47.

Steadman, J., 2023, Hillside Mineral Geochemistry: IOCG^3 Annual Sponsors' Meeting 2, September 2023, p. 48-67.

Steadman, J., 2023, Ernest Henry: geochemistry, geometallurgy…and geochronology: IOCG^3 Annual Sponsors' Meeting 2, September 2023, p. 116-141.

Sulyman, N., Hollings, P., and Dyer, J., 2023, Pyrite chemistry as a mineralisation vector in the Red Lake belt: Amira P1249 SRM #4, 6 & 7 December 2023, p. 243-286.

Turner, C., Hollings, P., and Zhang, L., 2023, Northwest Expo lithocap, Vancouver Island, Canada: Amira P1249 SRM #4, 6 & 7 December 2023, p. 242-266.

Vazquez, J., Le Madec, D., Garrity, J., Feria, S., Parker, P., and Sandfire mine and exploration teams, 2023, Proposed Module 1 Site AMIRA P1249 – Magdalena Deposit: Amira P1249 SRM #3, 13 & 14 June 2023, p. 241-258.

Yurdakul, E., Zhang, L., Baker, M., and Scott, R., 2023, Critical minerals in Mount Read Volcanics: RRC SRM #2, 29 November 2023, p. 35-53.

Yurdakul, E., Zhang, L., Baker, M., and Scott, R., 2023, Orebody knowledge of the Western Tharsis Cu-Au deposit, Tasmania: Implications for ore processing and mineral exploration: RRC SRM #1, 7 July 2023, p. 179-200.

Zhang, L., 2023, Introduction to Element 1: Unlocking Critical Metal Resources: RRC SRM #1, 7 July 2023, p. 52-63.

Zhang, L., and the AMIRA P1249 research team, 2023, Introduction: Amira P1249 SRM #3, 13 & 14 June 2023, p. 1-22.

Zhang, L., and the AMIRA P1249 research team, 2023, P1249 Module 1 vectoring and fertility program - Progress update: Amira P1249 SRM #4, 6 & 7 December 2023, p. 377-388.

Zhang, L., Hong, W., Belousov, I., White, N., Halley, S., Cooke, S., Goemann, K., Jones, R., and Seow, X., 2023, Research update of Kurpetai-3 prospect, Kazakhstan - an active exploration site: Amira P1249 London Tech Transfer Meeting, 24 August 2023, p. 30-37.

Zhang, L., Hong, W., Belousov, I., White, N., Halley, S., Cooke, S., Goemann, K., Jones, R., and Seow, X., 2023, Unveiling the Hidden Treasures of Kurpetai-3, Kazakhstan - an active exploration site: Amira P1249 SRM #3, 13 & 14 June 2023, p. 152-191.

Appendices

CODES postgraduate students 2023

Bachelor of Science (Honours) (7)

Student	Supervisors	Research Program	Project	Support
Emily Conn	Juetzler, Carey	4	Sediment core stratigraphy at Havre, Kermadec Arc/ Rangitāhua	ARC Discovery
Daniel Fisher ^	Miller, Cracknell	2	Lithological, geochemical and mineralogical drivers of water quality at the legacy Scotia Mine, northeast Tasmania	MRT
Harrison Keeble ^	Zhang, Cooke, Rodemann	1	Characterising the regolith profile of the E41 Gold Deposit, Cowal, NSW: implications for ore processing and mineral exploration	Evolution Mining
Madison Mulder ^	Carey, Meffre, Orth	3, 4	The Louisiade Ophiolite Obduction and implications on the tectonic evolution of the Southwest Pacific	ARC Discovery
Issi Port ^	Scott, Meffre	3	The structural and metamorphic history of the Eastern Tyennan Region, Lake Pedder, Tasmania	CODES, MRT
Sarah Purdom	Meffre, Steadman	1	Genesis of a possible IRGS deposit near Stawell, Victoria	Battery Minerals
Millie Young ^	Zhang, Cooke, Cajal	1	Geology, alteration, mineralization and geochemistry of the Peak Hill Au-Cu deposit, NSW – Genetic and exploration implications	Alkane Resources

Graduate Certificate in Economic Geology (9)

Student	Supervisors	Research Program	Project	Support
Sammy Bakie			coursework only	
Erick Camara Corona			coursework only	
Ristch Camille			coursework only	
John Carswell			coursework only	
Samuel Connell ^			coursework only	
Stephen Ledger			coursework only	
John Robinson			coursework only	
Ivan Stelzner			coursework only	
Alice Wilkinson			coursework only	

Degree completed, not yet graduated ^ Graduated § Withdrawn ᵛ Deceased

Master of Economic Geology (76)

Student	Supervisors	Research Program	Project	Support
Michael Adams #			coursework only	
Greg Amalric			coursework only	
Jessica Askew			coursework only	
John Ateny			coursework only	
Stuart Badock			coursework only	
Grace Barber			coursework only	
Joel Blake			coursework only	
Kymren Bolling-Mcdougall			coursework only	
Ryan Bonser			coursework only	
James Bresnahan			coursework only	
John Brewster			coursework only	
Callan Brown			coursework only	
Kaitlin Catalano			coursework only	
Brianna Clark			coursework only	
Jesse Coates-Marnane			coursework only	
Sarah Cochrane			coursework only	
Jamin Cristall			coursework only	
Craig Crossland			coursework only	
Roseanna Dale #			coursework only	
Jonathan Davis			coursework only	
Lieth de Selincourt	Cooke, Baker, Cracknell, Meffre	1	Application of mineral chemistry to aid exploration for Cu-Au-Mo porphyry mineralisation in the Temora district, New South Wales, Australia	Sandfire Resources
Alison Dines			coursework only	
Mark Eastlake			coursework only	
David Eddy ^			coursework only	
Paul Edmonds			coursework only	
Brynache Ellingworth			coursework only	
Benjamin Ferguson ^			coursework only	
Joshua Greene	Zhang	1	The geological and geochemical fingerprinting of high-grade gold mineralisation in the Shepherd deposit, Costerfield Victoria	Mandalay Resources
Shelley Greener			coursework only	
Brendan Hardwick ^	Meffre, Doyle (AngloGold Ashanti)	1, 3	Mineralised textures at the Tropicana gold mine: Implications for the genetic model and deportment of gold	AngloGold Ashanti
Michael Harris			coursework only	
Jane Harvey			coursework only	
Carl Jackman ^			coursework only	
Fungai (Grace) Jaravani			coursework only	
Riley Jenkins ^			coursework only	
Ashleigh Job	Cooke	1	Geology, structural control and exploration implications of Au mineralized Fenix gold project, Maricunga Belt, Chile	Rio2 Limited
Benjamin Johnson	Mukherjee, Large, Steadman	1, 3	Pyrite textures and trace element chemistry of the Century Deposit – implication for exploration	PY005 project
Lucy Jones	Escolme	2	An investigation into the mineral associations and relationship between chalcopyrite and sphalerite at Cannington Mine, North Queensland	South32

Degree completed, not yet graduated ^ Graduated § Withdrawn ᵛ Deceased

Student	Supervisors	Research Program	Project	Support
Greer Lane			coursework only	
Joel Logan			coursework only	
David Mallon ^			coursework only	
Francisco Maturana			coursework only	
Dev-orson Mbara			coursework only	
Todd McGilvray ^			coursework only	
Jonathan McLoughlin			coursework only	
Karl McNamara			coursework only	
Dominic Murphy			coursework only	
Ana Nichols			coursework only	
Christian Oviawe			coursework only	
Catherine Pearse			coursework only	
Craig Pereira			coursework only	
Luke Pickering			coursework only	
David Gerardo Portocarrero Ccaccya #			coursework only	
Nicholas Poznik			coursework only	
Steven Rennick			coursework only	
Alex Richards			coursework only	
Callum Richardson			coursework only	
Torrin Rowe			coursework only	
Nicholas Ryan			coursework only	
Henry Schaumburg	Zhang, Hong	1	The Kara Fe-W skarn: A mineral chemistry and age dating study to better determine controls on skarn formation	self-funded
Joel Sidoruk			coursework only	
Angelo Socio			coursework only	
Callum Spink			coursework only	
Antoinette Stryk			coursework only	
James Taylor			coursework only	
Alan Till			coursework only	
Madeline Wallace			coursework only	
Alexander Waters			coursework only	
Megan Weatherman			coursework only	
David Willis			coursework only	
Madeline Wallace			coursework only	
Megan Weatherman			coursework only	

Degree completed, not yet graduated ^ Graduated § Withdrawn ᵛ Deceased

Doctor of Philosophy (48)

Student	Supervisors	Research Program	Project	Support
Christopher Allen	Meffre, Miller, Cracknell, Missen, Jamieson (Queens U)	2	Optimising remediation of legacy mines – mineralogical controls on long-term waste rock weathering and mine drainage	UTAS, MRT, Bluestone Mines
Alfredtina Appiah	Hunt, Missen, Fathi	2	Pathways to production: Magnesite deposits at Prospect Ridge, northwestern Tasmania	UTAS, RRC, GWR
Fuseini Atanga	Baker, Zhang, Armistead	1	Deposit characterisation and exploration vectors for the Akyem orogenic gold deposit, Ghana	Newmont, UTAS, Amira P1249
Jose Barillas Diaz	Cooke, Zhang, Hong	1	Atypical nickel mineralization in metasomatic rocks – The Avebury Ni deposit, Western Tasmania	RRC, UTAS, Avebury Nickel Mine
Billy Beas	Cooke, Zhang	1	Orebody knowledge, halogen deportment and vectoring implications of the E44 Au-Cu deposit, Northparkes District, New South Wales, Australia	UTAS, Amira P1249
Isaac Brown	Zhang, Cooke, Rodemann (CSL)	1	Geology, geochemistry and genesis of the Havieron gold copper deposit, Paterson Province, Western Australia	Newmont, UTAS, SEG
Axel Cima	Belousov, Cooke, Cracknell	1, 5, 6	Microinclusions in porphyry Cu deposits	UTAS, Amira P1249, CODES
Acacia Clark	Carey, Jutzeler, Fox (IMAS)	4	Dynamics of subaerial silicic explosive volcanism: The 1315 CE Kaharoa eruption and the Late Bronze Age eruption of Santorini	UTAS, GNS, ANZIC, GSA Endowment Fund
Takeshy Coaquira	Cooke, Zhang, Escolme	1, 2	Resolving multiple generations of white mica and clay alteration at the Resolution porphyry Cu-Mo deposit, Arizona	ARC TMVC, Amira P1202, UTAS
Stephen Cooke	Cracknell, Baker, Zhang	1, 6	Pathways to mineral discoveries through computer-based modelling of geochemical data	UTAS, Amira P1249
Vinicius da Cruz	Cooke, Zhang, Carey	1, 4	Characterisation of the complex orebodies in the Rosebery Middle Mine: implications for ore processing and mineral exploration	RRC, UTAS, MMG
Rob Davidson ^	Gemmell, Cooke	1	Geology and genesis of the San Sebastian vein system, Durango, Mexico	Hecla Mining, UTAS
Isaac Evinemi	Cracknell, Baker, Zhang	1, 6	Mineralogical domaining and predictive modelling of porphyry copper deposits using deep learning approach	Amira P1249, UTAS
Alex Farrar #	Cracknell, Cooke	1, 3, 6	Tectonic and structural controls on the spatio-temporal distribution of giant porphyry copper deposits in the Central Andes	First Quantum Minerals
Shannon Frey	Jutzeler, Carey	4	Behaviour of submarine caldera-forming silicic eruptions in the Kermadec arc, New Zealand	UTAS
Javier Gil Rodriguez	Cooke, Missen, Hong	1	Characterisation of skarn-type deposits: Renison Bell Sn deposit	UTAS, RRC, Bluestone Mines
Declan Higgins	Carey, Oalmann	4	Volcanic architectures	UTAS
Richard Hill §	Scott, Cracknell, Roach	6	Exploring the East Tennant region: Unravelling the crustal architecture, tectonic evolution and mineral systems potential of an undercover Proterozoic terrane through the integrated use of geophysics, drill hole data and machine learning/geodata analysis techniques	MinEx CRC, UTAS, Strategic Energy Resources, Inca Minerals, Middle Island Resources, Encounter Resources
Max Hohl #	Steadman, Cloutier, Barker	3	Defining the mineral chemistry footprints of the Starra iron oxide-copper gold deposits in northwest Queensland	MRT, ARC TMVC, UTAS
Malai Ila'ava	Jutzeler, Carey, Cas	4	Volcanic architecture of the Cowal Igneous Complex, NSW	ARC Linkage, UTAS, Evolution Mining

Degree completed, not yet graduated ^ Graduated § Withdrawn ᵛ Deceased

Student	Supervisors	Research Program	Project	Support
Colin Jones #	Meffre, Cooke, Orovan	3, 4	The petrogenesis of the Devonian granites of the East Tasmania Terrane	MRT, ARC TMVC, UTAS
Rhiannon Jones #	Cooke, Zhang, Escolme	1, 2	The significance of phyllic alteration at the E26 porphyry Cu-Au deposit, NSW, Australia	MRT, ARC TMVC, UTAS
Joseph Knight ^	Cooke, Orovan, Zhang	1	The tectonic and metallogenic setting of Cu-Au mineralisation in Myanmar: Implications for mineral exploration in the Central Magmatic-Volcanic Arc	MRT, ARC TMVC, UTAS
Bridie Le'Gallais	Belousov, Olin, Carey	4	The tectonic significance of mafic/ ultra mafic igneous rocks in western Tasmania	AMIRA P1202, ARC TMVC, UTAS
Elena Lounejeva #	Steadman, Large	3	Trace element geochemistry of pyrite in sediments across the Permian Triassic boundary	ARC Discovery, CODES
Javier Merrill #	Cracknell, Escolme	2	Quantification of mineral texture for geometallurgical predictive modelling	Amira P1202, Minerals Council of Australia, BECAS Chile, ARC TMVC
Pratichee Mondal	Hunt, Zhang, Missen	2	Recovery of critical metals from legacy mine waste: Savage River magnetite deposit, northwest Tasmania	RRC, UTAS, Grange Resources
Hannah Moore	Carey, Jutzeler	4	Shallow conduit, vent, and sedimentation processes involved in the 1886 basaltic Plinian eruption at Tarawera Volcano, New Zealand	UTAS, UHawaii, UOtago, GNS Science
Joanne Morrison ᵛ	Steadman, Meffre, Hunt	2, 3	Geometallurgy of Australian IOCGs	UTAS
Annah Moyo ^	Cooke, Meffre, Miller, Parbhakar-Fox (UQ)	2	Controlling acid and metalliferous drainage at legacy sites in Tasmania using industrial wastes	UTAS, MRT, ARC TMVC
Emmanuel Dogara Musa	Hunt, Missen, Fathi	2	Pathways to production for critical metals: Kara W deposit, western Tasmania	RRC, UTAS, Tasmania Mines
Nelao Natukondje Naimbale	Cooke, Hong, Scott	1	Characterisation of the Heemskirk tin project	RRC, UTAS, Stellar Resources
Sibele Cristina do Nascimento ^	Cracknell, Cooke, Meffre, Parbhakar-Fox (UQ)	2, 6	Geoenvironmental characterisation of historic mine tailings: A multidisciplinary approach	ARC TMVC, UTAS
Jaime Osorio	Zhang, Cooke	1	Anatomy of the porphyry-epithermal transition in the Valeriano Cu-Au deposit, Chile	ARC TMVC, UTAS, Amira P1202, SEG, ATEX Resources
Giovana Pimentel	Baker, Cracknell, Hollings (Lakehead)	1, 6	Rock characterisation of the PlatReef	Anglo American, Amira P1249, UTAS
Olive Ponyalou	Cooke, Missen, Zhang	1	Geology, genesis, and exploration significance of Cu-Au veins and altered rocks in the Kainantu Cu-Au district, PNG	K92 Mining, UTAS
Arka Sahu	Zhang, Cracknell, Rodemann (CSL)	1, 6	Multi-scale hyperspectral and mineral chemistry data mining	UTAS, Amira P1249
Angela Isaura Santos Costa	Cooke, Zhang, Cajal, Hunt	1	Characterisation of tungsten mineralisation at Grassy, King Island, Tasmania – implications for ore genesis, exploration, and pathways to production	UTAS, RRC, Group 6 Metals
Thomas Schaap #	Meffre, Whittaker (IMAS), Cracknell, Roach	3, 6	Tectonic evolution of the early Palaeozoic Lachlan Orogen	ARC Linkage, UTAS
Xin Ni Seow #	Zhang, Cooke, Orovan	1, 5	Genesis, geochemistry and spectral characteristics of alunite supergroup minerals: Implications in lithocap and porphyry explorations	ARC TMVC, UTAS, Amira P1202, SEG
Emily Smyk #	Cooke, Baker, Cracknell	1	Geology, geochemistry, geochronology and exploration footprints of the Christmas porphyry Cu-Mo deposit, Arizona	Amira P1202, ARC TMVC, UTAS

Degree completed, not yet graduated ^ Graduated § Withdrawn ᵛ Deceased

Student	Supervisors	Research Program	Project	Support
Peerapong Sritangsirikul	Meffre, Khin Zaw, Charusiri (CU)	1, 3, 4	Tectonic evolution and related mineral deposits of mainland SE Asia: Insights from geochemistry and geochronology of zircons	Royal Thai Government Scholarship
Markus Staubmann	Cooke, Hunt, Cracknell	1, 2, 6	Geology, geochemistry, and geometallurgy of the GRE46 epithermal gold deposit, Cowal District NSW	Evolution Mining, UTAS, Amira P1249
Yi Sun #	Zhang, Escolme, Cooke	1, 2	Geology of the Quartz – Pyrite – Gold (QPG) mineralization and the new model of the Mankayan District, Northern Luzon, Philippines	ARC TMVC, Amira P1202, UTAS, SEG, Lepanto Consolidated
Victor Torres Pacheco	Cooke, Zhang, Hunt	1, 2	Geology, genesis, and geometallurgy of Cu-Au-Ag mineralized tourmaline breccia pipes at Soledad, central Peru	Chakana Copper, UTAS
Chuang Wang §	Jutzeler, Olivier, Roach, Carey	4	Application of seismic techniques to reconstruct volcanic architecture	MRT, UTAS, IMS
Emrecan Yurdakul	Zhang, Baker, Scott	1	Orebody knowledge of the Western Tharsis Cu-Au deposit, Tasmania: implications for ore processing and mineral exploration	UTAS, MRT, CMT, Sibanye-Stillwater
Zebedee Zivkovic #	Baker, Cracknell, Barker	1, 4	Trace element systematics in whole rock analysis of magmatic-hydrothermal ore deposits	MRT, Mineral Mapping, Dreadnought Resources

Degree completed, not yet graduated ^ Graduated § Withdrawn ᵛ Deceased

Major externally funded research projects^

ARC Discovery Grants 2023

Investigators	Project	Funding Body	Period	ARC Funding for 2023
Jutzeler, Carey, Gallagher (UMelb)	Eruption dynamics and tsunami potential from submarine volcanoes	ARC	2023–2026	$67,881
King (ANU), V Kamenetsky	Impact of hot gas on volcanic rocks and ore-forming processes	ARC	2020–2023	$19,895
Seton (USyd), Carey, Williams (IMAS), Coltice (ENS Lyon), Duncan (Oregon)	How Earth's deep interior communicates with the surface	ARC	2020–2023	**

ARC Linkage Grants 2023

Investigators	Project	Funding Body	Period	ARC Funding for 2023	Partner Funding for 2023
Carey, Cas, Cooke, Meffre, Bull (GSNSW), Rowland (U Auckland), Heap (IPGS)	Exploration targeting from next-generation volcanic facies reconstruction	ARC, Evolution Mining, Mineral Resources Tasmania	2020– 2023	**	**

Department of Education Grants 2023

Investigators	Project	Funding Body	Period	DESE Funding for 2023	Partner Funding for 2023
Cooke, Hunt, Fraser, Rodemann, Zhang, Belousov, Beasy, Cirkony, Cracknell, Missen, Fathi, Cajal, Hong, Armistead, Pirard (ULiege)	Building capacity in Regional Australia to enhance Australia's economy through research, training, and environmentally sustainable production of critical metals	Department of Education, Mineral Resources Tasmania	2022– 2025	$1,719,097	$16,875

Industry and other externally funded research grants 2023

Investigators	Project	Funding Body	Period	Funding for 2023
Cooke, Baker, Cracknell, Escolme, Zhang, Aillères (Monash), Halley (Mineral Mapping), Hollings (Lakehead), Piquer (UAustral)	Amira P1249: Exploring, characterising and optimising complex orebodies – upscaling orebody knowledge to add value across the Mining Value Chain	Amira Global representing: Anglo American, BHP, Boliden Mineral, Codelco, Evolution Mining, Fortescue Metals Group, Mount Isa Mines, Newcrest Mining, Newmont Goldcorp, Rio Tinto Exploration, South32, First Quantum Minerals, CMOC Mining, Sandfire Resources, AngloGold Ashanti	2022– 2027	$794,736
Cooke, Cloutier	Exploring for the future: uncovering Australia's exploration potential	Geoscience Australia	2021– 2024	$197,600
Meffre, Armistead, Steadman	Exploring for the future: Temporal controls on mineralisation	Geoscience Australia	2022–2026	$155,119

Investigators	Project	Funding Body	Period	Funding for 2023
Steadman	Iron oxide copper-gold deposits: Geochemistry and geometallurgy	Evolution Mining, Geological Survey of Queensland, Geological Survey of South Australia, Georgina Resources, Mineral Resources Tasmania, Mount Isa Mines, OZ Minerals, Red Metal, Rex Minerals, Spanish National Research Council	2022–2025	$150,000
Zhang, Cooke, Rodemann, Brown (student)	Geology, geochemistry and genesis of the Havieron gold-copper deposit, Paterson Provence, Western Australia	Newcrest Mining	2021–2025	$80,500
Zhang	Enhanced geochemical targeting at the Mount Gilmore Cu-Co-Au trend	Dept of Industry, Innovation and Science	2022–2023	$49,849
		Corazon Mining	2022–2023	$25,000
Meffre, Armistead	AuScope Geochemistry Laboratory Network	Curtin University	2022–2023	$50,000
Khin Zaw, Makoundi, Meffre	Ore deposit geochronology, pyrite chemistry, and drill targeting in Laos	Lane Xang Minerals	2023	$20,859
Cooke, Zhang, Hunt, Torres (student)	Geology, genesis and geometallurgy of Cu-Au-Ag mineralised tourmaline breccia pipes at Soledad, central Peru	Chakana Copper	2022–2028	$20,000
Carey, Jutzeler, Clark (student)	Submarine deposits from the Late Bronze Age (Minoan) eruption – IODP Exp 398: Hellenic Arc Volcanic Field	ANZIC-IODP (via Australian National University)	2023–2025	$20,000
Jutzeler	Antarctic volcanism record in the Amundsen Sea, IODP 379	ANZIC-IODP (via Australian National University)	2023	$20,000
Miller, Cracknell, Cooke, Hunt, Staubmann (student)	Integrated ore deposit knowledge: optimising mineralogical characterisation through the mining value chain	Evolution Mining	2022–2025	$14,932
Steadman	Geochemical characterization of the Federation deposit, Cobar basin, NSW; Geochemical characterisation of the Dargues deposit, Braidwood, NSW	Aurelia Metals	2022–2023	$10,881
Zhang, Cooke, Cajal, Young (student)	Geology, alteration, mineralization and geochemistry of the Peak Hill Au-Cu deposit, NSW - Genetic and exploration implications	Alkane Resources	2023	$10,000
Missen, Cooke	Sources and drivers of neutral mine drainage at the former Merrywood coal mine	Mineral Resources Tasmania	2023–2024	$8,800
Carey, Clark (student)	Dynamics of subaerial silicic explosive volcanism: The 1315 CE Kaharoa eruption and the Late Bronze Age eruption of Santorini	IODP (via Australian National University)	2023	$3,070
		Geological Society of Australia	2023	$3,042
Meffre, Missen, Cracknell, Miller, Jamieson (Queens U), Allen (student)	Optimising remediation of legacy mines - mineralogical controls on long-term waste rock weathering and mine drainage	Mineral Resources Tasmania	2022–2025	$0
		Bluestone Mines	2022– 2025	$5,000

Investigators	Project	Funding Body	Period	Funding for 2023
Meffre, Steadman, Goemann (CSL)	Mineral chemistry research for Battery Minerals	Battery Minerals	2022–2024	$4,713
Zhang, Greene (student)	The geological and geochemical fingerprinting of high-grade gold mineralisation in the Shepherd deposit, Costerfield Victoria	Mandalay Resources	2023–2025	$4,000
Meffre	Mineral chemistry research for Emmerson Resources	Emmerson Resources	2021–2023	$2,532
Scott, Cracknell, Roach, Hill (student)	Exploring the East Tennant region: Unravelling the crustal architecture, tectonic evolution and mineral systems potential of an undercover Proterozoic terrane through the integrated use of geophysics, drill hole data and machine learning/geodata analysis techniques	MinEx CRC	2021–2024	$0
Belousov, Olin, Le'Gallais (student)	The tectonic significant of mafic/ultramafic igneous rocks in western Tasmania	Mineral Resources Tasmania	2019–2023	$0
Cooke, Portocarrero (student)	Multi-stage intrusion, brecciation and mineralization at the Antakori Cu-Au-Ag project, northern Peru	Regulus Resources	2022–2024	**
M Kamenetsky	Olympic Dam fluid/melt inclusion project	BHP	2021–2024	**
Hunt	Methodology development for gangue liberation assessment	CSIRO	2022–2023	**
Cooke, Baker, Cracknell, Meffre, de Selincourt (student)	Application of mineral chemistry to aid exploration for Cu-Au-Mo porphyry mineralisation in the Temora district, New South Wales	Sandfire Resources	2021–2023	**
Cracknell, Cooke, Farrar (student)	The geodynamic and tectonic influence on giant porphyry copper deposit architectural controls	First Quantum Minerals	2020–2023	**

^ projects with greater than $2,000 external funding per year

** all project funding received, project still active

Visitors 2023

INDUSTRY VISITORS TO CODES IN 2023

NAME	COMPANY
Kristyn Adamczyk	Sandfire Resources
Jeffrey Bigelow	Newmont
Renato Bobis	South32
Alex Brown	Glencore Mount Isa
Jing Chen	AngloGold Ashanti
Karen Connors	AngloGold Ashanti
Iain J Dalrymple	Anglo American
Greg Doherty	Tasmania Mines
Rob Duncan	Rio Tinto
Katie Dunn	Newmont
Paloma Elvira	MMG
Dave Finn	Newmont
Bright Makafui Foli	Amira Global
Ingrid Flemons	Rio Tinto
Karyn Gardner	Evolution Mining Limited
Mohsen Hadizadeh	Rio Tinto
Scott Halley	Mineral Mapping
Ben Hames	AngloGold Ashanti
Ned Howard	Evolution Mining Limited
Jonathon Hoye	CMOC
Tim Ireland	First Quantum Minerals
Andrew Jenkins	AngloGold Ashanti
Alan Kobussen	Rio Tinto
Chun-Kit Lai	Fortescue Metals Group
Simon Marshall	Newmont
Ray Mostogl	Tasmanian Minerals, Manufacturing and Energy Council
Dana Olafson	Fortescue Metals
Adam Pacey	Rio Tinto
Paull Parker	Sandfire Resources
Cam Quinn	Fortescue Metals
Sarah Rice	Newmont
Kevin Robinson	MMG
Sophie Sciarrone	Rio Tinto
Xin Ni Seow	AngloGold Ashanti
Trevor Shaw	Glencore Mount Isa
Anil Subramanya	Amira Global
Michael Whitbread	Rio Tinto
Alexander Willcox	Newmont
Rocío Belén Gil Zwenger	First Quantum Minerals

INDUSTRY VISITORS TO CODES IN 2023 WHO DIALLED IN FOR MEETINGS

NAME	COMPANY
Debora Araujo	Rio Tinto
Natalie Caciagli	BHP
Kate Cocker	Rio Tinto
Kim Cook	South32
Patricia Durance	BHP

INDUSTRY VISITORS TO CODES IN 2023 WHO DIALLED IN FOR MEETINGS Cont.

NAME	INSTITUTION
Jason Dyer (student)	Lakehead University
Fernando Fontana	Rio Tinto
John Garrity	Sandfire MATSA
Melissa Gregory	Rio Tinto
Lachlan Hennessy	South32
Peter Hollings	Lakehead University
Tobias Hermansson	Boliden
Dave Le Madec	Sandfire MATSA
Josh Leigh	Anglo American
Matt Loader	Anglo American
Mitchell Marcelissen (student)	Lakehead University
Stephanie Montalvo	Curtin University
Dominic Murphy	Newmont
José Piquer	Universidad Austral de Chile
Ivan Semenov	Rio Tinto
Christian Stenvall	Boliden
Nafiu Sulyman (student)	Lakehead University
Chase Turner (student)	Lakehead University
Juan Carlos Videira Vazquez	Sandfire MATSA
Adriaan Van Herk	Sandfire MATSA
Marina Veter	Rio Tinto
Noel White	Consultant

NATIONAL ACADEMIC AND GOVERNMENT VISITORS TO CODES IN 2023

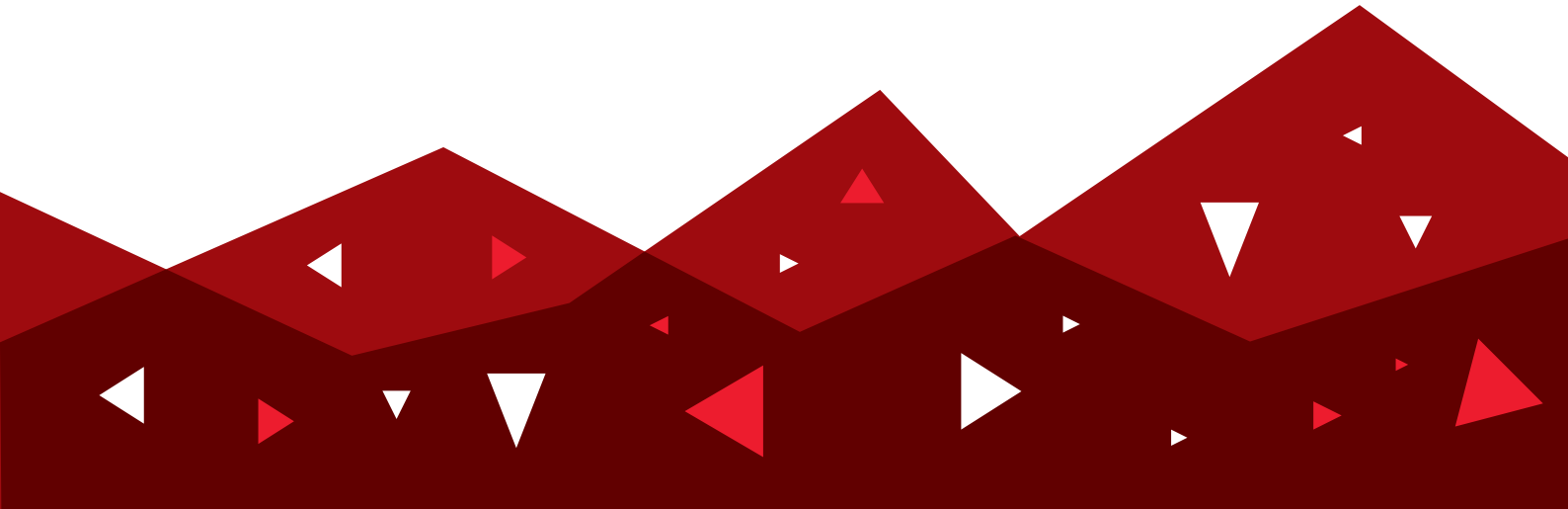
NAME	INSTITUTION
Terry Bailey	CoSE, UTAS
Ralph Bottrill	Mineral Resources Tasmania
Mark Duffett	Mineral Resources Tasmania
Simon Ellingsen	Physics, UTAS
Marco Fiorentini	CET, University of Western Australia
Sharon Fraser	School of Education, UTAS
Andrew McNeill	Mineral Resources Tasmania
Rachel Perkin	Business Development and Partnerships Lead, CoSE, UTAS
Thomas Rodemann	CSL, UTAS

INTERNATIONAL ACADEMIC AND GOVERNMENT VISITORS TO CODES IN 2023

NAME	INSTITUTION
Eric Forson	University of Ghana, Ghana
Pian Huayan	University of Geosciences, Beijing
Chen Jiawei	University of Geosciences, Beijing
Bernd Lottermoser	RWTH Aachen, Germany
His Excellency Johan Pontus Melander	Swedish Embassy, Canberra
Janne Scheffler	GEOMAR, Kiel, Germany
Li Yalin	University of Geosciences, Beijing
Liang Yong	University of Geosciences, Beijing
Zhao Zhidan	Vice President, University of Geosciences, Beijing
Gao Zhiqian	University of Geosciences, Beijing

CODES
Centre for Ore Deposit and Earth Sciences
University of Tasmania
Private Bag 79, Hobart, Tasmania 7001, Australia
Tel +61 (0) 3 6226 2472
ISSN: 1440-6411

Compilation: Caroline Mordaunt and Helen Scott
Editing: Caroline Mordaunt
Design: Before Creative, Hobart



CODES UNIVERSITY of TASMANIA CODES

www.utas.edu.au/codes