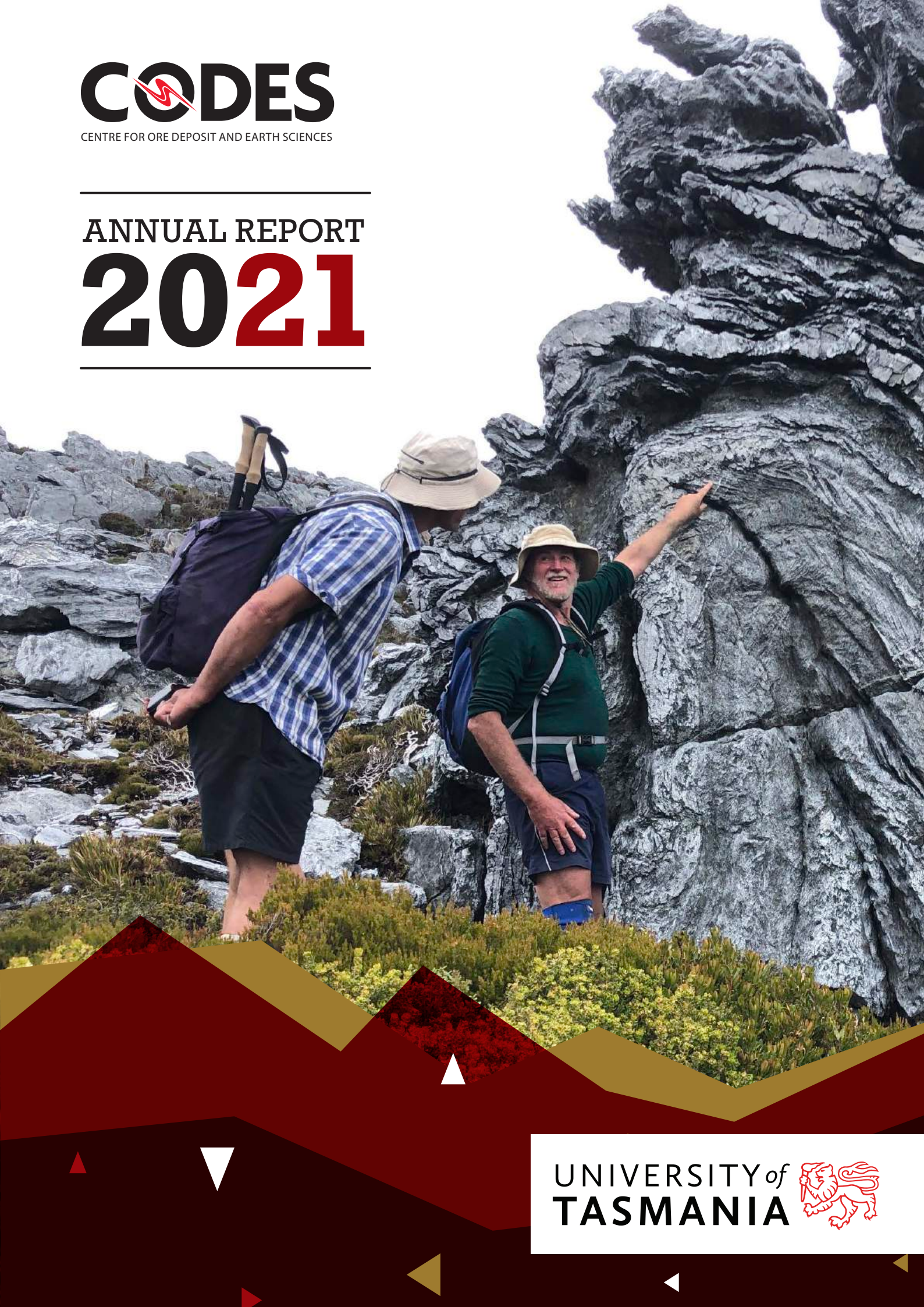

ANNUAL REPORT
2021





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: The start of it all: KEA101 students on the Waterworks Excursion examining and sketching Triassic Parmeener Supergroup sandstone, May 2021.

FRONT COVER: Earth Sciences Senior Lecturer Dr Michael Roach (right) and Dr David Green (Mineral Resources Tasmania) looking at complex folds in Tyennan quartzite on Cleft Peak in the Frankland Range, southwest Tasmania, March 2021. (Photo taken by Associate Professor Sebastien Meffre.)

BACK COVER: (Left) Dean's Summer Research Scholarship Student Madison Mulder examining turbidites in a quarry west of Falmouth as part of her summer project on the Mathinna Supergroup. Her project fell within CODES Program 3, Sedimentation, tectonics and Earth evolution. (Right) L-R: TMVC/CODES PhD student Rhiannon Jones examining core with CODES PhD student Hannah Moore and CODES staff member Dr Sheree Armistead during the Ores in Magmatic Arcs Masters short course in western Tasmania, November 2021.

OPPOSITE: Coarse-grained discordant galena and sphalerite in the pyritic carbonaceous dolomitic Urquhardt Shale, Mt Isa Pb-Zn-Ag deposit, Queensland.

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Director's report 2021



Although 2021 was another very challenging year in so many aspects of our lives, I was impressed with the continued resilience and kindness shown by CODES' staff and students as we completed several major research projects and started some new initiatives. Many of our team were focused on finalising data acquisition and interpretation, preparing final reports and presentations, and so experienced minimal disruption to their activities due to the pandemic. Others were not so fortunate, with international field activities curtailed and some interstate fieldwork disrupted, although it was pleasing to see Dr Michael Roach able to supervise Honours student Dina Chu in her fieldwork in the Northern Territory. 2021 did, however, provide some challenges with regards to sustainability of our research staff due to the unavoidable uncertainties that are associated with contract research positions.

Research highlights

It was a busy year for CODES researchers, with an unprecedented number of major collaborative research projects concluding in 2021, along with some new projects getting underway and others continuing. As such, 2021 was highly productive with regards to industry reporting.

Amira P1206, 'Identifying unique Resistate Indicator Mineral (RIM) chemistry as a guide in prospectivity for sediment-hosted copper mineralisation', was a one-year industry-funded pilot study completed in April 2021 as part of the Australian Research Council's Transforming the Mining Value Chain (TMVC) Research Hub. P1206 was designed to test whether the novel approach of resistate mineral chemical analysis could provide sufficiently distinct signatures to warrant further development into a practical exploration tool. The work was strategically and systematically undertaken on Central African Copperbelt samples, of which the research team has considerable experience, providing a basin-wide data set involving contrasting metal endowment, and hydrologic/metamorphic histories. The project, led by Dr Shaun Barker, was a collaboration between CODES and iCrag and successfully demonstrated proof of concept through the chemical distinction of hydrothermal and detrital resistate phases. The outcomes of this pilot study are being used as the foundation to develop a new sediment-hosted Cu Amira proposal in 2022.

The TMVC's largest research project for the past three years in terms of research funding and staff/student involvement, Amira P1202 'Far-field and

It was a busy year... with an unprecedented number of major research projects concluding in 2021.

near-mine footprints – Finding and defining the next generation of Tier 1 ore deposits', came to a successful conclusion at the end of June 2021. This project was sponsored by 14 industry partners, and involved research in Australia, North and South America, Europe and the Indo-Pacific region. CODES staff and students collaborated with key researchers from Monash University, Universidad Austral de Chile, Lakehead University and Mineral Mapping to deliver new exploration tools and characterisation methods for porphyry and epithermal



Participants of the CODES Masters short course *Ores in Magmatic Arcs*, November 2021. This photo was taken at the Mount Lyell mine, western Tasmania, by Dr Michael Roach.

deposits, and also for Archean Au, intrusion-related Au IOCG and sediment-hosted Cu deposits. The research team delivered a series of final meetings online over a two-month period to facilitate technology transfer. The successful outcome of P1202 has led to a new five-year Amira project, P1249 'Exploring, characterising, and optimising complex orebodies – Integrated deposit knowledge to add value across the Mining Value Chain', with 15 confirmed industry sponsors. P1249 is scheduled to commence in February 2022.

Completion of P1202 also brought the TMVC Research Hub to a successful conclusion in June 2021. This highly successful ARC-funded research initiative operated for six years and was the foundation of much of CODES' research activities over that time. The TMVC instigated a series of more than 40 sub-projects across its three major research themes: 1) Detecting proximity to ore; 2) Optimising geomettallurgical prediction; and 3) Minimising geoenvironmental risks; and also in the Underpinning Technology area, in order to meet the project's major aims and objectives. Individual sub-projects involved collaboration with partner

organisations Newcrest Mining Ltd, BHP Olympic Dam, Amira Global, Corescan, Laurin Technic and RWTH Aachen University, together with several additional industry and academic partners. The TMVC made considerable impacts across the Mining Value Chain – its exploration tools are now being used in conjunction with standard exploration methods by industry to aid decision-making, particularly with regards to whether to proceed or terminate exploration activity in a given district, and to help focus exploration activities within those districts assessed as most prospective. Several TMVC-funded PhD students are still completing their theses, with the final report to the ARC to be delivered in mid-2022.

CRC-ORE also came to a successful conclusion in June 2021. CODES' research was primarily conducted in CRC-ORE's 'Define' program in the collaborative project P1-006 ('Geological controls on grade-by-size fractionation'), led by Dr Julie Hunt. This project identified linkages to upgrading potential via screening and geological parameters and involved MSc students Nathaly Guerrero and Karla Morales. The team identified links between

The TMVC made considerable impacts across the mining value chain.

grade-by-size fractionation and geological parameters for gold and copper deposits using systematic logging, portable (hardness, magnetic susceptibility, hyperspectral, XRF) and bench-top (hyperspectral, XRF) tools. Ores associated with veins were found in general to have higher potential for pre-concentration by screening compared to disseminated ores. Although the project officially finished in 2021, additional work is continuing into 2022 with the completion of Karla's thesis and the compilation of a 'Library of mineralisation styles and upgrade potential via screening'.

Dr Jeff Steadman, Dr Jonathan Cloutier and PhD student Max Hohl brought the NW Queensland project to a successful conclusion in July 2021. The team demonstrated the potential for mineral chemistry to be used to detect

the distal geochemical footprints of IOCG, sediment-hosted Cu and Zn-Pb-Ag deposits in Mt Isa's eastern and western fold belts and provided new insights into ore genesis at several of the deposits investigated as part of this study. The successful outcomes of this project have led to a new three-year industry-funded IOCG research initiative that will commence in 2022. Max's PhD study of magnetite from the Starra IOCG project will also continue through 2022.

Late September saw the completion of the PY005 project, led by Dr Indrani Mukherjee with funding from the Ian Potter Foundation, seven mining companies and two state geological survey organisations. This innovative project applied pyrite chemistry to understanding nutrient availability in ancient oceans and how that impacted early life, and how pyrite analyses can also aid exploration for sediment-hosted ore deposits. The project generated an extensive database of around 4,000 pyrite LA-ICP-MS analyses and delivered several industry reports and journal articles.

The ARC Linkage project 'Exploration targeting from next-generation volcanic facies reconstruction', led by Associate Professor Rebecca Carey, continued throughout 2021. A key appointment was the recruitment of PhD student Malai Ila'ava, who is constructing a district-scale 3D model of the volcanic architecture of the Cowal volcanic complex, NSW. Malai conducted several months of fieldwork at the Cowal gold mine and has built an impressive geological foundation for his PhD study.

Following on from the conclusion of the TMVC, BHP Olympic Dam funded a new one-on-one collaborative two-year research project – the Olympic Dam fluid/melt inclusion project. This project commenced in June 2021 with Chief Investigator Dr Maya Kamenetsky collaborating with Dr Kathy Ehrig (BHP) to provide detailed orebody knowledge of the world's largest Cu-Au-U deposit.

In mid-2021, CODES entered a new research collaboration with Geoscience Australia (GA) as Dr Jonathan Cloutier was appointed as a CODES postdoctoral researcher working on GA's 'Exploring the future: Uncovering Australia's exploration

potential' initiative. Jonathan will be embedded with GA in Canberra for the next three years to facilitate the growth of this collaboration.

Awards and accolades

An impressive array of domestic and international accolades was bestowed on several researchers at CODES over the past year, with recognition of their sustained research excellence being provided by their peers. Domestically, Associate Professor Rebecca Carey was awarded the Royal Society of Tasmania's M.R. Banks Medal in 2021 – this medal is awarded biennially to a scholar of distinction in mid-career, in any field within the Royal Society's purview. Former PhD student Dr Alex Cherry was awarded the Geological Society of Australia's D.I. Groves Award for the best paper published in the *Australian Journal of Earth Sciences* by a young author, for an article based on his PhD research. Dr Michael Roach received the University of Tasmania's Vice-Chancellor's Innovation Award and UTAS' College of Science and Engineering (CoSE) Innovation Award for his novel and impactful work on 3D visualisations. Dr Indrani Mukherjee's sustained research excellence was recognised by the University of Tasmania when she received the Vice-Chancellor's Early Career Researcher and CoSE Early Career Researcher awards. Honours student Zak Weidinger was awarded the inaugural Richard Lane Scholarship from the Australian Society of Exploration Geophysicists. Another Honours student, Till Gallagher, was awarded the 2021 Geological Society of Australia's Endowment Fund Honours Award for Tasmania.

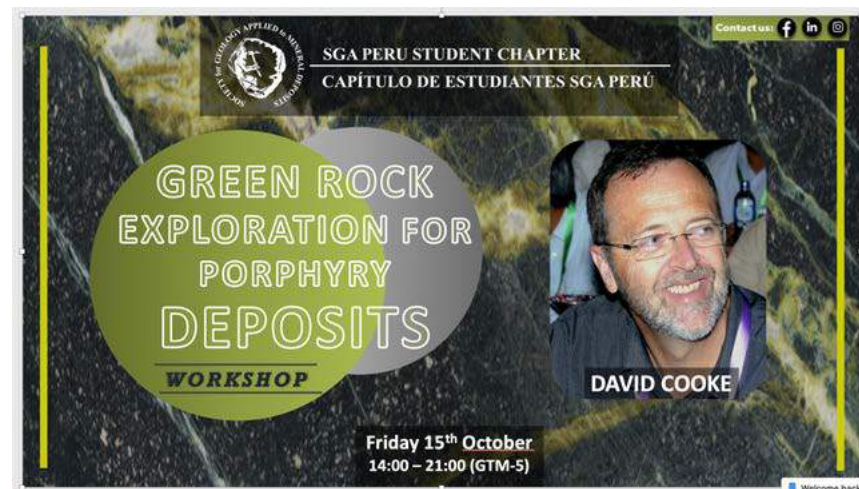
Internationally, Emeritus Professor David H. Green was awarded the Società Italiana Mineralogia e Petrologia Honorary Fellowship for 2021 "in recognition of an internationally relevant scientific and organising contribution to the advancement of the mineralogical and petrological sciences". Professor David Cooke was the 2021 Society of Economic Geologists Distinguished Lecturer. Master of Economic Geology student Victor Torres was a member of the winning 'Inca Team' for the 2021 Frank Arnott – Next Generation Explorers Award, an international competition for mineral geoscience



Emeritus Professor Ross Large, founder and former director of CODES, was awarded the highly prestigious Society of Economic Geologists' 2022 R.A.F. Penrose Gold Medal in late 2021, and is planning to travel to Denver, USA, to receive his medal in person in 2022.

university students. PhD students Xin Ni Seow, Jaime Osorio and Takeshy Coaquira were recipients of research grants from the Society of Economic Geologists. It's great to see such strong recognition of the excellence of our staff and students domestically and internationally – congratulations to all the award winners, and to our cohort of graduates in 2021.

A special mention is warranted for Emeritus Professor Ross Large, whose outstanding lifetime contributions to the field of Economic Geology were recognised by the Society of Economic Geologists in 2021 when they announced that he will be the recipient of the 2022 SEG R.A.F Penrose Gold Medal – the highest accolade offered by the Society. Ross will receive this award at the SEG conference in Keystone, Colorado, in August 2022. I cannot think of a more deserving winner than Ross and am sure you all join me in congratulating Ross on being awarded this prestigious honour from the SEG.



TOP: Professor David Cooke gave an online talk to the SGA Peru Student Chapter in October 2021 as part of his SEG Distinguished Lecturer 2021 series of talks. ABOVE: The new MEconGeol short course Advanced Field Skills in Economic Geology was held for the first time in February 2021, and seven participants were able to get out into the field in Tasmania while many more would have liked to join the course. Here CODES staff member Lejun Zhang (centre, wearing red vest) is pictured teaching at Bluestone Bay on the Freycinet Peninsula.

Masters program

We delivered three new masters short courses in 2021 as we expanded our course offerings to ensure sustainability of the degree. In February 2021, Advanced Field Skills in Economic Geology was offered face-to-face in Tasmania, with two weeks of advanced structural and alteration mapping at a variety of locations around Tasmania. A highlight was two days of Anaconda mapping directly above the unmined Western Tharsis Cu-Au orebody at Mt Lyell. Drs Rob Scott, Lejun Zhang and Mike Baker did a great job in delivering this unit, although COVID travel restrictions limited the number of participants who could travel to Tasmania for the unit. We also offered Fundamentals of Economic Geology for the first time in August–September.

This new online unit was designed as an entry-level unit to the Masters and Graduate Certificate of Economic Geology program. Drs Michael Roach, Lejun Zhang and Francisco Testa created a stunning 3D visualisation of the Dolphin W skarn deposit for this course, which was the basis of the major assignment for the unit, and which was well-received by the course participants. Our third unit, Special Topics in Economic Geology, is an independent research project, with Emma Beattie the first student to complete this unit in 2021. In November, we delivered a modified version of the Ores in Magmatic Arcs field course by including a one-week field trip to skarn and VHMS deposits of western Tasmania, and a one-week face-to-face overview of porphyry,

epithermal and skarn deposits of the Pacific Rim using the extensive samples collections housed at Hobart. We delivered Geodata Analytics for the second time, and Ore Deposit Geochemistry for its sixteenth iteration, and had several thesis completions, making 2021 our busiest year ever in the Masters program.

Conferences and trips

It was Tasmania's turn to host the biennial Australian Earth Sciences Convention in 2021, and many CODES staff and students were involved in organising and participating in this event, which ran online from 9–12 February. Around 400 abstracts were received for the conference, which had a diversity of themes. Dr Michael Roach prepared several virtual geology tours to supplant field excursions, which were not viable due to the pandemic. Congratulations to all involved for putting on a great show under difficult circumstances.

Tasmanian-based fieldwork and field trips were the year's main field activities for our cohort, providing our international and interstate students with the opportunity to become more familiar with Tasmania's exceptional geology and mineral deposits through two SEG Student Chapter field trips – one to King Island in April, and the other to the ore deposits of western Tasmania in November. Many of our team also attended the one-day in-person 11th Tasmanian Geoscience Forum in Tullah in December, and the accompanying field excursion. Participation in online conferences, workshops and seminars kept our team connected globally with the broader research community through 2021. CODES team members presented oral and poster presentations and workshops online at the Society of Economic Geologists 100th Anniversary Conference, Goldschmidt, ProExplo, AESC, GESSS, AGU, GAC-MAC and other events. As the SEG Distinguished Lecturer for 2021, Professor David Cooke presented talks online to SEG student chapters at Colorado School of Mines, Universidad Austral de Chile, San Marcos University, Hefei University and at the December 2021 SEG Distinguished Lecturers forum.



TOP: In March 2021 CODES Masters student Victor Torres led the Inca Team that took out the first prize in the highly regarded international competition, The Frank Arnott – Next Generation Explorers Award.
ABOVE: The annual Garry Davidson Memorial Footy Match was played on the oval at the Sandy Bay campus in May 2021 after the previous year’s match was cancelled due to COVID.

Staff changes

There were several new additions to the CODES team in 2021. Dr Sheree Armistead joined us as a postdoctoral research fellow, initially working on a casual basis to help to develop a follow-up project to P1206A and on several other initiatives. Dr Jeff Oalmann joined CODES Analytical Laboratories in December after finally negotiating protracted complications with regards to Australia’s international border closure. After a stint working at Mineral Resources Tasmania, Elena Lounejeva returned to work at CODES Analytical Laboratories on a casual basis. Eleanor Marshall temporarily joined the CODES administrative team for six months while Karen Huizing took a well-deserved long service break. Dr Jonathan Cloutier took up an offer to join Geoscience Australia as an embedded postdoctoral researcher in mid-2021. Although Jonathan is still employed by UTAS, he is now based in Canberra and is working with Geoscience Australia on their national mineral potential mapping and assessments for a variety of mineral systems. Terrie Sawyer left CODES Analytical Laboratories late in 2021 to take up a new challenge in Brazil – we wish Terrie all the best for the future.

Publications

Our total number of peer-reviewed journal articles for 2021, which stands at 50, was down compared to 92 in the previous year. This is due in part to many of our staff and students working on preparing final reports for the industry-funded projects that concluded in 2021. The flip side of this issue is that our industry reports increased from 188 in 2020 to 219 in 2021, reflecting the intense effort that went into final reporting for five major projects. Another factor affecting our publication outputs annually is participation in special issues. We were involved in four special issues in 2020 but none in 2021, and this contributes to the drop in publications. Our team are currently working on contributions to two new special issues that are scheduled for publication in the next couple of years, and so we expect to see a rebound in publication numbers moving forward as our industry reports and theses are transformed into publications.



LEFT: The Ores in Magmatic Arcs MEconGeol short course in November 2021, the fieldwork component of which took place in western Tasmania, provided a great opportunity for CODES students and staff to get out and experience some geology again. Pictured here are (L–R): Dr Clare Miller, Professor David Cooke, new PhD student Chris Allen, Earth Sciences visitor Professor Eric Roberts and CODES PhD student Tom Schaap. They are standing on the waste dump of the disused Spray Silver Mine near Zeehan.

BELOW LEFT: Scott Halley from Mineral Mapping making a point with assistance from Professor David Cooke during the Ores in Magmatic Arcs MEconGeol short course, which took place in November 2021.



The year ahead: what does 2022 hold?

Australia’s international borders opened at the end of 2021, and we are now seeing a return to international travel. This creates exciting opportunities for 2022, as we can once again recruit international students and conduct field research globally. Our volcanology PhD students are looking forward to getting into the field in New Zealand and taking part in oceanographic cruises. Our Amira footprints research team will be kicking off our major new five-year Amira project (P1249) with fieldwork in NSW, Queensland and in the latter half of 2022 hopefully will be working overseas. We are planning a major new research initiative into critical metals in Tasmania, which will increase our engagement with the Tasmanian minerals industry. We will also start up a new industry-funded project to investigate geochemical footprints of IOCG deposits. We have several major analytical and instrumentation developments planned for CODES Analytical Laboratories. Our Masters program will transition to a blend of online and in-person delivery, and in November 2022 we plan to run our highly popular volcanology field course once again in New Zealand and Tasmania.



David Cooke
Director of CODES

STATISTICS AT A GLANCE 2021

Academic research staff	61
Postgraduate students	138
Major research projects	46
Countries involved	38
Publications in refereed journals	50
Research reports to industry	219

Workshops and short courses

Number	20
Countries	Delivered online
Attendees	1,200+

Funding

Industry	\$1.36 million
UTAS	\$1.91 million
TMVC	\$0.96 million

Worldwide collaborations

Industry	45
Institutes and universities	130

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 61 highly qualified research staff and 138 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 45 industry companies, plus a host of joint research initiatives with 130 institutions and universities – 23 in Australia and 107 overseas. It currently has 46 major research projects spanning 38 countries, and all seven continents. It is also one of the leading academic groups to publish in *Economic Geology*. In the past year, despite the restrictions brought about by COVID-19, it maintained its reputation for delivering excellence in technology transfer by producing 219 reports to industry and conducting 20 short courses, workshops,

conferences and field trips. The majority of these were online, due to COVID-19 restrictions. However, the online format allowed participants from several continents, who would not otherwise have been able to attend, to join these courses and workshops.

Industry-focused research and training

CODES' research is conducted within and across six research programs (see CODES Program Structure graphic below). Our research spans a range of fundamental and applied activities, with our industry-focused research aiming to develop new exploration techniques for mineral discoveries, and new practices for sustainable mining,



Close inspection: (L–R) CODES Senior Research Fellow Dr Lejun Zhang, CODES Masters student Carl Jackman and Mark Aheimer, a geologist from Bluestone Mines Tasmania, at the Mt Bischoff Sn mine during the Master of Economic Geology short course *Ores in Magmatic Arcs*, which took place in Tasmania during November 2021. Lejun is examining cassiterite in the rock.

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

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 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 upskilling 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

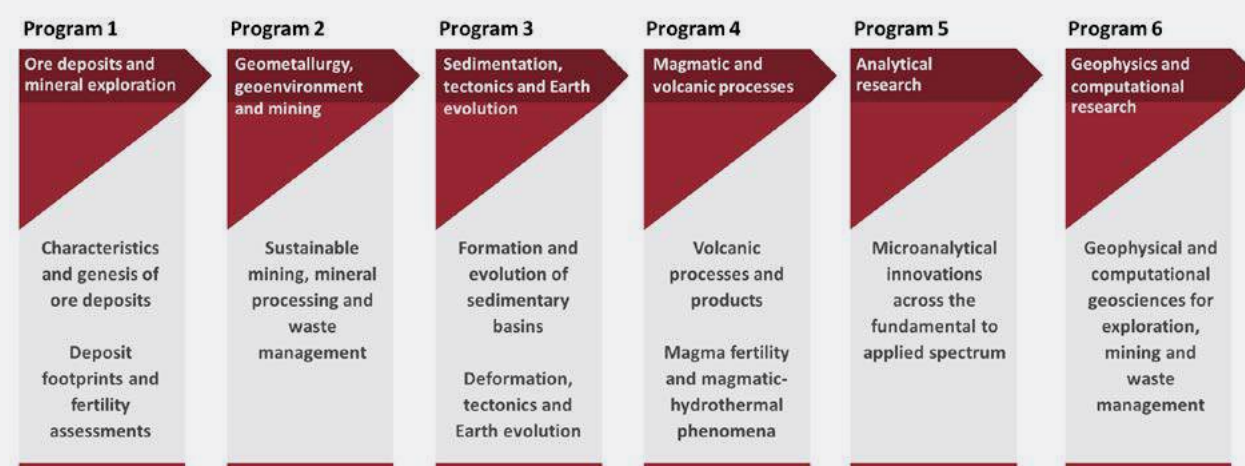
This new postgraduate offering, introduced in 2021, is designed for professional geoscientists keen to gain a stronger understanding of ore deposits, either for professional development, or as a foundation for further postgraduate training. The one-year degree requires completion of one compulsory unit and one other unit from our coursework Masters offerings, and can be counted as credit towards the Master of Economic Geology 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 thesis options. The degree is part of the national Minerals Geoscience Masters (MGM) program. 2021 saw the inaugural running of Fundamentals of Economic Geology, another new unit that will be offered annually into the program. This course was run online as were three other courses along with two face-to-face in Tasmania at the beginning and end of the year. In addition, another new course, Advanced Field Skills in Economic Geology, was run for the first time in 2021.

Codes Program Structure

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



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.

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 sulfide and oxide minerals, including the full range of platinum group elements; U/Pb dating of zircon and monazite; and multielement analysis of silicates. These facilities include four laser ablation ICP-MS laboratories specialising in ore deposit applications, an XRF laboratory, solution ICP-MS and clean room, 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.

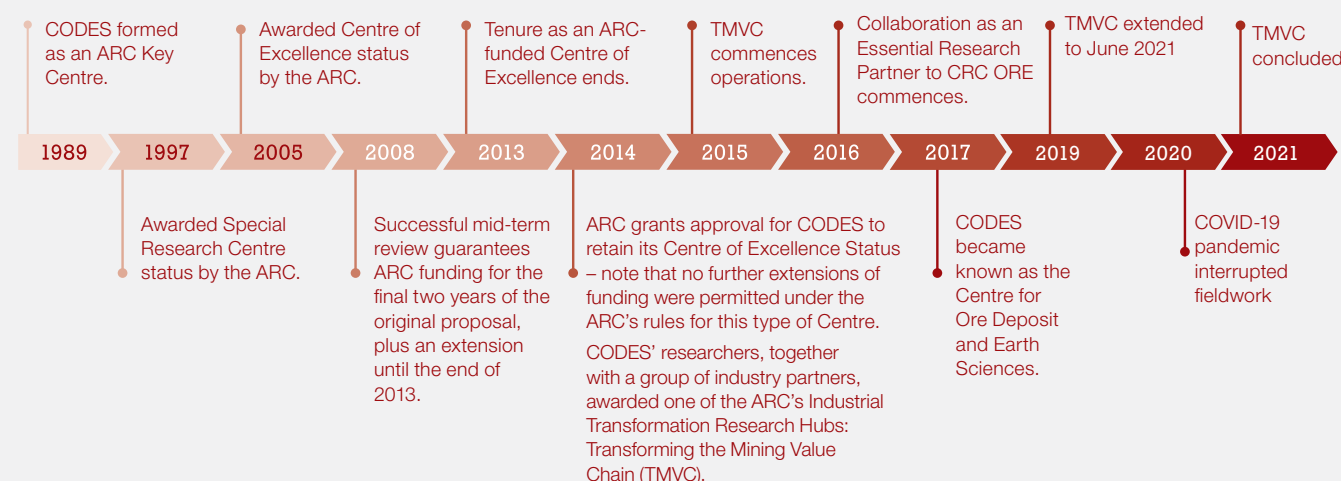
Transforming the Mining Value Chain

An ARC Industrial Transformation Research Hub

The Australian Research Council Industrial Transformation Research Hub for Transforming the Mining Value Chain (TMVC), which commenced operations in 2015, was based at CODES, and concluded in June 2021. The Hub encompassed a wide array of activities from exploration, discovery, ore deposit characterisation, to mineral processing and environmental management. The main objective of the TMVC was to improve efficiencies within the mining value chain, focusing on areas that will have a marked impact on the value of mineral resources. In addition to CODES, the industry partners involved in the Research Hub included BHP, Corescan, Newcrest Mining and a consortium of global companies co-ordinated by Amira Global. Other organisations affiliated with the initiative included Laurin Technic, UTAS Engineering and RWTH Aachen University in Germany.

TMVC activities for 2021 are covered later in this annual report.

Timeline



Staff and management 2021

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, and is assisted in this role by Professor Leonid Danyushevsky, Deputy Director of the Centre. Supporting them in these roles are the Advisory Board and the Executive Committee.

ARC TMVC Research Hub Director

Professor David Cooke was Director of the ARC Research Hub for Transforming the Mining Value Chain until it ceased operating at the end of June 2021. He was supported in these duties by Deputy Director Professor Leonid Danyushevsky.

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.

The Advisory Board met online during 2021 for the second year in a row due to COVID-19 restrictions. The meeting took place in November.

Executive Committee

The Executive Committee consists of the Centre Director, Deputy Director, Head of the Discipline of Earth Sciences, and a representative 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.

Due to COVID-19 restrictions, no Annual Review was held in 2021.

Staff movements 2021

Appointments

Academic/research staff

Dr Sheree Armistead joined CODES/IMAS in November as a Postdoctoral Research Fellow after finishing a two-year postdoc with the Geological Survey of Canada and Laurentian University in Ottawa. Her research explores the links between plate tectonics and mineral systems and she will be working mainly within Program 3: Sedimentation, tectonics and Earth evolution.

Professional/technical staff

Dr Jeffrey Oalmann was welcomed by the CODES Analytical Laboratories as a Laboratory Analyst in December 2021 although the official start date for his role will be mid-January 2022. He will be operating one of the LA-ICP-MS units, participating in the R&D program and performing analytical data reduction. Prior to joining CODES Analytical Laboratories Jeff worked at the Earth Observatory of Singapore (EOS) managing their LA-ICP-MS laboratory.

Elena Lounejeva returned to CODES to work as a Laboratory Analyst in late 2021, and will be assisting in the labs as a Laboratory Analyst while also completing her PhD, which is on the topic of the geochemical signature of pyrite.

Departures/role changes

Academic/research staff

Dr Jonathan Cloutier changed roles as Leader of Program 3 and Postdoctoral Research Fellow in July, and moved to Canberra where he is now working as a UTAS-embedded researcher for CODES at Geoscience Australia. He is a Senior Research Fellow in Mineral Systems.

Professional/technical staff

Terrie Sawyer left her role as a Laboratory Analyst at the CODES Analytical Laboratories in early December and moved overseas.

Eleanor Marshall finished up with her role in CODES Administration as the stand-in for Karen Huizing (who was on long service leave) at the end of 2021 and will return to her administrative role elsewhere at UTAS.

Trish McKay, Senior Administration Officer in the Earth Sciences office, moved to work in the UTAS Office of Research Services in June.



TOP LEFT: CODES and Earth Sciences staff and students pictured during the ‘Wear It Purple Day 2021’ event in the CODES Conference Room, August 2021. They are (L–R): Caroline Mordaunt, David Cooke, Helen Scott, Robert Scott, Acacia Clark, Zeb Zivkovic, Izzy von Lichten, Martin Jutzeler, Indrani Mukherjee, Sebastien Meffre, Max Hohl, Rhiannon Jones, Matthew Cracknell and Lejun Zhang. All happy campers, despite the bizarre lighting effects from the projector! TOP RIGHT: Dr Paul Olin (left) and Al Cuison from the CODES Analytical Laboratories taking part in a power tools training course during June 2021. MIDDLE LEFT: Professor Bruce Gemmell, former director of CODES, enjoying a drink with CODES Administrative Officer Karen Huizing at the 2021 Christmas BBQ held in the CODES Rock Garden during December. MIDDLE RIGHT: Dr Michael Roach, pictured during an event to mark him being presented with the UTAS College of Sciences and Engineering Innovation Award 2021. BOTTOM LEFT: CODES and Earth Sciences staff and students appreciate the efforts of the entrants in the singing competition at the annual Geology Dinner at Hadley’s Hotel in October 2021. BOTTOM MIDDLE: Associate Professor Sebastien Meffre (left) and Professor David Cooke hand out the accolades at the CODES Christmas BBQ in December 2021 – as the rain begins to fall in the CODES rock garden! BOTTOM RIGHT: CODES researcher Dr Indrani Mukherjee with her UTAS College of Sciences and Engineering Early Career Researcher Award 2021 certificate.

SENIOR MANAGEMENT

NAME	SPECIALISATION	%*	TMVC†
Director, Professor David Cooke, BSc Hons (Latrobe), PhD (Monash)	Porphyry Cu-Au, fluid-rock geochemistry	50	*
Deputy Director, Professor Leonid Danyushevsky, PhD (Vernadsky Inst.)	Petrology, geochemistry, LA-ICP-MS analysis	50	*

ACADEMIC/RESEARCH STAFF AT UTAS

NAME	SPECIALISATION	%*	TMVC†
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	80	*
Associate Professor Ron Berry, BSc, PhD (Flinders)	Structure of mineralised provinces, CHIME dating, geometallurgy	Hon	*
Dr Stuart Bull, BSc Hons, PhD (Monash)	Clastic and carbonate sedimentology and volcanology	Hon	
Associate Professor Rebecca Carey, BSc Hons (UTAS), PhD (U Hawaii)	Volcanology	50	
Dr Jonathan Cloutier, BSc, MSc, PhD (Queen's U, Canada)	Economic geology, geochemistry, hyperspectral reflectance	100	*
Dr Matthew Cracknell, BSc Hons, PhD (UTAS)	Geophysics, machine learning and data mining	50	*
Professor Tony Crawford, BSc Hons, PhD (Melbourne)	Petrology, geochemistry and tectonics of volcanic arcs	Hon	
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 Trevor Falloon, BSc Hons (Canterbury), BTeaching, PhD (UTAS)	Marine geoscience, petrology	Hon	
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 Jacqui Halpin, BSc Hons (Melbourne), PhD (Sydney)	Metamorphic petrology, geochronology	Hon	
Dr Julie Hunt, MSc (UBC), PhD (JCU)	Geometallurgy, economic geology	100	
Dr Martin Jutzeler, MSc (U Lausanne), PhD (UTAS)	Volcanology and clastic sedimentology	100	
Dr Maya Kamenetsky, PhD (UTAS)	MLA-SEM, geometallurgy, petrology	100	*
Professor Vadim Kamenetsky, BSc Hons (Moscow), PhD (Vernadsky Inst.)	Petrology and geochemistry of melt inclusions	50	
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 Peter McGoldrick, BSc Hons, PhD (Melbourne)	Ore deposits and their halos	Hon	
Professor Jocelyn McPhie, BA Hons (Macquarie), PhD (UNE)	Volcanic facies architecture and volcanic textures	Hon	
Associate Professor Sebastien Meffre, BSc Hons, PhD (Sydney)	Petrology and tectonics of the SW Pacific	50	*
Dr Clare Miller, BSc Hons, PhD (Queen's U, Canada)	Environmental geochemistry and remediation of mining-impacted environments	50	
Dr Indrani Mukherjee, BSc Hons, MSc (Delhi), PhD (UTAS)	Deep time geology and pyrite chemistry	50	
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/MTEC Senior Lecturer and Masters Program Coordinator	70	
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	100	

*Research percentage † TMVC affiliated

Dr Francisco Testa, MSc (UNS, Argentina), PhD (UTAS)	Magmatic-hydrothermal breccias, porphyry and epithermal deposits, geochemistry	100	*
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	100	*

ACADEMIC/RESEARCH STAFF BASED AT COLLABORATIVE INSTITUTIONS/INDUSTRY

NAME		%*	TMVC†
Dr Shaun Barker	MDRU, University of British Columbia	Hon	*
Dr John Bishop	Consultant	Hon	
Dr Daniel Bombardieri	Mineral Resources Tasmania	Hon	
Mr Ralph Bottrill	Mineral Resources Tasmania	Hon	
Dr Tony Brown	Consultant	Hon	
Dr Ana Liza Cuison	Emmerson Resources	Hon	
Dr Kathy Ehrig	BHP	Hon	*
Professor Andrea Gerson	Blue Minerals Consultancy	Hon	
Dr Scott Halley	Mineral Mapping	Hon	
Professor Mark Hannington	University of Ottawa	Hon	
Dr Anthony Harris	Newcrest Mining	Hon	*
Dr Margy Hawke	Hazina Geoscience	Hon	
Professor Peter Hollings	Lakehead University	Hon	
Mr Terry Hoschke	Consultant	Hon	
Dr David Huston	Geoscience Australia	Hon	
Dr Tim Ireland	First Quantum Minerals	Hon	
Professor Bernd Lottermoser	RWTH Aachen University	Hon	*
Mr Adi Maryono	J Resources	Hon	
Dr Andrew McNeill	Mineral Resources Tasmania	Hon	
Dr Gerrit Olivier	Institute of Mine Seismology	Hon	
Dr Evan Orovan	British Columbia Geological Survey	Hon	*
Dr Anita Parbhakar-Fox	SMI, University of Queensland	Hon	*
Dr Joshua Phillips	JP Geoscience	Hon	
Dr Steve Walters	MINOREvation	Hon	
Professor Noel White	Consultant	Hon	
Professor Jamie Wilkinson	Natural History Museum/Imperial College London	Hon	

TECHNICAL/ADMINISTRATIVE STAFF

Dr Ivan Belousov, BSc, MSc (Moscow), PhD (Vernadsky)	Laboratory Analyst	100
Mrs Michele Chapple-Smith, GDipAppSci (UTAS)	Lapidary Technician	80
Mr Alex Cuison, BSCE (SLU, Philippines)	Lapidary Manager	100
Ms Karen Huizing	Administrative Assistant	100
Dr Charles Makoundi, MSc, PhD (UTAS)	Research Assistant and Laboratory Assistant	20
Mrs Michelle Makoundi, B Acc (U Marien Ngouabi)	Laboratory Assistant	100
Ms Caroline Mordaunt, BA Hons (King's London)	Administrative Assistant	70
Mr Maxwell Morissette, BSc (McGill)	Laboratory Analyst	100
Dr Paul Olin, BA (SOU), MSc, PhD (WSU)	Deputy Leader – CODES Analytical Laboratories	100
Mrs Claire Rutherford, BBus (Acc) (RMIT)	Administrative Assistant	60

*Research percentage † TMVC affiliated

Ms Helen Scott, BSc Hons (UTAS), BEd (QUT)	Project Administration Manager	100	*
Ms Isabella von Lichtan, BSc Hons (UTAS)	Curator	25	

ADVISORY BOARD

NAME	
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
Dave Braxton	Anglo American
Clancy Carver	School of Natural Sciences, UTAS
Mike Christie	First Quantum Minerals
David Cooke	CODES, UTAS
Leonid Danyushevsky	CODES, UTAS
Mark Doyle	AngloGold Ashanti
Simon Ellingsen	School of Natural Sciences, UTAS
Anthony Harris	Newcrest Mining
Ned Howard	Evolution Mining
Jonathon Hoye	CMOC – Northparkes
Ray Mostogl	Tasmanian Minerals, Manufacturing and Energy Council
Sebastien Meffre	Earth Sciences, UTAS
Chris Reed	Teck
Michael Roach	Earth Sciences and CODES, UTAS
Kevin Robinson	Mineral Resources Tasmania
Robert Scott	CODES, UTAS
Trevor Shaw	Mt Isa Mines (Glencore)
Olga Verezub	Amira Global
Erik Wapstra	College of Sciences and Engineering, UTAS
Noel White	CODES, UTAS
Chris Wijns	First Quantum Minerals
Andy Wurst	Barrick

EXECUTIVE COMMITTEE

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

Note: In 2021 there was no Annual Review at CODES due to COVID-19 restrictions.

*Research percentage † TMVC affiliated

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-focused 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). Program 1 consists of five key sub-projects (as well as other smaller projects), which 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 and research outputs in 2021 despite the lingering effects of the COVID-19 pandemic. Program 1 continues to offer a range of multi-year projects that have provided significant outputs to both the academic and professional community, both locally and around the world.

SW Pacific

Yi Sun has continued his PhD study on the Lepanto quartz-pyrite-gold (QPG) veins in the Mankayan district, Philippines. Over the past year Yi has completed his analytical work and is now progressing towards final thesis write up and completion of his project in 2022.

SE Asia

Fundamental work on the 'Power of pyrite' project focused on the value of pyrite geochemistry in establishing deep-time trends of nutrient availability in ancient oceans and their impact on the evolution of early life was completed. This project produced five peer-reviewed publications, including articles in *Geology* and the *Encyclopedia of the UN Sustainable Development Goals: Life on Land*.

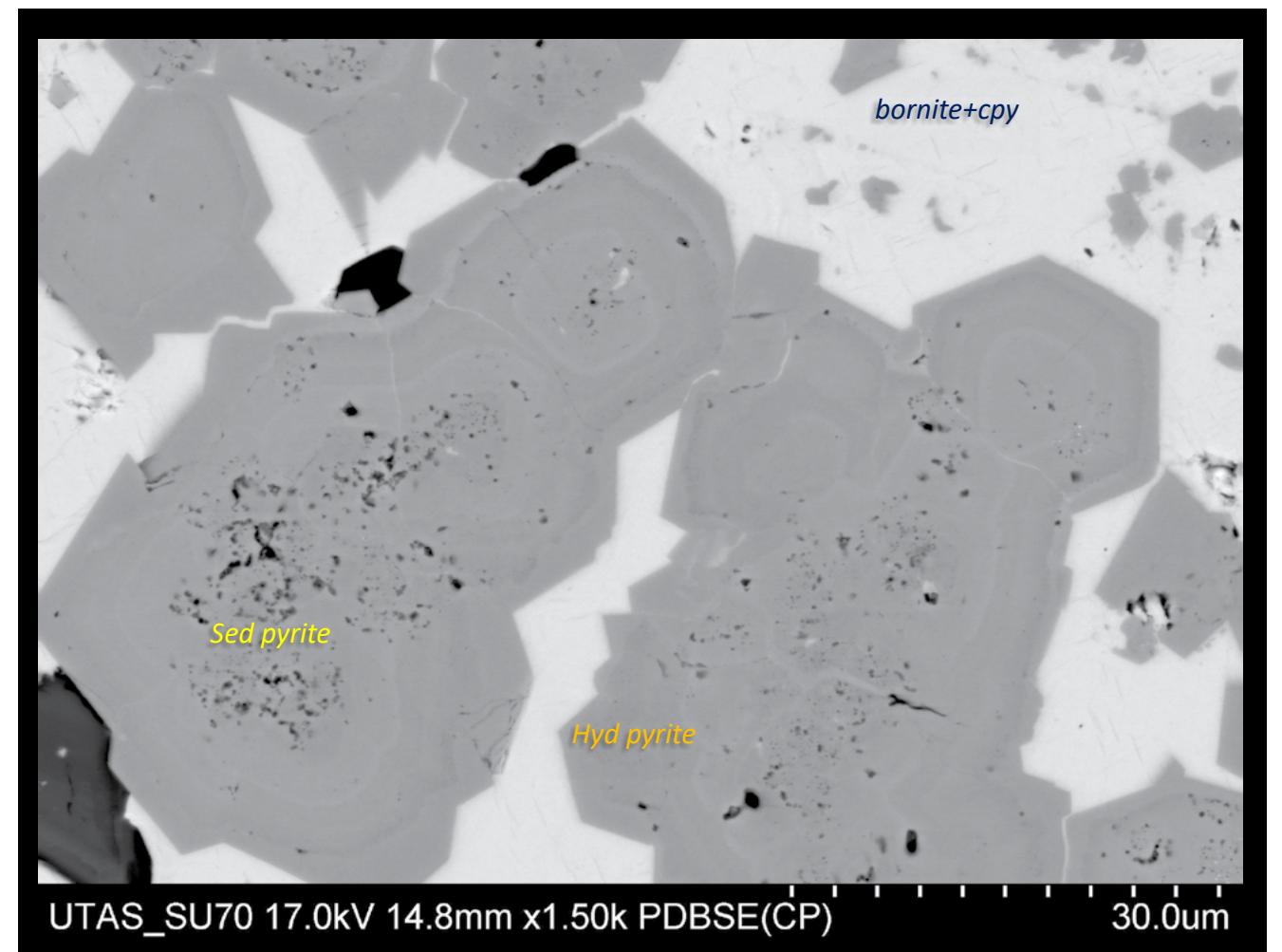
Research on trace element deportment in zircon from the Loei and Troung Son fold belts in SE Asia has led to the preparation of a publication that will document the geochemical controls and differences between pre-mineralisation and prospective intrusions in these significant resource-rich terranes.

North America

Rob Davidson completed his PhD research on the San Sebastian intermediate sulfidation, Ag-Au-Cu-Pb-Zn epithermal deposit, Saladillo district, Durango, Mexico, with support from Hecla Mining. As part of his research, a deposit-scale geologic model of the deposit was produced which will aid in future exploration activity in the Saladillo district.

South America

Carlos Diaz completed his Master of Economic Geology thesis on the Cascabel porphyry deposit cluster in Ecuador, supported by SolGold. Carlos has submitted a manuscript to *Economic Geology*, currently in review, based on some of the key outcomes into the genesis of the Cascabel deposit.



This image is a back-scattered electron photomicrograph of fine-grained sedimentary pyrite overgrown by fine-grained hydrothermal pyrite from the Johnny Lee deposit, Black Butte district, Montana, USA – one of the study areas in the 'Power of pyrite' sub-project PY005. Work done by Dr Jeff Steadman as part of this project revealed that the hydrothermal pyrite contains > 4 wt. % Co. Bornite with nano-scale chalcocite exsolution lamellae envelops the composite pyrite grains. This sample assayed over 12 wt. % Cu.

The research project of Victor Torres on the Soledad tourmaline breccia complex in central Peru, supported by Chakana Copper Corp, has been paused in 2021 while the scope of the project is upgraded to a PhD study that Victor will commence in 2022.

Australia

The 'Power of pyrite' sub-project PY005 has continued to investigate sedimentary pyrite chemical trace element and isotopic halos in high-priority black shale formations of northern Australia, with the goal of determining their potential to host stratiform Zn-Pb-Ag and stratiform Cu deposits. The sub-project generated over 4,000 pyrite mineral chemistry analyses over the life of the project, with final reporting presented to project sponsors in late 2021.

A new Master of Economic Geology project by Lieth de Selincourt has commenced on porphyry Cu-Au prospects of the Temora district in central NSW, sponsored by Sandfire Resources. It will use mineral chemistry and geochronology to investigate the prospectivity of the district.

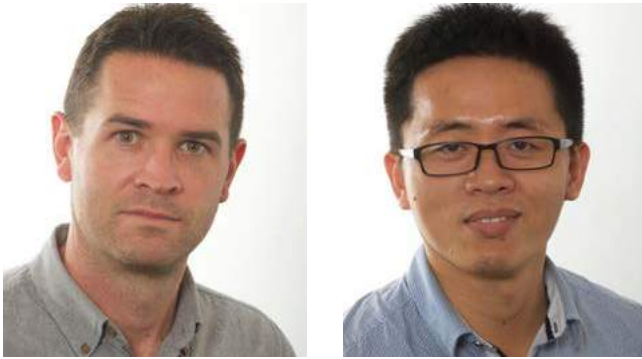
A new publication by Wei Hong has been published in *Economic Geology*, summarising the key findings from fluid inclusion and quartz LA-ICP-MS and CL analyses of magmatic-hydrothermal features from the Heemskirk Granite in Tasmania.

Program 1 continues to offer a range of multi-year projects that have provided significant outputs to both the academic and professional community, both locally and around the world.

*Research percentage † TMVC affiliated

The program team

LEADER MIKE BAKER
DEPUTY LEADER LEJUN ZHANG



TEAM MEMBERS:

Ron Berry, Stuart Bull, David Cooke, Matthew Cracknell, Leonid Danyushevsky, Angela Escolme, Bruce Gemmell, Ross Large, Charles Makoundi, Adi Maryono, Sebastien Meffre, Indrani Mukherjee, Asher Riaz, Michael Roach, Robert Scott, David Selley, Jeff Steadman, Francisco Testa, Khin Zaw

PHD STUDENTS:

Peter Berger, Takeshy Coaquira, Rob Davidson, Alex Farrar, Jacob Heathcote, Rhiannon Jones, Joseph Knight, Christopher Leslie, Xin Ni Seow, Jaime Osorio, Emily Smyk, Peerapong Sritangsirikul, Yi Sun, Jennifer Thompson, Tristan Wells, Zebedee Zivkovic

MASTERS STUDENTS:

Kim Boundy, Mertkan Bozoglu, Lieth de Selincourt, Carlos Diaz, Batbayar Enkhbold, Brendan Hardwick, Kyle Hughes, Corey Jago, Ashleigh Job, Ben Johnson, George Maroa

COLLABORATORS:

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Lin Sutherland

BRITISH GEOLOGICAL SURVEY, UK
Mike Crow

CHAKANA COPPER CORP
David Kelley, Doug Kirwin

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**COLORADO STATE
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Holly Stein

**DEPARTMENT OF MINERAL
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Punya Charusiri

DGO GOLD
Eduard Eshuys

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Zaw Htet

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Mike Gadd

**GEOLOGICAL SURVEY OF SOUTH
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Adrian Fabris, Anthony Reid

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John Everard

MONASH UNIVERSITY
Ray Cas

**NANYANG TECHNOLOGY
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NEWCREST MINING
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NYRSTAR
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SANDFIRE RESOURCES
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Joel Kitto, Jerry Zieg

SOLGOLD
Steve Garwin, Santiago Vaca

**TAUNG OO UNIVERSITY,
MYANMAR** Htet Sandar Aung

**TRINITY COLLEGE, DUBLIN,
IRELAND**
Seán H McClenaghan

**UNIVERSITAS PADJADJARAN,
INDONESIA**
Mega Rosana

**UNIVERSITI BRUNEI
DARRUSALAM, BRUNEI**
Chun-Kit Lai

**UNIVERSITI KEBANGSAAN,
MALAYSIA**
Mohd Basril Iswadi Bin Basori

UNIVERSITY OF ADELAIDE
Wei Hong

**UNIVERSITY OF GENEVA,
SWITZERLAND**
Robert Moritz

UNIVERSITY OF HONG KONG
Mei Fu Zhang

**UNIVERSITY OF MANITOBA,
CANADA**
Mostafa Fayek

UNIVERSITY OF MELBOURNE
Roland Maas

**UNIVERSITY OF NEW
BRUNSWICK, CANADA**
David Lentz

UNIVERSITY OF NEW MEXICO, USA
Karl Karlstrom

UNIVERSITY OF QUEENSLAND
Jonathan Aitchison, Nathan Fox

UNIVERSITY OF SYDNEY
Dietmar Müller, Sabin Zahirovic

**UNIVERSITY OF TORONTO,
CANADA**
Dan Gregory

US GEOLOGICAL SURVEY, USA
Jay Thompson

YANGON UNIVERSITY, MYANMAR
Nyein Nyein Sint

Projects

The power of pyrite:
Application in ore deposit
and deep-time geology

Tectonics, mineral deposits
and magma fertility of the
Loei and Troung Son fold
belts in SE Asia

Epithermal research

Porphyry research

Tasmanian tin granites

Project summaries

**THE POWER OF PYRITE:
APPLICATION IN ORE DEPOSIT
AND DEEP-TIME GEOLOGY**

Leaders: Indrani Mukherjee,
Ross Large

Team members: Stuart Bull,
Leonid Danyushevsky, Asher
Riaz, Jeff Steadman

Student: Ben Johnson

Collaborators: Mike Gadd,
Dan Gregory, Shuanhong Zhang

The ‘Power of pyrite’ project is split into two sub-projects owing to its fundamental and applied aspects:

- Using pyrite chemistry in marine black shales to track changes in ocean chemistry and associated evolutionary responses.
- Multi-client industry research on ‘Characterizing pyrite chemistry of black shales hosting stratiform Zn-Pb-Ag and stratiform Cu deposits: Application to mineral exploration’ (referred to as PY005).

The first sub-project investigated the value of pyrite geochemistry in establishing deep-time trends of

nutrient availability in ancient oceans and its profound impact on the evolution of early life. Dr Indrani Mukherjee, recipient of the Ian Potter Postdoctoral Fellowship, successfully completed this sub-project in 2021 including final reporting. The results provided insights into past ocean chemistry and the evolution of early complex life and generated five publications in peer-reviewed journals (including *Geology*). Also included in this number is an invited contribution to the *Encyclopedia of the UN Sustainable Development Goals: Life on Land*, published by Springer Nature. Indrani also fulfilled the Ian Potter commitments via actively disseminating her research results through conference presentations (Goldschmidt 2020) and public outreach (National Science Week, 2019; ABC Radio interviews).

The PY005 sub-project explored the use of the pyrite techniques in devising and informing exploration strategies for sediment-hosted ore deposits, and delivered its final results in September 2021. It comprised five case studies on sediment-hosted Zn-Pb and Cu deposits in Australia, Canada and the USA. This two-year sub-project was partly funded by the Ian Potter Foundation and partly by industry (seven mining companies and two state geological surveys). The team was comprised of four UTAS staff, two international collaborators, one Masters

and two Honours students. This project focused on both fundamental and applied aspects of pyrite geochemistry.

The research team met up with industry sponsors every six months. All case studies assessed the pyrite database (new and existing database), using both conventional and machine learning statistical techniques, in terms of basin fertility and stratigraphic potential for sediment-hosted Zn-Pb-Ag and sediment-hosted Cu. The project results clearly demonstrated the wide applicability of pyrite trace element chemistry in devising exploration vectors for sediment-hosted ore deposits. The project generated several industry reports including an extensive pyrite database of about 4,000 analyses. The sponsors were pleased with the project outcomes and welcomed suggestions on future research initiatives.

TECTONICS, MINERAL DEPOSITS AND MAGMA FERTILITY OF THE LOEI AND TROUNG SON FOLD BELTS IN SE ASIA

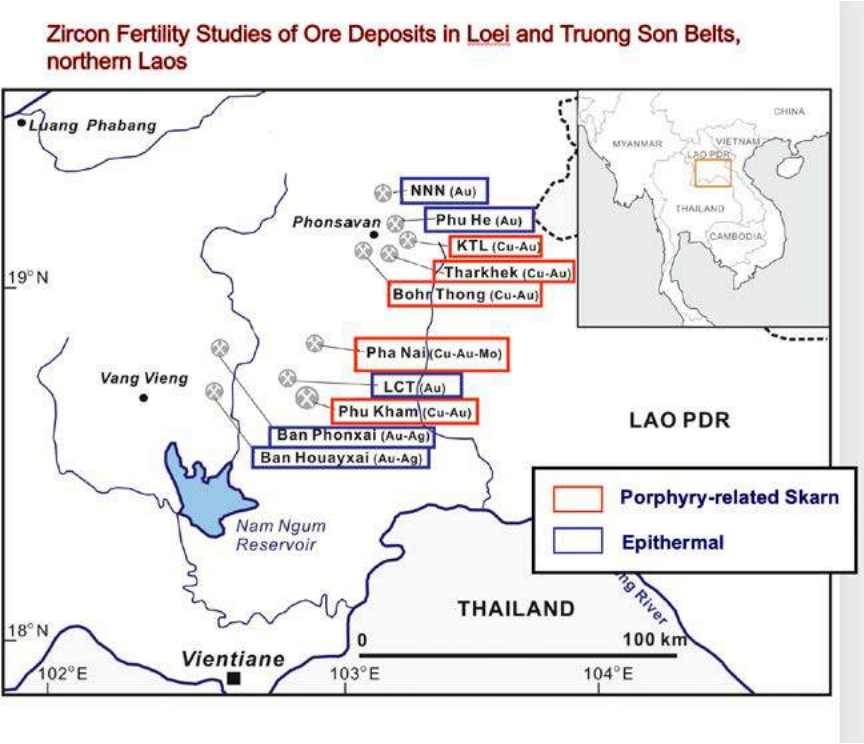
Leaders: Khin Zaw, Sebastien Meffre

Team members: David Cooke, Charles Makoundi, Lejun Zhang

Student: Peerapong Sritangsirikul

Collaborators: Mohd Basril Iswadi Bin Basori, Patthana Bounliyong, Clive Burrett, Punya Charusiri, Mike Crow, Htet Sandar Aung, Akira Imai, Chun-Kit Lai, Phisit Limtrakun, Lin Thu Aung, Abhisit Salam, Sokha Seang, Meifent Shi, Nyein Nyein Sint, Tin Aung Myint, Hai Thanh Tran, Zaw Htet

The Loei and Troung Son fold belts are the largest tectonic units in mainland SE Asia and are vastly rich in copper, gold, silver, base metals and tin–tungsten in a variety of deposit styles such as Cu-Au porphyry-skarn, epithermal Au, Sn-W veins and orogenic Au. The formation of both the LFB and TFB was related to Palaeozoic rifting from the Gondwanan margin and



TOP: Master of Economic Geology student Lieth de Selincourt undertaking fieldwork at the Sandfire Resources core facility in West Wyong in April 2021. His research project is looking at porphyry mineralisation in the Temora district of New South Wales. ABOVE: Map showing the area of research covered in the Southeast Asia project led jointly by University Associate, Professor Khin Zaw and Associate Professor Sebastien Meffre within Program 1.

accretion onto the SE Eurasia margin. The tectonic process has generated several phases of subduction, arc/back arc basin development and collision-related orogenesis. This project will be focused on the tectonic history, metallogenic settings and timing of mineralisation of the diverse deposit types using zircon geochronology and trace elements, whole-rock geochemistry, and Hf isotopes to evaluate the magma fertility and distinguish the geochemical features of mineralised and barren intrusions and which intrusions are likely to be fertile (oxidized and hydrous magmas).

Recent re-analyses of the trace elements of spatially well-located zircon mounts from Laos and Thailand studied under previous SE Asia ore deposit projects as a part of Peerapong Sritangsirikul's PhD research provided geochemical features and controls to discriminate pre-mineralisation magmas from mineralised fertile magmas, and insights into a complex petrogenesis. The outcome of this research is being prepared for publication in an international Earth science journal.

This project is also linked with the following four projects: 'Geochronology of ore deposits in Cambodia' led by Dr Seang (Sokha) Sirisokha of the Institute of Technology, Phnom Penh, Cambodia, and funded by the Japan International Cooperation Agency (JICA); 'Tectonic evolution and mineralization along the Loei Belt' led by Professor Punya Charusiri and funded by Chulalongkorn University; as well as 'IGCP 668: Equatorial Gondwanan History and Early Palaeozoic Evolutionary Dynamics' and 'IGCP 700: IGCP-700: Palaeozoic Carbonate Build-ups in SE Asia'.

EPITHERMAL RESEARCH

Leaders: Bruce Gemmell, David Cooke

Student: Rob Davidson

Collaborators: Kurt Allen, Stephen Redak

Rob Davidson completed his PhD research in 2021 on the San Sebastian intermediate sulfidation, Ag-Au-Cu-Pb-



Geophysics survey work taking place at the Soledad project in central Peru as part of Victor Torres' Masters-related research within Program 1. This project will be converted into a PhD and will recommence in 2022.

Zn epithermal deposit, Saladillo district, Durango, Mexico, with support from Hecla Mining. The district contains two known Ag-Au +/- Pb-Zn deposits (San Sebastian and Don Sergio), a historic mercury mine (La Roca) and a historic antimony mine (El Caballo). Since 2001, the San Sebastian mine has produced 23.7 Moz of Ag and 0.25 Moz of Au and sits within the Mexican Silver Belt. San Sebastian is hosted within mudstones and graywackes, as opposed to more common volcanic rocks. The San Sebastian deposit consists of parallel veins (Professor, Francine and Middle) offset by post-mineral movement along the San Ricardo fault.

A coherent, deposit-scale, geologic model, based upon 3D interpretations of major structures, lithology, alteration and veins, was developed. It allows for a broad understanding of how the main geological components of the deposit interact and influence one another, which in turn reveals key observations into the genesis of the deposit.

Characteristics of the district geology, vein geology, mineralogy, hydrothermal alteration and metal zoning at San Sebastian were combined to develop exploration criteria, which can be used to generate new targets in the San Sebastian district, as well as in other

intermediate sulfidation epithermal districts hosted in sedimentary rocks.

PORPHYRY RESEARCH

Leader: David Cooke

Team members: Michael Baker, Ivan Belousov, Matt Cracknell, Sebastien Meffre, Lejun Zhang

Students: Lieth de Selincourt, Carlos Diaz, Victor Torres

Collaborators: Steve Garwin, David Kelley, Doug Kirwin, Santiago Vaca, Joel Kitto

In 2021, Carlos Diaz completed his Master of Economic Geology thesis on the Cascabel porphyry deposit cluster in Ecuador, supported by SolGold. Cascabel contains the world-class Alpala Cu-Au porphyry deposit, with a maiden mineral resource estimate of 1.08 Gt @ 0.68% Cu Eq. Carlos documented the characteristics, genesis and exploration significance of porphyry Cu-Au-Ag mineralisation in the Cascabel district and conducted an extensive geochronological and geochemical study to understand the timing and controls of high-grade Cu-Au-Ag mineralisation at Alpala and other prospects in the district



Masters student Victor Torres with consultant geologist Jim Wise in the field at Soledad, central Peru. Victor graduated in December 2021 with a Master of Economic Geology degree but will be continuing his research by undertaking a PhD.

(Aguinaga and Tandayama – America). After completion, a draft manuscript was submitted to *Economic Geology*.

Master of Economic Geology student Victor Torres was conducting research into Cu-Au mineralisation in the Soledad tourmaline breccia complex, central Peru, supported by Chakana Copper Corp. This project was paused in 2021, with the scope of the project redesigned so that it could be conducted as a PhD study by Victor starting in 2022.

Lieth de Selincourt commenced a study of porphyry Cu-Au prospects of the Temora district in the Junee-Narromine belt of the Ordovician Macquarie Arc, Central West NSW. Lieth's Master of Economic Geology research is being supported by Sandfire Resources, and is generating new U-Pb zircon ages together with green rock and pyrite mineral chemistry studies to advance geological understanding of the evolution of the district and to aid ongoing mineral exploration (see below).

Cu-Au-Mo porphyry mineralisation in the Temora district, New South Wales, Australia

Leaders: David Cooke, Sebastien Meffre, Michael Baker, Matthew Cracknell

Student: Lieth de Selincourt

Collaborators: Kristyn Adamczyk, Joel Kitto

Lieth de Selincourt commenced the research component of his Master of Economic Geology degree on the application of mineral chemistry to aid exploration for Cu-Au-Mo porphyry mineralisation in the Temora district, New South Wales, Australia, in 2021 with support from Sandfire Resources. His research aims were to: map spatial trends in chlorite mineral chemistry at Donnington Cu-Au-Mo porphyry prospect and access its potential use as a vectoring tool towards the intrusive/fluid source; determine the ages of intrusive phases by U-Pb zircon dating; determine if zircon compositions can be used to access fertility within the district; and investigate pyrite mineral chemistry at Fields gold-base metal vein prospect to give insight into deposit genesis.

His research methods include hand sample descriptions, polished thin section descriptions, SEM analyses of alteration mineral assemblages, cathodoluminescence imaging of zircons, LA-ICP-MS spot analysis of selected chlorite and zircon grains, U-Pb zircon age dating of the intrusive rocks, etching with sodium hypochlorite and LA-ICP-MS maps of pyrite grains.

Despite COVID 19, Lieth was able to complete his field trip to West Wyalong in April 2021 as planned for core logging and sampling. Lieth has completed his chlorite studies at Donnington and will complete the remaining zircon and pyrite studies in the new year before finalising his thesis and submitting it for examination mid-2022.

TASMANIAN TIN GRANITES

Leader: David Cooke

Team members: Michael Roach, Francisco Testa, Lejun Zhang

Collaborators: Nathan Fox, Wei Hong, Jay Thompson,

The Western Tasmania Sn-W mineral province contains a spectrum of Sn, W and base deposits, and includes several large zoned mineral districts. In 2021, the final publication from Wei Hong's PhD study was published in *Economic Geology*, summarising key findings from fluid inclusion and quartz LA-ICP-MS and CL analyses of magmatic-hydrothermal features from the Heemskirk Granite. This study revealed a complex evolutionary history of the brines, vapours and waters from the crystallising granite that were involved in the formation of miarolitic cavities, unidirectional solidification textures, tourmaline orbicules and veins in the roof of the granite. These fluids migrated away from the granite roof, causing Sn-base metal mineralisation in the overlying and adjacent rock packages. A new field guide for the Trial Harbour transect through the Heemskirk Granite magmatic-hydrothermal features and adjacent magnetite skarns was put together by David Cooke and Lejun Zhang for the 'Ores in Magmatic Arcs' field trip to western Tasmania in November 2021.

In collaboration with Group 6 Metals, Michael Roach, Lejun Zhang and Francisco Testa built an immersive 3D visualisation of the Dolphin W open pit mine at Grassy, King Island, in western Tasmania. This visualisation was constructed for the inaugural Fundamentals in Economic Geology Masters short course in August 2021. The visualisation includes detailed analyses of ore and gangue samples from the Dolphin orebody placed in their spatial context. This work has contributed to the development of a new major research initiative at CODES into critical metals in Western Tasmanian mine sites, which will commence in 2022, and which will include new PhD studies at Dolphin, and at the Kara Fe-W and Renison Sn deposits.



Sunset in central Peru, taken by Masters student Victor Torres while doing fieldwork relating to Cu-Au mineralisation.

Looking forward

The short-term future of projects within Program 1 appears bright with several key projects continuing or commencing next year, including postgraduate student sub-projects nearing completion, or to be completed in 2022.

Student projects continue to be the lifeblood of this Program, as they generate high-quality research outcomes including theses, peer-reviewed publications, and models for the development of mineralised systems in a diverse range of environments.

Postgraduate research projects continuing into 2022 include Yi Sun's project on the Lepanto QPG veins in the Philippines; Victor Torres' project on the Soledad tourmaline breccia complex in central Peru; and Lieth de Selincourt's project on porphyry Cu-Au prospects in the Temora district of central NSW. There is also the potential for new postgraduate research projects in the Program 1 space that will align with the new major research initiative at CODES into environmentally sustainable critical metal resources in Tasmania. The scope and alignment of these projects will be defined over the coming year.

A major new research project within Program 1 led by Associate Professor Sebastien Meffre and Dr Sheree Armistead is also due to commence in mid-2022 and will focus on constraining the timing of mineralisation in some of western Tasmania's ore deposits, including Savage River, Henty, Darwin South and Mount Lyell. This two-year project will form part of the Temporal Controls on Mineralisation Module within Geoscience Australia's Exploring for the Future Program.

Program two: Geometallurgy, geoenvironment and mining

Objectives

- Create an integrated, cross-disciplinary geometallurgical research platform that delivers fundamental knowledge, tools and methods to the global mining industry for optimising sustainable and profitable mineral extraction.
- Develop more effective approaches to the definition of mineralogy, element deportment and texture using new technologies that can be linked to mineral processing performance and waste management, at a range of scales.
- Provide improved attributes or indices of processing performance that can be embedded into block models to define processing domains, which can be exploited in mine planning and optimisation.
- Deliver new cross-discipline geometallurgical education, training and awareness.

Introduction

Program 2: Geometallurgy, geoenvironment and mining

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 ore bodies 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 ore body 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.

Over the past ~15 years, CODES has established itself as a national centre for geometallurgical research, spurred on and supported by an increased interest in the discipline by the minerals industry. This increase in industry involvement led to the large Amira P843 and P843A (GeM^{III}) projects collaboratively run with the JKMRC, University of Queensland, from 2005 to 2013. In these projects, an array of geometallurgical methods and protocols were developed in the areas of mineralogy, comminution, heap leaching and flotation – and were tested on case study sites culminating in the publication of a series of technical reports released to the Amira sponsors.

The outcomes of the GeM^{III} project provided a solid foundation for further research, particularly in relation to understanding mineralogical and textural controls on processing performance. Further research in this field was carried out in the Amira P1202 Module 4 project (described under the TMVC section of this report) and as part of CRC ORE's (Cooperative Research Centre for Optimising Resource Extraction) remit, of which CODES was

PROGRAM 1: DEFINE

GEOLOGICAL CONTROLS ON GRADE-BY-SIZE FRACTIONATION

Project number: P1-006
 Program 1 Coordinator: Greg Wilkie, CRC ORE
 Project Leader: Dr Julie Hunt, CODES/UTAS
 Timing: June 2019 – May 2021
 Participants: CODES (Centre for Ore Deposit and Earth Science) University of Tasmania (UTAS)

crcore.org.au

PROJECT OUTCOMES

Links between grade-by-size fractionation and geological parameters were identified for gold and copper deposits using systematic logging, portable (hardness, magnetic susceptibility, hyperspectral, XRF) and bench-scale (hyperspectral, XRF) tools.

Ores with vein textures tend to have higher potential for pre-concentration by screening than those with disseminated textures. Upgrade potential, defined by Response Ranking (RR), a parameter developed by CRCORE, is related to: distribution of valuable phase(s) – vein density and spacing, dense disseminations vs barren rock; rock hardness – soft vs hard minerals, fracture frequency, mineralogy; abundance of altered rock.

Example of porphyry copper deposit rocks with different RR values for Cu. Left = vein, Right = disseminated sulphides.

(Low grade) heterogeneous zones suitable for pre-concentration can be identified through incorporation of detailed systematic logging and testing into routine drill core logging during exploration programs or on mine sites. Use of data from (semi-) automated data collection techniques can be used to improve efficiency and precision of logging. Logging and testing in P1-006 includes:

- core logging that identifies vein mineralogy, vein spacing, vein volume (visual, high-resolution imaging)
- hardness and petrophysical parameters (rebound hardness, magnetic susceptibility)
- chemistry that reflects mineralization and/or degree of alteration (whole rock chemistry, portable/bench-scale XRF)
- mineralogy (portable/bench-scale hyperspectral SWIR, TIR; calculated from assay)
- deportment and distribution/heterogeneity of valuable phase(s) (visual logging; low-resolution rapid laser-activation ICP-MS for drill core pieces)

BACKGROUND TO THE PROJECT

Grade-by-size fractionation is the tendency for rocks to break into barren/low grade particles and particles containing valuable minerals/elements and for these particles to be separable by screening. This propensity for fractionation had been identified anecdotally and by earlier CRCORE programs, however, predictive models to identify potential targets were at concept level (TRL2). The aim of this project was to identify geological drivers that can contribute to prediction and provide an early indication of the variability in grade-by-size response based on drill cores as this is critical in identifying which deposits have strong potential for pre-concentration via screening and are viable for larger-scale testing.

Detailed logging requires vein mineralogy, alteration and paragenesis plus vein volume and spacing. Information can be obtained from detailed, systematic visual logging and/or analysis of high-resolution images. This image was collected during (semi-) automated bench-scale XRF logging.

Example of Au deportment in drill core, identified using low-resolution laser ablation at CODES technology services. Au peaks are shown in red.

Examples of different amounts of veins, vein types and host rock in two intervals (each 10 m long) from a gold deposit. Upper interval (RR Au = 100) has more abundant V1 and V2 veins and less altered rock than the interval with a lower RR Au.

*RR = Response Ranking, a measure of upgrade potential developed by CRCORE

Results summary published in 2021 from the CRC ORE/CODES joint project called 'Geological controls on grade-by-size fractionation' (CRC ORE P1-006). The project was led by Dr Julie Hunt.

an Essential Research Participant. Both of these projects were completed in 2021. Further geometallurgy-focused research will continue within the Amira P1249 project which commences in January 2022. An extension project for CRC ORE based at CODES is continuing until mid-2022.

CRC ORE came to a successful conclusion in mid-2021. It supported mining sector growth through implementation of technological innovations in minerals characterisation, extraction and processing. Fundamental to CRC ORE's research was the concept of Grade Engineering®, which focuses on the ability to improve mill feed quality by implementing specific technological levers at critical points in the extraction and processing circuit. CRC ORE's research was organised

into five programs: Define, Separate, Extract, Control and Operate. Project P1-006 ('Geological controls on grade-by-size fractionation'), which operated at CODES, sat within Program 1 – Define.

The P1-006 project evaluated geological controls that influence the preferential partitioning of ore phases between different size fractions during early comminution stages (blasting, crushing). The tendency for some ores to naturally fractionate ore minerals into finer size fractions, termed natural deportment or fractionation, is fundamental to effective Grade Engineering® levers that upgrade ores by size-based screening. Using a range of deposit and mineralisation styles, P1-006 evaluated geological drivers that influence natural grade by size deportment. The workflow

integrated existing geological, geochemical, mineralogical and metallurgical data sets with innovative new technologies for mapping mineralogy and geochemistry in drill cores to provide predictive indices relating to the amenability of ore domains to Grade Engineering® levers. P1-006 concluded successfully in mid-2021 and delivered snapshot, summary and full technical reports to CRC ORE. P1-006 included two Masters projects, one of which was completed in 2021. The second is scheduled for completion in early 2022.

Geometallurgical research activities at CODES carried out under the Optimising Geometallurgical Prediction and Minimising Geoenvironmental Risks themes within the ARC Industrial Transformation Research Hub – Transforming the Mining Value Chain (TMVC) also came to a conclusion in mid-2021. The largest of these projects was the major Amira P1202 Module 4 sub-project which included five PhD projects, one Economic Geology Masters project and one Honours project across six study sites. The project developed new workflows for ore characterisation, specifically in porphyry-epithermal transition zones. This and several other stand-alone geometallurgy sub-projects within the TMVC Research Hub are described in the TMVC section of this report.

The CODES Environmental Geology Research portfolio continued to grow this year with continued collaborations between industry, state government and UTAS disciplines outside CODES. Several Tasmanian-based research projects were launched in 2021, including two Honours projects, focused on multidisciplinary characterisation of mining-impacted environments. Dr Miller and Dr Escolme were awarded funding for a pilot project, which aims to bridge the worlds between Geometallurgy and Geoenvironment and is currently underway. There are a number of exciting projects on the horizon for the Environmental Geology Research group, with the successful funding awarded for a PhD focused on 'Geoenvironmental and geometallurgical characterisation of weathered polymetallic wastes: Implications for mine closure, western Tasmania'.



CODES Honours student Kate Cheesman sampling the sediment, water and macroinvertebrates of the Arthur River for her 2021 Honours research focused on developing a multidisciplinary tool for monitoring the effectiveness of mine remediation in western Tasmania. Kate's research was funded by Mineral Resources Tasmania and Bluestone Mines Tasmania.

The CODES Environmental Geology Research portfolio continued to grow this year with collaborations between industry, state government and UTAS disciplines.

Highlights

- The Master of Economic Geology short course on Geometallurgy (KEA711) was held for the sixth time in October–November 2021 and attended by a high turnout of 23 students. The course was coordinated by Dr Hunt, Dr Escolme and Dr Rob Scott and included speakers from CODES and UTAS plus many guest presenters.
- Nathaly Guerrero submitted her Masters thesis, titled 'Geological controls on grade-by-size fractionation in gold systems'. This project sits within CRC ORE project P1-006.
- Masters student Nathaly Guerrero gave an oral presentation entitled, 'Estimation of preferential grade-by-size deportment in gold systems', at the Sustainable Minerals '21 conference in the session 'Efforts to reduce energy consumption in mining and mineral processing'. She described the role of geological parameters in influencing rock breakage and how a machine learning approach is being used to estimate upgrade potential, based on results from an intrusion-related gold system.
- Geoenvironmental research initiatives – including three collaborative and multidisciplinary Honours projects to characterise and remediate acid and metalliferous drainage at legacy mine sites in Tasmania generated by Dr Clare Miller in 2020 – continued into 2021. In addition, in 2021 Dr Miller developed and strengthened new collaborations with mining industries across Tasmania including research programs with Copper Mines of Tasmania and Bluestone Mines Tasmania.
- Completion of Honours thesis by Kate Cheesman titled 'Invertebrate biomonitoring: A geoscience tool for AMD remediation, North-West Tasmania', supported by MRT and Bluestone Mines Tasmania.
- Zak Weidinger completed his MRT-supported Honours thesis titled 'Time-lapse geophysical investigation of the Royal George Tailings Repository, Northeast Tasmania', which crosses over with Program 6.

- Dr Miller received funding through the UTAS SNS Small Grants Initiative to build on research findings of the 2020 collaborative research projects of Honours students Wei Xuen Heng, Eliza Fisher and Olivia Wilson.
- Dr Escolme and Dr Miller were awarded funding through the UTAS SNS Small Grants Initiative for a pilot project aimed at integrating geometallurgical and geoenvironmental characterisation through the mining value chain; this project will continue into 2022.
- Abstracts highlighting the multidisciplinary research 'Multidisciplinary characterisation of groundwater flow and contaminant transport in legacy mine wastes' were accepted for oral presentations at ICARD and Goldschmidt, which Dr Miller will deliver in early 2022.

- Dr Miller received funding from UTAS' CoSE Capital Investment Grants to expand the capacity and upgrade the facilities of the CODES Environmental Geology labs.

Technology transfer

Snapshot, summary and full technical reports were completed for CRC ORE project P1-006 and are available to CRC ORE members on the CRC ORE website.

Short course

Dr Hunt, Dr Escolme and Dr Rob Scott co-ordinated the Master of Economic Geology short course on Geometallurgy (KEA711) in October and November 2021, the sixth time the course has been run at CODES. This year the course had 23 participants: seven Masters students, 13 industry participants and three other students. Due to travel restrictions the course was held online. Presentations were given by UTAS staff and guest presenters. Guest speakers included Dr Toni Kojovic (SimSAGE), Dr Teresa McGrath (Curtin University), Joe Pease (Mineralis), Scott Halley, Dr Laurence Dyer (Curtin University), Dr Luke Keeney (CRC ORE), Dr Naomi Boxall (CSIRO), Sefton Darby (Voconiq), Dr Kathy Ehrig (BHP), Karyn Gardner (Newcrest Mining) and Dr James Cannel (MMG). In lieu of in-person field trips a virtual mine tour was created by Dr Michael Roach. Virtual information on analytical techniques, in lieu of lab visits, was created by staff of the CSL, CODES and Earth Sciences and Mineral Resources Tasmania (MRT).

Conferences

In 2021 research outcomes were presented by staff and students at several conferences and geological society meetings, including:

- Masters student Nathaly Guerrero gave an oral presentation entitled 'Estimation of preferential grade-by-size deportment in gold systems' at the Sustainable Minerals '21 conference.
- Dr Hunt gave a presentation titled 'Increasing efficiency through understanding geological controls on Grade Engineering' at the SEG 100 virtual conference in the session '2020 vision – the next 100 years' (the conference was rescheduled from September 2020 to September 2021).
- CODES Masters student Karla Morales gave an oral presentation entitled 'Preconcentration via screening: A path to optimise ore processing' at the GSA Earth Sciences Student Symposium.
- Dr Hunt gave an oral presentation at the Ore Geology virtual conference covering advances in geometallurgy, in July 2021.
- Dr Hunt gave an invited oral presentation at the Applied Geochemistry in Exploration virtual conference, titled 'Rocks first geometallurgy' in September 2021.
- Dr Escolme gave an invited oral presentation at the Applied Geochemistry in Exploration virtual conference, titled 'Using exploration datasets in geometallurgical models', in September 2021.
- Former Honours student Wei Xuen Heng gave an oral presentation of



TOP: KEA348 Environmental Geology students heading out across the tailings which comprise the King River Delta to collect geochemical, mineralogical and geophysical data. ABOVE: Third-year students, Dan Fisher and Austin Reeve, sampling and logging the tailings which have accumulated along the banks of the King River; this photo was taken on the KEA348 Environmental Geology field excursion in 2021 run by Dr Clare Miller.

- his collaborative research 'Integrated geophysics for three-dimensional modelling of mine waste' at GAC-MAC in the session titled 'Geophysical imaging of the paleo- and present environment', November 2021.
- Dr Miller presented findings of her research entitled 'Post-depositional mobility of As in a changing climate: Implications for cumulative effects assessments at northern mine sites' at GAC MAC in a session titled 'Cumulative Effects Monitoring', November 2021.
- The progress of Dr Miller's collaboration with Natural Resources Canada and Environment and Climate Change Canada were presented at the 47th Canadian Ecotoxicity Workshop, Halifax, Nova Scotia, titled 'Understanding the risk of climate change on water quality in Canada – development of a nation-wide database for machine learning'.

The program team

LEADER JULIE HUNT

DEPUTY LEADER ANGELA ESCOLME



TEAM MEMBERS:

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

PHD STUDENTS:

Takeshy Coaquira, Rhiannon Jones, Javier Merrill, Annah Moyo, Sibele Nascimento, Angela Rodrigues (Monash), Yi Sun

MASTERS STUDENTS:

Nathaly Guerrero, Lucy Jones, Karla Morales

HONOURS STUDENTS:

Kate Cheesman, Erik Fabreschi, Eliza Fisher, Fu Rong Mah, Hugh Sayers, Zak Weidinger

COLLABORATORS:

ALS GLOBAL

Shengli Zhao

ANGLOGOLD ASHANTI

Vaughan Chamberlain

BHP

Mario Avendaño, Alina Gaibor, Simon Gatehouse

BLUESTONE MINES TASMANIA

Ben Wraith, Louise Cherrie

CENTRAL SCIENCE LABORATORY (UTAS)

Sandrin Feig, Karsten Goemann

COPPER MINES OF TASMANIA

Geoff Cordery

CORESCAN

Neil Goodey, Cassady Harraden



CODES Masters student Karla Morales loading samples into the crusher while Dr Julie Hunt adjusts settings on the high-speed camera, UTAS Engineering Workshop, March 2021.

CRC ORE

Luke Keeney, Paul Revell, Greg Wilkie

CSIRO

Louise Fisher, Carsten Laukamp, Mark Pearce, Steven Peacock

CURTIN UNIVERSITY

Teresa McGrath

FORTESCUE MINERALS GROUP

Cameron Quinn, Dana Olafson

MERDEKA COPPER GOLD

Julian Bartlett, Rob Taube

MINALYZE

Annelie Lundström, Mark Manly, Angus Tod

MINERAL RESOURCES TASMANIA

Ralph Bottrill, David Green, Andrew McNeill, Carol Steyn

MMG

Steve Scott

NEWCREST MINING

Karyn Gardner, Anthony Harris, Mary Harris

RIO TINTO

Paul Agnew, Debora Araujo, Adam Pacey, Michael Whitbread

OLYMPUS AUSTRALIA

Dane Burkett, Jake Jarvinen

OREXPLORE

Rob Downard, Russell McChesney

TERRACORE

Paul Linton

TRUSCAN

Rod Fowler, Shaun O'Brien,

CARL ZEISS MICROSCOPY

Shaun Graham, Matthew Andrew

Project

Geological controls on grade-by-size fractionation (CRC ORE P1-006)

NB. Additional geometallurgy and geoenvironment activities are reported in the TMVC section of this annual report.

Project summary

GEOLOGICAL CONTROLS ON GRADE-BY-SIZE FRACTIONATION (CRC ORE P1-006)

Leader: Julie Hunt

Team members: Ron Berry, Matthew Cracknell, Angela Escolme, Michael Roach,

Students: Nathaly Guerrero, Karla Morales

Collaborators: Luke Keeney, Paul Revell, Greg Wilkie, Patrick Walters

The Cooperative Research Centre for Optimising Resource Extraction (CRC ORE) held the final Annual Assembly in May 2021 and came to a successful conclusion at the end of June 2021. CRC ORE delivered significant results in five program areas (Define, Separate, Extract, Control, Operate) that focused on improving the productivity, energy and water signatures of mining operations (crcore.org.au). CODES was involved in the CRC ORE 'Define' program in a collaborative project called 'Geological controls on grade-by-size fractionation' (known as P1-006) to identify links between upgrade potential via screening and geological parameters. P1-006 successfully completed deliverables – snapshot, summary and detailed final reports – that are included in the final outputs of CRC ORE and are available via the CRC ORE website to members. Summaries of work were presented at the Preconcentration 2020 Conference: 'Grade Engineering at Gramalote gold



Dr Julie Hunt at work in her office at CODES; Julie was the leader of the CRC ORE P1-006 project that came to a successful conclusion in June 2021.

deposit, Colombia'; the Sustainable Minerals '21 Conference: 'Estimation of preferential grade-by-size deportment in gold systems'; and the SEG 100 Conference: 'Increasing efficiency through understanding geological controls on Grade Engineering'. In addition, Nathaly Guerrero completed her Masters thesis entitled 'Geological controls on grade-by-size fractionation in gold systems'. A second P1-006 Masters thesis is expected to be submitted for examination in early 2022.

Specific P1-006 project outcomes include identification of links between grade-by-size fractionation and geological parameters for gold and copper deposits using systematic logging, portable (hardness, magnetic susceptibility, hyperspectral, XRF) and bench-scale (hyperspectral, XRF) tools. Ores with vein textures tend to have higher potential for preconcentration by screening than those with disseminated textures. Upgrade potential, defined by Response Ranking (RR), a parameter developed by CRC ORE, is related to:

- distribution of valuable phase(s) – vein density and spacing, dense disseminations vs barren rock;
- rock hardness – soft vs hard minerals, fracture frequency, mineralogy; abundance of altered rock.

P1-006 background information: In some rocks, mineral phases naturally preferentially fractionate into specific size fractions when the rock is broken. This propensity can be exploited and has the potential to generate an upgraded ore stream through rejection of lower-grade, larger-sized particles. Thus, reducing the amount of energy and water usage in later grinding and processing steps. It can also be used to upgrade very low-grade ore or mineralised waste leading to a reduction in the amount of material sent to waste dumps.

P1-006 research summary: Research within P1-006 was directed towards identifying predictors for preconcentration from intact rocks and drill core and was divided into an over-arching research stream and two Masters projects. One Masters project focused on grade-by-size deportment of gold systems using the Gramalote and Telfer deposits as examples; the second focused on understanding mineralisation styles that show a tendency for pre-concentration in early comminution stages. Within the main research stream there were several projects: grade-by-size fractionation of gold at Carosue Dam, WA, (completed in 2019); grade-by-size fractionation of copper and gold at a Chilean porphyry deposit (completed in May 2021); and a library of grade-by-size fractionation



CODES geoenvironment students and graduates at Tullah Lakeside Lodge in December 2021 on Tasmania's west coast with Dr Clare Miller (centre). They were attending the 11th Annual Tasmanian Geoscience Forum organised by the AusIMM, GSA, AIG and Minerals Resources Tasmania.

response for various mineralisation styles at different deposit types (e.g., porphyry, Sedex, VHMS, fault-related) with the ultimate aim of early prediction of amenability for preconcentration (completion in 2022).

As part of the project, researchers and students tested equipment for its suitability to assist with predicting grade-by-size response. This included measurement of elements and mineralogy (e.g., portable XRF, micro XRF, bench-scale XRF, hyperspectral SWIR & TIR) and rock hardness (e.g., Equotip). This work was done in conjunction with a range of equipment suppliers and labs (e.g., CSIRO, Minalyze, Orexlore, HyLogger, TerraCore, Corescan, TruScan, Zeiss).

Looking forward

2021 saw the completion of major projects in Program 2 and the TMVC (CRC ORE P1:006 and AMIRA P1202 Module 4). Some results from these projects were presented in 2021 and publications are underway. Further presentations are planned for 2022.

Although the P1-006 project completed deliverables to CRC ORE in June 2021 it will continue until June 2022 in order to deliver additional outcomes. Masters student Karla Morales is scheduled to submit her thesis titled 'Geological predictors for pre-concentration' in February 2022. Work is ongoing on a 'Library of mineralisation styles and upgrade potential via screening' which will be available online. Summaries of the work will be presented at the 16th SGA Conference in 2022: 'Geological characterisation to identify upgrade potential and enhance mining efficiency' and 'Geological controls for pre-concentration in an intrusive related gold deposit'.

The new Amira project P1249 includes geometallurgy and geoenvironmental research in Program 2, led by Dr Escolme. Markus Staubmann has joined CODES and the Amira project to pursue a PhD project entitled 'Integrated ore deposit knowledge: Optimising mineralogical characterisation through the mining value chain'.

The CODES Environmental Geology Research Group will continue to grow in early 2022 with the addition of two PhD students and two industry-sponsored Honours projects. Christopher Allen has returned to Tasmania from the mineral exploration industry in western Canada to embark on a PhD. His research will focus 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. As mentioned, Markus Staubmann has returned to CODES after a decade in industry to pursue a PhD which will develop workflows, methods and tools for mineralogical

characterisation that allows effective upscaling from the microscopic to the deposit-scale, and that will aid opportunity recognition and decision-making through all stages of the mining value chain. New collaborations with the Cradle Coast Authority will kick off in early 2022 with Eva Knight's Honours which will inform the implications for contaminant release following Rice Grass eradication in the Rubicon Estuary, northern Tasmania. Dr Miller and Dr Cracknell will also be working closely with Mineral Resources Tasmania in 2022 as part of the Mining Sector Innovation Initiative Program (MSIIP) that will include Daniel Fisher's Honours, 'Multidisciplinary characterisation of dam materials and drivers of pit lake water quality: Scotia Mine, NE Tasmania'.



The old Dolphin scheelite mine on King Island photographed during the CODES SEG Student Chapter field trip, April 2021.

Program three: Sedimentation, tectonics and Earth evolution

Objective

This program aims to understand the formation and evolution of sedimentary basins, including their metamorphic and deformation histories, within the broader context of geodynamic processes and Earth evolution through time. A new branch of the program includes assessment on the stability of the modern Australian shelf, by studying Tertiary to Pleistocene mass-wasting events on the western Tasmanian coast and the eastern Australian seaboard. Our goal is ultimately to develop new and refined genetic and exploration models for diverse sediment-hosted mineral systems across all time periods of Earth history, and to assess natural hazards linked to submarine landslides.

Introduction

Program 3: Sedimentation, tectonics and Earth evolution encompasses all aspects of sedimentary basin geologic history and the development of life on Earth, including how cycles of marine geochemistry profiles and craton amalgamation may influence the location and timing of sediment-hosted mineral systems. 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 Zambian-style Cu-Co-Au.

Catastrophic events count for a substantial part of the geological record, and inform occasional but extreme events that 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

2021 was a big year for Program 3. One of the main research projects in Program 3, 'Mineral geochemistry vectoring: Uncovering Northwest Queensland's hidden potential', was brought to a successful conclusion in September. Key outcomes of the project were presented virtually to the primary sponsor, the Queensland Department of Resources, in December, along with other relevant industry stakeholders in the Northwest Queensland Mineral Province. This project generated over 8,000 LA-ICP-MS analyses across ten different minerals – a major achievement,

considering the long history of research in the province. Follow-on work in this province will commence in 2022 by way of a new collaborative industry-funded research project, 'Iron oxide copper-gold deposits: Geochemistry and geomaterials', led by Dr Jeff Steadman.

The year also saw the departure of a team member from Program 3: Our program leader, Dr Jonathan Cloutier, accepted a position as a CODES researcher embedded at Geoscience Australia in July and relocated to Canberra, though he is still on the staff at UTAS. Jonathan was a driving force on the 'Mineral geochemistry vectoring' project, in which he identified a previously unrecognised spatial association between a large mafic intrusive body and Cu-Au mineralisation at the SWAN IOCG deposit. Dr Rob Scott took on the role of program leader.

As with 2020, the COVID-19 pandemic rolled on throughout all of 2021, although national and international borders were opened by December. The protracted nature of the pandemic again stymied out-of-state fieldwork and travel to conferences across multiple projects in Program 3. Here is hoping that 2022 brings a return to somewhat normal operations in this regard!



Ben Johnson (then an industry geologist but now a CODES Masters student working with Dr Indrani Mukherjee) surveys the landscape near the Mount Elliot IOCG deposit, Cloncurry district, Queensland. The original smelter chimney is visible on the left-hand side of the photo. Dr Jonathan Cloutier's research on Mount Elliot as part of the 'Mineral geochemistry vectoring' project revealed that the Mount Elliot and SWAN deposits are linked geologically.

Publications in 2021

The Program 3 research team was again productive in publications in 2021. Professor Ross Large, Dr Indrani Mukherjee, Dr Jeff Steadman and collaborators from UTAS (Dr Ross Corkrey), the Yukon Geological Survey (Dr Patrick Sack) and the University of Queensland (Professor Trevor Ireland) co-wrote a paper on variations in S isotopes through geologic time; and PhD candidate, Ms Elena Lounejeva, published the first paper of her thesis on sedimentary marcasite geochemistry at the Permian-Triassic Boundary, a globally significant period during which the largest known mass extinction occurred. Other authors on the latter paper included Dr Jeff Steadman, Professors Ross Large and Leonid Danyushevsky, and collaborators from UTAS (Dr Thomas Rodemann), Morgan-Goddard Palaeo (Dr Daniel Mantle), Curtin University (Professor Kliti Grice), and the University of Cincinnati (Professor Thomas Algeo). Both these papers were published as chapters in an AGU Geophysical Monograph (Monograph 255: Large Igneous Provinces: A Driver of Global Environmental and Biotic Changes).

2021 was a big year for Program 3. One of the main research projects in Program 3, 'Mineral geochemistry vectoring: Uncovering Northwest Queensland's hidden potential', was brought to a successful conclusion in September.



2021 Dean's Summer Research Scholarship Student Madison Mulder, whose research was part of the 'Building Tasmania' project, is seen here contemplating Mathinna Supergroup outcrops beside the Arm River, west of Scamander. Her project was supported by Mineral Resources Tasmania.

The program team

LEADER ROBERT SCOTT

DEPUTY LEADER JEFF STEADMAN



TEAM MEMBERS:

Ron Berry, Stuart Bull, David Cooke, Jonathan Cloutier, Matthew Cracknell, Leonid Danyushevsky, Martin Jutzeler, Ross Large, Peter McGoldrick, Sebastien Meffre, Indrani Mukherjee, Karin Orth, Michael Roach

PHD STUDENTS:

Alex Farrar, Umer Habib, Jacob Heathcote, Max Hohl, Colin Jones, Christopher Leslie, Elena Lounejeva, Thomas Schaap, Peerapong Sritangsirikul, Tristan Wells

MASTERS STUDENTS:

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DEAN'S SUMMER RESEARCH SCHOLARSHIP STUDENT:

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CURTIN UNIVERSITY

William Collins

FIRST QUANTUM MINERALS

Tim Ireland, Louis van Heerden

GEOLOGICAL SURVEY OF NSW

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UNIVERSITY OF SYDNEY

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UNIVERSITY OF WESTERN ONTARIO, CANADA

Nigel Blamey

Projects

Trace elements in ancient oceans

Kansanshi gold

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

Building Tasmania: The Cambrian and beyond

Ore deposit cycles and ocean/atmosphere conditions

Mineral geochemistry vectoring: Uncovering Northwest Queensland's hidden potential

Stability of the Australian continental shelf

Project summary

TRACE ELEMENTS IN ANCIENT OCEANS

Leader: Ross Large

Team members: Leonid Danyushevsky, 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.

Two new collaborations were commenced in 2021 to apply the previously developed sedimentary pyrite proxy for atmosphere oxygenation to understanding

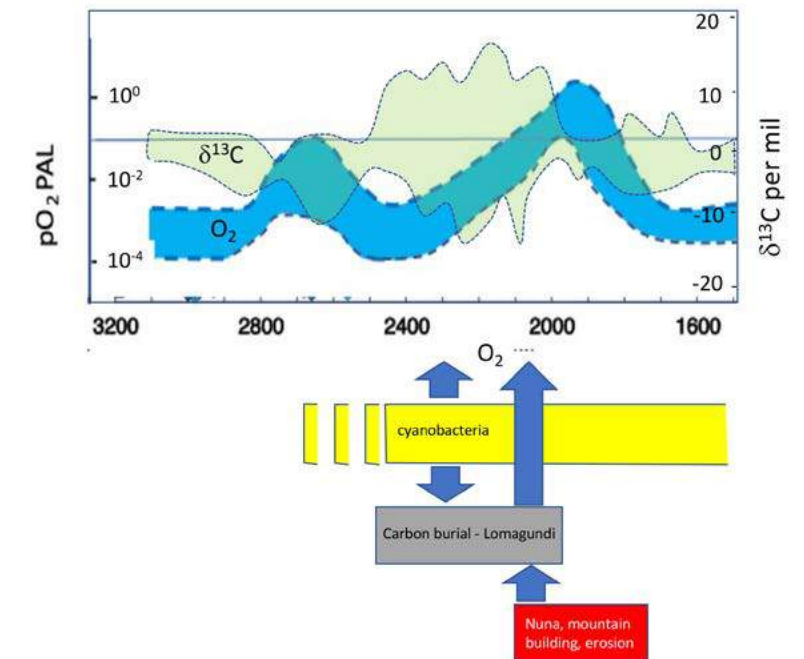


Figure 1: The preferred scenario for the Paleoproterozoic showing the relationship between predicted atmospheric oxygenation (this study) and carbon isotope composition of marine carbonates (Shields and Veizer (2002)). The rise in oxygen levels at the start of the Paleoproterozoic, due to the build up of cyanobacteria, caused perturbation in the carbon isotope cycle and the burial of organic carbon. This was followed by Earth's second supercontinent cycle, Nuna, that led to the formation of massive mountain ranges whose erosion promoted continuous organic carbon burial producing the Lomagundi event (2400 to 2000 Ma). This led to a renewed and more vigorous oxygen input to the atmosphere that would finally end with the conclusion of Nuna amalgamation and associated active erosion.

Figure taken from Professor Ross Large's research on the 'Trace elements in ancient oceans' project (and to be published in an upcoming issue of the journal *Geoenvironment and Geosystems*).

evolutionary processes in the Neoproterozoic and Phanerozoic. Alan Cannell, an engineer/palaeontologist, has worked with the team to develop a revised calibration of the pyrite Se/Co atmosphere proxy which better matches our data for the Phanerozoic. Several past attempts to model the variation in atmospheric oxygen through the Paleozoic give generally conflicting results, but all agree that pO₂ rose to a peak in the late Paleozoic between 320 and 260 Ma. The Pyrite Proxy, based on the concentrations of Se and Co in sedimentary pyrite, provides an alternative to the modelling approach. The proxy exhibits systematic variations in pO₂ (by weight) through the Silurian to Carboniferous period that are shown to closely correlate with evolutionary changes in the biosphere. In particular the proxy demonstrates how oxygen levels increased through the Silurian and early Devonian along with the

development of vascular plants, the first hexapods and giant fish, followed by a sharp decline through the late Devonian coinciding with a period of high-frequency magnetic reversals, the hexapod and charcoal gaps and the Devonian mass extinction events. This research is being written up for publication.

The second collaboration is with Professor Fabricio Caxito, from Brazil, who has a major project on conditions of sedimentation and evolution of life in the Neoproterozoic Bambui Basin in Brazil. Samples of pyritic shales from the basin have been analysed at CODES to determine the nutrient concentrations in the basin during its evolution from Cryogenian to Early Cambrian. Results to date suggest the Bambui Basin was cut off from the global ocean during much of its history, and followed a different trajectory of nutrient flux and biological evolution.

KANSANSHI GOLD

Leader: Robert Scott

Student: Jacob Heathcote

Collaborators: Tim Ireland, Louis van Heerden

This research project commenced in early 2014 and is funded by Kansanshi Mining Plc (KMP), a subsidiary of First Quantum Minerals. PhD student Jacob Heathcote has been researching the origins, distribution, mineral associations and paragenesis of gold at the Kansanshi Cu-Au deposit in NW Zambia. Key results from this study highlight the importance of (i) exsolution (i.e., chemical unmixing of minerals precipitated at higher temperatures) and recrystallisation, and (ii) variations in host rock composition, in determining certain aspects of metal and element distribution at the deposit.

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: Umer Habib, Corey Jago, Christopher Leslie, Thomas Schaap, Peerapong Sritangsirikul, Tristan Wells

Collaborators: Mark Arundell, Elena Belousova, William Collins, John Greenfield, David Huston, Roland Maas, Robert Musgrave, Marc Norman, Joanne Whittaker

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 four PhD students and three Masters students continued in 2020 and 2021. All of the students have now submitted their theses. Highlights from this work include:



Photo (looking north) of the open pit at the Osborne IOCG deposit, Cloncurry district, Queensland, which was part of the ‘Mineral geochemistry vectoring’ project. The magnetite ironstones which host pyrite-chalcopyrite mineralisation in this deposit are visible in the sidewalls of the pit (white lines running up the walls).

- The new tectonic model developed in the program G-Plates by Thomas Schaap.
- The new understanding of the Cowal mine and surrounding area developed by Chris Leslie using information from the chemistry of zircons, molybdenite and pyrite. The zircon paper has been accepted for publication in *Economic Geology*, and two other papers will be published in the near future.
- The new understanding of the Northparkes mine and surrounding area developed by Tristan Wells using information from the chemistry of hydrothermal and magmatic minerals and whole rock chemical data. Tristan published five papers during his PhD candidature and has drafted a further two for publication.
- The new constraints on age, Hf isotopic composition and provenance of Cambrian to Ordovician igneous and sedimentary rocks in Victoria and Tasmania acquired by Umer Habib. Umer published two papers during his PhD candidature and has drafted a further two for publication.
- Peerapong Sritangsirikul was awarded an MSc for his thesis on the geological evolution of the Oberon area in NSW and has started a PhD on the tectonics and metallogenesis of Thailand.



Osborne open pit (looking east). The Cu-Au mineralisation at Osborne is buried under approximately 30 m of flat-lying Mesozoic cover rocks (tan-white, from surface to third bench). The magnetite ironstones (white lines) run downwards at a ~30-degree angle from right to left across the photo. Drs Jeff Steadman and Jonathan Cloutier studied the ore host magnetite ironstones as part of the ‘Mineral geochemistry vectoring’ project, including new U/Pb age data on apatite hosted within the ironstones.

BUILDING TASMANIA: THE CAMBRIAN AND BEYOND

Leaders: Sebastien Meffre, Robert Scott

Team members: Ron Berry, Karin Orth

Student: Umer Habib

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

This project, focused on Tasmanian-based geochronology and tectonics, has been running for a number of years and has provided some major new insights into the tectonic history of the island. In 2021 Colin Jones and Karin Orth (with student Madison Mulder) continued work in northern and eastern Tasmania, while Umer Habib and Sebastien Meffre worked in western and southern Tasmania. Some of the findings on the origins of Paleozoic igneous and sedimentary rocks have been submitted for publication in the *Australian Journal*

of Earth Sciences, Gondwana Research and in MRT reports.

ORE DEPOSIT CYCLES AND OCEAN/ATMOSPHERE CONDITIONS

Leader: Ross Large

Team members: Sebastien Meffre, Indrani Mukherjee, Jeff Steadman

Collaborators: Janaína Ávila, Nigel Blamey, Ross Corkrey, Ray Coveney, Mihir Deb, Dan Gregory, Robert Hazen, Valeriy Maslennikov

A collaboration with Professor Robert Hazen, mineralogist at the Carnegie Institution, involves an investigation of the relationship of mineral evolution in the Precambrian, to atmosphere evolution over the same period. Bob Hazen’s group has been producing a vast database on the timing and occurrence of mineral species through geological time. His data suggests bursts of mineral evolution correspond to major periods of global ore formation related to the supercontinent cycles. When combined with our data on pyrite chemistry, the result has prompted a new theory on Earth’s oxygenation and mineral formation in the Precambrian. The combination of data sets indicates that the Great Oxygenation Event (GOE) was not a short (geologically) abrupt rise in oxygen at around 2400 Ma, but rather a slow rise over a billion years peaking around 2000 to 1900 Ma. This study has been submitted for publication.

MINERAL GEOCHEMISTRY VECTORING: UNCOVERING NORTHWEST QUEENSLAND’S HIDDEN POTENTIAL

Leader: Jeff Steadman

Team members: Jonathan Cloutier, David Cooke

Student: Max Hohl

Collaborators: James Austin, Shaun Barker, Helen Degeling, Courteney Dhnaram, Vladimir Lisitsin, Rick Valenta

The ‘Mineral geochemistry vectoring’ project came to a successful conclusion in 2021. A final report and database were submitted to the Queensland Department of Resources in September, and the results were presented virtually at the Strategic Resources Exploration Program’s Technical Workshop in December.

At Starra, PhD student Max Hohl outlined a revised paragenetic sequence for Cu-Au ore formation that incorporated new petrographic and trace element data. Max found mineralogical and geochemical evidence for the involvement of mafic intrusions during formation of the Cu-Au orebodies along the Starra Shear Zone, which had not been recognised previously. Likewise, at SWAN, Dr Jonathan Cloutier demonstrated that the shape and extent of the Cu-Au orebody is controlled primarily by a large body of mafic intrusive rock that had previously been logged as basalt. Both Max’s and Jonathan’s results carry significant exploration implications for IOCG-style targets in the Cloncurry district, as most previous research has minimised the role of mafic igneous intrusives as drivers of Cu-Au mineralisation in this province. As for Ernest Henry, Dr Jeff Steadman presented a revised mineral paragenesis based upon new petrographic studies and trace element data. These included the identification of extremely Co- and As-rich pyrite immediately surrounding the ore zone, as well as the recognition of anomalously Cl- and K-rich amphiboles in the footwall to the ore zone.

Trace element vectoring at all three IOCG study sites yielded several promising indicators of proximity to potential zones of Cu-Au mineralisation. For instance, chlorite chemistry at SWAN and Ernest Henry exhibits distinct changes that are correlated with distance from the ore zones. Chlorite from within the ore zones of both deposits is enriched in Mn (up to 2.5 wt. %) and Fe (up to 30 wt. %), whereas distal samples have much lower values of these elements. In a similar vein, epidote trace element chemistry at Ernest Henry is also correlated with distance, in that proximal samples are lower in As than their distal counterparts, but they are

higher in Sb than the same. At Starra, pyrite chemistry correlates well with distance from the Starra 276 orebody, with Se contents being lowest there and rising progressively with increasing distance along the Starra Shear.

At the Lady Annie sediment-hosted Cu deposit, north of Mount Isa, pyrobitumen was identified in ore samples by Dr Cloutier, where it is intergrown with hydrothermal dolomite and chalcopyrite. This indicates that hydrocarbons (oil) may have been involved in the creation of the Cu mineralisation, potentially as a trap for metal-rich fluids. At the Esperanza South sediment-hosted Cu deposit, 5 km east of Lady Annie, hydrothermal hematite was identified in a distinct breccia zone immediately above the ore horizon. It contains a diverse suite of trace elements, including Cu, which indicates that it may have grown simultaneously with Cu mineralisation at this deposit.

Taken together, the results show substantial promise for mineral chemistry vectoring using silicates, magnetite and pyrite, especially for IOCG deposits of the Cloncurry region. Follow-on work with IOCG systems in the Cloncurry district as well as in the Gawler Craton and Tennant Creek Inlier will form the foundation for the new CODES research project, 'Mineral chemistry in iron oxide copper-gold deposits: Geochemistry and geometallurgy'.

STABILITY OF THE AUSTRALIAN CONTINENTAL SHELF

Leader: Martin Jutzeler

Team member: Stuart Bull

Collaborators: David Airey, Michael Clare, Samantha Clarke, Tom Hubble, Claire Kain, Michael Kinsela, Vanessa Lucieer, Scott Nichol, Hannah Power, Maria Seton, Joanne Whittaker

Western Tasmania submarine slide

In 2019 Dr Martin Jutzeler and IMAS colleagues were successful in an application for a 42-day voyage in the



The Corbould collapse zone, Mt Elliot IOCG deposit, which was studied in the 'Mineral geochemistry vectoring' project. After mine closure, an area of structural weakness at depth propagated to the surface, resulting in the exposed void. Note the steeply dipping bedding in the far wall of the pit.

first trimester of 2023 on board the CSIRO research vessel RV *Investigator*. The team will investigate the deposits of a giant submarine landslide off the western Tasmania shelf. This landslide is undated and has never been formally identified before; its features suggest that it is a recent event (Pleistocene to Holocene?). They will map, image and sample the landslide from its headscarp on the continental shelf to its distal deep-sea deposits, using seismic reflection, coring and deep-tow cameras. The study will contribute to risk mitigation and tsunami hazard assessment for shelf-initiated tsunami and map the benthic habitat of the western Tasmanian shelf. Moreover, the team will identify the offshore continuation of the Mount Read Volcanics, with implications for improving the geological map of Tasmania and possible identification of further ore deposits offshore (see Program 4).

Old And NSW Neogene slides

Numerous Neogene landslides are spread along the passive margin of the eastern Australian seaboard. Dr Martin

Jutzeler is part of the team led by Associate Professor Tom Hubble (University of Sydney) to characterise the architecture of the landslides and canyons that dissect the continental shelf. This study is based on a future voyage on the RV *Investigator* in May 2022. This project will emphasise the influence of plate tectonics for triggering mass wasting events, and will contribute to hazard assessment for shelf-initiated tsunami.

Testing of new Giant Piston Corer

Dr Martin Jutzeler and PhD student Acacia Clark participated in two one-week sea trial voyages (IN2021_E02 and IN2021_E03) as geologists to assist with commissioning of the newly acquired OSIL Giant Piston Corer on CSIRO research vessel RV *Investigator*. This giant piston corer can core from 4.4 to 24 m of sediment and can be deployed in open sea down to 6,000 m below sea level. Acacia participated in the commissioning voyage by herself, and Martin joined her on the second voyage, with successful recovery of several metres of core.



Copper-gold magnetite breccia ore in drill core from the Ernest Henry IOCG deposit, Cloncurry district, Queensland. Dr Jeff Steadman developed mineral trace element vectors at Ernest Henry as part of his work on the 'Mineral geochemistry vectoring' project. Note the zone of specular hematite on the left-hand side of the core (blue-grey colour).

Looking forward

Using Pb isotopes to understand early Earth geodynamics, and how this influenced some of Earth's most endowed terranes, will be investigated in a new project led by Dr Sheree Armistead and Dr Jacqueline Halpin, along with international collaborators Professor Bruce Eglington (University of Saskatchewan) and Dr Sally Pehrsson (Geological Survey of Canada). This project continues the research Dr Sheree Armistead undertook during a two-year postdoctoral fellowship at the Geological Survey of Canada, which

was funded through the Metal Earth program at Laurentian University. This new six-month project, funded by the University of Saskatchewan, will see continued development of a global Pb isotope database, which will contribute to our understanding of Pb isotope signatures of ancient (Archean and Proterozoic) mantle and crust. Researchers seek to understand how Pb isotope anomalies throughout Earth's history are linked to supercontinent cycles, geodynamic processes and the evolution of metallogenic provinces, with a particular focus on the Superior Province in Canada.

A new project funded by Geoscience Australia and led by Associate Professor Sebastien Meffre and Dr Sheree Armistead is expected to be underway by mid-2022. This project will fund CODES' newest Postdoctoral Researcher, Dr Armistead, to undertake geochronology research on some of western Tasmania's ore deposits. These new constraints on the timing of mineralisation will help researchers unravel the complex tectonic and metallogenic evolution of western Tasmania.

Program four: Magmatic and volcanic processes

Objective

This program investigates processes of magma genesis, magma's ascent and eruption on Earth's surface. We unravel the interactions and connections between the mantle and crustal tectonics in magmatism, volcanism and in magmatic-hydrothermal mineral systems.

Introduction

Program 4: Magmatic and volcanic processes conducts fundamental research about magma genesis and ascent, and volcanic eruptions in a range of tectonic settings and subaerial and submarine environments. The fundamental research of Program 4 underpins novel approaches to further understand magmatic and volcanic environments that are prospective for buried ore deposits. Our collaborative network is diverse and highly valued, consisting of national and international industry partners, research institutions and geological surveys and observatories.

Highlights

2021 has been a year in which we have seen excellent progress and achievements in research following the disruption felt across the group in 2020 due to challenges associated with COVID restrictions. The resumption in interstate travel in 2021 has allowed our staff and students to access field sites, and for our research partners to have face-to-face meetings with Program 4 members. Highlights include eight publications in high-impact journals in the field of Earth Sciences led by two former CODES PhD students, Dr Jodi Fox and Dr Sam Holt. In 2022 our group will be busy, with international conferences, workshops, research voyages and fieldwork scheduled. We are looking forward to building our group with both domestic and international PhD and Masters students in 2022 to lead research stemming from our four large active grants, and the research data and samples that will be collected during the upcoming 2022 voyage to New Zealand with Australia's research ship, the RV *Investigator*.

Awards

Associate Professor Rebecca Carey was awarded the Royal Society of Tasmania's M.R. Banks Medal in 2021. This medal is awarded biennially to a scholar of distinction in mid-career, in any field of the Society's purview. The medal honours Dr Maxwell R. Banks' contributions to science and the Royal Society of Tasmania. Rebecca will give the M.R. Banks Lecture at the Royal Society of Tasmania in October 2022.

Current CODES PhD student Hannah Moore received an award in 2021: the Best Oral Presentation at the GSA Earth Sciences Student Symposium. Hannah also received an Honourable Mention for the CoSE Executive Dean's Award for Demonstrated Excellence in Research and Community Engagement.

CODES PhD student Acacia Clark was awarded the best lightning talk for Day 1 of the Tasmanian GESSS conference in November.

Publications in 2021

In 2021 our group published eight articles in international peer-reviewed journals, including *Geology*, *G3* and *Lithos*. This list includes two publications from former CODES PhD students Dr Jodi Fox and Dr Sam Holt.

The program team

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DEPUTY LEADER MARTIN JUTZELER



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Alexander Sobolev

**UNIVERSITY OF AUCKLAND, NEW
ZEALAND**
Michael Rowe, Julie Rowland

**UNIVERSITY OF BARCELONA,
SPAIN**
Marc Campeny, Juan Carlos Melgarejo

UNIVERSITY OF BIRMINGHAM, UK
Sebastien Watt

**UNIVERSITY OF BRITISH
COLUMBIA, CANADA**
Jim Mortensen

**UNIVERSITY OF CALIFORNIA,
BERKELEY, USA**
Michael Manga

**UNIVERSITY OF CALIFORNIA,
DAVIS, USA**
Cathy Busby

**UNIVERSITY OF CALIFORNIA,
SANTA CRUZ, USA**
James Gill

UNIVERSITY OF CAMBRIDGE, UK
Clare Donaldson

**UNIVERSITY OF HAWAII AT
MANOA, USA**
Bruce Houghton

**UNIVERSITY OF HEIDELBERG,
GERMANY**
Alex Schmidt

**UNIVERSITY OF ICELAND,
ICELAND** Maria Janebo,
Thor Thordarson

UNIVERSITY OF LEEDS, UK
Ivan Savov

UNIVERSITY OF MELBOURNE
Stephen Gallagher, Andrea Giuliani,
Roland Maas

**UNIVERSITY OF NEWCASTLE,
NSW**
Hannah Power

**UNIVERSITY OF NEW HAMPSHIRE,
USA**
Alexander Proussevitch

**UNIVERSITY OF NOTRE DAME,
USA**
Anthony Simonetti

UNIVERSITY OF OREGON, USA
Ilya Bindeman

**UNIVERSITY OF OTAGO, NEW
ZEALAND**
Tobi Durig, James White

**UNIVERSITY OF OTTAWA,
CANADA**
Mark Hannington

UNIVERSITY OF OXFORD, UK
Jane Barling, Michael Cassidy,
Ekaterina Kiseeva

**UNIVERSITY OF
SOUTHAMPTON, UK**
Robert Marsh

**UNIVERSITY OF STRASBOURG,
FRANCE**
Michael Heap

UNIVERSITY OF SYDNEY
David Airey, Samantha Clarke,
Tom Hubble, Michael Kinsela,
Maria Seton, Ben Mather

**UNIVERSITY OF UTRECHT,
NETHERLANDS**
Erik Van Sebille

**UNIVERSITY OF WAIKATO,
NEW ZEALAND**
Adrian Pittari

UPPSALA UNIVERSITY, SWEDEN
Abigail Barker

VANDERBILT UNIVERSITY, USA
Kristen Fauria

**WESTERN WASHINGTON
UNIVERSITY, USA**
Sue DeBari

**WOODS HOLE OCEANOGRAPHIC
INSTITUTION, USA**
Daniel Fornari, Adam Soule

**SECOND INSTITUTE OF
OCEANOGRAPHY, MINISTRY OF
NATURAL RESOURCES, CHINA**
Shaoru Yin

Projects

Volcanology research
related to ore deposits

Subaerial and submarine
volcanology and natural
hazards

Sedimentary volcanology

Olympic Dam fluid/melt
inclusion project

Subduction magmatism in
the Southwest Pacific

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 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: Malai Ila'ava,
Gilles Ngoran, Chuang Wang

Collaborators: Andrew Barker,
Ray Cas, Matthew Crawford,
Kim Denwer, Rob Duncan,
Leon Grimbeek, Ned Howard,
Andrew McNeill, Declan Radford,
Gary Sparks



A brand-new shiny box corer on board the RV Investigator in the Derwent Estuary during a trial voyage in November/December 2021.

This research group conducts research on diverse aspects of volcanic processes and architectures related to mineralisation and ore deposits.

We continue to study volcanic facies architecture on the modern seafloor and in modern and ancient terrestrial settings. In 2021 we employed a range of multidisciplinary tools together with traditional facies reconstruction for many sub-projects within the group. One tool in development is the use of machine learning and image analysis of crystals contained within coherent and clastic volcanic fragments for correlation between locations or within core. This methodology is still being tested, but looks promising for volcanic units which are fit-for-purpose (see ‘ARC Linkage project’ described below). Another tool we have employed is passive and active seismic and

physical properties data sets with volcanic facies analysis to aid in 3D volcanic architecture reconstruction (see ‘Cenozoic volcanism in Tasmania’ described below).

A separate component of our work in this area is understanding syn-eruptive alteration of volcanic rocks during fluid and vapour transport during magma degassing in the shallow conduit and lava emplacement. This early alteration is not well understood in modifying the strength and physical properties of volcanic lithologies which in turn influence fluid pathways (see ‘ARC Linkage project’ below).



Dr Martin Jutzeler on board the RV Investigator in late 2021 holding the very first piece of core extruded from the successful deployment of the ship's new giant piston corer, which was acquired by the CSIRO during COVID.

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

This Linkage project is a multidisciplinary study aimed at understanding alteration and mineralisation of various volcanic lithologies, and the reconstruction of volcanic architectures with traditional facies analysis augmented with a new developing technique on modern image analysis and machine learning. The machine learning technique is based on photos of volcanic facies in core to quantitatively constrain crystal shape, abundance and size distribution and use statistical analysis to correlate volcanic units. Our aim is to make this tool available such that it can be used in a focused way for individual units

and stratigraphic reconstruction. We are testing this tool on key facies associations in the Mount Read Volcanics in Tasmania, the Cowal gold mine in NSW and the Waihi gold mine in New Zealand. This research is being led by Dr Martin Jutzeler at CODES, in collaboration with DataRock (which incorporates Solve Geosolutions), Evolution Mining, OceanaGold and Mineral Resources Tasmania.

CODES student Malai Ila'ava started his PhD in December 2020 and is focused on the reconstruction of the volcanic architecture of the Cowal Igneous Complex (CIC) at basin scale. He spent several months at Cowal with Evolution geologists to undertake an analysis of volcanic facies which will delineate stratigraphy and underpin

interpretations of eruption and transport processes in the CIC. Malai will create 3D reconstructions of the volcanic architecture in Leapfrog by integrating this work with other geological and geophysical data sets from industry and government. This work will support stratigraphic correlations in the structurally complex GRE46 deposit and more broadly in other epithermal and porphyry prospects in the CIC. Longer term objectives include interpreting the volcano-magmatic and structural evolution of the CIC, where results may have implications for metallogeny, exploration targeting and existing regional scale models for the Juneee-Narromine Volcanic Belt.

Associate Professor Rebecca Carey, Dr Shaun Barker and Professor Michael Heap are investigating the physical properties of intermediate-felsic rocks that favour high-grade mineralisation. We are selecting non-altered and variably altered volcanic samples from the Waihi mine, New Zealand, to conduct various rock stress tests in world-class facilities in Michael's rock properties laboratory. The aim of this project is to understand how alteration affects rock strength and ability to fracture for fluid transport.

Submarine mapping of the Mount Read Volcanics, offshore Tasmania

Dr Martin Jutzeler is the lead CI on a 42-day voyage west of Tasmania on the RV *Investigator*. Initially the voyage was planned for 2021; however, due to COVID and voyage rescheduling, Martin will be sailing in 2023. The plan is to use active seismic reflection; the team will investigate the offshore continuation of major fault zones and the highly mineralised Mount Read Volcanics. Using seismic reflection from the RV *Investigator*, this study will map the offshore extent of the prospective Mount Read Volcanics, and thus provide further understanding on the tectonism of the Tasmanian crust, and formation of the Dundas trough. This research is combined with research on a large continental shelf landslide (see Program 3) and habitat mapping surveys.

SUBAERIAL AND SUBMARINE VOLCANOLOGY AND NATURAL HAZARDS

Leader: Rebecca Carey

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

Students: Acacia Clark, Fumihiko Ikegami, Hannah Moore, Gilles Ngoran, Chuang Wang

Collaborators: Daniele Andronico, Ralph Bottrill, Cathy Busby, Fabio Caratori-Tontini, Ray Cas, Grace Cumming, Nathan Daczko, Robert Duncan, John Everard, Richard Fiske, Daniel Fornari, Michael Heap, Bruce Houghton, Geoff Kilgour, Michael Manga, Gerrit Olivier, Tim Orr, Matthew Patrick, Christopher Phillips, Ryan Portner, Michael Rosenberg, Maria Seton, Jack Simmons, Adam Soule, Kenichiro Tani, James White, Joanne Whittaker, Simon Williams, Richard Wysoczanski.

The 2021 highlights in this research theme are the publication of two CODES PhD graduate-led publications: by Dr Jodi Fox on the volcanic history of Heard Island in the Australian Antarctic Territory, and by Dr Sam Holt on Hawaiian-style volcanism.

The sub-projects within 'Subaerial and submarine volcanology and natural hazards' also achieved excellent progress:

Tarawera Volcano, New Zealand

The drivers of powerful explosive basaltic volcanism are still debated after two decades of research. Associate Professor Rebecca Carey published a review article on the 1886 eruption of Tarawera with colleagues from Auckland University. CODES PhD student Hannah Moore has used crystallinity of the 1886 erupted products to further elucidate those drivers for the Tarawera 1886 eruption, New Zealand. Her manuscript is going through the final stages of review prior

to publication. She is currently preparing her second manuscript on a shallow conduit model to understand the timing of crystal nucleation and growth during final stages of magma ascent at Tarawera.

Our volcanology research also incorporates the 1315 CE (Kaharoa) eruption of Tarawera volcano. This eruption is thought to accompany the arrival of Maori on Aotearoa (New Zealand). It is not only an important event in the context of Maori culture, but also it is New Zealand's most recent powerful explosive eruption of silicic eruptions from this volcanic centre is that they involve the sustained discharge of magma but are highly pulsatory – a key factor in the transition between stable and collapsing eruption plumes. The drivers for pulsatory unsteady eruptions are not at all understood, which is a science question that new CODES PhD student Acacia Clark will address in the years to come.

Cenozoic volcanism in Tasmania

CODES PhD student Chuang Wang is working on passive seismic analysis in western Tasmania in collaboration with the Institute of Mine Seismology and MRT. Using field data from a dense network of seismometers north of Hellyer mine, Chuang has reconstructed the depth of Tertiary basalts overlying the mineralised Mount Read Volcanics. Corroborated with a few drill holes in the area, this passive seismic survey provides a novel way to target exploration where the mineralised Palaeozoic basement is covered by tens to hundreds of metres of younger successions.

Mantle plume-plate interactions – Coral Sea volcanism and tectonics

Associate Professor Rebecca Carey and colleagues Dr Maria Seton, Associate Professor Jo Whittaker, Dr Simon Williams and Bob Duncan have a funded ARC Discovery Project to understand age-progressive submarine seamount chains offshore Eastern Australia. The aims of this research are to (i) determine the controls of plate tectonic motions and plate boundaries on mantle plume activity, and vice

versa; and (ii) constrain the temporal and spatial scales of volcanic output and vertical motion change of these underwater seamounts, and explore the mechanisms driving the vertical motion change. This project is underway with a significant geochemical and geochronological analytical program, and we look forward to sharing the outcomes in 2022.

Havre submarine volcano and the 2012 eruption

Havre volcano is a caldera volcano in the Kermadec Arc, New Zealand, and last erupted in 2012. The volcano was mapped at 25 m-scale resolution by research vessels 13 years before the eruption, and three times after the eruption. These spatial and temporal data represent an exceptional suite of bathymetric surveys to understand eruption and mass-wasting processes that are driving geomorphic change after a large volume deep submarine eruption. PhD student Erica Spain from the Institute for Marine and Antarctic Science (IMAS) is conducting this research together with Associate Professors Rebecca Carey, and Jo Whittaker and Vanessa Lucieer from IMAS. Research outcomes will inform models of intra- and extra-submarine caldera facies associations and reconstructions.

Heard Island, Kerguelen Plateau, Australian Antarctic Territory

IMAS researcher Dr Jodi Fox is leading research about the volcanic history of Heard Island, Australia's only active stratovolcano. Most recently our focus has been on understanding the most recent volcanic rocks produced as a result of the Kerguelen mantle plume. In 2016 a UTAS-led research voyage on the RV *Investigator* went to Kerguelen Plateau and dredged fresh phonolite and basaltic rocks. Jodi's publication on the geological history of Heard Island was published in 2021. Her second study of the whole-rock, mineral and isotope geochemistry data together with ⁴⁰Ar/³⁹Ar geochronology of phonolites is underway, and provides the first evidence for zonation of a Kerguelen mantle plume. This research will be published in 2022 together with input from CODES researchers Dr

Trevor Falloon, Associate Professor
Rebecca Carey, Dr Paul Olin, Emeritus
Professor Mike Coffin (IMAS), Jane
Barling (Oxford) and ANU Emeritus
Professor Richard Arculus.

**Balleny volcanic chain,
offshore Tasmania**

Under the Tasman Sea and Southern
Ocean lies a volcanic chain that is
hypothesised to be age-progressive
and a manifestation of the Balleny
Mantle Plume. This seamount chain
contains a rich and important record of
continental breakup between Australia,
Zealandia and Antarctica ~90-80 Myr
ago, which opened the Southern
Ocean ~50-30 Myr ago and allowed
Earth’s mightiest current, the Antarctic
Circumpolar Current (ACC), to be born.
In 2018, a CODES research team of
staff and students participated in a
voyage on the RV *Investigator*, led by
Associate Professor Jo Whittaker from
IMAS. 16 seamounts were dredged
returning mafic rocks. Preliminary
whole-rock geochemistry and argon
geochronology support the mantle
plume hypothesis as data show an
age-progression HIMU mantle source
geochemistry. These data are now
being used to understand plume-plate
interactions to address questions about
late-stage (Cretaceous-Paleogene)
breakup of Gondwana.

**SEDIMENTARY
VOLCANOLOGY**

Leader: Martin Jutzeler

Team members: Stuart Bull,
Rebecca Carey, Jocelyn McPhie,
Karin Orth

Collaborators: Cathy Busby,
Ray Cas, Cornel de Ronde, Sue
DeBari, Steffen Kutterolf, Emily
Lane, Michael Manga, Robert
Marsh, Adam Soule, Erik van
Sebille, Sally Watson, Suzi Woelz,
Richard Wysoczanski, Shaoru Yin

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

**Caldera-forming submarine
volcanic and sedimentary
processes and deposits**

In 2019 Dr Martin Jutzeler and co-CI
Associate Professor Rebecca Carey
were successful in obtaining time on
the RV *Investigator* for a 36-day voyage
they will lead in March 2022 at several
silicic calderas in the Kermadec arc,
north of New Zealand. The aim of this
voyage is to link the behaviour of deep
submarine silicic eruptions with the
morphology of their structures and their
deposits, using seismic reflection and
piston coring. This voyage will target
sediment waves on the caldera apron
of a volcano, which are voluminous
dune-like deposits formed during
caldera-forming eruptions. Submarine
landslide deposits are secondary
targets. Comparative data of the
various types of volcanic architectures
and presence – or not – of sediment
waves will provide exceptional data to
better reconstruct past and future
eruptions, and inform the tsunamigenic
potential of large-magnitude eruptions.
The high-resolution seismic transects
will enable new ore vectoring strategies
for exploration in Australia and provide
essential data to propose an IODP
expedition to drill these calderas.
Moreover, this voyage will complement
our dataset of the 2012 eruption at
Havre, collected during our 2015
voyage. Ship-time for this voyage is
funded by CSIRO and Dr Martin
Jutzeler obtained a \$19,000
infrastructure grant from the College of
Science and Engineering (CoSE) at
UTAS to acquire equipment for the
voyage.

Shannon Frey remotely started her PhD
in sedimentary volcanology in 2021,
and will travel to Hobart in early 2022.
Her PhD research includes analysis of
sediment ripples at Havre volcano,
using ROV-based videos to reconstruct
post-eruption bottom current activity.
The other part of her PhD will be based
on cores and seismic reflection data
from the 2022 voyage to the Kermadec
Arc, in particular on giant (30 km3)
submarine sediment waves
surrounding Macauley volcano. These
sediment waves are internally cross-
bedded and represent syn-eruptive
high-regime sedimentation dynamics,
and inform on eruption style.

**Contourites and volcanic
seamounts**

Volcanic seamounts act as topographic
obstacles to deep ocean currents,
enhancing local erosion and deposition
of muddy deposits, named contourites.
These contourites effectively record
fluctuations in strength and direction of
ocean currents, from which global
tectonic events and climatic trends can
be inferred. Dr Martin Jutzeler is
collaborating with Dr Shaoru Yin on
seismic reflection data and sediment
cores from IODP Expedition 350 in
2015, where hundreds of metres-thick
of contourite were drilled. A first
manuscript based on this project was
submitted in late 2021.

**OLYMPIC DAM FLUID/MELT
INCLUSION PROJECT**

Leader: Maya Kamenetsky

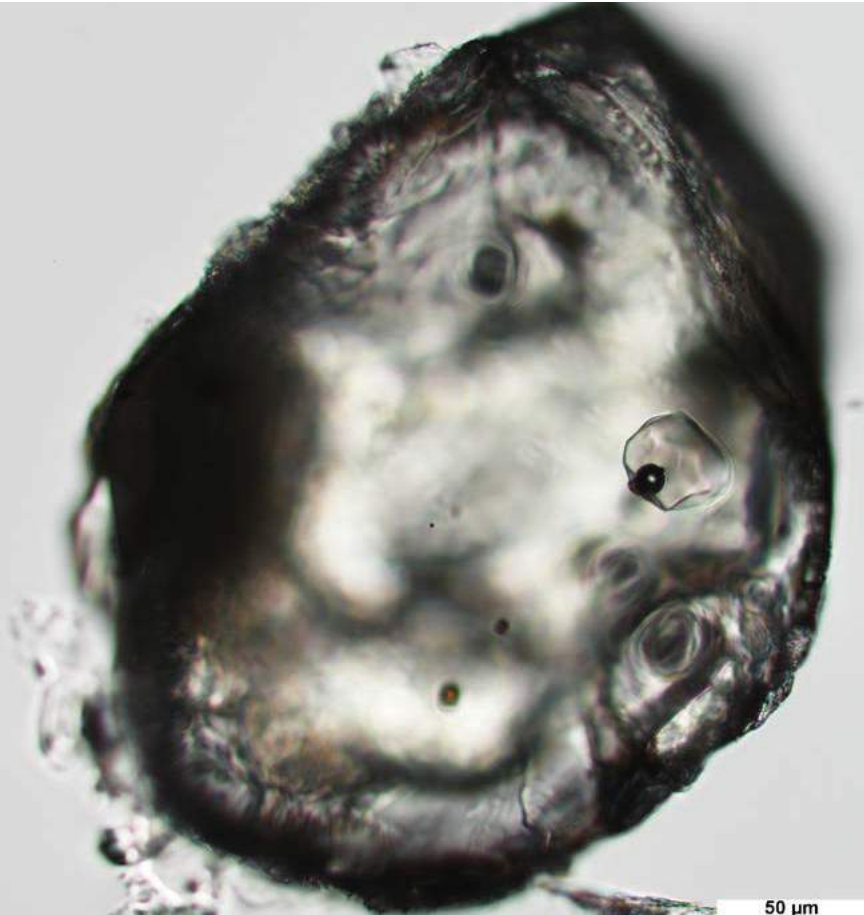
Team member: Vadim
Kamenetsky

Collaborators: Kathy Ehrig,
Alkis Kontonikas

This project, which began in 2021, is
focused on the study of phase
evolution and compositional changes
of fluids recorded in melt/fluid
inclusions from quartz and other
minerals (carbonate, fluorite and barite)
from distal to proximal granite hosting
the Olympic Dam deposit.

Formation of hydrothermal ore deposits
requires a fluid with the capability to
transport and deposit metals. Among
the most important factors driving the
formation of hydrothermal mineral
deposits are the temperature, pressure
and compositions of the ore-forming
fluids. Melt/fluid inclusions in ore and
gangue minerals provide the best tool
available to obtain this information.

In 2021 we carried out a
comprehensive petrographical study of
selected samples from four drill holes
with various types of quartz and
quartz-tourmaline veins. This allowed
us to distinguish and characterise
different types of host mineral (quartz
and carbonates) and melt/fluid
inclusion assemblages using optical
microscopy, scanning electron
microscopy and cathodoluminescence
(CL) techniques.



CODES PhD student Bridie Le’Gallais is researching the tectonic significance of mafic/ultramafic igneous rocks in western Tasmania: This image show an olivine from the Whyte River Complex area, western Tasmania, from a Cambrian ultramafic olivine-bearing lava or shallow sill. The olivine is immersed in oil and viewed with a polarised microscope using a 20x objective lens (see image for scale). This olivine contains a glassy melt inclusion (in-focus, right side of olivine) which contains a vapour bubble, small sulphide globule, and is in contact with a chromite grain. This and other melt inclusions were re-melted and quenched using a heating stage, and then polished to expose the glassy inclusion. Combining electron microprobe analysis and laser-ablation ICP-MS we are able to sample the chemical makeup of the melt inclusion, which is a small sample of the parental liquid from which the olivine formed. Whilst also taking into consideration possible elemental exchanges between the host olivine and the inclusion, and losses of some elements such as H from the inclusion, we can use the chemical makeup of the glass to better understand the tectonic origins of the magma which the olivine formed in, by comparing incompatible and trace elements to that of the whole-rock chemical makeup.

Compositions of melt/fluid inclusions
will be determined using Raman
spectroscopy (volatiles, such as H₂O
and CO₂) and LA-ICP-MS (major and
trace elements in melt/fluid inclusions
as well as evaluating the relative metal
budget of magmatic and hydrothermal
fluids).

**SUBDUCTION MAGMATISM IN
THE SOUTHWEST PACIFIC**

Leaders: Trevor Falloon, Leonid
Danyushevsky

Collaborators: Julien Collot,
Roland Maas, Anders McCarthy,
Martin Patriat, Ivan Savov, Osamu
Ishizuka

This project is an ongoing investigation
of magma generation processes in
subduction zones and back-arc basins
in the southwest Pacific, and their links
with the tectonic evolution of this
region.

In 2021, a manuscript aimed at
understanding the processes leading
to the formation of adakite magmas in
the modern subduction was submitted
and accepted for publication. This
study is based on samples from active
adakite volcanoes within the
underwater section of the Hunter
Ridge. Several volcanic samples from
the Hunter Ridge were analysed for
Boron isotopes in collaboration with
Dr Ivan Savov from Leeds University,
and dated using the Ar-Ar method in

collaboration with Dr Osamu Ishizuka
from the Geological Survey of Japan.
The results are planned for publication
in 2022.

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

Leaders: Leonid Danyushevsky,
Paul Olin

Student: Bridie Le’Gallais

Collaborators: Ralph Bottrill,
Grace Cumming, John Everard,
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 positions.

In 2021, new samples of picritic lavas
and olivine cumulates were collected
from the Whyte River Complex during
fieldwork near Waratah in western
Tasmania. These samples were
prepared for mineral analysis, which
revealed that the chemistry of olivine
and spinel in these rocks is unlike those
found in modern boninites and arc
tholeiites. Melt inclusions in fresh olivine
fragments were identified and prepared
for reheating experiments using the
Vernadsky heating stage. Five
reheating experiments were
conducted, and more are planned for
2022. Analysis of melt inclusions using
EPMA and LA-ICP-MS are planned for
2022.

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

Leader: Karin Orth

Team members: Rebecca Carey, Sebastien Meffre

Student: Till Gallagher

Collaborators: Ralph Bottrill, Grace Cumming

Till Gallagher's Honours project aims to re-appraise the volcanic architecture of the St Marys Porphyrite in northeastern Tasmania. The project targets one drillhole, coastal outcrops between Falmouth and Four Mile Creek and other outcrops between Falmouth and St Marys in the west. The drillhole includes core from the underlying Mathinna Supergroup, the basal contact breccia and basal portion of the St Marys Porphyrite. New work has been undertaken on the distribution of the lithic clasts. This, along with macroscopic and microscopic studies, will allow Till to identify emplacement and post-emplacement processes related to formation of the St Marys Porphyrite. Some zircon dating has been completed on the St Marys Porphyrite, underlying Mathinna Supergroup and proposed feeder dyke. The new dates will help to constrain the connections of the St Marys Porphyrite with the crustal architecture and development of NE Tasmania, and to compare it with similar units in Victoria.

Till suspended his studies for part of 2021 but has returned to finalise his data acquisition and write up his thesis. He will be completing his Honours in May 2022.

PEGMATITES AND PEGMATITE-RELATED ORES

Leader: Paul Davidson

Collaborators: Adolf Rericha, Rainer Thomas

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.

A paper entitled 'An unusual paragenesis of diamond, graphite, and calcite: A Raman spectroscopic study' by Rainer Thomas, Adolf Rericha and Dr Paul Davidson was published online in 2021 in *Estudos Geológicos*, vol. 31, no. 2, with a print version to follow in 2022. Two further papers are in review and will be published in 2022.

VHMS RESEARCH – ANCIENT

Leader: Jonathan Cloutier

Team members: Mike Baker, Leonid Danyushevsky, Ross Large, Charles Makoundi, Sebastien Meffre, Khin Zaw

Collaborators: Shaun Barker, Mohd Basril Iswadi Basori, David Green, Scott Halley, Andrew McNeill

SE ASIA

Due to the COVID-19 pandemic, no fieldwork was possible in 2021. However, laboratory work continued and a presentation was made at an international conference organised by IGCP 668: Equatorial Gondwanan History and Early Palaeozoic Evolutionary Dynamics, Annual Meeting 2021, in Japan. Throughout the long history of the Gondwana supercontinent break-up and subsequent accretion of these crustal terranes during the Phanerozoic, several VHMS deposits occurred in the SE Asia region (e.g., Duc Bo deposit in Vietnam; Tasik Chini deposit in central Malaysia; Leymyetna, Mahar San and Bawdwin deposits in Myanmar; and



Zeb Zivkovic is undertaking a PhD at CODES on lithogeochemical fertility indicators for VHMS deposits within the 'VHMS Research – Ancient' project. Here he holds this sample of radial chlorite on Archean banded iron formation, from the Ilaara Greenstone Belt, Yilgarn, Western Australia (discovered during fieldwork in April 2021).

Wetar in Indonesia). Our LA-ICP-MS zircon U/Pb dating provided precise emplacement ages of the host rocks. For instance, the Duc Bo deposit in Vietnam is hosted in Ordovician-Silurian mafic-felsic volcanic and metavolcanic rocks and our LA-ICP-MS zircon age yielded 417.3 ± 7 Ma to 459.5 ± 9.7 Ma. LA-ICP-MS U/Pb zircon dating of the host rhyolites from the Bukit Botol and Bukit Ketaya deposits in Malaysia yielded Early Permian 286 ± 4 to 292 ± 3 Ma and 286 ± 2 to 288 ± 4 Ma ages. Formation of these VHMS deposits in SE Asia is related to the protracted history and development of Paleo- to Meso-Tethyan Oceans and there is a significant potential for future discovery of these deposit types in SE Asia. Further research led by Khin Zaw is continuing to establish magmatic, tectonic and hydrothermal alteration histories for better targeting of the prospective grounds in the region.



CODES PhD student Acacia Clark cutting the first core from the new Giant Piston Corer on the CSIRO research vessel Investigator in late 2021. Acacia's PhD looks at the Kaharoa eruption in 1315 CE.

TASMANIA

Dr Mike Baker, Professor Leonid Danyushevsky and Dr Shaun Barker (MDRU) are leading a project entitled 'Lithogeochemical fertility indicators for VHMS deposits' initiated in June 2019 as a Masters by Research, which has been upgraded to a PhD project undertaken by candidate Zebedee Zivkovic that started in 2020. The project focuses on the lithogeochemical characteristics of different stratigraphic rock packages in the Mount Read Volcanics to evaluate whether distinctive geochemical signatures exist within the VHMS mineralisation host units. It will take advantage of recent improvements in geochemical assay methods to resolve variations in Zr/Hf and other ratios of geochemical elements of volcanic units across the province. Horizons of low Zr/Hf ratios have been observed at or below the horizons that are host to mineralisation right across the Mount Read Volcanics. These variations are inferred to be related to fractionation of the underlying magma chamber and the associated build-up of concentrated metals and/or hydrothermal fluids. If this hypothesis is correct, it suggests that the lithogeochemistry of VHMS host rock



CODES Honours student Till Gallagher is investigating enigmatic foliations in the St Marys Porphyrite, eastern Tasmania. Here he is pictured north of Little Beach on Tasmania's east coast.

packages could be used to fingerprint prospective horizons and thus guide exploration activities.

Research has been focused on identifying how the immobile trace elements are distributed within the respective mineral phases of the rock using a combination of SEM and

LA-ICP-MS. Additionally, some resistive mineral phases are known to be impervious to different types of digestion methods. To understand how these resistive phases might affect the whole-rock interpretation, a multi-digestion method study was initiated to analyse how the different digestion



CODES PhD student Malai Ila'ava underground in the Cowal mine in April 2021 during fieldwork for his project on the volcanic architecture of the Cowal Igneous Complex.



Till Gallagher's Honours project aims to investigate the volcanic-plutonic relationships of the St Marys Porphyry through mapping, geochemistry and structural analysis.

methods might provide different results. The study reviewed fusion and acid digestions compared to control samples analysed at CODES Analytical Laboratories. The results showed significant loss in recovery of Zr-Hf-Nb-Ta and Ti in the acid digestion. The resultant lithogeochemical interpretation using only acid digestion data would produce more mafic and more alkaline rock compositions compared to the fusion data. Additionally, fertility indicators such as Zr/Hf would contain numerous false positives in the acid digestion data. This study highlights the importance of using fit-for-purpose geochemical methods when undertaking lithogeochemical analysis.

In parallel with this work is an Innovations Connections research collaboration with an industry partner

with projects in the Yilgarn and Kimberley regions of Western Australia. In addition to whole-rock lithogeochemistry, work on these projects will also include mineral geochemistry of greenrock, pyrite and zircon indicator minerals from a variety of different mineralisation styles, rock types and ages.

By applying these methods to a variety of deposits, we can test the robustness of the techniques across a range of magmatic-hydrothermal mineralisation styles and geologic settings.

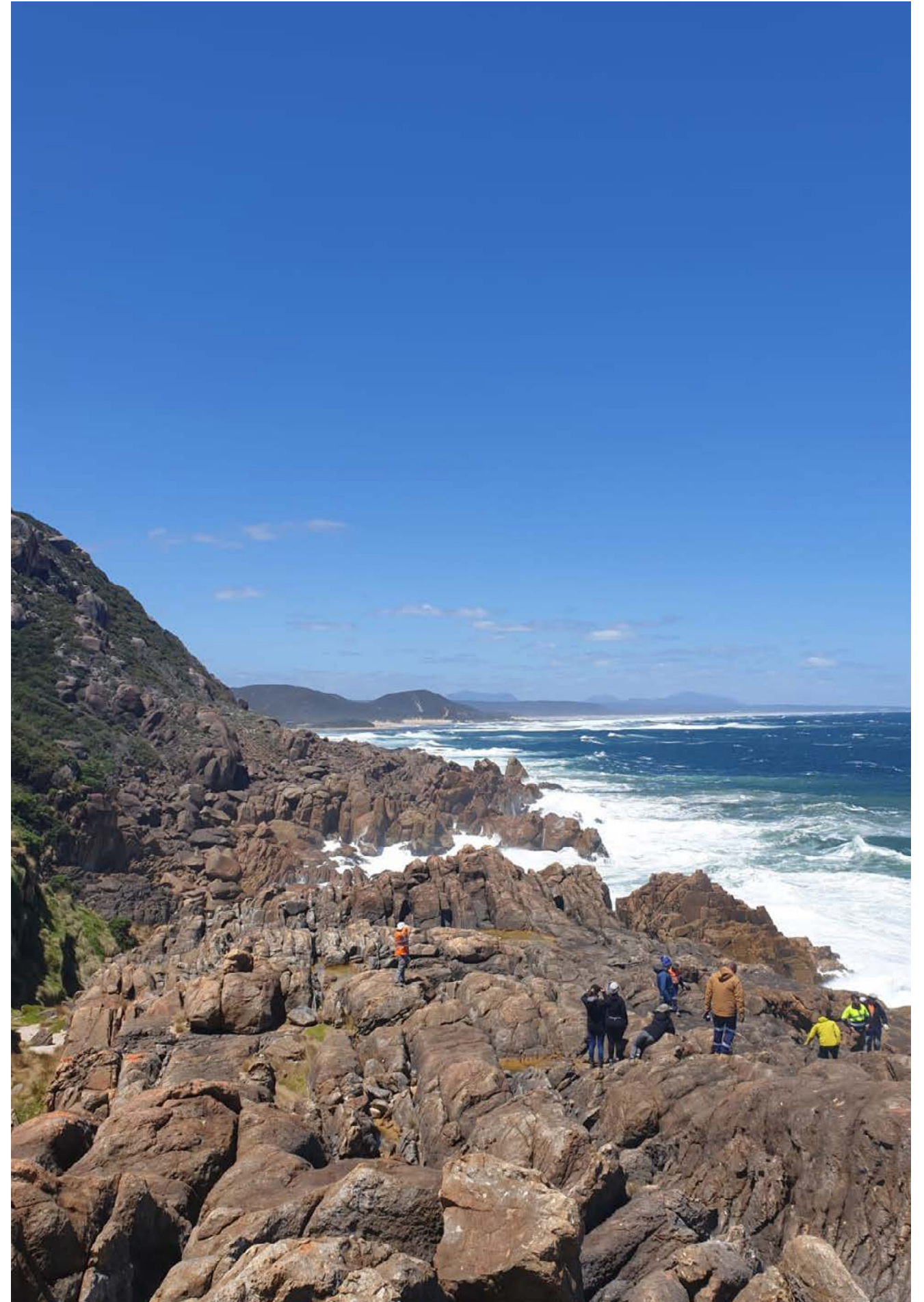
The implications of this study go beyond VHMS systems in the Mount Read Volcanics and may speak to a whole host of magmatic-hydrothermal deposits. As such, we are also conducting a review of global crustal geochemistry to compare with known mineralised data sets to test the method's ability to characterise other mineralisation systems and attempt to develop a more robust magmatic fertility indicator that can be used in a variety of exploration settings.

Dr Charles Makoundi continues to work on downhole hyperspectral mineralogy and multi-element analysis for the Mount Julia (Henty) deposit in the Mount Read Volcanic Belt to characterise the types of alteration minerals downhole and their relationships with precious and base metal distribution. This research is undertaken in collaboration with Dr Jonathan Cloutier (CODES/Geoscience

Australia); University Associate, Professor Khin Zaw (CODES); and Dr David Green and Dr Andrew McNeill (both Mineral Resources Tasmania). This project has the support of two mining companies, namely Diversified Minerals Pty Ltd (former owner) and Catalyst Metals Limited (new owner). The project will further look at thermal-infrared mineralogy focusing on plagioclase and quartz alteration and how wavelengths play out across the deposit. The research team has recently received an approval from the Manager of Catalyst Metals Limited to publish the findings in a peer-reviewed journal.

Looking forward

2021 has been a year where excellent progress has been achieved by students and staff on science initiatives across Program 4. The thirst for critical minerals for a net-zero carbon economy is certainly keeping our staff and postdoctoral researchers busy defining new projects in Tasmania, Australia and globally. We look forward to those projects coming to fruition and an influx of new PhD and Masters students within Program 4 in the coming years.



Participants on the 2021 Ores in Magmatic Arcs MEconGeol short course, taken by CODES PhD student Richard Hill at Trial Harbour on the west coast of Tasmania.

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 geochronology, mineral processing, ore genesis, igneous geochemistry and volcanology, and waste management.
- CODES Analytical Laboratories also provide 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 a number of high spatial resolution microprobes, advanced data-reduction algorithms and application of new techniques. 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 2021, a significant proportion of research activities was focused on developing U/Pb dating methods for rutile, ilmenite and garnet.

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

Many of the projects involve close collaborations with national and international research groups and equipment manufacturers.

Highlights

Research

A total of three publications were published in 2021:

- Publications on a method for U/Pb dating of ilmenite.
- Publication on accurate analysis of calcite by LA-ICP-MS.
- Publication on synchronisation device between a laser and ICP-MS.

Papers on epidote U/Pb dating and development of reference material for sulfide analysis by LA-ICP-MS are being prepared for publication.

Equipment

A triple-quad 8900 ICP-MS instrument was installed at the CODES Analytical Laboratories in 2021. A new ATL laser has been ordered for the Resolution SE laser ablation system to replace one of the old instruments. An order for a LIBS attachment to the other Resolution SE system has been initiated.

Software

Several versions of LADR, a data reduction software for LA-ICP-MS, were released throughout the year. The latest version significantly enhances handling of data reduction for U/Pb dating and introduces capabilities for automatic integration interval selection.



Members of the CODES Analytical Laboratories team photographed during a mandatory power tools course in June 2021. They are (L-R): Ivan Bolousov (Laboratory Analyst); Al Cuisson (Lapidary Manager); Leonid Danyushevsky (Leader); Terrie Sawyer (Laboratory Analyst); Paul Olin (Deputy Leader); and Maxwell Morissette (Laboratory Technician).

A triple-quad 8900 ICP-MS instrument was installed at the CODES Analytical Laboratories in 2021.

Graduations

Congratulations to Jay Thompson, who graduated in 2021. Jay is now employed by the US Geological Survey as a Research Scientist. His thesis was titled 'Improving the understanding of H₂O-free aerosol behaviour in the inductively-coupled plasma for geochemical LA-ICP-MS applications: U/pb dating and trace element analysis in silicate minerals and glasses'.

Staff

In December 2021 the team welcomed Dr Jeffrey Oalmann as a Laboratory Analyst. He will be operating one of our LA-ICP-MS units, participating in our R&D program and performing analytical data reduction. Prior to joining CODES Analytical Laboratories Jeff worked at the Earth Observatory of Singapore (EOS) managing their LA-ICP-MS laboratory.

In November 2021 Terrie Sawyer moved to a different job outside Australia.

Conferences

No conference participation in 2021 due to COVID-19 restrictions.



Dr Jeffrey Oalmann, who joined CODES towards the end of December 2021, works as a Laboratory Analyst. He will be operating one of our LA-ICP-MS units, participating in our R&D program and performing analytical data reduction.

The program team

LEADER LEONID DANYUSHEVSKY
DEPUTY LEADER IVAN BELOUSOV



TEAM MEMBERS:

Paul Olin, Matthew Cracknell, Sebastien Meffre, Maxwell Morissette, Terrie Sawyer, Jeffrey Oalman

PHD STUDENTS:

Xin Ni Seow, Jay Thompson, Jennifer Thompson

HONOURS STUDENT:

Kate Jenkins

COLLABORATORS:

AGILENT TECHNOLOGIES

Fred Fryer

CENTRAL SCIENCE LABORATORY, UTAS

Karsten Goemann

LAURIN TECHNIC

Michael Shelley

MOSCOW STATE UNIVERSITY, RUSSIA

Pavel Plechov

MDRU, CANADA

Shaun Barker

NORRIS SCIENTIFIC

Ashley Norris

UNIVERSITY OF BRISTOL, UK

Jon Blundy

UNIVERSITY OF KIEL, GERMANY

Dieter Garbe-Schönberg

UNIVERSITY OF MELBOURNE

Roland Maas

RIO TINTO

Alan Kobussen, Will Powell

Projects

Fundamentals of ICP-MS

Fundamentals of laser ablation

Calibration standards for LA-ICP-MS

LA-ICP-MS instrumentation development

U/Pb dating

LA-ICP-MS data reduction software

Interpretation of LA-ICP-MS time-resolved signals

Project summaries

FUNDAMENTALS OF ICP-MS

Leader: Leonid Danyushevsky

Team members: Ivan Belousov, Maxwell Morissette, Paul Olin, Terrie Sawyer

Students: Xin Ni Seow, Jennifer Thompson

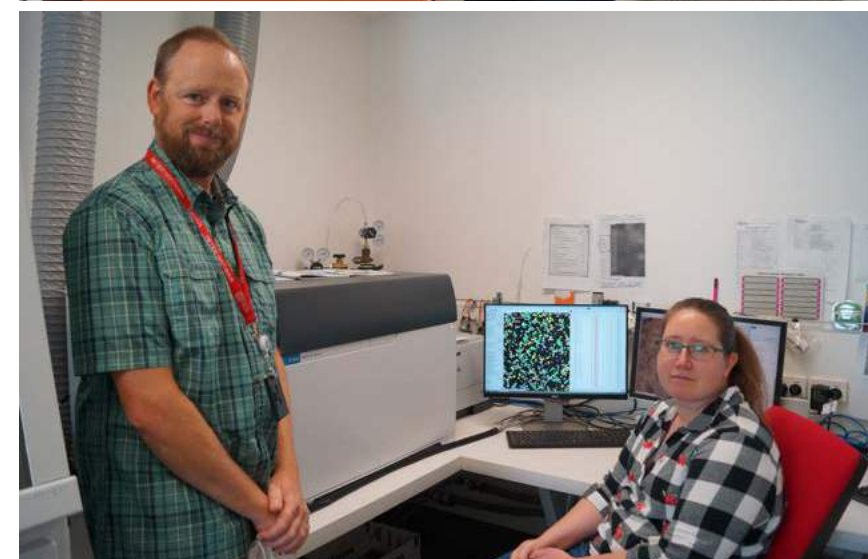
Collaborator: Fred Fryer

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 2021 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 paper on the accurate analysis of calcite by LA-ICP-MS was published in the journal *Geostandards and Geoanalytical Research*.



TOP: Technical Officer Michelle Makoundi in the sample preparation laboratory holding an agate mill for making fine powders of silicate rocks. ABOVE: Dr Paul Olin, Deputy Leader of the CODES Analytical Laboratories, and PhD student Bridie Le'Gallais preparing to analyse pyrite and arsenopyrite grains in a grain mount. Grains are located based on previously acquired AMICS coloured images which can be uploaded into the GeoStar laser controller software, coordinated and digitally overlain onto a live sample image for rapid programming.

FUNDAMENTALS OF LASER ABLATION

Leader: Leonid Danyushevsky

Team members: Ivan Belousov, Maxwell Morissette

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 sulfide minerals.

In 2021 there was no activity due to COVID-19. A publication describing the relationship between matrix composition, ablation rate and elemental fractionation is in preparation with submission planned for 2022.

CALIBRATION STANDARDS FOR LA-ICP-MS

Leaders: Ivan Belousov, Leonid Danyushevsky

Team member: Paul Olin

Collaborators: Jon Blundy, Dieter Garbe-Schönberg, Karsten Goemann, Pavel Plechov

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 sulfide analysis has been distributed to several more analytical laboratories worldwide. A manuscript describing this new reference material is in preparation.

In 2021 collaboration continued with the University of Kiel, the University of Bristol and Moscow State University on reference material for plagioclase analysis by LA-ICP-MS and the use of pressed nanoparticle pellets as reference materials.

LA-ICP-MS INSTRUMENTATION DEVELOPMENT

Leader: Leonid Danyushevsky

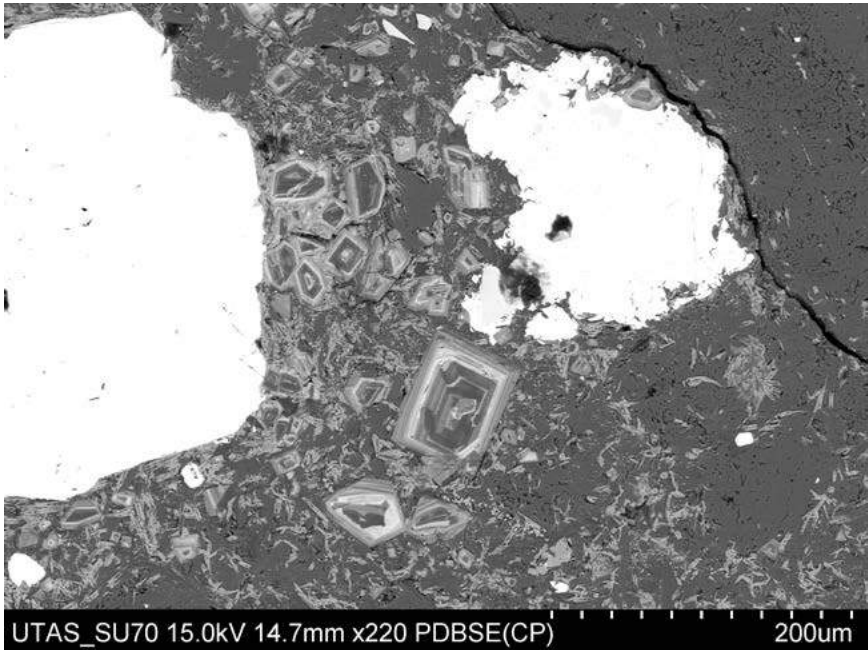
Team members: Paul Olin, Ivan Belousov

Student: Jay Thompson

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 2021, in collaboration with Norris Scientific, a synchronisation device has been developed which allows for matching the timing of laser firing to the cycling of the quadrupole on the mass-spectrometer. This allows for improved precision of LA-ICP-MS results acquired using quadrupole mass-spectrometers, without significant mixing of individual laser pulses. It is best applicable when using fast washout cells in conjunction with single quadrupole mass-spectrometers. A publication describing the approach has been published in the *Journal of Analytical Atomic Spectrometry*.



TOP: In 2021 CODES Analytical Laboratories installed a new Agilent 8900 Triple Quad (QQQ) ICP-MS. The 8900 QQQ can be run as a traditional single quadrupole mass spectrometer for continuing routine lab business, but the additional capabilities of the 8900 QQQ will allow for new analytical methods involving reaction gases, mass shifting, and reduction or elimination of interferences. Methods developments are currently underway and implementation of new methodologies within the Lab is expected during 2022. ABOVE: CODES PhD student Xin Ni Seow is working within the Fundamentals of ICP-MS project. Here her research results show a backscattered electron (BSE) image of coarse-grained and beautifully zoned aluminium phosphate-sulfate (APS) minerals from the Resolution porphyry Cu-Mo deposit. APS minerals have been overlooked in porphyry-epithermal deposits in the past and recent studies have revealed their potential in vectoring application.

U/PB DATING

Leaders: Leonid Danyushevsky, Ivan Belousov

Team members: Maxwell Morissette, Jeffrey Oalmann

Students: Kate Jenkins, Jay Thompson

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.

Understanding the ablation behaviour of garnet and rutile and its impact on the accuracy and precision of U/Pb dating of these minerals was part of Honours degree work by Kate Jenkins. A publication is in preparation.

A paper describing the development of a method for U/Pb dating of ilmenite has been published in the *Journal of Analytical Atomic Spectrometry*.

LA-ICP-MS DATA REDUCTION SOFTWARE

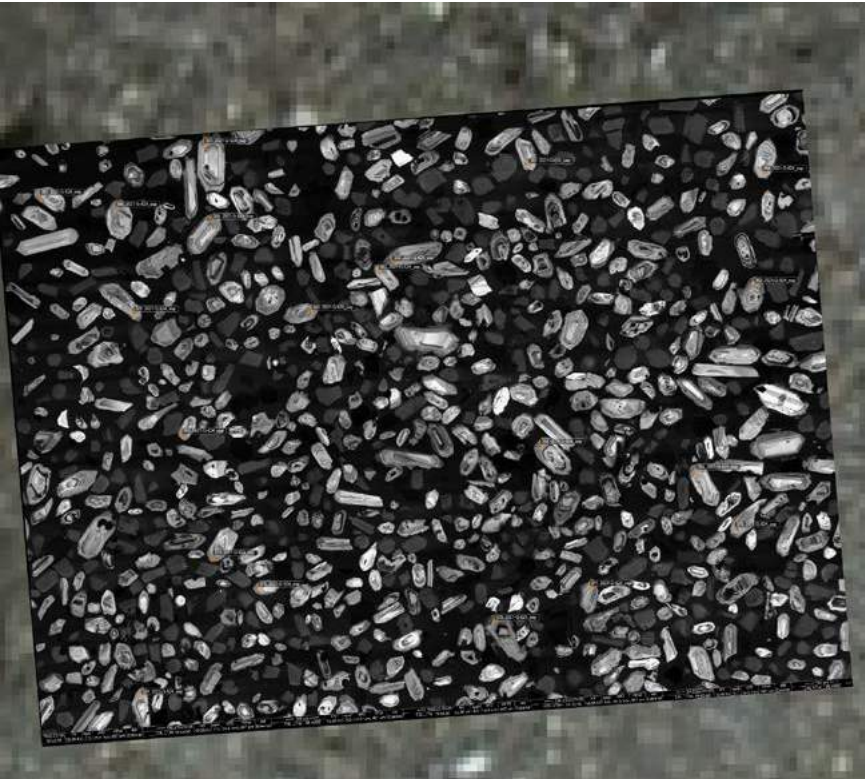
Leader: Leonid Danyushevsky

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 sulfides, silicates, phosphates and carbonates; and



Cathodoluminescence images of zircons used to guide locations of laser ablation analyses for age determination. This work falls within the U/Pb dating project.

- identification of mineral phases in, and sizes of, micro inclusions in minerals.

Activities in 2021 were directed towards developing algorithms for automatic integration interval selection and imaging elemental distributions in minerals. A software version with added capabilities for automatic integration interval selection has been released and is currently being tested. This new version also allows for common Pb corrections in standards used for U/Pb dating. These capabilities are being used when dating such minerals as apatite, titanite, epidote, etc. A new version of the software capable of processing images of elemental distributions will be released in 2022.

INTERPRETATION OF LA-ICP-MS TIME-RESOLVED SIGNALS

Leaders: Leonid Danyushevsky, Ivan Belousov

Team members: Matthew Cracknell, Sebastien Meffre

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 formation of hydrothermal and magmatic minerals and their use could significantly improve our understanding of ore deposit formation and could be used in vectoring and fertility studies for a range of deposit styles.

During 2021, we have continued to improve algorithms for identification of micro-inclusions in time-resolved LA-ICP-MS signals from a range of minerals. A PhD project looking at the influence of micro-inclusions on vectoring and fertility assessment for porphyry Cu deposits was initiated in collaboration with the AMIRA P1249 team.

Looking forward

The team will further develop its analytical research in 2022. Developments using Agilent 8900 QQQ, LA-LIBS tandem systems and ICP-ToF are expected to include:

- Lu/Hf dating of garnet and Re/Os dating of molybdenite by Agilent 8900 QQQ MS.
- Investigating applicability of LA-LIBS systems for quantitative analysis of halogens in different minerals following installation of a LIBS add-on to one of the RESOLUTION SE laser ablation systems.
- 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 the geosciences. It seeks solutions to issues associated with managing, processing, visualising and interpreting minerals industry data sets at all stages from exploration to mining and mineral processing to waste management.

Introduction

Program 6: Geophysics and computational geosciences focuses on the applications of new methods for data collection, data analysis, data integration, data-driven decision making, and novel visualisation techniques. It includes a diverse range of projects researching three-dimensional geophysical interpretation, seismic array studies, near surface and environmental geophysics, geodata analytics, data visualisation, exploration targeting and geoscience education.

Modern minerals industry activities are undertaken in highly 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, multi-element 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 process 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

2021 was a big year for PhD completions with several PhD students working within Program 6 graduating. All of these – Stephen Kuhn, Peter Morse, Thomas Ostensen and Tobias Stål – were supervised primarily by Professor Anya Reading.

Tobias Stål was presented with the 2020 PhD Award for Outstanding Performance during Postgraduate Studies in Earth Sciences/CODES at a ceremony in May 2021, which he said he was very grateful to accept.

From a geophysical perspective, 2021 highlights for Program 6 include:

- CODES PhD student Tom Ostensen gave the keynote presentation for 'The Australian lithosphere in 2021: What do we know and future challenges' session at AESC 2021. In the presentation Tom covered the key findings of his PhD research into the deep geoelectric structure of Tasmania.



CODES/IMAS PhD student Tobias Stål (far right) after receiving his PhD Award for Outstanding Performance during Postgraduate Studies in Earth Sciences/CODES at a UTAS School of Natural Sciences ceremony held in May 2021 in Hobart.

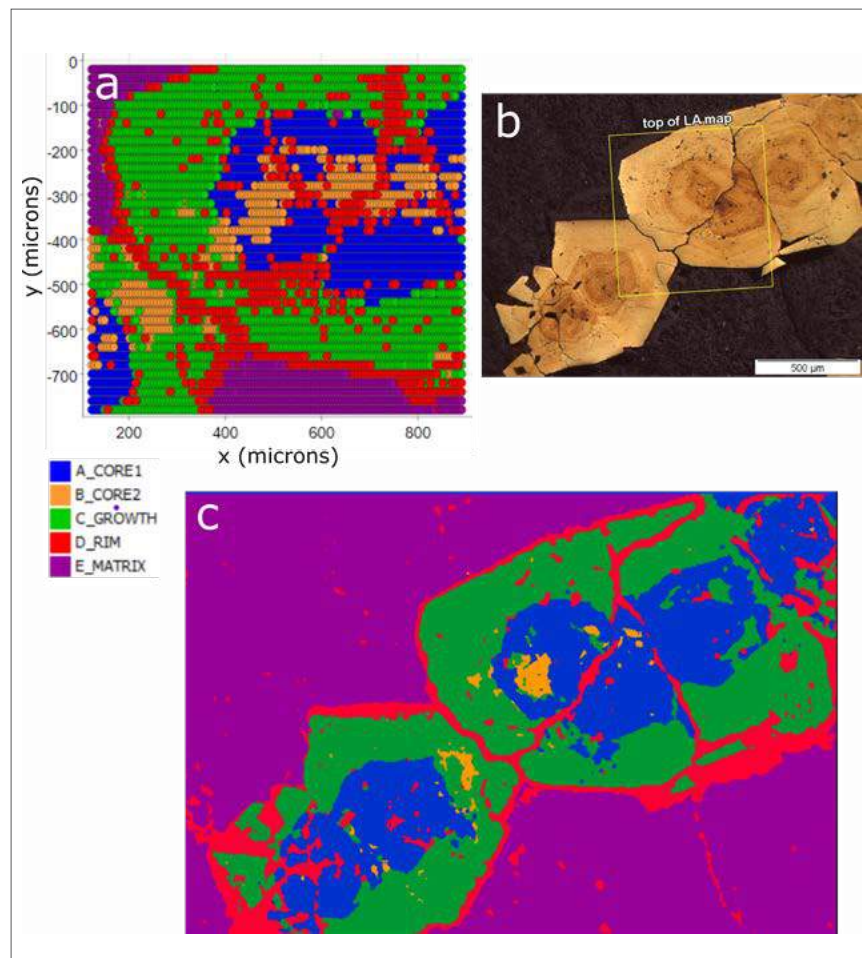
2021 was a big year for PhD completions with several PhD students working within Program 6 graduating.

- CODES Honours student Zak Weidinger used time-lapse near surface geophysical methods to image and model the internal structure and hydrological characteristics of the Royal George legacy tailings dump. This project was supported by Mineral Resources Tasmania through the Mining Sector Innovation Program. The outcomes of this research identified previously unknown hydrological inputs to the tailings dump. This information will guide rehabilitation and management at the Royal George site. Zak was also awarded the Inaugural Richard Lane Scholarship from the Australian Society of Exploration Geophysicists.
- CODES Honours student Dina Chu investigated the geophysical responses of ore and host materials in the Pine Creek goldfield in the Northern Territory. Dina acquired detailed petrophysical measurements on several hundred drill core samples and used these data to evaluate the potential for geophysical detection of mineralised rocks. Dina's research was supported by Kirkland Lake Gold.
- Former CODES Honours student Wei Xuen Heng presented the results of his project that modelled the internal structure and contents of mine waste at the legacy Endurance mine in northeast Tasmania at the GACMAC conference in Ontario, Canada.
- In collaboration with Mineral Resources Tasmania, Dr Matthew Cracknell and Professor Anya Reading contributed to a paper in a special issue of *Minerals* that presented the results of explicit and implicit 3D geophysical modelling of the highly prospective regions of west and northeast Tasmania.
- CODES PhD student Alex Farrar presented recent results from his project mapping long-lived, deep large-scale structures across the Central Andes at AESC 2021 in Hobart, Tasmania.

- A paper by CODES/IMAS PhD student Tobias Stål titled 'Antarctic geothermal heat flow model: Aq1' was selected as an Editor's Highlight in the AGU journal *Eos*; fewer than 2% of journal articles are featured in this way.
- Tobias Stål chaired a session on 'Polar geothermal heat flow: Estimation and ice sheet interactions' at the AGU Fall Meeting in 2021.

In the field of computational science and data visualisation, the major achievements of 2021 were:

- The use of Dr Michael Roach's very high-quality 3D high-resolution visualisations of key Australian geological field locations continued to be extremely important to CODES researchers and Earth Sciences teaching staff for online research delivery and teaching during 2021 due in large part to COVID-19 travel restrictions.



Dr Matthew Cracknell's work uses machine learning tools to develop new layers of information for mineral exploration modelling. This figure shows the input data, data processing and final product of classifying optical microscopy images of NaOCl etched pyrite into geochemical domains defined within LA-ICP-MS map data. (a) geochemical domains defined by clustering pyrite LA-ICP-MS map data; (b) optical microscopy image of NaOCl etched pyrite (yellow outline indicates LA-ICP-MS map coincident region); and (c) optical microscopy image (in b) classified as geochemical domains (in a).

- Dr Matthew Cracknell presented the results of a pilot study investigating the use of geochemical data clustering and image classification to extend geochemical domaining to optical microscopy imagery at Goldschmidt 2021, Lyon, France.
- Dr Matthew Cracknell co-authored a paper with former CODES PhD student Dr Shawn Hood (GoldSpot) and collaborator Dr Michael Gazley (RSC Mining and Mineral Exploration) on the use of clustering and classification to generate geoscience products that guide data processing methods that highlight geochemical anomalies.
- Dr Matthew Cracknell co-chaired the 'New geology analytics and machine learning in data-rich and data-poor environments' session with Dr Phil Blevin (GSNSW) and

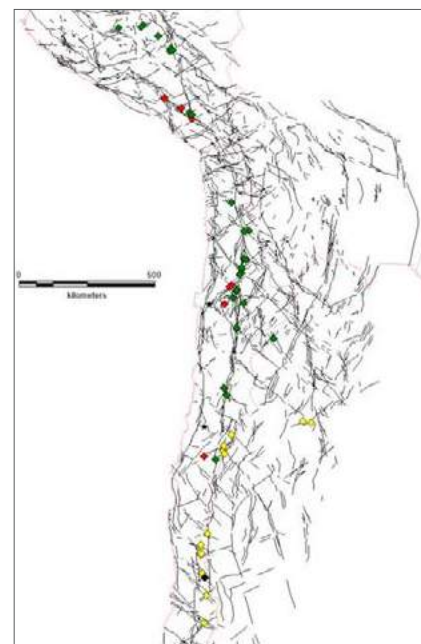
Mark Biggs (ROM Resources) at AESC 2021, Hobart, Tasmania.

In the area of technology transfer the major highlights for 2021 were:

- In Semester 1, Dr Matthew Cracknell delivered 'Geodata Analytics' to around 40 Master of Economic Geology students and industry participants. This online short course covers aspects of geoscience data management, processing, analysis and interpretation, and is designed to give geologists fundamental knowledge and skills in the rapidly-evolving field of geodata analytics. This unit draws on the skills and experience of digital data-focused geoscientists from industry, government and academia, including MRT, CSIRO, BHP, IMDEX and Monash. 'Geodata Analytics' is not only

available to Masters students but also open to industry-based participants through the UTAS short course platform. This course will run again in Semester 2 of 2022 as part of the Masters degree, the Graduate Certificate in Economic Geology and as a stand-alone unit offered via Open Universities Australia.

- Dr Matthew Cracknell co-presented in the 'Data Integration and Machine Learning Across the Mining Value Chain – A Practical Introduction' two-day workshop as part of the SEG conference in September 2021, Whistler, Canada. This workshop was well attended and featured geochemical data analysis and machine learning experts from CSIRO Mineral Resources, GoldSpot and RSC Mining and Mineral Exploration.



An image of a large-scale structural analysis in the central Andes completed by CODES PhD student Alex Farrar. It is a regional scale-structural interpretation of the central Andes based on geology, geophysics and field traverses. The fault pattern is a rhomb-shaped mesh that likely formed in response to Palaeozoic and Mesozoic extensional tectonics. Coloured diamonds represent giant porphyry copper deposits, coloured by metallogenic epoch. Red = Paleocene-early Eocene; green = mid Eocene-early Oligocene; yellow = Miocene-Pliocene.

The program team

LEADER MICHAEL ROACH

DEPUTY LEADER MATTHEW CRACKNELL



TEAM MEMBERS:

David Cooke, Anya Reading (Physics)

PHD STUDENTS:

Stephen Cooke, Alex Farrar, Umer Habib, Richard Hill, Stephen Kuhn, Peter Morse, Thomas Ostensen, Thomas Schaap, Tobias Stål (CODES/IMAS)

HONOURS STUDENTS:

Dina Chu, Zak Weidinger

COLLABORATORS:

CSIRO OCEANS AND ATMOSPHERE FLAGSHIP

Mark Hemer

FIRST QUANTUM MINERALS

Mike Christie

GEOLOGICAL SURVEY OF SOUTH AUSTRALIA

Kate Robertson, Stephan Thiel

GHD

Hugh Tassell, Wei Xuen Heng

GOLDSPOT

Shawn Hood

GRANGE RESOURCES

Gilbert Charles

INSTITUTE OF MARINE AND ANTARCTIC STUDIES (IMAS)

Jacqueline Halpin, Joanne Whittaker

INSTITUTE OF MINE SEISMOLOGY

Gerrit Olivier, Brian Salmon

KIRKLAND LAKE GOLD

Meg Ellis

MINERAL RESOURCES TASMANIA

Daniel Bombardieri, Mark Duffett, Carol Steyn, Clint Siggins

MITRE GEOPHYSICS

John Bishop

RSC MINING & MINERAL EXPLORATION

Michael Gazley

UNIVERSIDAD AUSTRAL DE CHILE, CHILE

José Picquer

UNIVERSITY OF SOUTH AUSTRALIA David Giles, Tom Raimondo

WESTERN MINING SERVICES

Jon Hronsky

Projects

Integrating geology and geophysics for resources targeting

Geological visualisation and virtual education

Exploring the East Tennant region, Northern Territory

Machine learning and data integration for mineral exploration

Project summaries

INTEGRATING GEOLOGY AND GEOPHYSICS FOR RESOURCES TARGETING

Leader: Matthew Cracknell

Team member: David Cooke

Student: Alex Farrar

Collaborators: Mike Christie, Jon Hronsky, José Piquer

CODES PhD student Alex Farrar, generously supported by First Quantum Minerals, aims to investigate the mysteries surrounding geodynamic and structural controls, in particular the

presence of trans-lithospheric faults (TLF), 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 2021, Alex finalised his TLF interpretations with a related paper in review with *Economic Geology*. He has constructed a number of GPlates



CODES Honours student Dina Chu undertaking Pine Creek drill core sample selection at Kirkland Lake Gold's Union Reef core shed, Northern Territory, during 2021.

models of the western margin of South America that are based on existing tectonic models. Outputs from these models, such as timing, location orientation and magnitude of compression and extension along the Peru–Chile Trench, are being combined with independent geochemical and chronological data as a means to assess model ‘usefulness’. In the coming year, Alex will use his new data analytics skills to combine tectonic and TLF models with other data to generate a porphyry Cu deposit model.

GEOLOGICAL VISUALISATION AND VIRTUAL EDUCATION

Leader: Michael Roach

In 2021 the focus of geological visualisation and virtual education was again motivated by the COVID pandemic and focused on the generation of educational material for use in undergraduate and postgraduate teaching programs and also professional education. During 2021 over 500 samples were digitised 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).

A series of virtual tours documenting Tasmania's diverse geology were produced for the Australian Earth Sciences Convention (AESC) that was

originally scheduled to be held in Hobart but which was run as a virtual event. The AESC tours were generated in close collaboration with staff from Mineral Resources Tasmania. The AESC virtual tours can be accessed from: <https://www.ausgeol.org/assets/media/uploads/tours/AESC/index.html>.

A highlight of the visualisation and virtual education program in 2021 was production of a highly detailed virtual tour of the Dolphin tungsten mine on King Island that integrated geological visualisations with a wide range of geochemical and mineralogical data. The tour was produced with significant input from Dr Lejun Zhang who provided microprobe, MLA and laser data. The Dolphin mine tour was specifically developed for use in the new Master of Economic Geology ‘Fundamentals of Economic Geology’ short course.

EXPLORING THE EAST TENNANT REGION, NORTHERN TERRITORY

Leader: Rob Scott

Team members: Matthew Cracknell, Michael Roach

Student: Richard Hill

Collaborator: David Giles

CODES PhD student Richard Hill, supported by MinEx CRC, Strategic Energy Resources, Inca Minerals,

Encounter Resources, Middle Island Resources and Datacode, is combining traditional geological and geophysical methods with data analytics and machine learning to understand the tectonic history and mineral potential of the East Tennant region of the NT. The East Tennant is an area of cover-obscured Proterozoic basement lying between the Tennant Creek mineral province in the NT and the Mount Isa mineral province in far NW Queensland. Geoscience Australia's ‘Exploring for the Future’ program identified crustal scale features in the area favourable for mineral systems, resulting in the follow-up collection of geophysical data and, in 2020, a ten-hole stratigraphic drilling program, run as a part of MinEx CRC's ‘National Drilling Initiative’. Richard's work will focus on utilising the recently collected drilling and geophysical data sets, and a range of other data sets (including those of sponsor companies) to unravel the crustal architecture and tectonic evolution of this poorly understood region. To understand the 4D evolution of the area, 3D geological models will be made, consistent with the geophysical data and constrained by observations from drill holes. Structural/kinematic analysis will be performed, along with geochronology and thermochronology to provide a temporal framework. A geodata analysis approach will then be used to identify areas of high potential for mineral systems identified as being likely present in the area.



Dr Michael Roach in the field at Rossarden in northeast Tasmania collecting data for production of a virtual field trip for first-year geology students.



CODES Honours student Zak Weidinger examining acid mine drainage in a seep at the Royal George tailings repository during his August 2021 fieldwork.

MACHINE LEARNING AND DATA INTEGRATION FOR MINERAL EXPLORATION

Leader: Matthew Cracknell

Collaborators: Michael Gazley, Shawn Hood

Dr Matthew Cracknell has been working closely with geochemist Dr Michael Gazley and former CODES PhD student Dr Shawn Hood in the development of geoscience products with machine learning tools that can be



CODES PhD student Alex Farrar conducting field mapping near George Town in Tasmania.

used as new layers of information for mineral exploration modelling. In 2021, the team published in the *Ore Geology Reviews* special issue ‘Recent Advances in Machine Learning for Geological Applications To Mineral Systems and Mine Scale Data’. The paper, titled ‘Soil-sample geochemistry normalised by class membership from machine-learned clusters of satellite and geophysics data’, summarised unsupervised learning for regolith domain modelling and supervised learning for bedrock classification. These machine learning products were

the starting point for normalising soil geochemical data to highlight Cu and Au anomalies. This information was used to identify mineral exploration targets in a remote region of southeast Eritrea. This research team, in collaboration with the CSIRO Mineral Resources group, continues to run entry-level workshops for geologists wanting to gain an understanding of the potential for machine learning to guide mineral exploration.

Looking forward

In late 2021 we welcomed new CODES PhD student Stephen Cooke, who will start his research in 2022 and will join the Amira P1249 team working on the new project ‘Exploring, characterising, and optimising complex orebodies – Upscaling orebody knowledge to add value across the mining value chain’. Stephen's project will focus on the development of new algorithms and software for mineralisation vectoring and

magmatic/hydrothermal geochemical modelling. Dr Matthew Cracknell will be heavily involved in this new project.

Dr Matthew Cracknell will coordinate another offering of the Master of Economic Geology short course ‘Geodata Analytics’ in Semester 2, 2022. We wish him luck as the cap on student numbers has been lifted.

Dr Matthew Cracknell plans to co-present in the ‘Machine Learning for Geologists’ workshop as part of SGA 2022 Rotorua, New Zealand.

A suitable applicant will be sought in 2022 by Dr Matthew Cracknell and adjuncts Dr Gerrit Olivier (Institute of Mine Seismology) and Dr Daniel Bombardieri (MRT) for a new PhD project entitled ‘3D geological and geophysical modelling’.

We look forward to highlighting the great work from our research students as they gain insight and make discoveries that will transform the way geophysicists and geoscientists process, analysis and interpret digital data.

TMVC: The ARC Research Hub for Transforming the Mining Value Chain

Objectives

The Australian Research Council Research Hub for Transforming the Mining Value Chain (TMVC) aims to resolve some of the greatest challenges currently facing the minerals industry, by improving efficiencies along the entire mining value chain. Its principal objectives are to:

- Achieve real-time automated acquisition and interpretation of detailed mineralogical, textural and geochemical data in mine site core sheds that can be used immediately for 3D-modelling of geometallurgical and geoenvironmental parameters and ore zone footprints.
- Move the mining industry from the data-rich, but comparatively knowledge-poor, environment it currently works in, to a data-rich, knowledge-rich environment that allows for rapid decision making during the exploration and development phases of mining operations.

- Develop tools and protocols that allow near-instantaneous identification of proximity to ore zones, together with geometallurgical and geoenvironmental characterisation of ores and waste through automated core logging and spectral analyses of drill core. This will enable 3D exploration, mining and geometallurgy models to be developed that are continually updated as the exploration or resource drilling program continues.

Introduction

The ARC Research Hub for Transforming the Mining Value Chain (TMVC) encompasses a wide array of activities from exploration, discovery, ore deposit characterisation and environmental assessment, through to mining, ore processing and waste rock disposal. It sets out to improve efficiencies within this value chain, focusing on areas that will have a marked impact on the value of Australia's mineral resources. By helping to develop more efficient and environmentally sustainable practices throughout the mining value chain, it is anticipated that the TMVC's research outcomes will extend the lives of mines and create employment opportunities across Australia's regional mining centres.

The TMVC provides substantial benefits for the minerals industry through advanced mineral characterisation methods, and innovative technologies for their implementation, which can be applied much earlier in the mining value chain. This enhances decision making and maximises productivity and profitability at Australian mine sites.

The TMVC is housed within CODES at the University of Tasmania (UTAS) – the Administering Organisation. In addition to CODES, the industry partners involved in the Research Hub include BHP, Corescan, Newcrest Mining, and a consortium of global companies co-ordinated by Amira Global. Other organisations affiliated with the initiative include Laurin Technic and RWTH Aachen University in Germany.

Highlights

2021 saw the official windup of the TMVC mid-year; however, there were still several notable achievements during the year including a series of final reports and meetings for the Amira P1202 project to the sponsors group in June and early July. This project represented the culmination of the TMVC's research over the past six years, bringing together the major research themes of the Hub to deliver industry transformational workflows to the research partners that facilitate exploration, processing and geoenvironmental assessments.

The year also saw the successful completion of Amira project P1206, a pilot study that demonstrated proof of concept with regards to using resistate mineral chemistry in exploration for sediment-hosted Cu deposits in the African Copperbelt. Another achievement, which came out of Annah Moyo's PhD study, was the decision by Mineral Resources Tasmania to apply shells as a cover to an abandoned mine waste facility in Tasmania during 2022.

It was also another productive year for student completions, with the graduation of six students: one PhD, one Masters and four Honours, and thesis submission from a further four: two PhD and two Masters. Our publication outputs included 11 refereed journal articles, eight conference presentations and 75 reports to industry.



Theme 1: Magmatic-hydrothermal transition features in Sn granites of Tasmania. The sources of melt of east coast granites from Freycinet Peninsula to Musselroe Bay were investigated as part of the project by measuring zircon O and Hf isotopes. Dr Evan Orovan is pictured straddling the contact of two different granites at Bicheno.

The TMVC provides substantial benefits for the minerals industry through advanced mineral characterisation methods, and innovative technologies for their implementation, which can be applied much earlier in the mining value chain.



White and green mica alteration halos surrounding quartz-pyrite veins in volcaniclastic breccia from the Resolution porphyry Cu-Mo deposit, Arizona. The Amira P1202 project investigated variations in white mica compositions around Resolution to test its potential for exploration vectoring.

The program team

LEADER DAVID COOKE

DEPUTY LEADER LEONID DANYUSHEVSKY



TEAM MEMBERS:

CODES: Mike Baker, Shaun Barker, Ivan Belousov, Ron Berry, Jonathan Cloutier, Matthew Cracknell, Angela Escolme, Bruce Gemmell, Ross Large, Sebastien Meffre, Clare Miller, Paul Olin, Terrie Sawyer, David Selley, Lejun Zhang

ENGINEERING, UTAS: Danchi Jiang

PHYSICS, UTAS: Anya Reading

Amira Global: Adele Seymon

BHP: Kathy Ehrig

CORESCAN: Neil Goodey

LAURIN TECHNIC: Michael Shelley

NEWCREST MINING: Anthony Harris

RWTH AACHEN UNIVERSITY:
Bernd Lottermoser

PHD STUDENTS:

CODES: Takeshy Coaquira, Colin Jones, Rhiannon Jones, Stephen Kuhn, Javier Merrill, Peter Morse, Annah Moyo, Sibeles Nascimento, Jaime Osorio, Xin Ni Seow, Emily Smyk, Yi Sun, Jennifer Thompson

MONASH UNIVERSITY:
Angela Rodrigues

MASTERS STUDENTS:

CODES: Kim Boundy, Mertkan Bozoglu, Batbayar Enkhbold

LAKEHEAD UNIVERSITY, CANADA:
Patrick Hamilton, Andrew Jedemann, Mitch Marcelissen

HONOURS STUDENTS:

CODES: Erik Fabreschi, Eliza Fisher, Fu Rong Mah, Riley Winter

UNIVERSIDAD AUSTRAL DE CHILE: Reinaldo Gonzalez, Francisco Torres

COLLABORATORS:

AUSTRALIAN NATIONAL UNIVERSITY
Trevor Ireland

COPPER MINES OF TASMANIA
Geoff Cordery

CORESCAN
Ekaterina Savinova

CSIRO
Michael Gazley

CURTIN UNIVERSITY
Fred Jourdan

FIRST QUANTUM MINERALS
Mike Christie, Tim Ireland, Stephanie Sykora, Chris Wijins

GEOSCIENCE AUSTRALIA
Simon Bodorkos

GOLDSPOT DISCOVERIES CORP, CANADA
Shawn Hood

INDEPENDENT
Noel White

IRISH CENTRE FOR RESEARCH IN APPLIED GEOSCIENCES (ICRAG), IRELAND
Murray Hitzman, Sean Johnson

LAKEHEAD UNIVERSITY, CANADA
Peter Hollings

LEPANTO CONSOLIDATED MINING COMPANY
Mervin Delos Santos, Leo Subang

MACQUARIE UNIVERSITY
Elena Belousova

MINERAL MAPPING PTY LTD
Scott Halley

MINERAL RESOURCES TASMANIA
Ralph Bottrill, John Everard, Andrew McNeill, Clint Siggins, Carol Steyn

MONASH UNIVERSITY
Laurent Ailleres, Robin Armit

NORRIS SCIENTIFIC
Ashley Norris

UNITED STATES GEOLOGICAL SURVEY, DENVER, USA
Jay Thompson

UNIVERSIDAD AUSTRAL DE CHILE
José Piquer

UNIVERSITY OF QUEENSLAND
Anita Parbhakar-Fox

UNIVERSITY OF MELBOURNE
Roland Maas

Projects

The TMVC is focused on the country's highest earning precious metal, gold; the base metal, copper; and the main energy metal, uranium. Each of these commodities has its own scientific challenges, which the TMVC is tackling through three principal research themes. In addition, Underpinning Technologies, Knowledge Transfer and Training are essential parts of the TMVC, encompassing all research themes. The full scope of research activities gains considerably from the expertise, state-of-the-art facilities and technological developments within the TMVC, and benefits to end-users are assured through extensive, hands-on technology transfer and training programs.

THEME 1:

DETECTING PROXIMITY TO ORE (FOOTPRINTS)

- Magmatic-hydrothermal transition features in Sn granites of Tasmania
- Far-field and near-mine footprints: Finding and defining the next generation of Tier 1 ore deposits (Amira P1202) – Modules 1–3
- Identifying unique Resistate Indicator Mineral (RIM) chemistry as a guide in prospectivity for sediment-hosted copper mineralisation (Amira P1206)

THEME 2:

OPTIMISING GEOMETALLURGICAL PREDICTION

- Far-field and near-mine footprints: Finding and defining the next generation of Tier 1 ore deposits (Amira P1202) – Module 4

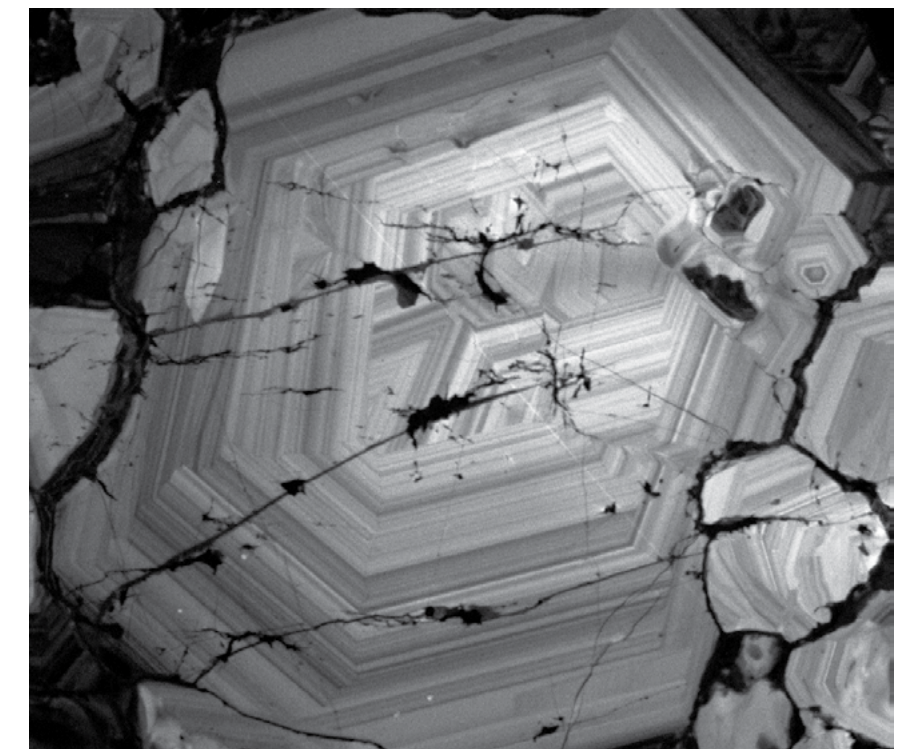
THEME 3:

MINIMISING GEOENVIRONMENTAL RISKS

- Utilising industrial waste materials for AMD control
- Geometallurgy of historic mine waste: Evaluating options for reprocessing

UNDERPINNING TECHNOLOGIES

- Development of the fast-throughput sample cell for laser ablation applications
- Corescan data feature extraction and classification for mineralogical and textural information analysis
- Integrating chemical and mineralogical data layers for element deportment
- Interpreting structural and geochemical patterns using machine learning
- Geological feature discovery from quantitative data integration (algorithm development)
- Method development for laser ablation ICP-MS applied to complex matrices



Quartz cathodoluminescence image showing multiple complex zonations, from a quartz – pyrite vein from the E26 porphyry Cu-Au deposit, New South Wales. This image was obtained by PhD student Rhiannon Jones as part of her work on the Amira P1202 Module 4 project in the TMVC Theme 2: Optimising Geometallurgical Prediction. This imaging is important to reveal growth textures in quartz that can be used to interpret the evolution of hydrothermal fluids over time.

Project summaries

THEME 1: DETECTING PROXIMITY TO ORE (FOOTPRINTS)

MAGMATIC-HYDROTHERMAL TRANSITION FEATURES IN SN GRANITES OF TASMANIA

Leaders: Sebastien Meffre, Evan Orovan, David Cooke

Team member: Ivan Belousov

Student: Colin Jones

Collaborators: Elena Belousova, Simon Bodorkos, Ralph Bottrill, John Everard, Trevor Ireland, Fred Jourdan, Roland Maas, Andrew McNeill, Jay Thompson

This project is focused on aspects of Devonian granites in Tasmania, including how they relate to mineralisation. Petrogenetic questions involving the genesis of I- and S-type granites, pluton construction, and the magmatic-hydrothermal transition are being addressed. In 2021, Colin Jones completed data acquisition and drafted three manuscripts as part of the third year of his PhD candidature. These manuscripts are titled:

- Zircon O and Lu-Hf isotope evidence of mantle and supracrustal origins of Tasmanian Devonian granites
- Genesis of the Early Devonian Haleys New Country mafic and metamorphic complex, eastern Tasmania
- Petrogenetic information from quartz oxygen isotope and titanium concentrations in Tasmanian Devonian granites

FAR-FIELD AND NEAR-MINE FOOTPRINTS: FINDING AND DEFINING THE NEXT GENERATION OF TIER 1 ORE DEPOSITS (AMIRA P1202) – MODULES 1–3

Leaders: Mike Baker, Shaun Barker, David Cooke, Leonid Danyushevsky, Angela Escolme, Lejun Zhang

Team members: Ivan Belousov, Matthew Cracknell, Sebastien Meffre

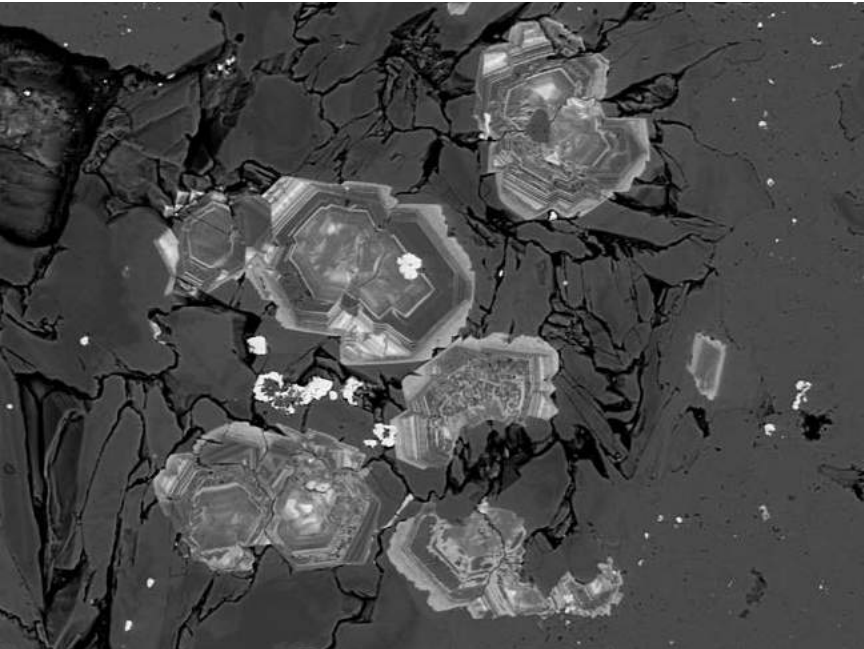
Students: Batbayar Enkhbold, Reinaldo Gonzalez, Patrick Hamilton, Andrew Jedemann, Mitch Marcelissen, Xin Ni Seow, Emily Smyk, Yi Sun, Francisco Torres

Collaborators: Peter Hollings, José Piquer, Mervin Delos Santos, Leo Subang, Noel White

Amira P1202 was conducted by a large team of researchers including 12 UTAS staff, six collaborators and 17 students (PhD, Masters and Honours) from four academic institutions (UTAS, Monash University, Lakehead University and Universidad Austral de Chile). Over the course of the project, researchers worked on 28 sites across five continents to further our geological understanding and develop tools for explorers and miners. Building upon the results of the Amira P1153 project, this multi-year project developed new methods for discovering porphyry and/or epithermal deposits through improved geochemical detection of far-field and near-mine ore deposit footprints. Analysis of the geochemical signals recorded in hydrothermal alteration halos will provide explorers with methods for assessing district fertility (how large?), vectoring information (how far, and in what direction?), as well as developing workflows for ore body characterisation in the near-mine environment. This will facilitate the presence, location and significance of porphyry and/or epithermal copper, gold and molybdenum deposits in an exploration tenement to be determined during the early stages of exploration. This approach has relevance to exploration

involving drilling under post-mineralisation cover, or in areas where outcrop is limited or difficult to access. The project was split into four research Modules. Modules 1–3 of the project focus on three key alteration domains within the porphyry-epithermal system. These include the green rock and lithocap environments, and aspects of magmatic fertility. Module 4 was an optional module that explored the complex overprinting alteration relationships of white micas and clays in the ‘transition zone’ of porphyry-epithermal systems. The main research outcomes will be the development of geochemical tools for testing the fertility of mineral districts, tools for vectoring to mineralised centres and depth assessments in lithocap environments. This will involve the use and analysis of key alteration minerals from green rock, white rock and lithocap environments. Cost-effective field-based methods will also be developed that can be applied by explorers who do not have access to suitable laboratory facilities for LA-ICP-MS analyses.

The project was concluded in mid-2021 through a series of successful final reports and meetings that were held online and in-person at CODES. Leading into the final meeting, a blind test study was also successfully completed on the Coffee district gold deposits and prospects in west-central Yukon, Canada. Several sub-projects within P1202 involved postgraduate students. Xin Ni Seow, Emily Smyk and Yi Sun continued their PhD studies on alunite and APS mineral chemistry, the Christmas porphyry Cu-Mo deposit (USA) and Lepanto district (Philippines), respectively. Patrick Hamilton (Lakehead University) continued his MSc study of the Pemberton Hills deposit lithocap (Canada). Mitch Marcelissen, also at Lakehead University, continued his MSc project on magma fertility in the Sunda-Banda Arc, Indonesia. The Honours projects of Reinaldo Gonzalez (Santa Marta lithocap, Chile) and Francisco Torres (Tibetano prospect, Chile) also continued at Universidad Austral de Chile. In 2021, Batbayar Enkhbold and Andrew Jedemann (Lakehead University) completed their MSc studies of green rock alteration and mineral



A backscattered electron (BSE) image of zoned aluminium phosphate-sulfate (APS) minerals from Peru. Recent studies revealed that APS minerals have been overlooked in porphyry and lithocap exploration and they provide important vectoring information and insights into fluid chemistry. This microanalytical work was carried out by PhD student Xin Ni Seow, whose research comes under the TMVC’s P1202 (Modules 1–3) project.

chemistry at the Mt Isa deposit and Pemberton Hills deposit, respectively.

The P1202 research project delivered new methods, tools and workflows that are now being applied by the industry partners in their exploration programs and mining operations. It has led to increased industry engagement with CODES Analytical Laboratories for provision of high-quality mineral chemistry data via the LA-ICP-MS technique that are being used to test exploration targets domestically and internationally. The software program LocatOre is now being used by industry partners to visualise and interpret their geochemical datasets, and the first version of this software has begun to be rolled out to the broader academic, industry and government communities through a series of training workshops. The success of the P1202 project has generated several exciting new and follow-up research initiatives that will form a new Amira project (P1249) that will commence in early 2022.

IDENTIFYING UNIQUE RESISTATE INDICATOR MINERAL (RIM) CHEMISTRY AS A GUIDE IN PROSPECTIVITY FOR SEDIMENT-HOSTED COPPER MINERALISATION (AMIRA P1206)

Leader: Shaun Barker

Team members: David Cooke, Leonid Danyushevsky, David Selley

Collaborators: Murray Hitzman, Sean Johnson

This one-year project began in late 2019, and was designed to provide a rapid assessment of whether the chemistry of resistate mineral phases (apatite, rutile and tourmaline) formed during the hydrothermal alteration associated with sediment-hosted copper mineralisation can be used to provide information on proximity to ore, and the fertility of the aquifer systems responsible for copper mineralisation. The project was supported by Anglo American; First Quantum Minerals; Independence Group; the Japan Oil, Gas and Metals National Corporation (JOGMEC); and Rio Tinto, and utilised the world-leading expertise of the

CODES Analytical Laboratories laser ablation ICP-MS instrumentation and University of Tasmania CSL MLA instrument to provide a quantitative, detailed assessment of the paragenesis and mineral chemistry of samples that were analysed from throughout the Central African Copper Belt. The final report for the project was delivered to the sponsors group in May, and contained results from a series of samples from across the Central African Copper Belt reporting on apatite and rutile textures, mineral associations and compositions associated with alteration.

THEME 2: OPTIMISING GEOMETALLURGICAL PREDICTION

FAR-FIELD AND NEAR-MINE FOOTPRINTS: FINDING AND DEFINING THE NEXT GENERATION OF TIER 1 ORE DEPOSITS (AMIRA P1202) – MODULE 4

Leaders: Angela Escolme, David Cooke

Team members: Mike Baker, Shaun Barker, Ivan Belousov, Jonathan Cloutier, Matthew Cracknell, Leonid Danyushevsky, Sebastien Meffre, Lejun Zhang

Students: Mertkan Bozoglu, Takeshy Coaquira, Rhiannon Jones, Javier Merrill, Jaime Osorio, Angela Rodrigues

Collaborators: Laurent Ailleres, Robin Armit, Scott Halley, José Piquer

Details of the overall Amira P1202 project are outlined in the TMVC Theme 1 section of this annual report. The optional research module of P1202 (Module 4) is reported here in the Geometallurgy Theme, as it is the major geometallurgical research activity being conducted in the TMVC from year 4 onwards. P1202 had six sponsors of Module 4 (BHP, FMG, Merdeka, Newcrest, Rio Tinto and Northparkes) with Rio Tinto and Northparkes joining the project in 2019. The Module 4 research initiative involves both near-mine exploration



Kinetic leach test columns from Annah Moyo's PhD study, where industrial wastes were trialled as covers for mine wastes over a period of 100 weeks. Each column was subjected to wetting and heating cycles and water quality was monitored weekly to assess the effectiveness of the industrial waste covers in managing water quality.

vectoring and geometallurgical assessments of the porphyry transition zone, where clay and mica alteration overprint early formed potassic alteration. The research team worked closely with Corescan at Module 4 sites to optimise mineralogical characterisation of the transition zone for exploration, evaluation and mining.

In 2021, P1202 Module 4 concluded with two final sponsors review meetings held in June and July. These meetings involved the presentation of final outcomes for key project objectives, including algorithms for textural classification of hyperspectral imagery, and new white micas mineral chemistry data sets and exploration tools. Calculated mineralogy methods of domaining mineralogy in complex orebodies were rolled out to industry partners through METS sector partner Mineral Mapping, who are now routinely modelling orebodies for mining companies using this method. New methods for interpreting textural features from visual and hyperspectral images have now been published and are being applied at several mining and exploration projects by industry partners and are being incorporated

into workflows by METS sector partner CoreScan. Several P1202 Module 4 student projects continued through 2021, including the PhD studies of Rhiannon Jones (Spatial variations and geological controls on white mica compositions at the E26 deposit, Northparkes, NSW), Jaime Osorio (Rincones de Araya prospect, Argentina and Valeriano porphyry-HS Cu-Au deposit, Chile), Javier Merrill (Identification and characterisation of geological domains for geometallurgical and geoenvironmental modelling), Takeshy Coaquira (White mica and clay alteration in the Resolution porphyry Cu-Mo deposit, Arizona) and Angela Afonso-Rodrigues at Monash University (Automated mineral and textural extraction from hyperspectral data). In addition, Mertkan Bozoglu completed his Master of Economic Geology project on the geological characterisation of the E20 deposit, Northparkes. The P1202 Module 4 PhD student projects are all continuing into 2022 and will be rolled into the new Amira P1249 project commencing in early 2022.

THEME 3: MINIMISING GEOENVIRONMENTAL RISKS

UTILISING INDUSTRIAL WASTE MATERIALS FOR AMD CONTROL

Leader: David Cooke

Team members: Sebastien Meffre, Clare Miller

Student: Annah Moyo

Collaborators: Anita Parbhakar-Fox, Clint Siggins, Carol Steyn, Geoff Cordery

Cost-effective waste management of materials producing acid and metalliferous drainage (AMD) is essential for successful remediation. Considering this, using alkaline waste materials generated by other industrial processes represents a potential option for managing acid-forming mine wastes and is the focus of this sub-project being undertaken by PhD student Annah Moyo. The long-term kinetic leach tests ended after 100 weeks of

experiments in late 2021, bringing the data acquisition phase of this project to a successful completion. The only remaining tasks are writing and revising thesis chapters, with thesis submission on track to be completed in mid-2022. The successful outcomes of these experiments led Mineral Resources Tasmania to decide to apply shells as a cover to an abandoned mine waste facility in Tasmania in 2022.

GEOMETALLURGY OF HISTORIC MINE WASTE: EVALUATING OPTIONS FOR REPROCESSING

Leader: Matthew Cracknell

Team members: David Cooke, Clare Miller

Student: Sibeles Nascimento

Collaborator: Anita Parbhakar-Fox

Strategic mine waste planning has only been actively pursued in the past decades, with historical mining operations having used inappropriate disposal methods by today's environmental standards. This can result in environmental degradation to downstream catchments. One such example is the King River delta/Macquarie Harbour, western Tasmania, and is the focus of this project. Approximately 100 Mt of mine tailings and slag materials have been discharged into the Queen and King rivers from the Mount Lyell copper mine, Queenstown, since the 1890s. Furthermore, the 2.5 km² King River delta contains approximately 10 Mt of mine tailings, with a further 10 Mt of fine tailings deposited beyond it. Whilst the tailings properties and the geochemistry of Macquarie Harbour have been documented, the sulfide chemistry of individual minerals (i.e., pyrite) has yet to be detailed at the micro-scale. This research project aims to mineralogically and geochemically characterise tailings and slag materials in the riverine and deltaic systems and establish if reprocessing of these

materials is an environmentally and economically viable rehabilitation option.

While PhD student Sibeles Nascimento's progress was slowed due to COVID-19 travel restrictions, she submitted a manuscript in 2021 detailing water chemistry analysis of the King and Queen river systems, which is under review, and has also completed a draft manuscript documenting geochemical and mineralogical analysis of the King River delta anthropogenic sediments. She is currently working on a third manuscript that investigates critical metal (Ni, Co and Cu) deportment in secondary mineral precipitates within deltaic sediments using SEM and LA-ICP-MS mapping. Sibeles plans to return to Hobart early in 2022 to complete her thesis and submit by the end of the year.

UNDERPINNING TECHNOLOGIES

DEVELOPMENT OF THE FAST-THROUGHPUT SAMPLE CELL FOR LASER ABLATION APPLICATIONS

Leaders: Leonid Danyushevsky, Michael Shelley

Team members: Ivan Belousov, Paul Olin

Collaborator: Ashley Norris

This project aims to develop a new sample cell capable of high-throughput applications using laser ablation instruments, which may involve LA-ICP-MS and/or LIBS. The instrumentation developed would be used for the scanning of large sections of drill half-core. Stages within this project include prototype development and performance testing. Due to COVID-19 related delays, fast imaging using the synchronisation device will continue into 2022.

Further developments in this space will be reported under Program 5.

CORESCAN DATA FEATURE EXTRACTION AND CLASSIFICATION FOR MINERALOGICAL AND TEXTURAL INFORMATION ANALYSIS

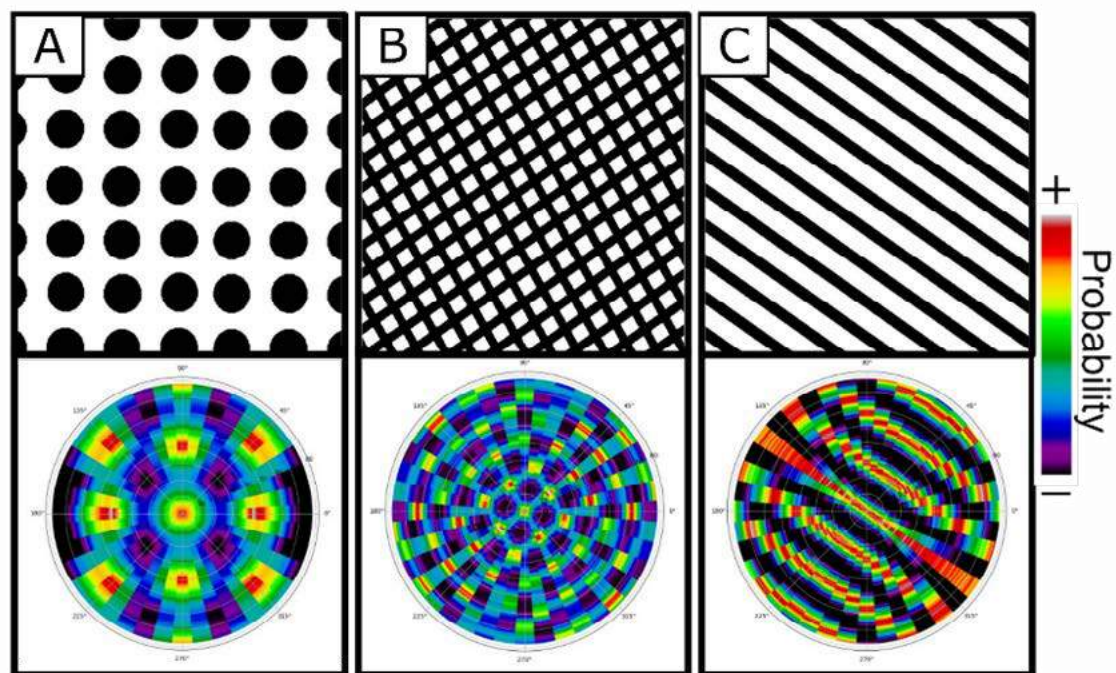
Leader: Matthew Cracknell

Team members: Ron Berry, Leonid Danyushevsky, Neil Goodey, Anthony Harris, Anya Reading

Students: Javier Merrill, Angela Rodrigues

Collaborators: Laurent Ailleres, Robin Armit, Ekaterina Savinova

Corescan generates a range of drill core image products including Digital Surface Models (DSM), Red-Green-Blue (RGB) colour photographs and Visible-Near Infrared-Short Wave-Infrared (VNIR-SWIR)-derived mineral interpretations. Despite the rich geological information implicitly contained within these data, they are primarily used to provide percentages of identified minerals down hole to Corescan customers. The aim of this project is to classify and extract mineralogical and textural features from Corescan imagery, adding value to their data products. For example, the two-dimensional imagery generated by Corescan contains information on the geometric characteristics and spatial arrangement of interpreted minerals, while there are key economic mineral species, such as sulfides, that do not have characteristic absorption features in VNIR-SWIR spectra and are therefore not identified accurately. In 2021, PhD candidates Javier Merrill (CODES) and Angela Rodrigues (Monash) continued with their PhD projects, which are embedded within Amira P1202 Module 4. Javier finalised deployed his mineral texture clustering algorithm on several kilometres of drill core imagery from two porphyry Cu deposits. This algorithm uses Corescan mineral maps to automatically identify drill core with similar mineral textures and is being shown to enhance the prediction of geometallurgical parameters such as Cu recovery and rock hardness. A manuscript on this ground-breaking research is in the final



PhD student Javier Merrill Cifuentes has developed the Mineral Co-Occurrence Probability Field (MCOPF) textural feature extraction method. From drill core imagery, MCOPF outputs are used to generate mineral texture domains that have been shown to improve the prediction of geometallurgical properties. This diagram shows a range of synthetic image textures and their respective MCOPF polar representation for the black-black pair. This research will be published in an upcoming issue of Minerals Engineering.

stages of peer review. Angela has developed a Deep Learning system for classifying minerals from drill core hyperspectral imagery and Bayesian inference methods for predicting mineral compositions from assay data. Angela submitted her thesis at the end of 2021.

INTEGRATING CHEMICAL AND MINERALOGICAL DATA LAYERS FOR ELEMENT DEPARTMENT

Leaders: Sebastien Meffre, Matthew Cracknell, Leonid Danyushevsky, Ivan Belousov, Lejun Zhang

Team members: Ron Berry, Angela Escolme, Paul Olin

This project aims to integrate mineralogical and chemical data from various spectral and analytical techniques to extract information on element deportment, mineral chemistry, mineral association and other mineral-based information, such as the ability to automatically recognise mineral inclusions, gold in solid solution, and gold in particles. Further progress on this project including work

with Dr Matthew Cracknell on the automatic identification and characterisation of inclusions from LA-ICP-MS data is progressing with new capability in the LADR data reduction software to become available in 2022. This project plans to recruit a PhD student in 2022 to enhance LA-ICP-MS signal analysis for mineral identification and inclusion characterisation.

INTERPRETING STRUCTURAL AND GEOCHEMICAL PATTERNS USING MACHINE LEARNING

Leaders: Anya Reading, Matthew Cracknell

Collaborators: Michael Gazley, Shawn Hood

Although Shawn Hood submitted his PhD thesis titled 'Machine-assisted modelling of lithology and metasomatism' in 2019, his research outcomes continue to impact minerals exploration. In 2021, Shawn Hood, Matthew Cracknell and Michael Gazley published an article for a special edition of *Ore Geology Reviews* on the practical use of machine learning in the

minerals industry. In this contribution, the use of machine learning data products, namely a clustering-derived regolith map and classification-derived bedrock map, are used to level soil geochemical data to highlight porphyry-related Au and Cu anomalies.

Shawn Hood, Matthew Cracknell and Michael Gazley continue to run workshops, in conjunction with the CSIRO Mineral Discovery team that introduce geochemical data analysis and machine learning methods to exploration geologists. Workshops were held online in February for AESC2021 and in September for SEG2021.

GEOLOGICAL FEATURE DISCOVERY FROM QUANTITATIVE DATA INTEGRATION (ALGORITHM DEVELOPMENT)

Leaders: Anya Reading, Matthew Cracknell

Students: Stephen Kuhn, Peter Morse

Collaborators: Mike Christie, Tim Ireland, Stephanie Sykora, Chris Wijins



Dr Ivan Belousov is involved with the 'Development of the fast-throughput sample cell for laser ablation application' project in the TMVC Underpinning Technologies area. Here he is pictured with an Agilent mass spectrometer used for LA-ICP-MS analyses.

This project was finalised in 2020; however, Professor Anya Reading convened a session at the Australian Earth Sciences Convention (early 2021) that focused on 'Data-driven and computational methods to reveal hidden or changing surfaces, volumes and environments'. The session attracted a good number of quality contributions, and confirms the high interest in geodata analytics going forward.

METHOD DEVELOPMENT FOR LASER-ABLATION ICPMS APPLIED TO COMPLEX MATRICES

Leader: Leonid Danyushevsky

Team members: Paul Olin, Terrie Sawyer

Student: Xin Ni Seow

This project aims to develop quantitative methods, including full uncertainty budgets, for analysis of a range of mineral matrices, and covering a wide range of major and trace elements. The successful outcome of this project would allow performing quantitative LA-ICP-MS analyses

without a requirement for data on mineral major element contents obtained by a different analytical technique. COVID-19-related issues have continued to affect the progress of this project. Methods for plagioclase and apatite have not yet been finalised. A method for analyses of white mica has been developed and tested. A publication of the alunite method is planned for 2022.

Knowledge transfer and training

Knowledge transfer and training were an integral part of the TMVC, encompassing all research themes and impacting all parts of the mining value chain. During the final year of the TMVC staff and students produced 11 refereed journal articles, provided 75 reports to industry, and delivered eight conference presentations.

Looking forward

With the TMVC officially ended, any remaining student project updates and completions, as well as other research outputs in the form of journal publications and conference-related activities, will be reported through the CODES Programs.

Training and education



LEADERS REBECCA CAREY, MATTHEW CRACKNELL AND ROBERT SCOTT

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 of Research), Master of 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 details about these short courses and workshops).

This year Dr Matthew Cracknell joined Associate Professor Rebecca Carey as joint Graduate Research Co-ordinators, while Dr Robert Scott remains the Master of Economic Geology Program Co-ordinator.



Participants on the new Advanced Field Skills in Economic Geology Master of Economic Geology short course that ran in February 2021 are pictured here at Beechford on the north coast of Tasmania after a day's intensive learning in the field.

Highlights

Congratulations to PhD students Chris Leslie, Stephen Kuhn, Peter Morse, Thomas Ostensen, Tobias Stål and Jay Thompson who graduated in 2021; several of these graduates have gone on to positions in industry, and Tobias Stål is presently an ARC-funded research fellow in Antarctic seismology at UTAS and working on statistical and multivariate methods to understand ice-bedrock interaction, the tectonic architecture of Antarctica, and global heat flow distribution.

This year has also seen the submission of four PhD theses for external examination. Well done to Robert Davidson, Joe Knight, Tom Schaap and Jen Thompson, who have worked tirelessly in adverse conditions during COVID. A further highlight for 2021 was the return of a lively and supportive PhD student cohort to campus in addition to their virtual appearances via Zoom. There have been lots of social activities and many instances where we have seen student leadership and support of one another – so thank you PhD students.

The PhD student cohort has reduced in size over the past couple of years,

due both to a large number of completions and the impacts of COVID, restricting the arrival of new students into Tasmania. In 2021 we welcomed four new students from around the world to CODES. There is an uptick of interest from prospective students as we live with COVID and the reopening of borders and greater alignment between university and government policies, so hopefully 2022 delivers more PhD students to CODES to sustain our vibrant postgraduate community.

The Master of Economic Geology (MEconGeol) program experienced substantial growth in student numbers in 2021, and a total of six short courses were delivered instead of the usual three. Two of these – Advanced Field Skills in Economic Geology and Fundamentals of Economic Geology – were new offerings, and both were very well received. A record number of MEconGeol students – 16 in all – graduated or completed their degrees during the year. COVID-19 again provided some challenges for fieldwork aspects of the short courses. Only seven Tasmanian-based students could attend the Advanced Field Skills in Economic Geology course, which

A further highlight for 2021 was the return of a lively and supportive PhD student cohort to campus...

ran in February. With state borders slowly reopening, a larger number of students were able to attend a greatly modified version of the Ores in Magmatic Arcs short course in November (a week in the field in western Tasmania, and a week of lectures and practical exercises at CODES). However, the re-opening of international borders and return of quarantine-free travel is needed before delivery of the field-based short courses can get back to normal

Fewer students were enrolled in the Honours program in 2021 – four completed their studies during the year, with a fifth part-time student expected to graduate in 2022. The upturn in the mining industry has drawn geology students away from completing an Honours year, but we hope to see a return to higher numbers in the future.

Postgraduate programs

CODES has 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 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 67% 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 2021, 36 + XXX graduating students were enrolled in research at PhD or Masters level. We welcomed Shannon Frey (Canada), Acacia Clark (Australia), Richard Hill (Australia), and Stephen Cooke (Australia). We wish them all the best for their PhD studies.

COVID-19 continues to impact all of us but a special shout out for the resilience of the higher degree research student cohort – 2021 was another challenging COVID year impacted by restrictions including travel to field sites and for students to travel and spend time with family and friends overseas. We continue to strongly support all our students in fulfilling their PhD research aims and goals.



Shore thing: Master of Economic Geology student Carl Jackman inspecting a quartz vein array in the multiply deformed Ordovician Stony Head Sandstone at Beechford on the north coast of Tasmania. Beechford was visited during the Advanced Field Skills in Economic Geology Masters short course.

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.

2021 was another busy and successful year for the Master of Economic Geology (MEconGeol) program. Twenty-two new students and two re-admissions raised the total number of students in the program to 84, easily eclipsing the previous record of 65 students set in 2020. For the first time, CODES delivered six short courses in a

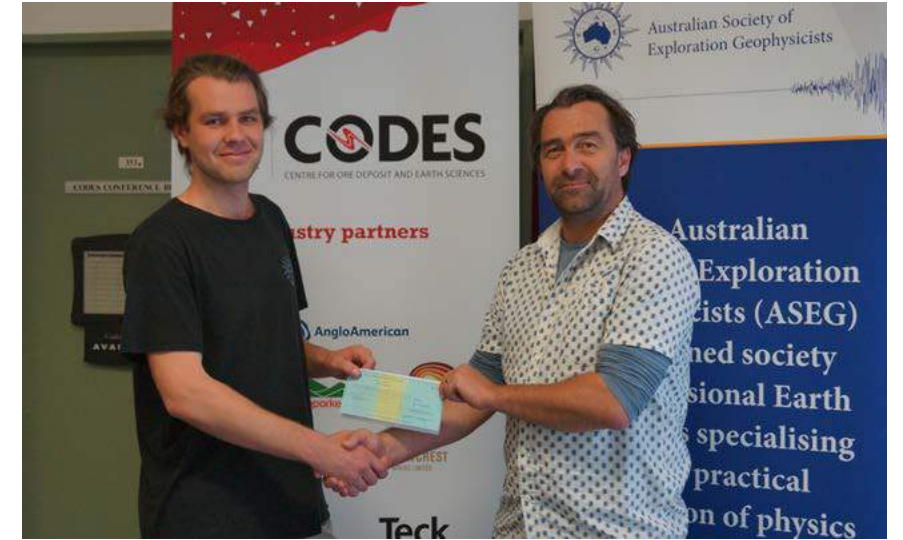
year, beginning with a new field-based unit, Advanced Field Skills in Economic Geology, in February. Unfortunately, border closures at that time restricted attendance to just seven Tasmanian-based participants. Ore Deposit Geochemistry, Hydrology and Geochronology (82 participants, including 19 Masters students); Geometallurgy (23 participants, including seven Masters students); Geodata Analytics (21 participants, including six Masters students) and another new unit, Fundamentals of Economic Geology (61 participants, including 23 Masters students) were all delivered online. Three courses – Geometallurgy, Fundamentals and Ore Deposit Geochemistry – were delivered in two, week-long intensive blocks, three to four weeks apart, while Geodata Analytics was split into three blocks with two longer self-paced modules and a one-week, live, intensive teaching block in between. The final Masters unit for the year was another in-person, largely field-based

short course: Ores in Magmatic Arcs (36 participants, including five Masters students). Ores in Magmatic Arcs is normally taught in either Indonesia or South America, but due to special circumstances in 2021, it was delivered in Tasmania, where it involved a six-day field trip to western Tasmania followed by five days of lectures and practical classes in Hobart. A record number of students (16) either graduated or completed their degrees in 2021. Chris Booth, Jimmy Carranza Meza, Carlos Diaz Castro, Batbayar 'Baggy' Enkhbold, Daniel Foulds, Corey Jago, Sitthithon 'Gun' Kultaksayos, George Maroa, Hugo Rios Mansilla, Markus Staubmann and Victor Torres Pacheco all graduated, while Mertkan Bozoglu, Glen Cathers, Kyle Hodges, Pascal Kabilo and Alister Orton completed their degrees and will graduate in 2022.

Summaries of the six UTAS-based Masters short courses held during 2021 follow:

ADVANCED FIELD SKILLS IN ECONOMIC GEOLOGY 7–20 FEBRUARY 2021

This short course was a new addition to the Master of Economic Geology degree in 2021 and is aimed at industry professionals as well as those already enrolled in the degree. A snap lockdown in Perth prevented five WA-based registrants from attending. However, the remaining seven participants were treated to excellent weather for the inaugural delivery of the course, taught in various locations on the west, northeast and east coasts of Tasmania. The course provides instruction and training in fundamental and advanced mapping and field skills suitable for use in the minerals industry. These include field-based rock and mineral identification, fact mapping, form surface mapping and digital mapping techniques, 'Anaconda-style' mapping, structural measurement and graphic logging techniques and the use of spectral, geochemical and remote sensing data sets in making and interpreting geological maps. CODES hopes to be able to offer this course annually in coming years.



TOP: Dr Matthew Crackell (right) presents CODES Honours student Zak Weidinger with a cheque for \$5,000 from the Australian Society of Exploration Geophysicists; Zak was the inaugural winner of the newly created Richard Lane Scholarship in 2021 and gained the scholarship for his project entitled 'Geophysical investigation of the Royal George tailings repository, northeast Tasmania'.

ABOVE: CODES Honours students concentrate hard during the Exploration Field Skills Mapping Camp in February 2021. Here they are collecting structural data in the Hall Rivulet Canal, western Tasmania.

GEODATA ANALYTICS 8 FEBRUARY–19 MARCH 2021 AND 22–27 MARCH 2021 AND 29 MARCH–16 APRIL 2021

The 2021 offering of Geodata Analytics, as part of the Master of Economic Geology program, did not disappoint. Around 40 students took part and immersed themselves in a diverse range of fundamental data analytics topics applied to geological problems, including data wrangling, machine learning and image processing. This unit is run entirely online and comprises three sections. The first section is self-paced, and involves a series of pre-recorded lectures, prescribed readings and associated exercises. Participants

carry out a literature review that involves uploading videos to YouTube – a great way to get students engaging with one another and fostering a sense of shared learning. The second section involves a week of live lectures and practicals, with guest presenters from across the world discussing such topics as geochemical exploratory data analysis, hyperspectral image classification and what the future of geodata analytics might hold. In the third section course participants are split into teams and tackle a geodata analytics problem; the results of these sessions are shared in a series of group presentations.

**ORE DEPOSIT GEOCHEMISTRY,
HYDROLOGY AND
GEOCHRONOLOGY
31 MAY–5 JUNE AND 5–9 JULY**

This short course was delivered entirely online due to COVID-19 restrictions in 2021, but the silver lining in this mode of delivery was that 82 participants were able to take part as the costs of participating online are substantially less than flying to Tasmania from overseas. The course provided an up-to-date review of the theory and practice of geochemistry, hydrology and geochronology as applied to studies of mineral exploration and ore deposit genesis. The first week covered the basic principles of ore fluid chemistry, the use of magmatic minerals and whole-rock geochemistry in exploration, geochronology, granite metallogeny, advanced geochemical exploration techniques and the uses of pyrite in mineral exploration (using samples provided by short course participants). The second week (held in early July) covered fluid-rock interaction and the physical hydrology of fracture-controlled hydrothermal systems, mass balance calculations from lithogeochemical data, stable isotope and fluid inclusions applications for exploration, and alteration mineral chemistry vectoring in porphyry and epithermal environments. A range of presenters from CODES, other institutions and from industry gave illuminating talks, and the short course was once again a big success – with three times as many participants as when it last ran in 2019.

**FUNDAMENTALS OF
ECONOMIC GEOLOGY
30 AUGUST–4 SEPTEMBER AND
27 SEPTEMBER–1 OCTOBER**

The inaugural delivery of this short course was another first for CODES in 2021. More than 50 participants from around the world took part. Again, a mixture of CODES staff and guest presenters instructed participants in the fundamental skills and theory needed by all economic geologists including ore deposit classes, environments of ore formation, mineralogy and textures, paragenesis, zoning, geochemical and geophysical characteristics of ore deposits, supergene features and the economics of economic geology. The course

included a major virtual field mapping exercise based on the Dolphin scheelite deposit, King Island, Tasmania. CODES is grateful to King Island Scheelite for providing access to the mine and samples in order to facilitate the development of this activity.

**GEOMETALLURGY
18–23 OCTOBER 2021 AND
15–19 NOVEMBER**

Dr Julie Hunt and Dr Angela Escolme co-ordinated the Master of Economic Geology short course on Geometallurgy in October and November 2021, the sixth time the course has been run at CODES. This year the course had 23 participants: seven Masters students, 13 industry participants and three other students. Due to travel restrictions the course was held entirely online. Presentations were given by UTAS staff and guest presenters. Guest speakers included Dr Toni Kojovic (SimSAGE), Dr Teresa McGrath (Curtin University), Joe Pease (Mineralis), Scott Halley, Dr Laurence Dyer (Curtin University), Dr Luke Keeney (CRC ORE), Dr Naomi Boxall (CSIRO), Sefton Darby (Voconiq), Dr Kathy Ehrig (BHP), Karyn Gardner (Newcrest Mining) and Dr James Cannel (MMG). In lieu of in-person field trips a comprehensive virtual tour of the Savage River Mine, covering exploration, mining and mineral processing, was created by Dr Michael Roach. Virtual information on analytical techniques, in lieu of lab visits, was created by staff of CSL, CODES and Earth Sciences and Mineral Resources Tasmania.

**ORES IN MAGMATIC ARCS:
TASMANIA AND THE
CIRCUM-PACIFIC
22 NOVEMBER–3 DECEMBER
2021**

With the lifting of some COVID restrictions, this Masters short course was able to take place in person, but it was not run in its usual locations of either South America or Indonesia. Instead, it provided a welcome chance for CODES staff and students to join with those from industry and other institutions to look at some of the mines and minerals to be found on Tasmania’s west coast. A total of 21 students took part, travelling in the first week of the course to look at Cambrian

polymetallic VHMS and high sulfidation mineralisation that formed in a back-arc setting, and Devonian Carboniferous skarn, vein, and granite-related carbonate replacement-style Sn-W-Fe-Cu-Zn-Pb-Ag deposits that formed in a post-collisional orogenic belt. The second week of the course involved lectures and practical exercises at CODES, reviewing case studies of ores from magmatic arcs from South America (Chile, Peru), Indonesia, the Philippines, Papua New Guinea (Lihir, Porgera, Wafi-Golpu) and eastern Australia (Macquarie Arc), utilising the extensive sample and teaching collections from the CODES archives.

**The Master of Economic
Geology short course
program for 2022:**

- 13–26 February: Advanced Field Skills in Economic Geology
- 4–9 April AND 2–6 May: Fundamentals of Economic Geology
- 30 May–4 June AND 4–8 July: Ore Deposit Models and Exploration Strategies
- 8–18 September, 19–24 September AND 26 September–16 October: Geodata Analytics
- 24–29 October AND 28 November–2 December: Exploration in Brownfield Terrains
- 11–24 November: Volcanology and Mineralisation in Volcanic Terrains

HONOURS PROGRAM

The Honours degree in Earth Sciences is designed to train our students for both industry and academia. The program consists of thesis-based research balanced with a literature review and four weeks of short units that take place in Tasmania or at universities in Victoria. 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.

The 2021 academic year saw successful completion of four Honours projects; all four students graduated in December 2021. We also have one 2020 part-time mid-year starter who will graduate in April 2022: this student is currently taking a break from his Honours studies while employed by Flynn Gold Ltd in the search for gold in northeast Tasmania. The student numbers for 2022 look to be promising, demonstrating continued interest from graduate students in obtaining additional qualifications before joining the workforce. We hope to attract students from UTAS and externally, given the diversity of research topics and projects on offer at the moment!

The four Honours students covered a broad spectrum of research topics in their theses. These include geophysics, economic geology, biology, environmental geology, geochemistry, palaeontology and volcanology. 2021 provided some opportunities to travel for fieldwork but was still marred by lockdown uncertainties. The students, however, persevered. Dedicated supervisors, supportive staff and hard-working students made for an excellent Honours program.

Thank you to all our industry partners for giving our students a fantastic opportunity in their careers. Industry sponsors include Bluestone Mines Tasmania and Kirkland Lake Gold Ltd. We are also grateful to the ASEG and the Geological Society of Australia’s Endowment fund. We also thank the UTAS Foundation, Mineral Resources Tasmania, the Amira P1202 sponsor group and CODES Analytical Laboratories. In addition, a proportion of the project work was supported by internal, university-based funding.

**Honours coursework
program – VIEPS**

In 2021, CODES offered three short courses as part of the Victorian Institute of Earth and Planetary Sciences (VIEPS) Honours coursework program:

**EXPLORATION FIELD SKILLS
MAPPING CAMP
Course leader: Dr Rob Scott**

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 ~5 km² area in the highly mineralised Cambrian Mount Read Volcanics. Prior to travelling to Tasmania’s west coast participants spent a day examining drill cores from the mapping area at Mineral Resources Tasmania’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.

**ORE DEPOSIT MODELS
Course leader:
Dr Angela Escolme**

Seven students took part in the 2021 Ore Deposit Models course, which was run by Dr Angela Escolme. The course provides an introduction to several major classes of economically important mineral deposits. Deposit styles covered included VHMS, magmatic-hydrothermal, IOCG, sediment-hosted uranium, copper, lead and zinc, Carlin-type gold and orogenic gold. Students took part in a mixture of lectures and practical exercises covering the deposit styles and the various genetic models that have been proposed to explain their formation.

**PRACTICAL IGNEOUS
PETROLOGY
Course leader: Professor
Leonid Danyushevsky**

In June, six students attended the Practical Igneous Petrology course presented by Leonid Danyushevsky. The five-day program is a mixture of lectures and practical exercises, aimed at postgraduate students at Honours level and above with an interest in the formation and evolution of basic and ultrabasic magmas and their relationship to magmatic ore deposits. Topics covered included:

- key theoretical aspects of petrology, including units of concentration, solid solution and mineral formulas, activities and equilibrium, the phase rule, mass balance, phase diagrams, and equilibrium/fractional crystallisation
- examination of a large layered intrusion (the Dovyren Magmatic Complex in Siberia), the effect of pressure and H₂O on melting and crystallisation, and the causes of melting and crystallisation
- an introduction to the concept of distribution coefficients for trace elements
- trace elements in the main rock-forming minerals
- modelling of crystallisation and studies of melt inclusions
- examples from MORB, subduction-related lavas and komatiites.

Honours skills workshops

Workshops leader:

Angela Escolme

Course presenters:

Mike Baker, Matt Cracknell,
Tony Crawford, Leonid
Danyushevsky, Angela
Escolme, Clare Miller,
Indrani Mukherjee,
Terrie Sawyer, Lejun Zhang

From August to September, Honours and postgraduate students were invited to attend several half- to day-long skills workshops, consisting of both lectures and practical sessions. Students were encouraged to bring their own project data to many of the sessions in order to get expert advice on how the data should be interrogated and presented. The workshops were organised by Angela Escolme, and led by various in-house and external presenters. In 2021 a number of the workshops were held completely online for the first time because of the COVID-19 pandemic. Skills and software covered during the sessions included:

- **Introduction to ioGAS** (Mike Baker) covered importing data, constructing and using diagrams, and interrogating geochemical data. These topics were followed by an interactive practical session.
- **Leapfrog Basics** (Angela Escolme) provided students and staff with an introduction to importing geochemical data and plotting this in a 3D context with case study examples given. Students learnt how to manipulate downhole data to generate geological and numerical models using both training and real data sets as they worked through a range of practical exercises.
- **QGIS for Geoscientists** (Matthew Cracknell) covered a number of GIS-related topics including QGIS software basics, data querying, and data analysis and interrogation in the Earth sciences. Students were able to work with existing GIS data sets, as well as creating their own from freely available raster and tabular data.

- **Data Analytics with KNIME** (Matthew Cracknell) provided an introduction to the application of machine learning algorithms to data analysis and data inference. It covered the basic principles of supervised classification and unsupervised clustering, using the KNIME data analytics package. The course focused heavily on the development of practical skills for classification and clustering of geochemical data, including the calculation and analysis of model uncertainty.
- **Laser software and geochronology** (Leonid Danyushevsky) introduced students to the fundamentals of the laser ablation analytical technique, its application to geochronology using U/Pb analysis of zircon, the principles of LA-ICP-MS data reduction and its implementation in data reduction software LADR.
- **Introduction to X-ray diffraction (XRD) for mineralogy and Topas** (Angela Escolme and Terrie Sawyer) provided an introduction to the XRD theory, the instruments available at CODES and how to acquire data, and how to process the data using Rietveld refinement software.

- **Shortwave Infrared (SWIR) and The Spectral Geologist (TSG) workshop** (Lejun Zhang) covered a series of topics including the introduction of a TerraSpec 4 instrument, the basics of The Spectral Geologist (TSG) software, data acquiring, data interpreting and integrating with Ore Deposit Geology. Students were able to operate the TerraSpec 4 instrument to collect data from hand specimens and interpret the data using TSG software.
- **PowerPoint and presentation skills** (Indrani Mukherjee) taught students how to structure a presentation, design slides for effective communication and techniques for effective presentation style.
- **Scientific Writing Course** (Tony Crawford, Honorary Professor and Consultant) remains a popular course for Honours students looking to improve their written scientific communication skills.
- **Word for Thesis** (Clare Miller) took students through the setup of a thesis using a Microsoft Word template, from tables to captions, figures to fonts.



Participants of the 2021 Exploration Field Skills Mapping Camp for Honours students are here pictured near Hall Rivulet Canal in western Tasmania.

Student projects

IN AUSTRALIA

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

Projects related to the ARC TMVC are marked with an asterisk.

1. **Boundy, Kim. NT (Masters)***

Geochemistry and geochronology of lithium-enriched pegmatites in the Bynoe pegmatite field, Northern Territory.

2. **Bozoglu, Mertkan. NSW (Masters)***

Phyllic alteration at Northparkes.

3. **Cheesman, Kate. TAS (Honours)**

Invertebrate biomonitoring: A geoscience tool for AMD remediation, north-west Tasmania.

4. **Chu, Dina. NT (Honours)**

Geophysical characteristics of the Pine Creek Deposit through petrophysical properties.

5. **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.

6. **Enkhbold, Batbayar (Baggy). QLD (Masters)***

Alteration sequence of Eastern Creek Volcanics of Mount Isa.

7. **Fisher, Eliza. TAS (Honours)***

Geochemical analysis of mine waste and pit lakes at Endurance Mine, northeast Tasmania.

8. **Gallagher, Till. TAS (Honours)**

Nature, structure and origin of the St Marys Porphyry, northeastern Tasmania.

9. **Habib, Umer. VIC, NSW**

Tectonic evolution of the Paleozoic rocks in southeast Australia using geophysical, geochronological, geochemical and Hf isotope systematics.

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

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

11. **Hill, Richard. NT**

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.

12. **Hohl, Max. QLD**

Defining the mineral chemistry footprints of IOCG deposits in northwest Queensland.

13. **Hughes, Kyle. NSW (Masters)**

Paragenesis of the Dobroyde Deposit, central NSW.

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

Volcanic architecture of the Cowal Igneous Complex.

15. **Jago, Corey. NSW (Masters)**

Spectral analysis of hydrothermal alteration associated with the Northparkes porphyry Cu-Au deposits, New South Wales.

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

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

17. **Jones, Colin. TAS***

Petrogenesis of northeast Tasmanian granites.

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

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

19. **Jones, Rhiannon. NSW***

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

20. **Kultaksayos, Sitthinon (Gun). TAS (Masters)**

Provenance of early to mid-Paleozoic sediments in Tasmania: When did Tasmania join with Australia?

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

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

22. **Leslie, Christopher. NSW**

Metallogeny of the Cowal district, New South Wales, Australia.

23. **Mah, Fu Rong. TAS (Honours)***

Investigating passive remediation of copper and acid mine drainage using *Baloskion tetraphyllum*, Western Tasmania.

24. **Morrish, Stephanie. CORAL SEA (Honours)**

The geological evolution of Frederick and Sula Seamounts, Coral Sea.

25. **Nascimento, Sibe Cristina do. TAS***

Geoenvironmental characterisation of historic mine tailings: Evaluating opportunities for reprocessing.

26. **Ostersen, Thomas. TAS**

Geoelectric structure of the Tasmanian lithosphere.

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

Tectonic evolution of the Palaeozoic Lachlan Orogen.



28. Wang, Chuang. TAS

Application of seismic techniques to reconstruct volcanic architecture.

29. Weidinger, Zak. TAS (Honours)

A geophysical investigation of the Royal George tailings repository, northeast Tasmania.

30. Wells, Tristan. NSW

Magmatic fertility in the Macquarie Arc.

31. Winter, Riley. NSW (Honours)*

Geology, geochemistry and genesis of advanced argillic alteration at Kurrajong Hills, Warrinya District, NSW, Australia.

32. Zivkovic, Zebedee. TAS, WA

Lithogeochemical and mineral analysis of magmatic-hydrothermal mineralisation systems: Implications on mineralisation and exploration.

OUTSIDE AUSTRALIA

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

Projects related to the ARC TMVC are marked with an asterisk.

1. Clark, Acacia. NEW ZEALAND

Silicic explosive volcanism: Understanding the conditions of steady and unsteady eruptive behaviour of silicic magma – the Kaharoa 1315 eruption

2. Coaquira, Takeshy. USA*

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

3. Davidson, Rob. MEXICO

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

4. Diaz Castro, Jamie Carlos. ECUADOR (Masters)

The Cascabel Cu-Au-Ag porphyry cluster in northern Ecuador.

5. Fabreschi, Erik. CHILE (Honours)*

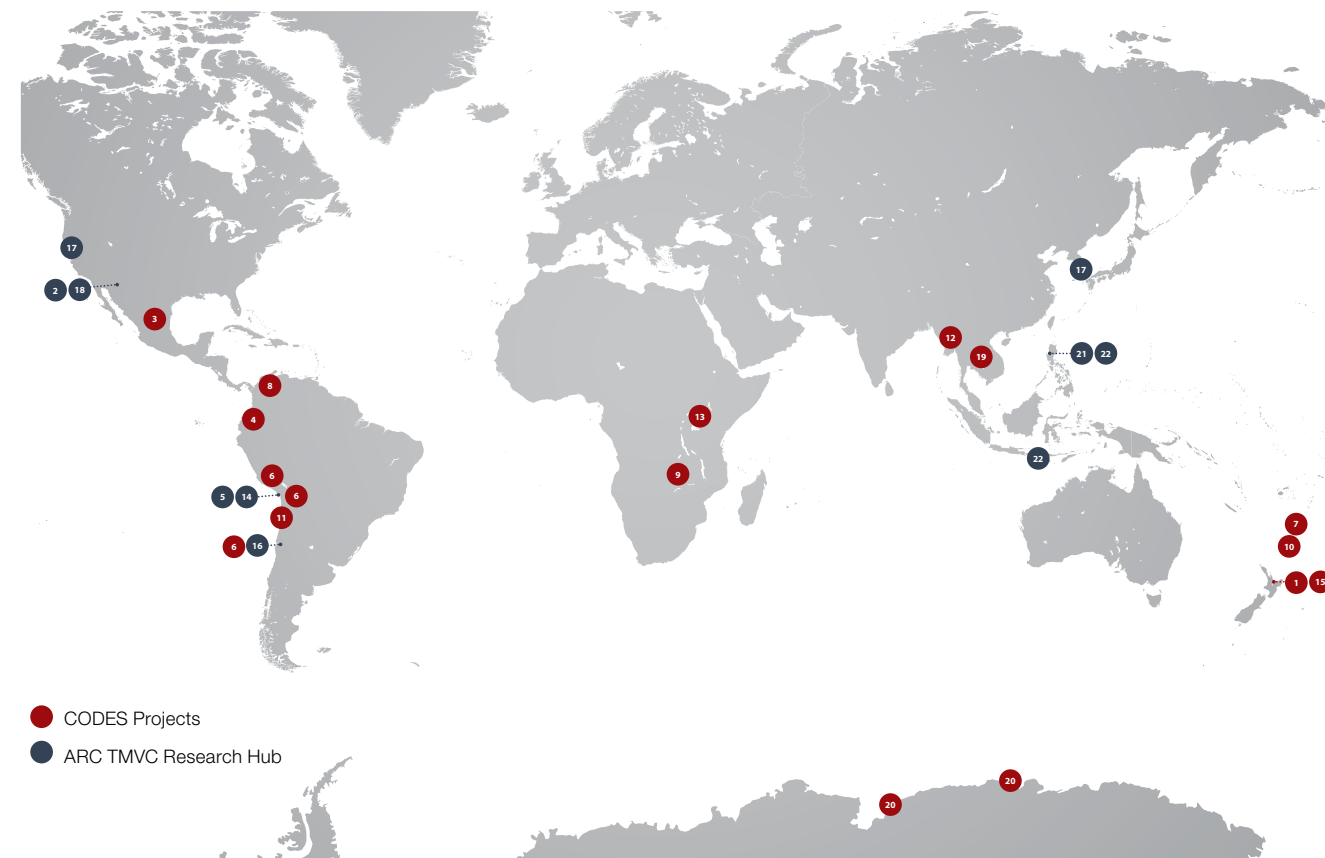
Pyrite trace element geochemistry at the Spence Cu Mo porphyry deposit, Chile.

6. Farrar, Alex. PERU, CHILE, ARGENTINA

Spatial and temporal controls on the formation of giant porphyry Cu Au deposits in the Central Andes.

7. Frey, Shannon. NEW ZEALAND

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



8. Guerrero Ramirez, Nathaly. COLOMBIA (Masters)

Geological controls on grade-by-size fractionation in gold systems.

9. Heathcote, Jacob. ZAMBIA

Gold distribution and association at the Kansanshi copper-gold deposit Zambia: Processes responsible for gold precipitation and implications for ore zone delineation and recovery.

10. Ikegami, Fumihiko. NEW ZEALAND

2012 submarine silicic eruption of Havre volcano and implications for ancient submarine successions in Australia.

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 geodynamic and metallogenic setting of base- and precious-metal mineralisation in Myanmar: Implications for Cu and Au exploration.

13. Maroa, George. KENYA (Masters)

Characterization of the geology, mineralization and genesis of the Bumbo polymetallic sulphide deposit within the Busia-Kakamega Greenstone Belt, Western Kenya.

14. Merrill, Javier. CHILE*

Evaluating applications of hyperspectral data for predicting mineral processing attributes and waste characteristics of slurries.

15. Moore, Hannah. NEW ZEALAND

Investigation of the shallow conduit processes involved in the 1886 basaltic Plinian eruption at Tarawera Volcano, New Zealand.

16. Osorio, Jaime. CHILE*

Porphyry to epithermal transition in the Valeriano Cu-Mo-Au deposit, Chile.

17. Seow, Xin Ni. SOUTH KOREA, USA*

Geochemistry, mechanism of formation and exploration implications of alunite supergroup minerals.

18. Smyk, Emily. USA*

A characterisation of the intrusive rocks and magmatic minerals and their related propylitic and skarn alteration at the Christmas porphyry Cu deposit, Arizona, USA: assessing the potential for mineral chemistry vectoring to mineralisation.

19. Sritangsirikul, Peerapong. MAINLAND SE ASIA

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

20. Stål, Tobias. ANTARCTICA

The Antarctic lithosphere revealed by multivariate analysis.

21. Sun, Yi. PHILIPPINES*

Mineralogical, textural, geochemical characterisation and geometallurgical models of Lepanto Quartz – Pyrite – Gold vein and breccia system, Philippines.

22. Thompson, Jennifer. INDONESIA, PHILIPPINES*

Carbonate mineral chemistry in epithermal and porphyry hydrothermal systems.



Participants in the CODES SEG Student Chapter field trip to King Island silhouetted against the evening sky, April 2021.

Lab-based projects

Berger, Peter.

Understanding and predicting hypogene and supergene footprints of Carlin-type gold deposits using a hydrochemical modelling approach.

Cooke, Stephen.

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

Jenkins, Kate. (Honours)

Characterisation of elemental fractionation in U/Pb dating by LA-ICP-MS analysis of rutile and garnet.

Kuhn, Stephen.*

Machine learning for mineral exploration: prediction and quantified uncertainty at multiple exploration stages.

Lounejeva, Elena.

Geochemical signature of syngenetic and diagenetic pyrite from marine sediments as a paleo-environmental tool.

Morales, Karla. (Masters)

Geological predictors for pre-concentration.

Morse, Peter.

Interactive visualisation for data inference in the geosciences.

Moyo, Annah.*

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

Sayers, Hugh. (Honours)

Understanding framboidal pyrite formation mechanisms and their potential environmental implications.

Thompson, Jay.

Understanding the specifics of H₂O-free aerosol behaviour in the inductively-coupled plasma in geochemical LA-ICPMS applications involving U/Pb dating and accurate trace element analysis in silicate minerals and glasses.



CODES SEG Student Chapter members and guest speakers pictured during the very successful April 2021 King Island field trip, which included visits to see the disused tungsten mine (to be reopened in coming months), the oldest rocks of the southeast Australian region and beautiful minerals, such as scheelite and garnet.

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.

The 2021 calendar year was a challenging one with the ongoing COVID-19 pandemic. Despite this, the Chapter enjoyed a busy year that included two Tasmanian field trips and a host of social events, fundraisers, skills workshops and technical talks.

The Chapter held its Annual General Meeting (AGM) in September 2021 and

elected a new committee. The 2021/2022 committee members are: Zebedee Zivkovic (President), Acacia Clark (Vice-President), Max Hohl (Secretary), Alex Farrar (Treasurer), Rhiannon Jones (Social Secretary) and Richard Hill (Quartermaster). The outgoing co-presidents, Hannah Moore and Alex Farrar, and the 2021 committee are thanked for their tremendous efforts in what was a very successful year for the Chapter despite the difficulties involved.

Field trips

The SEG Student Chapter were lucky enough to have the opportunity to go on two field trips in 2021, one to King Island and the other to western Tasmania.

KING ISLAND

Between 13 and 18 April 2021, 12 UTAS CODES postgrad students and four staff participated in a student-run SEG Student Chapter field trip to King Island. The aim of this trip was to discover the unique geology of the island, particularly focusing on the

economic geology, a mutual interest amongst all students and staff on the trip. The trip was made possible by the Stewart R. Wallace Fund (received in late 2020), the Geological Society of Australia sponsorship and fundraising activities by the Student Chapter. The geological history of King Island is long and complex; however, the most exciting key features that we saw while on the island included:

- The skarn mineralisation and hornfels of the Grassy Group (including exquisite minerals such as scheelite and garnet). The Dolphin Mine at Grassy hosts Australia's largest tungsten deposit. The deposit was formed in the Early Carboniferous (ca. 351 Ma) when a large mass of granite intruded a sequence of Neoproterozoic calcareous sedimentary rocks.
- The oldest rocks of the southeast Australian region: sediments deposited on an ancient sea floor ~1.3 billion years ago.
- Spectacular metamorphic rocks formed when the sedimentary



The CODES Ores in Magmatic Arcs Masters short course held in November 2021 also encompassed a CODES SEG Student Chapter field trip. Here students are pictured at the Mount Bischoff mine with Scott Halley from Mineral Mapping (in blue with cap) pointing out significant features of the area.

rocks were subjected to great heat and pressure deep within the crust.

- Lava flows and breccias formed by ancient volcanic eruptions during the final stages of break-up of the supercontinent Rodinia.
- Glacial deposits from Earth's most severe ice age ('Snowball Earth') 636 million years ago.

Extended information on the field trip can be found in the 2021 SEG CODES Student Chapter Field Report. A video diary was also created to document the trip.

WESTERN TASMANIA

A second field trip was run from 22–27 November which toured the Western Tasmanian Cambrian-Devonian metallogenic belt. The field trip was jointly run with the CODES Ores in Magmatic Arcs Masters short course and was attended by SEG student members and industry members enrolled in the Masters program, and was led by Professor David Cooke.

A number of mines and core sheds were visited, highlighting the diversity and wealth of mineralisation in western Tasmania. The following sites were included:

- Mt Lyell mine (copper)
- Rosebery mine (copper, zinc, lead, silver, gold)
- Henty mine (gold)
- Alpine core (copper)
- Queen Hill core (tin)
- Renison Bell mine (tin)
- Mt Bischoff mine (tin)
- Kara mine (iron, tungsten)

A visit to the state core library at Mineral Resources Tasmania in Mornington was held in the week prior to the field trip where participants were able to view drill cores from other major deposits in western Tasmania, which were not possible to visit on the field trip.

A field guide was prepared by the Chapter members to provide participants with additional information on the site localities visited, as well as additional important mine sites and

areas of interest in the western Tasmanian metallogenic belt.

Social events

The SEG ran several social events during 2021 which included screening 'Picture A Scientist' in March, a jaunt on the Hobart Fun Bus, a trivia night, and a members 'old and new' pub gathering. These events fostered the relationships between existing members and attracted new students to join the society.

Lectures and meetings

In March the SEG teamed up with the GSA Tasmania Division to hold a joint lecture given by Dr Sheree Armistead who spoke about the tectonic evolution of Madagascar and Earth's supercontinent cycles. In July, CODES Alumni James Cannell presented virtually to CODES and SEG members on the Las Bambas deposit in Peru. Liam Webb, the CEO of Datarock, gave a presentation on the new age of geology in November. Two Python workshops were also run by CODES PhD student Tobias Stål. In addition,

the SEG Student Chapter met monthly to ensure the smooth running of the society.

Finances and fundraising

Fundraising in 2021 was achieved mostly through BBQs, a trivia night and a film screening. The SEG Student Chapter received \$2,000 USD of Stewart R. Wallace Funding from the Society of Economic Geologists in late 2021. This money was used to fund the field trip to western Tasmania in November.

Geological equipment such as hammers, hand lenses (with LEDs!), a variety of field notebooks and scribes, is sold by the SEG Student Chapter as part of the society's fundraising activities. These fieldwork necessities are provided nearly at cost price. This service helps to keep students in possession of key geological equipment and introduces undergraduates to the SEG Student Chapter.

Future plans

The SEG Student Chapter has big plans for 2022 with a field trip to mainland Australia currently being planned, and a mentor program that will aim to better connect undergraduate students to postgrads. The Chapter has several fundraising opportunities lined up to help fund social events and field trips throughout 2022, and with the re-opening of borders and the addition of some new faces, the year is sure to be a big one.

Looking forward

With COVID restrictions on domestic and international travel slowly easing, the Training and Education program at CODES looks towards 2022 with a growing sense of optimism. This will enable many of our existing students to commence or complete their fieldwork and opens the door to new domestic and international students to study at CODES. 2022 will also see the completion of a major revamp to the Master of Economic Geology as part of a University-wide restructure of postgraduate coursework degrees. In the new degree structure (planned for 2023 onwards), all students will be required to complete two core units: Fundamentals of Economic Geology and Ore Deposit Models and Exploration Strategies, and at least one of the three field-based units (Volcanology and Mineralisation in Volcanic Terrains, Ores in Magmatic Arcs, Advanced Field Skills in Economic Geology). To complete the degree MEconGeol students will choose either a research (i.e., two-unit research thesis) or professional pathway. For the professional pathway, students complete any two of: Exploration in Brownfield Terrains; Ore Deposit Geochemistry, Hydrology and Geochronology; Geometallurgy; or a one-unit research project. In the new degree structure, MEconGeol students will still be able to complete the equivalent of up to three units by cross-institutional study at the University of Western Australia or Curtin (partners in the national Minerals Geoscience Masters program).

Outreach and media

Restrictions lifted during the second year of COVID-19 in Tasmania and so there were many more opportunities to get out and meet prospective students and interested members of the public and talk to them about geology. The outreach program for Tasmanian schools was expanded in 2021, and open days were a thing once more.

UTAS Open Days

In 2021 UTAS cautiously moved to having face-to-face open days as COVID-19 restrictions gradually lifted across the state. In September, CODES Masters student Karla Morales and PhD student Zeb Zivkovic hosted the Earth Sciences/CODES presence at the Cradle Coast campus Open Day. And in November it was the turn of CODES PhD students Hannah Moore and Acacia Clark to do the honours on the Sandy Bay campus. Masks were mandatory at Sandy Bay but this did not discourage large numbers turning out.

The Rock Library

In February 2021 our Earth Sciences/CODES Rock Library Curator Izzy von Lichten was instrumental in facilitating a visit to, and filming session of, the extensive rock collection here at UTAS; the resulting film formed part of the slow-publishing artwork called *Lost Rocks* (2017–2021).

Robyn Banks, daughter of one of the founding UTAS geology professors (Professor Max Banks) was researching



TOP: CODES Masters student Karla Morales (centre) is pictured running the Earth Sciences/CODES stall at the Cradle Coast campus UTAS Open Day during September 2021.
ABOVE LEFT: CODES PhD students Hannah Moore and Acacia Clark give the thumbs up at the Sandy Bay campus Open Day held during November 2021.
ABOVE RIGHT: A general view of the Open Day proceedings on the Sandy Bay campus, November 2021.



TOP: Associate Professor Sebastien Meffre giving a talk entitled 'East meets West: the geological development of northern Tasmania' to a meeting of the Northern Branch of the Royal Society of Tasmania in Launceston during September 2021.
MIDDLE: Honorary CODES staff member Dr Peter McGoldrick captures the attention of participants in the second Science in the Park event held at Tolosa Park, Glenorchy, during November 2021. ABOVE: CODES PhD students (L–R) Acacia Clark, Hannah Moore and Alex Farrar with Masters student Karla Morales pictured while volunteering at the Festival of Bright Ideas in Hobart during November (with Rosie the dinosaur assisting).

fossils as part of the artwork, from which a book also resulted.

Also in February, Izzy hosted artist Gabrielle Rish, who spent part of the day drawing sections of the rock collection, and returned to photograph it as part of an art project about the STE buildings at Sandy Bay campus, looking at their history, sense of place, and hopefully capturing some of their soul.

In October Izzy hosted a visit from Luke Campbell, a Tasmanian artist and performer with Second Echo Ensemble, which is based in Hobart. As a person with Down syndrome, Luke is changing perceptions of what leadership looks like as he completes the Australia Council Future Leaders training program exploring the intersection of his practice in theatre and digital technologies

He was interested in the UTAS collections in terms of a potential commission for performative works in response to their contents. His interests lie in fossils, minerals and ore rocks.

And during 2021 Izzy reported an encouraging trend: samples from the Rock Library were loaned to school teachers who are starting to teach geology in their classes. Items lent out included basic rocks showing sedimentary, igneous and metamorphic features, and ore rocks.

The Festival of Bright Ideas

On 20–21 August the Festival of Bright Ideas (FoBI) was held at the Princes Wharf in Hobart. An Earth Sciences stall run by CODES PhD students Hannah Moore and Acacia Clark with help from Alex Farrar, Zeb Zivkovic and Masters student Karla Morales delighted visitors with volcanic explosions, gemstone identification samples of fossilised wood and ferns, and Rosie the Utah Raptor. Both days were jam-packed with visitors – the Friday was a schools-only day and the Saturday was open to the public. A total of 5,000 people visited FoBI, a testament to the love of all things science, technology, engineering and maths.

Rosie, a life-size, life-like robotic dinosaur who roamed the exhibit hall roaring, chirping and showing her



The Young Tassie Scientists event is held every year across Tasmania; here CODES PhD student Acacia Clark is seen presenting on the topic of volcanoes at Oatlands in Tasmania's Midlands district.

impressive teeth, was a crowd favourite as was the miniature volcanic explosion. This demonstration involved participants filling a suspended bucket with weights that was connected to a party popper, which was meant to resemble a filling magma chamber which increased in pressure until the limit was reached and an explosion occurred (the party popper went off). To add to the excitement, a Lego figurine was carefully positioned on top of the popper and participants were asked when they should evacuate the individual. Most preferred to leave it to chance, sending the Lego figurine flying high into the air. This was very popular amongst the youngest individuals. Pieces of fossilised wood and ferns were shown under the microscope and their origin explained. Many people were amazed that such beautiful and detailed pieces could be found in Tasmania. Gemstones of all colours and textures were also popular as people tried to work out the names of their favourites.

FoBI is a key event for Tasmania's participation in National Science Week. Thanks to all the wonderful volunteers who inspired activity ideas, provided equipment and gave up their time to help Earth Sciences rock the event!

Geohug

Several CODES past and present staff and students took part in the regular Geohug online forum geology discussions during 2021. Geohug has the tagline 'humans united with geology' and its aims are 'to connect, laugh, share ideas, information and knowledge with the wider geology community'. You can see past presentations at: <https://geohug.rocks/past-presentations>

The Royal Society of Tasmania

During 2021 CODES staff and students were once more able to spread the word and give talks in front of a gathered audience. Three people gave presentations to the Royal Society:

- In August Dr Adam Abersteiner talked about 'Kimberlites – Volcanic insights into Earth's deep interior'; this talk is available from the RS YouTube channel:

<https://rst.org.au/view-recording-of-the-lecture-by-dr-adam-abersteiner-august-2021/>

(As Adam is now working in Finland his talk was via Zoom!)

During 2021 CODES staff and students were once more able to spread the word and give talks in front of a gathered audience.

- Associate Professor Sebastien Meffre gave a talk in Launceston on 12 September to the Royal Society Northern Branch jointly with the Geological Society of Australia entitled 'East Meets West, the geological development of northern Tasmania'.
- Associate Professor Rebecca Carey gave a Royal Society talk in October 2021 on volcanoes on the sea floor. It is available from the RS website: <https://rst.org.au/view-recording-of-the-lecture-by-associate-professor-rebecca-carey-october-2021/>

Science in the Park

The second ever 'Science in the Park' extravaganza took place on a grey and slightly windy Saturday afternoon at Tolosa Park, Glenorchy, during November 2021.



TOP: CODES PhD student Tom Schaap answers questions posed by students from Waimea Heights Primary School during a tour of the Earth Sciences exhibits at UTAS in March 2021. ABOVE: Reprocessing of mine waste is the topic of TMVC PhD student's Sibeile Nascimento's project; it was mentioned in a news article in The Sunday Tasmanian.

The event is a broad science outreach activity begun in 2019 as a spin-off from the popular 'Science in the Pub' meetings (<https://www.facebook.com/SciPubTas>). The unseasonably wet Spring had forced the postponement from the originally advertised early October date. Despite this, and COVID rules that meant everyone had to pre-register, the event was a great success with around 250 adults and children turning out. Plenty of diverse and engaging activities for the young and curious, and even a few for the old and curious. Bushwalks for plant- and bird-spotting, and Petri dishes and tweezers for collecting small living things. Earthworms and spiders were particularly popular. Phil Sansom, Madison Mulder and Peter McGoldrick presented a 'tale of ice and fire' (Permian fossils, dropstones and dolerite) to family groups who signed up for short or long geology walks.

Conveniently placed blocks of fossiliferous Permian marls from the nearby quarry and boulders of dolerite large enough to climb on, in the park, made excellent props.

The University of Tasmania is the major sponsor of the event, and Emily Flies and Penny Jones did an amazing job co-ordinating both the activities and the scientists who gave their time to help out. With any luck, the event will continue into the future, and if the weather is good next year, there may even be dinosaurs roaming Tolosa Park.

School visits and trips

During the second year of the COVID-19 pandemic health restrictions eased in Tasmania and it was possible for staff and postgraduates from CODES/Earth Sciences to get out and visit schools and colleges across the

state, albeit with social distancing and COVID protocols in place. A new page on the UTAS website specifically geared to publicising outreach to schools has resulted in many more requests for these visits.

During 2021 there were no fewer than 23 outreach visits by CODES staff and postgrads to schools and colleges in Tasmania ranging from students in Grade 4 through to those at the end of their schooling in Grade 12. Topics ranged from volcanoes to metal contamination in the Derwent. Once again, many put their hands up to assist, travelling out to the schools and colleges when necessary. For some schools outside the Greater Hobart area some sessions were conducted via Zoom. A few examples were:

- 21 February: Associate Professor Sebastien Meffre talked about 'Earth Sciences in society' at Rosebery High School, western Tasmania. Fifty students from Grades 7–10 attended.
- 5 May: Associate Professor Rebecca Carey did a talk via Zoom to students at The Nature School in Port Macquarie entitled 'How volcanoes work'.
- 10 June: Associate Professor Rebecca Carey talked about 'Tectonics' at the Lenah Valley Primary School. Around 26 students from Grades 4–5 took part.
- 28 June: CODES PhD student Tom Schaap spoke to 120 Grade 9 students from St Aloysius Catholic College at Huntingfield on the topic of 'Earthquakes'.
- 10 September: CODES Honours students Kate Cheesman and Zak Weidinger led a Derwent Contamination Excursion for six Grade 11 and 12 students from Calvin Christian School at Kingston.

Tas Youth Science Forum

The Tasmanian Youth Science Forum (TYSF) was run at UTAS between 7 and 9 July. This event is for Grade 11 and 12 students who want to pursue a career in science and allows them the chance to discover the numerous opportunities available. CODES PhD students Tom Schaap and Acacia Clark gave the geology lecture this year

and intrigued the students with the science behind earthquakes and volcanoes. Students got involved by generating their own earthquake – which was recorded on a seismometer – and participating in an interactive poll on styles of volcanic edifices.

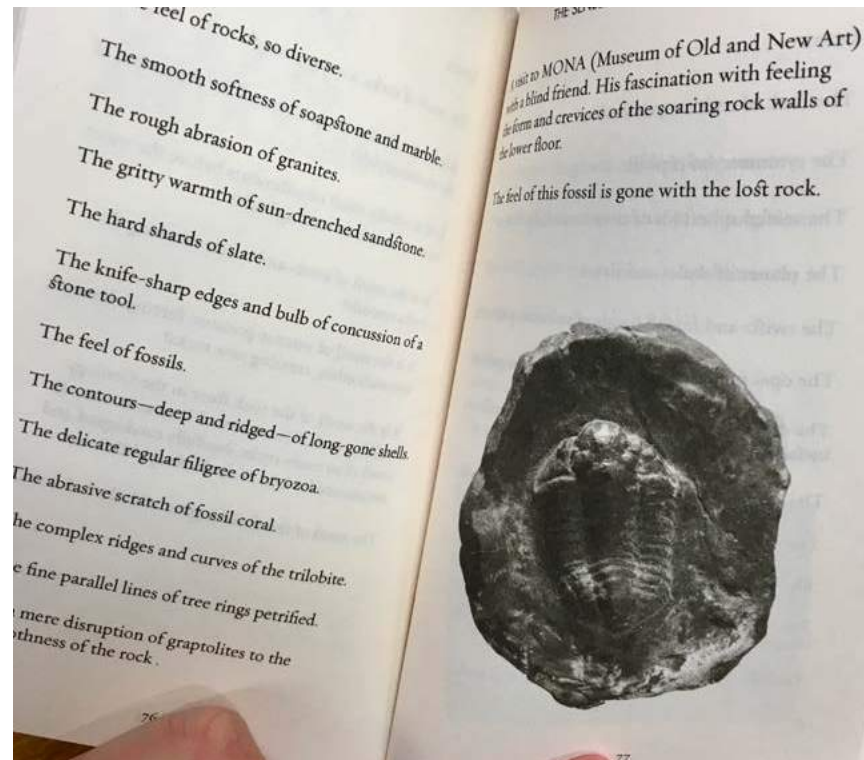
Young Tassie Scientists

Various dates for the Central, Southern and Northwest Tasmania road trips

This year postgraduate students Hannah Moore, Karla Morales and Acacia Clark participated in the Young Tassie Scientists (YTS) program which saw them travel to numerous primary and secondary schools around Tasmania during August, and present engaging hands-on activities with a focus on Earth Science. The YTS program provides dynamic and inspiring role models who are widely profiled ambassadors for science, engineering and technology, and encourages young people to consider studying STEM subjects. To see more about YTS check out the website at: <http://youngtassiescientists.com/>.

Media

- In January, Associate Professor Sebastien Meffre did a short interview with Fiona Breen for ABC's *Tas Country Hour* about the upgrades to the MRT's Mornington Core Library. See: <https://www.abc.net.au/news/rural/2021-01-19/hobart-rock-library-filled-with-mineralsamples/13060914>
- Also in January, Dr Indrani Mukherjee gave an ABC Hobart radio interview with Rick Goddard about AESC diversity and inclusion initiatives.
- In early March, Dr Indrani Mukherjee took part via Zoom in a Women in Science panel discussion (organised by the Australian National Maritime Museum) designed to encourage female high school students, primarily in Grades 9–12, to study STEM subjects.
- In April, Dr Martin Jutzeler did an interview with Sarah Hall for the ABC National News Radio network talking about the imminent volcanic eruption of La Soufrière on the



Pages from *Fossil* by Robyn Banks; this short book was part of the Lost Rocks (2017–2022) art project; Earth Sciences/CODES Rock Library Curator Izzy von Lichten facilitated a visit by the author to the Rock Library so she could carry out research. Filming of the library was also part of the project.

Caribbean island of Saint Vincent, and the subsequent evacuation of the island. See: <https://www.abc.net.au/radio/newsradio/thousands-evacuate-as-a-caribbean-island-volcano/13296600>

- In April, Dr Indrani Mukherjee took part in the WOMEESSA (Women in Earth and Environmental Sciences in Australasia) monthly seminar; her topic was: 'The brilliant billion in Earth's history – life and mineral deposits'.
- In May the *Sunday Tasmanian* newspaper featured a story on remediation of mine sites in Tasmania and TMVC PhD student Sibebe Nascimento's research into reprocessing mine waste was mentioned as an example of the sort of research that needs to be done in this space.
- In early May Dr Indrani Mukherjee did an interview with Radio Marinara in Triple R (Melbourne) on the topic of 'Evolution of early complex life'.
- In June, Dr Clare Miller did an interview with Fiona Breen for ABC Radio Hobart's *Mornings* program on the topic of tailings.

- Professor David Cooke spoke on ABC Northern Tasmania radio about the EDGI drilling grants initiative. He was also interviewed on ABC TV News about the re-opening of the Mt Lyell mine.

UTAS media

CODES and Earth Sciences researchers, students and staff continued to be showcased in several UTAS intranet articles during 2021. Some examples were:

- The increasing number of Master of Economic Geology courses: <https://universitytasmania.sharepoint.com/sites/news-and-events/SitePages/Economic-Geology-enrolments-are-up.aspx>
- Student grants and funding success: <https://universitytasmania.sharepoint.com/sites/news-and-events/SitePages/Geologists-win-big-in-grant-bids.aspx>
- King Island SEG CODES Student Chapter trip in April 2021: <https://universitytasmania.sharepoint.com/sites/news-and-events/SitePages/Economic-Geologists-travel-to-King-Island.aspx>

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.

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 critical for funding CODES' research, and for technology transfer to the mining and mineral exploration community. In 2021, the group of CODES' Industry Partners comprised eleven Australian and international mining companies: Anglo American, AngloGold Ashanti, Barrick, CMOC-Northparkes, Evolution, First Quantum Minerals, Mount Isa Mines (Glencore), Newcrest Mining, Newmont, Rio Tinto and Teck.



After more than 18 months CODES was finally able to host a face-to-face meeting with Amira Global and Industry Partners. Here participants are pictured outside the CODES offices at UTAS during a break in the P1249 Planning Meeting in November 2021.

Partner companies have been providing support of up to \$60,000 in cash per year to the core research budget 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. However, due to COVID-19 restrictions, no Annual Review was held in 2021.

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.

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. For this reason, our partnership opportunities are offered on an annual



CODES Research Fellow Dr Martin Jutzeler undertaking an in-depth explanation of volcanic facies for Evolution Mining staff at the Lake Cowal Mine core sheds.

CODES has strong, enduring and mutually beneficial links with a group of major Australian and international mining companies.

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. Further details can be found at: <http://www.utas.edu.au/codes/aboutus/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 four years. In 2021 it funded Amira P1202 'Far-field and near-mine footprints: Finding and defining the next generation of Tier 1 ore deposits', as well as Amira P1206 'Identifying unique Resistate Indicator Mineral (RIM) chemistry as a guide in prospectivity for sediment-hosted copper mineralisation', both of which sat within the ARC TMVC Research Hub.

Research collaborations

In 2021, despite the COVID-19 pandemic, CODES continued its reputation for cultivating research collaborations with other Australian and international research organisations. Throughout the year, collaborative research was conducted with 107 international and 23 national organisation. Once again, many research meetings, including most of those with Amira, took place online during 2021, which enabled many collaborators in remote locations to take part.

CODES Industry Partners 2021

PLATINUM



GOLD



SILVER



COPPER



Technology transfer

Objectives

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

Technology transfer activities

CODES undertakes strategic and applied research into 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 2021, 219 research reports were presented to industry clients. Meetings (mainly online) were also held to present and discuss progress and adoption of research results.

Projects that have delivered significant technology transfer objectives during 2021 included the CRC-ORE project (led by Dr Julie Hunt), the Amira P1202 and P1206 projects (TMVC sub-projects led by Professor David Cooke and Associate Professor Shaun Barker respectively) and the NW Queensland project (led by Dr Jeff Steadman).

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 2021.

- *Altered volcanic rocks: A guide to description and interpretation* (2005). Authors: C. Gifkins, W. Herrmann and R. Large (31 copies).
- *Geophysical signatures of copper-gold porphyry and epithermal gold deposits, and implications for exploration* (2011). Author: T. Hoschke (11 copies).
- *Giant ore deposits: Characteristics, genesis and exploration. CODES Special Publication 4* (2002). Editors: D. Cooke and J. Pongratz (1 copy).
- *Earth, Universe, Cosmos* (1996). Author: S. Warren Carey (1 copy)
- *The expanding Earth: A symposium* (1981). Editor: S Warren Carey (3 copies).
- *New developments in Broken Hill type deposits. CODES Special Publication 1* (1996). Editors: J. Pongratz and G. Davidson (2 copies).



Participants of the inaugural running of the CODES Masters short course *Advanced Field Skills in Economic Geology*, which took place in February 2021 despite interstate travel restrictions. They are pictured here at Bluestone Bay, on the east coast of Tasmania.

- *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 (30 copies).
- *24ct Au workshop. CODES Special Publication 5* (2004). Editors: D. Cooke, C. Deyell and J. Pongratz (1 copy).

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

Despite the restrictions caused by COVID-19, a mixture of face-to-face and online short courses, workshops, conferences and field trips continued to play a key role in the Centre's technology transfer activities during 2021. Throughout the year, a total of 20 such events were held either within Australia or online.

Total attendance by industry geologists, academic researchers and postgraduate students was markedly higher than in previous years at around 1,200 with 38 presenters from CODES involved in delivering the courses or

leading the conferences or field trips. This higher-than-normal number of attendees was due mainly to many presentations going online.

CODES and Earth Sciences staff and students also played major roles in other events such as the AusIMM Tasmanian Geoscience Forum held in Strahan in December.

Invited talks

Throughout the year CODES staff and HDR students are regularly asked to give invited talks either as specific speaking engagements or as conference add-ons. In 2021 Professor David Cooke was the SEG Distinguished Lecturer and in this role he gave a number of online talks (which would normally be face-to-face and involve overseas travel). Among these were:

- Colorado School of Mines, USA (5 March): 'New advances in geochemical exploration – Detecting the subtle, but giant, geochemical footprints of porphyry Cu and Au deposits using mineral chemistry'

Despite the restrictions caused by COVID-19... conferences and field trips continued to play a key role in the Centre's technology transfer activities in 2021.

- SEG 100 Conference, Whistler, Canada (15 September): 'Porphyry Copper Deposits – from Empirical Models to Mineral Systems'.
- Universidad Austral de Chile (12 November): 'New advances in geochemical exploration – Detecting the subtle, but giant, geochemical footprints of porphyry Cu and Au deposits using mineral chemistry'.
- Hefei University of Technology, China (18 November, 300 participants): 'New advances in geochemical exploration – Detecting the subtle, but giant, geochemical footprints of porphyry Cu and Au deposits using mineral chemistry'.
- SEG Lecturer Symposium (10 December): 'New advances in geochemical exploration – Detecting the subtle, but giant, geochemical footprints of porphyry Cu and Au deposits using mineral chemistry'.

2021 SHORT COURSES, WORKSHOPS, CONFERENCES AND FIELD TRIPS LED BY CODES

TITLE	PRESENTERS	NO.	LOCATION	DATE
Advanced Field Skills in Economic Geology (MEconGeol short course) NEW	Mike Baker, Robert Scott, Lejun Zhang	8	Western, eastern and northeastern Tasmania	7–20 February
Exploration Field Skills Mapping Camp (VIEPS)	Robert Scott, Zeb Zivkovic	6	Hobart/Western Tasmania	7–14 February
Australian Earth Sciences Convention 2021 (Earth Sciences/CODES were organisers of this conference)	Jacqui Halpin, Julie Hunt, Peter McGoldrick, Sebastien Meffre, Hannah Moore, Indrani Mukherjee, Karin Orth	600	Online	9–12 February
Geodata Analytics (MEconGeol short course)	Rocky Barker, Shaun Barker , Natalie Caciagli, Matthew Cracknell , Michael Gazley June Hill, Shawn Hood, Kyen Knight, Javier Merrill , Angela Rodrigues	21	CODES, Hobart (online)	8 February–19 March AND 22–27 March AND 29 March–16 April
ProEXPLO2021 conference: short course – Alteration and mineralization in porphyry deposits	David Cooke	30	Online to Peru	27 March
SEG CODES Student Chapter Field Trip to King Island	David Cooke, Nicholas Direen, Lejun Zhang	16	King Island, Tasmania	13–18 April
Ore Deposit Models (VIEPS)	Angela Escolme, Jonathan Cloutier, David Cooke, Robert Scott, Lejun Zhang	7	CODES Hobart (online)	10–14 May
AMIRA P1202 Module 1 Final Meeting	Mike Baker, Shaun Barker, David Cooke, Matthew Cracknell , Sean Helm, Emily Smyk	71	CODES, Hobart	20 May
AMIRA P1202 Module 2 Final Meeting	David Cooke , Sean Helm, Xin Ni Seow, Yi Sun, Lejun Zhang	68	CODES, Hobart	27 May
Ore Deposit Geochemistry, Hydrology and Geochronology (MEconGeol short course)	Mike Baker , Shaun Barker, Phil Blevin, Farhad Bouzari, David Cooke , Stephen Cox, Matthew Cracknell , Rob Creaser, Leonid Danyushevsky , Sarah Dare, Scott Halley, Christian Ihlenfeld, Fred Jourdan, Rob Lee, Chris Leslie , Matthew Loader, Robert Loucks, Yongjun Lu, Sebastien Meffre , Nick Oliver, Dave Rhys, Robert Scott, Jeff Steadman , Lesley Wyborn, Lejun Zhang	82	CODES, Hobart (online)	31 May–5 June AND 5–9 July
AMIRA P1202 Module 4 Final Meeting	Sean Helm, Angela Escolme, Lejun Zhang, Rhiannon Jones, Takeshy Coaquira, Jaime Osorio	52	CODES, Hobart	10 June
Practical Igneous Petrology (VIEPS)	Leonid Danyushevsky	6	CODES, Hobart	June
AMIRA P1202 Final Meeting	Ivan Belousov , Jeff Bigelow, Jonathan Cloutier, David Cooke, Matthew Cracknell, Leonid Danyushevsky, Angela Escolme , Scott Halley, Sean Helm, Javier Merrill , Angela Rodrigues, Francisco Testa , Olga Verezub, Lejun Zhang	67	CODES, Hobart	30 June–1 July
Python Workshop	Tobias Stål	12	CODES, Hobart	2 July
Python Workshop	Tobias Stål	12	CODES, Hobart	16 July
Fundamentals of Economic Geology (MEconGeol short course) NEW	Rodney Allen, Tim Callaghan, David Cooke, Angela Escolme , Karsten Goemann, David Green, Scott Halley, Cassady Harraden, David Huston, Glen Masterman, Larry Meinert, Michael Roach, Robert Scott, Francisco Testa , Rick Valenta, Noel White, Lejun Zhang	61	CODES, Hobart (online)	30 August–10 September
Peru SGA Student Chapter Workshop: Green rock exploration for porphyry deposits workshop	David Cooke	25	Online to Peru	16 October
Geometallurgy (MEconGeol short course)	Ron Berry , Naomi Boxall, James Cannell, Matthew Cracknell, Leonid Danyushevsky , Sefton Darby, Laurence Darby, Kathy Ehrig, Angela Escolme , Sandrin Feig, Karyn Gardner, David Green, Nathaly Guerrero , Scott Halley, Julie Hunt , Luke Keeney, Toni Kojovic, Teresa McGrath, Sebastien Meffre, Javier Merrill, Clare Miller , Joe Pease, Michael Roach , Thomas Rodemann, Robert Scott, Lejun Zhang	23	CODES, Hobart (online)	18–23 October AND 15–19 November
Ores in Magmatic Arcs (MEconGeol short course) incorporating SEG CODES Student Chapter field trip to western Tasmania	Mike Baker, David Cooke, Alex Farrar , Pete Hollings, Jonathon Hoye, Scott Halley, Andrew Rae, Andrew McNeill, Sebastien Meffre, Michael Roach, Francisco Testa, Victor Torres Pacheco , Andrew Rae, Lejun Zhang	21	Western Tasmania and CODES, Hobart	22 November–3 December
AMIRA P1249 Planning meeting	Laurent Ailleres, Mike Baker , Shaun Barker, Ivan Belousov, Takeshy Coaquira, David Cooke, Stephen Cooke, Matthew Cracknell, Alex Farrar , Scott Halley, Peter Hollings, Rhiannon Jones , Mitchell Marcelissen, Javier Merrill, Clare Miller, Jaime Osorio , Angela Rodrigues, Xin Ni Seow, Emily Smyk , Olga Verezub, Noel White, Lejun Zhang	42	CODES, Hobart	7–8 December

Performance indicators

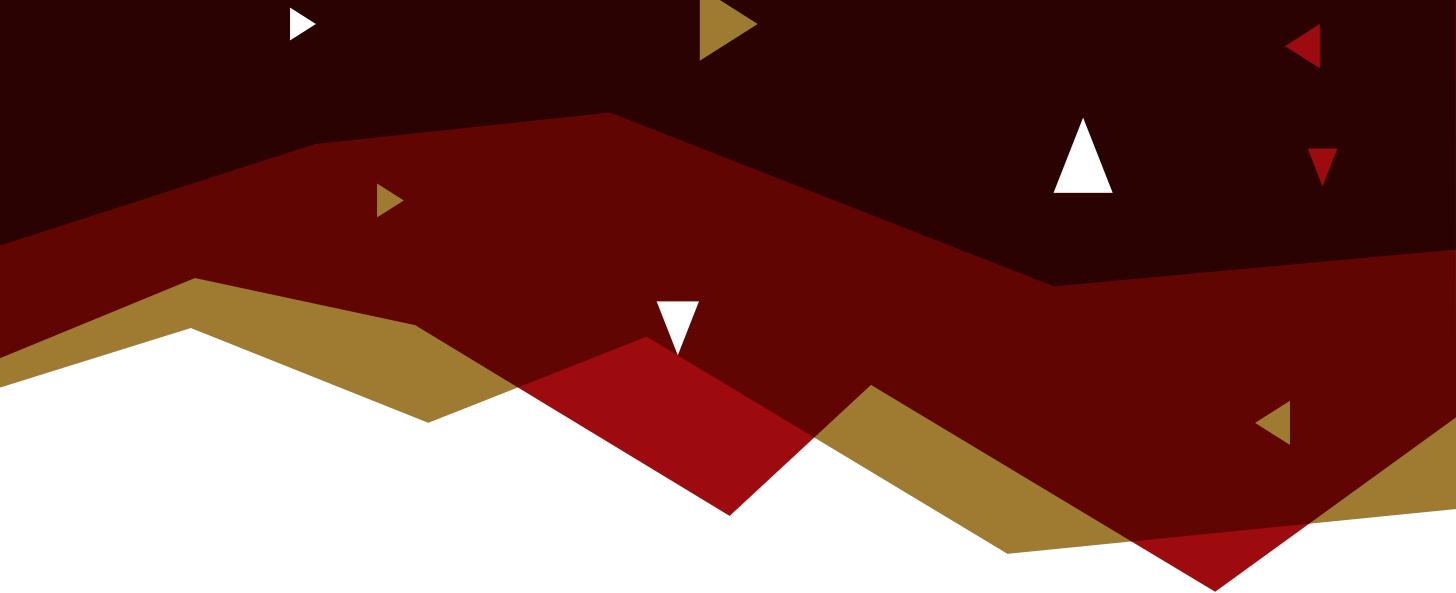
PERFORMANCE MEASURES

	TARGET	2021
Research Findings (CODES and Earth Sciences)		
Publications in international journals	50pa	50
Percentage of publications in high-quality international journals	70%	73%
Reports to industry collaborators	80pa	219
Special issues and/or research monographs	1 per 2 years	0
Invitations to give keynote conference presentations	10pa	2
Papers at national/international meetings	70pa	59
Research Training and Professional Education		
Percentage of HDR students attracted from interstate	25%	14%
Percentage of HDR students attracted from overseas	65%	53%
Number of Honours students in CODES' programs	15	11
Number of HDR students in CODES' programs	50	43
Percentage of students in projects linking with industry	80%	63%
Professional short courses/workshops for industry	4pa	20
International, National and Regional Links and Networks		
CODES' national or international conferences/workshops	1 per 2 years	1
Registrants at CODES' conferences/workshops	600pa	1,200+
End-user Links		
Frequency of meetings with industry representatives	15pa	20+
National Benefit		
CODES' research has input into a major mineral discovery	1 per 5 years	9 in 30 years

NOTE: The COVID-19 pandemic again dramatically reduced the number of conferences that CODES researchers and HDR students were able to attend in person in 2021. Similarly, international HDR student commencements were again impacted due to Australian border restrictions. Meetings with industry representatives were online via Zoom for the most part.

View from the shoreline at Currie Harbour, King Island, taken by David Cooke during the CODES SEG Student Chapter field trip to the island in April 2021.





Finances

2021 income

Total CODES income was \$6.6 million (see Table 1). This was derived principally from UTAS (29%), Contracts/Consultancies/Revenue Raising (27%), and Industry (21%) (see Figure 1). The main income streams over time are compared in Figure 2, showing a decrease in overall income to CODES in 2021 when compared to 2020. This decrease occurred in the combined income streams of the ARC TMVC Research Hub which came to its conclusion at the end of June. Most other categories remained reasonably stable.

- Summary of the main income streams to CODES in 2021:
- Host institution support:** Funding from UTAS in 2021 was \$1.9 million, comparable to the figure for 2020, mostly due to sustained research salaries and PhD scholarship funding (living and tuition fee) from central sources. 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 \$1.8 million comprises funding related to Short Courses (\$235k), Analytical Services (\$1.5 million) and Book Sales (\$12k).

- Industry income:** Industry funding of \$1.4 million comprises funding related to Industry Partner support and industry-funded student and other research projects. This figure does not include industry-based support for the ARC TMVC Research Hub (see below).
- ARC TMVC Research Hub:** The combined income sources for the TMVC amounted to \$962k in 2021, comprising of funding from industry Partner Organisations (\$860k), and other sources including Additional Funder Projects (\$102k).

2022 income estimates

There is expected to be an increase in external research funding to CODES in 2022 when compared to 2021, due to several new research projects coming online during the year. UTAS and Other funding to CODES is expected to remain steady into 2022.



King Island: participants in the CODES SEG Student Chapter field trip to King Island with presenter Dr Michael Roach (in yellow high-vis jacket).

TABLE 1: CASH INCOME FINANCIAL STATEMENT 2021
ARC Transforming the Mining Value Chain Research Hub

ARC Industrial Transformation Research Project	0
Partner Organisations	860,139
- Amira Global	860,139
- BHP Billiton Olympic Dam	0
- Newcrest Mining	0
Host Institution	0
Additional Funder Projects	51,244
Miscellaneous	51,053
	962,435

ARC Grants	
Discovery Grants	132,343
Linkage Grants	176,519
	308,862

Other Commonwealth Government	
Specific Projects	264,332
Student Projects	2,836
	267,168

State Government	
Specific Projects	4,884
Student Projects	18,239
Miscellaneous	8,850
	31,972

Industry/private	
CODES Industry Partners	380,000
Cooperative Research Centre Projects	438,025
Directly Funded Research Projects	402,764
Directly Funded Student Projects	135,453
Miscellaneous	3,645
	1,359,887

Contracts/consultancies/revenue raising	
Short Courses	234,831
Book Sales	11,817
Miscellaneous (incl. Analytical Services)	1,518,621
	1,765,270

University of Tasmania – host institution support	
Operating Grant	780,692
Scholarships and Tuition Fee Waivers	1,024,404
Strategic Projects	100,000
	1,905,096

Other income sources/interest	
Miscellaneous	3,836
	3,836

Total annual income	6,604,526
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FIGURE 1:
Total Cash Income 2021

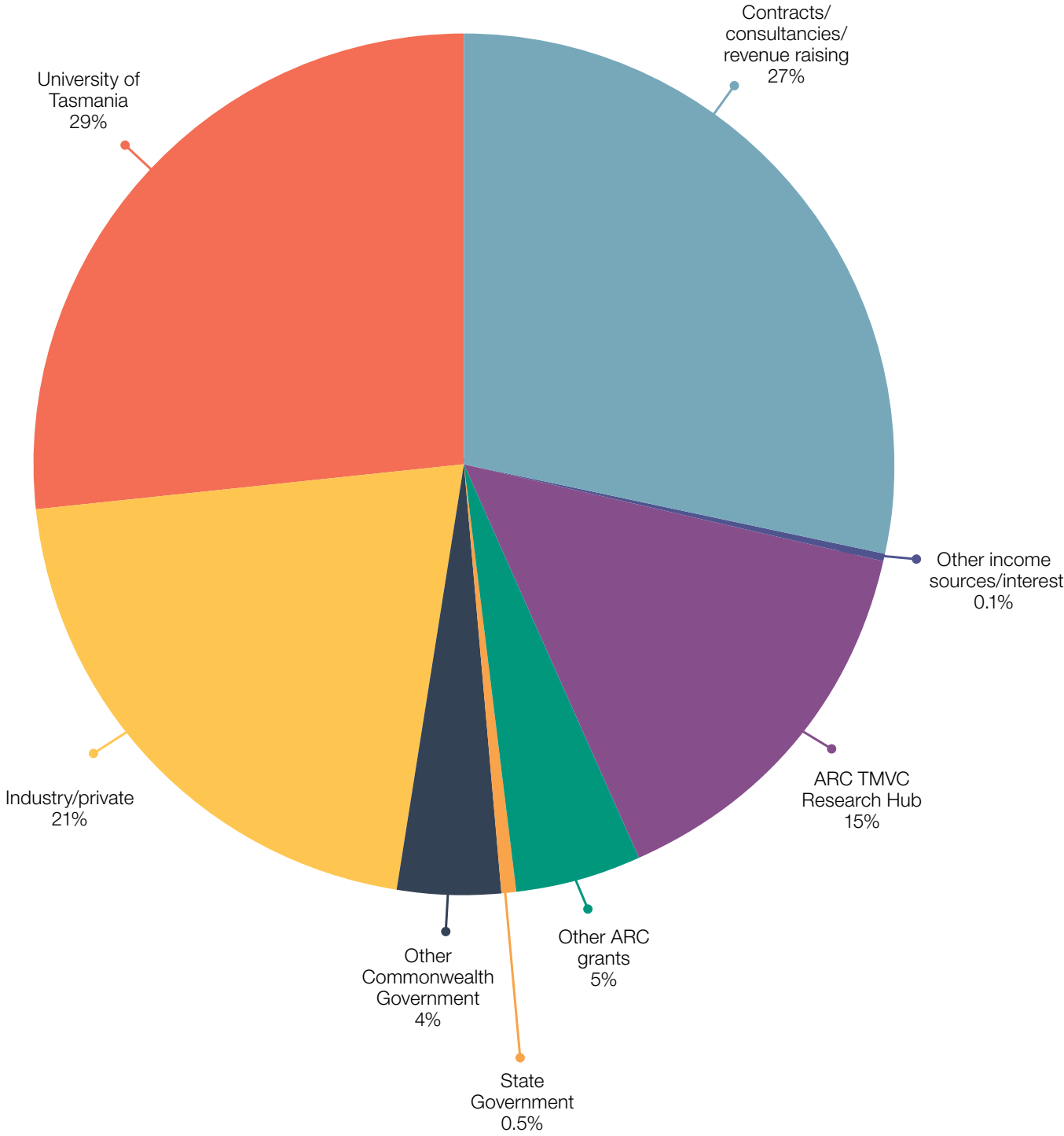
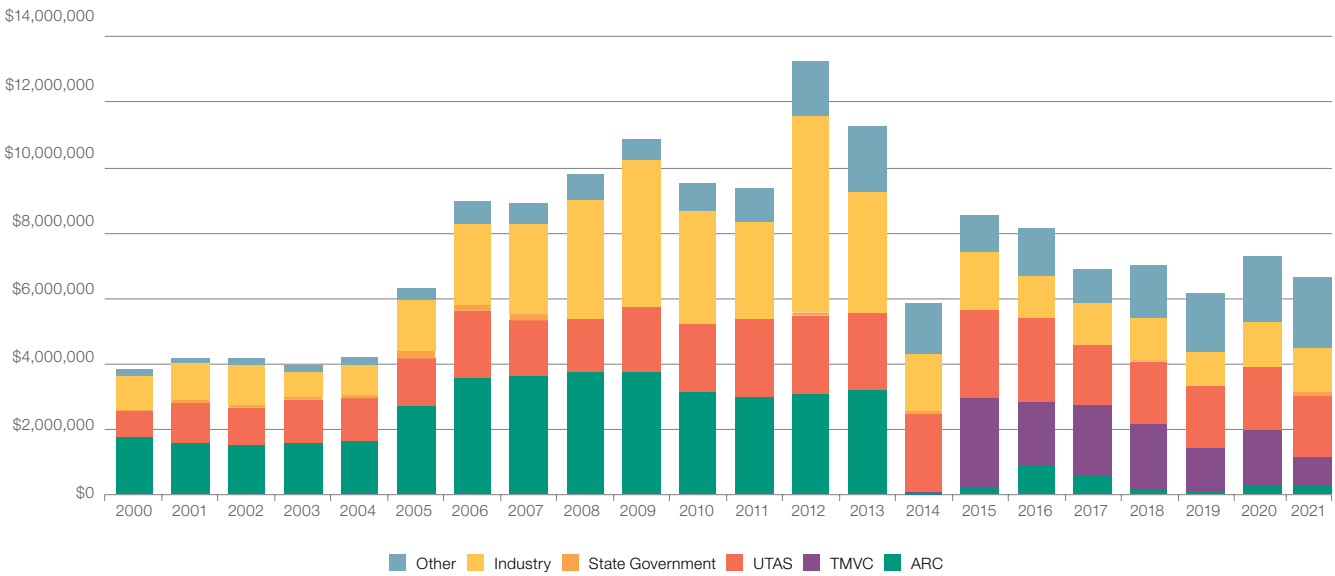


FIGURE 2:
Comparison of CODES
main income streams 2000–2021



Notes to, and forming part of, the financial statements for 2021

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 2021, or centrally administered for CODES RHD students (as in the case of scholarships and tuition fee waivers).



2021 Publications

Please note: Outputs related to the TMVC Research Hub are marked with an asterisk.

Refereed journal articles (50)

Aulback, S., Giuliani, A., Fiorentini, M.L., Baumgartner, R.J., Savard, D., **Kamenetsky, V.S.**, Caruso, S., **Danyushevsky, L.V.**, Powell, W., and Griffin, W.L., 2021, Siderophile and chalcophile elements in spinels, sulphides and native Ni in strongly metasomatised xenoliths from the Bultfontein kimberlite (South Africa): *Lithos*, v. 380–381, Article 105880.

Basori, M.B.I., Gilbert, S.G., **Khin Zaw** and **Large, R.R.**, 2021, Geochemistry of sphalerite from the Permian Volcanic-Hosted Massive Sulphide (VHMS) deposits in the Tasik Chini area, Peninsular Malaysia: Constraints for ore genesis: *Minerals* v. 11(7), Article 728.

Belousov, I., Batanova, V., Sobolev, A., Savelieva, G., **Danyushevsky, L.**, and **Draayers, E.**, 2021, Pyroxenites from mantle section of Voykar Ophiolite – Melt/peridotite reaction and crystallization in SSZ mantle: *Lithos*, v. 388–389, Article 106063.

Berger, P., Freiburg, J.T., and **Barker, S.L.L.**, 2021, Simulation and sensitivity of isotopic alteration and vein development in carbonate rock formations: *Journal of Geochemical Exploration*, v. 229, Article 106841.

Bombardieri, D., Duffett, M., McNeill, A., **Cracknell, M.**, and **Reading, A.**,

2021, Insights and lessons from 3D geological and geophysical modeling of mineralized terranes in Tasmania: *Minerals*, v. 11(11), Article 1195.

*Cao, M.J., Evans, N.J., Hollings, P., **Cooke, D.R.**, McInnes, B.I.A., and Qin, K., 2021, Apatite texture, composition, and O-Sr-Nd isotope signatures record magmatic and hydrothermal fluid characteristics at the Black Mountain porphyry deposit, Philippines: *Economic Geology*, v. 116(5), p. 1189–1207.

Chapman, N.D., **Meffre, S.J.**, Maas, R., and Ehrig, K., 2021, Pb-isotope ratios and the petrogenesis of the Tunkillia Suite, Gawler Craton: *Australian Journal of Earth Sciences*, v. 68(8), p. 1071–1091.

Cloutier, J., Piercey, S.J., and Huntington, J., 2021, Mineralogy, mineral chemistry and SWIR spectral reflectance of chlorite and white mica: *Minerals*, v. 11(5), Article 471.

Conde, C., Tornos, F., **Danyushevsky, L.V.**, and **Large, R.**, 2021, Laser ablation-ICPMS analysis of trace elements in pyrite from the Tharsis massive sulphide deposit, Iberian Pyrite Belt (Spain): *Journal of Iberian Geology*, v.47, p. 429–440.

Denholm, J.L., Stepanov, A.S., **Meffre, S.**, Bottrill, R.S., and **Thompson, J.M.**, 2021, The geochronology of Tasmanian tin deposits using LA-ICP-MS U-Pb cassiterite dating: *Economic Geology*, v. 116(6), p. 1387–1407.

Ehrig, K., **Kamenetsky, V.S.**, **McPhie, J.**, Macmillan, E., **Thompson, J.**, **Kamenetsky, M.**, and Maas, R., 2021, Staged formation of the supergiant Olympic Dam uranium deposit, Australia: *Geology*, v. 49(11), p. 1312–1316.

Fan, Y., Zhang, W., Liu, Y., Zhou, T., **Zhang, L.**, Chen, X., and Hong, H., 2021, Geochemical characteristics of chlorite in the Luohe iron deposit in the Middle-Lower Yangtze Metallogenic Belt, Eastern China: *Ore Geology Reviews*, v. 133, Article 104062.

Fox, J.M., **McPhie, J.**, **Carey, R.J.**, Jourdan, F., and Miggins, D.P., 2021, Construction of an intraplate island volcano: the volcanic history of Heard Island: *Bulletin of Volcanology*, v. 83(5), Article 37.

*Gazley, M., **Hood, S.B.**, and **Cracknell, M.J.**, 2021, Soil-sample geochemistry normalised by class membership from machine-learned clusters of satellite and geophysics data: *Ore Geology Reviews*, v. 139, Article 104442.

Gianfriddo, C., **Bull, S.W.**, and **Andrew, T.M.**, 2021, The Rosie pyrite hydrothermal system in the McArthur Basin: tectono-sedimentary constraints on mineralization and alkali metasomatism in stratiform sediment-hosted sulfide deposits of northern Australia: *Mineralium Deposita*, <https://doi.org/10.1007/s00126-021-01069-w>

Habib, U., Musgrave, R., and Meffre, S., 2021, Paleomagnetic testing of the Lachlan Orocline hypothesis:



Old haulage tunnel near Zeehan, western Tasmania, photographed by CODES PhD student Alex Farrar during the Ores in Magmatic Arcs Master of Economic Geology short course, November 2021.

overprinting of remanence in Paleozoic rocks of the Lachlan Orogen in southeast Australia: *Australian Journal of Earth Sciences*, doi.org/10.1080/08120099.2021.1918246

*Hao, H., Campbell, I.H., **Cooke, D.R.**, Nakamura, E., and Sakaguchi, C., 2021, Geochronology, petrogenesis and oxidation state of the Northparkes igneous suite, New South Wales, Australia: Implications for magma fertility: *Economic Geology*, v. 116(5), p. 1161–1187.

Holt, S.J., **McPhie, J.**, and **Carey, R.J.**, 2021, Apparently ‘dry’ littoral rootless cones in Hawai’i formed by sustained, ‘confined’ mixing of lava and sea water: *Journal of Volcanology and Geothermal Research*, v. 419, Article 107352.

***Hong, W.**, **Cooke, D.R.**, **Zhang, L.**, **Fox, N.**, and **Thompson, J.**, 2021, The formation of magmatic-hydrothermal features in Sn-mineralized and barren Tasmanian intrusions, southeast Australia: Insights from quartz textures, trace elements, and microthermometry: *Economic Geology*, v. 116(8), p. 1917–1948.

*Hu, Y., Wei, C., Lin, Y., Huang, Z., **Danyushevsky, L.**, and Wang, H., 2021, LA-ICP-MS sphalerite and galena trace element chemistry and mineralization-style fingerprinting for carbonate-hosted Pb-Zn deposits: Perspective from early Devonian Huodehong deposit in Yunnan, South China: *Ore Geology Reviews*, v. 136, Article 104253.

Jiang, H., Zhao, K-D., Jiang, S-Y., Li, W-Q., **Khin Zaw** and Zhang, D., 2021, Late Triassic post-collisional high-K two-mica granites in Peninsular Thailand, SE Asia: Petrogenesis and Sn mineralization potential: *Lithos*, v. 398-399, Article 106290.

Kanouo, N.S., Lentz, D.R., **Khin Zaw**, **Makoundi, C.**, Basua, E.A.A., Yongué, R.F., and Njonfang, E., 2021, New insights into Pre-to-Post Ediacaran zircon fingerprinting of the Mamfe PanAfrican Basement, SW Cameroon: A possible link with rocks in SE Nigeria and the Borborema Province of NE Brazil: *Minerals*, v.11(9), Article 943.

Khin Mar Phyu, **Khin Zaw**, Mernagh, T.P., and Thu Zar Aung, 2021, Characterisation and genesis of sapphires from the Yenya-U Area, Thabeikkyin Township, Mandalay Region, Myanmar: *The Journal of Gemmology*, v. 37(8), p. 802–815.

Kutterolf, S., Freundt, A., Druitt, T.H., **McPhie, J.**, Nomikou, P., Pank, K., Schindlbeck-Belo, J.C., Hansteen, T.H., and **Allen, S.**, 2021, The medial offshore record of explosive volcanism along the central to eastern Aegean Volcanic Arc, part 2: Tephra ages and volumes, eruption magnitudes and marine sedimentation rate variations: *Geochemistry, Geophysics, Geosystems*, v. 22(12), Article e2021GC010011.

Kutterolf, S., Freundt, A., Hansteen, T.H., Dettbarn, R., Hampel, F., Sievers, C., Wittig, C., **Allen, S.R.**, Druitt, T.H., **McPhie, J.**, Nomikou, P., Pank, K., Schindlbeck-Belo, J.C., Wang, K-L., Lee, H-Y., and Friedrichs, B., 2021, The medial offshore record of explosive volcanism along the central to eastern Aegean Volcanic Arc, part 1: Tephrostratigraphic correlations: *Geochemistry, Geophysics, Geosystems*, v. 22(12), Article e2021GC010010.

Li, W., Zhang, F., Hu, C., **Zhang, L.**, and Qiao, X., 2021, Ore genesis and tectonic setting of the Bieluwutu Cu-Pb-Zn volcanogenic massive sulfide deposit in Xing’an-Mongolia orogenic belt, China: *Ore Geology Reviews*, v. 130, Article 103951.

Liao, Y., Zhang, D., **Danyushevsky, L.V.**, Li, T., and Liu, Y., 2021, Protracted lifespan of the late Mesozoic multistage Qianlishan granite complex, Nanling

Range, SE China: Implications for its genetic relationship with mineralization in the Dongpo ore field: Ore Geology Reviews, v. 139(Part A), Article 104445.

Liao, Y., Zhao, B., Zhang, D., **Danyushevsky, L.V.**, Li, T., Wu, M., and Liu, F., 2021, Evidence for temporal relationship between the late Mesozoic multistage Qianlishan granite complex and the Shizhuyuan W–Sn–Mo–Bi deposit, SE China: Scientific Reports, v. 11, Article 5828.

Makoundi, C., Endut, Z., **Large, R.R., Khin Zaw, Lounejeva, E.**, Leman, M.S., Mohamed, K.R., and Basori, M.B., 2021, Geochemistry of pyritic mudstones from the Singa formation, Malaysia: insights into gold potential, source of sulfur and organic matter: Geosciences, v. 11(7), Article 279.

Myo Kyaw Hlaing, Yonezu, K., **Khin Zaw**, Aung Zaw Myint, May Thwe Aye and Watanabe, K., 2021, Origin and characteristics of the Shwetagun Deposit, Modi Taung-Nankwe gold district and the Kunzeik and Zibyaung deposits, Kyaukhto Gold District in Mergui Belt, Myanmar: Implications for fluid source and orogenic gold mineralization: Frontiers in Earth Science, v. 9, Article 772083.

Nekrylov, N., Popov, D.V., Plechov, P.Y., Shcherbakov, V.D., and **Danyushevsky, L.V.**, 2021, The origin of the Late Quaternary back-arc volcanic rocks from Kamchatka: evidence from the compositions of olivine and olivine-hosted melt inclusions: Contributions to Mineralogy and Petrology, v. 176(9), Article 71.

Nie, L., Zhou, T., White, N., **Zhang, L., Olin, P.**, and **Meffre, S.**, 2021, Textures, trace elements and Pb isotopes of pyrite from the Donggushan tungsten polymetallic deposit, Eastern China: Deciphering the source of a skarn tungsten polymetallic deposit: Ore Geology Reviews, v. 133, Article 104077.

*Norris, C.A., **Danyushevsky, L., Olin, P.**, and West, N.R., 2021, Elimination of aliasing in LA-ICP-MS by alignment of laser and mass spectrometer: Journal of Analytical Atomic Spectrometry, v. 36, p. 733–739.

Pearce, M., and **Escolme, A.**, 2021, Phase heritage during replacement reactions in Ti-bearing minerals: Contributions to Mineralogy and Petrology, v. 176(3), Article 21.

Rose-Koga, E.F., Bouvier, A.S., Gaetani, G.A., Wallace, P.J., Allison, C.M., Andrys, J.A., Angeles de la Torre, C.A., Barth, A., Bodnar, R.J., Bracco Gartner, A.J.J., Butters, D., Castillejo, A., Chilson-Parks, B., Choudhary, B.R., Cluzel, N., Cole, M., Cottrell, E., Daly, A., **Danyushevsky, L.V.**, DeVitre, C.L., Drignon, M.J., France, L., Gaborieau, M., Garcia, M.O., Gatti, E., Genske, F.S., Hartley, M.E., Hughes, E.C., Iveson, A.A., Johnson, E.R., Jones, M., Kagoshima, T., Katzir, Y., Kawaguchi, M., Kawamoto, T., Kelley, K.A., Koornneef, J.M., Kurz, M.D., Laubier, M., Layne, G.D., Lerner, A., Lin, K-Y., Liu, P-P., Lorenzo-Merino, A., Luciani, N., Magalhaes, N., Marschall, H.R., Michael, P.J., Monteleone, B.D., Moore, L.R., Moussallam, Y., Muth, M., Myers, M.L., Narvaez, D.F., Navon, O., Newcombe, M.E., Nichols, A.R.L., Nielsen, R.L., Pamukcu, A., Plank, T., Rasmussen, D.J., Roberge, J., Schiavi, F., Schwartz, D., Shimizu, K., Shimizu, K., Shimizu, N., Thomas, J.B., Thompson, G.T., Tucker, J.M., Ustunisik, G., Waelkens, C., Zhang, Y., and Zhou, T., 2021, Silicate melt inclusions in the new millennium: A review of recommended practices for preparation, analysis, and data presentation: Chemical Geology, v. 570, Article 120145.

Rowe, M.C., **Carey, R.J.**, White, J.D.L., Kilgour, G., Hughes, E., Ellis, B., Rosseel, J-B., and Segovia, A., 2021, Tarawera 1886: an integrated review of volcanological and geochemical characteristics of a complex basaltic eruption: New Zealand Journal of Geology and Geophysics, v. 64(2–3), p. 296–319.

Shi, M., **Khin Zaw**, Liu, S., Xu, B., **Meffre, S.**, Cong, F., Nie, F., Peng, Z., and Wu, Z., 2021, Geochronology and petrogenesis of Carboniferous and Triassic volcanic rocks in NW Laos: Implications for the tectonic evolution of the Loei Fold Belt: Journal of Asian Earth Sciences, v. 208, Article 104661.

Silveira Braga, F.C., Rosiere, C.A., Santos, J.O.S., Hagemann, S.G., **Danyushevsky, L.**, and Valle Salles, P., 2021, Geochemical and tectonic constraints on the genesis of iron formation-hosted magnetite-hematite deposits at the Guanhães Block (Brazil) by contact metasomatism with pegmatite intrusions: Ore Geology Reviews, v. 129, Article 103931.

Sokół, K., Finch, A.A., Hutchison, W., **Cloutier, J.**, Borst, A.M., and Humphreys, M.C.S., 2021, Quantifying metasomatic high-field-strength and rare-earth element transport from alkaline magmas: Geology, doi.org/10.1130/G49471.1



Beach detritus on King Island taken by PhD student Peter Berger during the SEG CODES Student Chapter field trip in April 2021.

***Steadman, J.A., Large, R.R., Olin, P.H., Danyushevsky, L.V., Meffre, S.**, Huston, D., Fabris, A., Lisitsin, V., and **Wells, T.**, 2021, Pyrite trace element behavior in magmatic-hydrothermal environments: An LA-ICPMS imaging study: Ore Geology Reviews, v. 128, Article 103878.

Stepanov, A.S., **Large, R.R.**, Kiseeva, E.S., **Danyushevsky, L.V.**, Goemann, K., **Meffre, S.**, Zhukova, I., and **Belousov, I.A.**, 2021, Phase relations of arsenian pyrite and arsenopyrite: Ore Geology Reviews, v. 136, Article 104285.

Stueken, E.E., Gregory, D.D., **Mukherjee, I.**, and **McGoldrick, P.**, 2021, Sedimentary exhalative venting of bioavailable nitrogen into the early ocean: Earth and Planetary Science Letters, v. 565, Article 116963.

Thomas, R., Rericha, A., **Davidson, P.**, and Beurlen, H., 2021, An unusual paragenesis of diamond, graphite, and calcite: A Raman spectroscopic study: Estudos Geologicos, v. 31(2), 13p.

*Thompson, J.M., Goemann, K., **Belousov, I., Jenkins, K.**, Kobussen, A., Powell, W., and **Danyushevsky, L.**, 2021, Assessment of the mineral

ilmenite for U–Pb dating by LA-ICP-MS: Journal of Analytical Atomic Spectrometry, v. 36, p. 1244–1260.

***Thompson, J.A., Thompson, J.M.**, Goemann, K., **Lounejeva, E., Cooke, D.R.**, and **Danyushevsky, L.**, 2021, Use of non-matrix matched reference materials for the accurate analysis of calcium carbonate by LA-ICP-MS: Geostandards and Geoanalytical Research, doi.org/10.1111/ggr.12405

*Wei, C., Ye, L., Hu, Y., Huang, Z., **Danyushevsky, L.**, and Wang, H., 2021, LA-ICP-MS analyses of trace elements in base metal sulfides from carbonate-hosted Zn-Pb deposits, South China: A case study of the Maoping deposit: Ore Geology Reviews, v. 130, Article 103945.

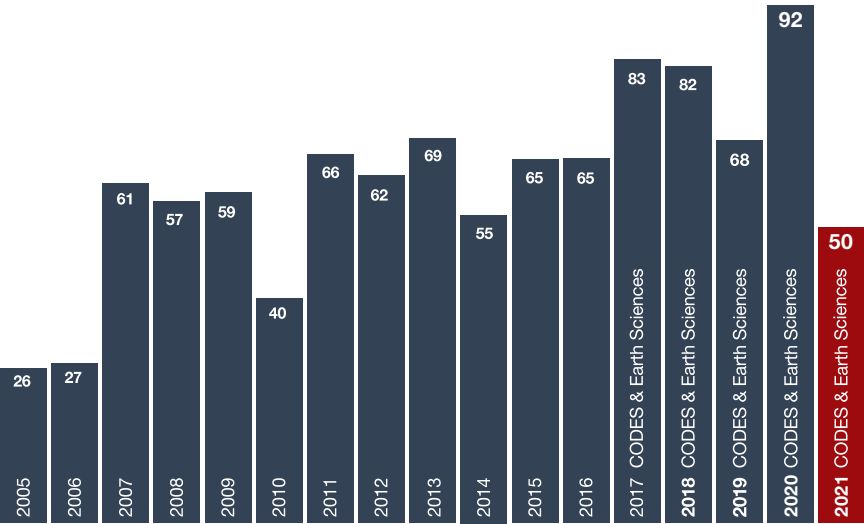
***Wells, T.J., Cooke, D.R., Baker, M.J., Zhang, L., Meffre, S., Steadman, J.**, Norman, M.D., and Hoye, J.L., 2021, Geology and geochronology of the Two-Thirty prospect, Northparkes district, NSW: Australian Journal of Earth Sciences, v. 68(5), p. 659–683.

Xiao, X., Zhou, T., **White, N.C.**, Fan, Y., **Zhang, L.**, and Chen, X., 2021, Porphyry Cu mineralization processes

of Xinqiao deposit, Tongling ore district: Constraints from the geochronology and geochemistry of zircon, apatite, and rutile: Ore Geology Reviews, v. 138, Article 104340.

Xu, R., Deng, M-G., Li, W-C., Lai, C-K., **Khin Zaw**, Gao, Z-W., Chen, Y-H., Niu, C-H., and Liang, G., 2021, Origin of the giant Luziyuan Zn-Pb-Fe(-Cu) distal skarn deposit, Baoshan block, SE Tibet: Constraints from Pb–Sr isotopes, calcite C–O isotopes, trace elements and Sm–Nd dating: Journal of Asian Earth Sciences, v. 205, Article 104587.

Zhong, R., Deng, Y., Li, W., **Danyushevsky, L.V., Cracknell, M., Belousov, I.**, Chen, Y., and Li, L., 2021, Revealing the multi-stage ore-forming history of a mineral deposit using pyrite geochemistry and machine learning-based data interpretation: Ore Geology Reviews, v. 133, Article 104079.



REFEREED JOURNAL ARTICLES



Participants on the King Island SEG Student Chapter trip, April 2021, inspecting a mixture of shale and basalt (Photo by Peter Berger).

Book Chapters (3)

***Leslie, C., Meffre, S., Cooke, D.R., Thompson, J.,** Howard, N., and Barker, A., 2021, Complex petrogenesis of porphyry-related magmas in the Cowal District, Australia: Insights from LA ICP-MS zircon imaging, in Sholeh, A., and Wang, R., (eds), Society of Economic Geologists Special Publication Number 24 Vol 2: Tectonomagmatic Influences on Metallogeny and Hydrothermal Ore Deposits: A Tribute to Jeremy P. Richards, United States, Society of Economic Geologists, Inc, p. 159–180.

Lounejeva, E., Steadman, J.A., Rodemann, T., Large, R.R., Danyushevsky, L., Mantle, D., Grice, K., and Algeo, T.J., 2021, Marcasite at the Permian-Triassic Transition, in Ernst, R.E., Dickson, A.J., and Bekker, A., (eds), Geophysical Monograph 255: Large Igneous Provinces, United States, John Wiley and Sons, Inc and the American Geophysical Union, p. 377–399.

Large, R.R., Steadman, J.A., Mukherjee, I., Corkrey, R., Sack, P., and Ireland, T.R., 2021, Trends in Ocean S-Isotopes May Be Influenced by Major LIP Events, in Ernst, R.E.,

Dickson, A.J., and Bekker, A., (eds), Geophysical Monograph 255: Large Igneous Provinces, United States, John Wiley and Sons, Inc and the American Geophysical Union, p. 341–376.

Conference abstracts, papers and presentations (59)

Aung Min Oo, Xinbiao, L., and Khin Zaw, 2021, Genesis of the Lyhamyar antimony deposit, Hopong Township, Southern Shan State, Myanmar: Constraints from fluid inclusions and H-O-S-Pb isotopic compositions: Virtual GEOSEA 2021.

Berry, R., Goemann, K., and Danyushevsky, L., 2021, Geology of the Mutis Complex, Miomaffo, West Timor: AESC Online 2021, Abstract, 1p.

Bottrill, R., Everard, J., Duncan, D., Sutherland, L., Meffre, S., and Matchan, R., 2021, Gem sapphires and zircons in a basalt diatreme, northeastern Tasmania: AESC Online 2021, Abstract, 1p.

Burrett, C., Thassanapak, H., Udchachon, M., Gibson, L., Khin Zaw and Meffre, S., 2021, Indochina – New Palaeozoic data, terranes and new

tectonic hypotheses: GEOTHAI 2021 (virtual), Abstract (keynote), 2 p.

Burrett, C., Thassanapak, H., Udchachon, M., Gibson, L., Khin Zaw and Meffre, S., 2021, Peri-Gondwana terranes – New Palaeozoic data and new tectonic hypotheses: IGCP 668 Annual Meeting (virtual), Abstracts, p. 28–29.

Clark, A., Carey, R.J., Jutzeler, M., and Mitchell, S., 2021, Transitions in eruptive style during the 2012 deep submarine silicic eruption of Havre Volcano, Kermadec Arc, New Zealand: AESC Online 2021, Oral presentation.

Clark, A.S., Mitchell, S.J., and Carey, R.J., 2021, Using cristobalite to interpret the outgassing history of submarine silicic lavas: GESSS 2021, Abstract, 1p.

Cloutier, J., and Piercey, S.J., 2021, Tracing mineralogy and alteration intensity using the spectral alteration index and depth ratios at the Northwest Zone of the Lemarchant VMS deposit, Newfoundland, Canada: AESC Online 2021, Abstract, 1p.

*Coaquira, T.X., Escolme, E., Zhang, L., and Cooke, D.R., 2021, Mineralogy, textures, and paragenesis of the

Resolution Cu-Mo porphyry deposit, Arizona: SEG100 Conference, Sep 14–17, Whistler, Canada, Abstract, 2p.

Cracknell, M., Scott, R., and Foulds, D., 2021, Extending cluster derived LA-ICP-MS geochemical domains through optical microscopy image classification: Goldschmidt Virtual 2021, Abstract, 1p.

Cumming, G.V., Bottrill, R.S., Calver, C., and Meffre, S., 2021, Geochronology of various fault bound units at Savage River: a melange of different terranes: AESC Online 2021, Abstract, 1p.

Cumming, G., Orth, K., Bottrill, R., Everard, J., and Vicary, M., 2021, Evidence for fire fountaining at Skillion Hill, southern Tasmania: AESC Online 2021, Abstract, 1p.

Escolme, A., 2021, Using exploration datasets in geometallurgical models: Applied Geochemistry in Exploration Conference (virtual), Invited oral presentation.

Farrar, A., Cooke, D., Hronsky, J., Cracknell, M., and Piquer, J., 2021, Lithospheric architecture of the central Andes and the localization of giant porphyry copper deposits: SEG100 Conference, Sep 14–17, Whistler, Canada, Abstract, 2p.

Farrar, A., Cracknell, M., Cooke, D., Hronsky, J., and Piquer, J., 2021, Interpreting and validating trans-lithospheric faults in the Central Andes to investigate their control on the localisation of giant porphyry copper deposits: AESC Online 2021, Abstract, 1p.

Gallagher, T., Bottrill, R., Carey, R., Cumming, G., and Orth, K., 2021, Does the St Marys Porphyry represent a super eruption in eastern Tasmania?: AESC Online 2021, Abstract, 1p.

Gregory, D., Lui, T., Wu, S., and Large, R., 2021, Do rocks deposited during time periods with high gold in sedimentary pyrite host more gold mineralization?: AESC Online 2021, Abstract, 1p.

Guerrero, N., Hunt, J., Clarke, N., Barros, A., and Keeney, L., 2021, Grade engineering at Gramalote gold deposit, Colombia: an example of industry-research collaboration, Part 2: Preconcentration Digital Conference, Proceedings, p. 409–415.

Guerrero, N., Hunt, J., Cracknell, M.J., and Keeney, L., 2021, Estimation of preferential grade-by-size deportment in gold systems: Sustainable Minerals '21 (virtual), Abstract.

Habib, U., Meffre, S., and Bottrill, R., 2021, Age constraints on the formation and emplacement of Cambrian Ophiolites along Heathcote, Dookie, and Governor fault zones, Central Victoria: AESC Online 2021, Abstract, 1p.

Habib, U., Meffre, S., Kultaksayos, S., and Berry, R., 2021, Provenance of late Cambrian–Ordovician sedimentary rocks in western, northeastern Tasmania and southern Victoria: constraints from U/Pb dating, zircon geochemistry and ϵ_{Hf} isotope: AESC Online 2021, Abstract, 1p.

Habib, U., Musgrave, R., and Meffre, S., 2021, Overprinting of remanence in Paleozoic rocks of the Lachlan Orogen in southeast Australia: AEGC Online 2021, Abstract, 1p.

*Hamilton, P., Holling, P., Zhang, L., Goemann, K., Hemming, S., Arellano, I., and Taningco, R., 2021, Characterizing advanced argillic and silicic alteration of the Pemberton Hills lithocap, British Columbia using SWIR, XRD, and SEM – implications for lithocap formation: SEG100 Conference, Sep 14–17, Whistler, Canada, Abstract, 1p.

Harraden, C., Hong, W., and Deyell-Wurst, C., 2021, Characterising the hyperspectral SWIR features of tourmaline from two western Tasmanian granites: AESC Online 2021, Abstract, 1p.

Hasterok, D.P., Gard, M., Halpin, J.A., Hand, M.P., Staal, T., Raimondo, T., and McLaren, S., 2021, Improving thermal properties estimates of the Antarctic crust and their uncertainties: AGU 2021 Fall Meeting Online, Abstract, 1p.

Heng, W.X., Wilson, O., Fisher, E., Roach, M.J., Miller, C.B., and Cracknell, M.J., 2021, Integrated geophysics for three-dimensional modelling of mine waste: GAC-MAC 2021, Oral presentation.

Hohl, M., Barker, S., Cloutier, J., and Steadman, J., 2021, Using trace element chemistry of magnetite as an indicator mineral at the Starra iron-

oxide copper gold deposits, Northwest Queensland: AESC Online 2021, Abstract, 1p.

Hunt, J., 2021, Advances in geomettallurgy: Ore Geology conference (virtual), Invited abstract.

Hunt, J., 2021, Rocks first geomettallurgy: Applied Geochemistry in Exploration Conference (virtual), Invited oral presentation.

Hunt, J., Guerrero, N., and Wilkie, G., 2021, Increasing efficiency through understanding geological controls on Grade Engineering. SEG 2020: Vision for the next 100 years, Abstract.

Jackson, L., K ng, L., Parbhakar-Fox, A., and Meffre, S., 2021, Opportunities for reprocessing polymetallic tailings in western Tasmania: AESC Online 2021, Abstract, 1p.

*Jedemann, A., Hollings, P., Cooke, D.R., Orovan, E., Dietz, C., Barker, S., Olin, P., and Arellano, I., 2021, Characterization of assemblages in the porphyry environment at Pemberton Hills, Vancouver Island, British Columbia, Canada: SEG100 Conference, Sep 14–17, Whistler, Canada, Abstract, 2p.

Jutzeler, M., Dagasan, Y., Carey, R.J., and Ila'ava, M., 2021, Quantification of crystal size distribution in volcanic rocks with machine-learning image analysis: AGU 2021 Fall Meeting Online, Oral presentation.

Jutzeler, M., van Seville, E., and Marsh, R., 2021, Real-time tracking of the 2019 pumice raft in the southwest Pacific: AESC Online 2021, Oral presentation.

Khin Zaw, 2021, Cu-Au skarn deposits in SE Asia and their exploration potentials: AOGS Virtual Conference 2021.

Khin Zaw, 2021, Holocene volcanism at Mount Popa Volcano, central Myanmar: Implications for tectonic setting, mineralisation and geohazard: Virtual GEOSEA 2021.

Khin Zaw, 2021, Metallogeny of Cu-Au skarn deposits in SE Asia and their exploration potentials: GEOTHAI 2021 (virtual).

Khin Zaw, 2021, Tectonic, geochronological and metallogenic framework of ore deposits along Loei Fold Belt, Laos PDR and Thailand:

Extension into Myanmar and Cambodia: 4th International Virtual Conference on Substantial Scientific Collaboration of Ocean and Earth Science Between Myanmar and China.

Khin Zaw, Basori, M.B.I., Meffre, S., Large, R.R., Makoundi, C., Burrett, C., Tran, H.T., and Lai, C.K., 2021, Geochronology and tectonic setting of volcanic-hosted massive sulphide deposits in SE Asia: IGCP 668; Equatorial Gondwana History, and Early Palaeozoic Evolutionary Dynamics Conference Online.

Makoundi C., Khin Zaw, Large, R.R., and Endut, Z., 2021, Geochemistry of cherts and trace element of pyrite from the BRSZ Unit 2 Formation, Central Gold Belt of Peninsular Malaysia: Virtual GEOSEA 2021.

Meffre, S., Leslie, C., Wells, T., Habib, U., and Schaap, T., 2021, New constraints on the tectonic and metallogenic history of Lachlan Orogen: AESC Online 2021, Abstract, 1p.

Miller, C.B., Parsons, M.B., Jamieson, H.E., Ardakani, O.H., Nasser, N.A., Gregory, B.R., Patterson, T., and Galloway, J.M., 2021, Post-depositional mobility of As in a changing climate: Implications for cumulative effects assessments at northern mine sites: GAC-MAC 2021, Oral presentation.

Moore, H.C., Carey, R.J., Houghton, B.H., Jutzeler, M., and White, J.D.L., 2021, High-temperature oxidation of pyroclasts in the proximal 1886 Tarawera basaltic deposits, New Zealand: GESSS 2021, Abstract, 1p.

Moore, H.C., Carey, R.J., Houghton, B.H., Jutzeler, M., and White, J.D.L., 2021, Shallow conduit and vent processes during the 1886 basaltic Plinian eruption at Tarawera, New Zealand: AESC Online 2021, Abstract.

Morales Leiva, K.A., Hunt, J., Cracknell, M.J., and Roach, M.J., 2021, Preconcentration via screening: A path to optimise ore processing: GESSS 2021, Abstract, 1p.

*Moyo, A., Parbhakar-Fox, A., Meffre, S., and Cooke D.R., 2021, Application of alkaline industrial wastes in remediation of acid and metalliferous drainage generated by legacy mine wastes: AESC Online 2021, Abstract, 1p.

*Moyo, A., Parbhakar-Fox, A., Meffre, S., Miller, C.B., and Cooke D.R., 2021, Application of alkaline industrial wastes in the remediation of acid and metalliferous drainage generated by legacy mine wastes: Goldschmidt Virtual 2021, Abstract, 1p.

Ostensen, T., Reading, A., Cracknell, M., Roach, M., McNeill, A., Duffett, M., Bombardieri, D., Thiel, S., Robertson, K., Duan, J., and Heinson, G., 2021, Geoelectric structure of Tasmania from multi-scale magnetotelluric data: AESC Online 2021, Abstract, 1p.

*Phillips, J., Thompson, J., Meffre, S., Cracknell, M.J., Danyushevsky, L.V., and Cooke, D.R., 2021, Epidote U-Pb geochronology and multivariate analysis of green rock mineral chemistry – Fingerprinting the fertile porphyry signal in a sea of green: AESC Online 2021, Oral presentation.

*Phillips, J., Thompson, J., Meffre, S., Maas, R., Danyushevsky, L., and Cooke, D., 2021, Using epidote U-Pb geochronology and multivariate statistics to unravel overprinting propylitic alteration around the Resolution porphyry-Cu-Mo deposit: Fingerprinting the fertile porphyry signal: AESC Online 2021, Abstract, 1p.

Reading A., Morse, P., and Staal, T., 2021, Parallel coordinate visualisations for knowledge generation in the geosciences: AESC Online 2021, Abstract, 1p.

Roach, M., Orth, K., and Scott, R., 2021, Coping with COVID – using virtual geological objects for on-line Earth Science Education: AESC Online 2021, Abstract, 1p.

*Seow, X.N., Zhang, L., Orovan, E., Roach, M., White, N.C., Cooke, D.R., and Kim, E-J., 2021, Advanced argillic alteration at the Ogmaesan clay mine in Seongsan district, South Korea: SEG100 Conference, Sep 14–17, Whistler, Canada, Abstract, 1p.

Staal, T., Reading, A.M., Cracknell, M.J., Halpin, J.A., Latto, R.B., Morse, P.E., Turner, R.J., and Whittaker, J.M., 2021, Data-driven tectonic regionalization of Antarctica: Appreciate the similarity: AESC Online 2021, Abstract, 1p.

Staal, T., Reading, A.M., Halpin, J.A., McCormack, F., Roberts, J.L., and Whittaker, J.M., 2021, Modelling

Antarctic subglacial geothermal heat transfer in higher resolution, with reduced uncertainty and assumptions addressed: AGU 2021 Fall Meeting Online, Abstract, 1p.

Wang, C., Olivier, G., and Jutzeler, M., 2021, Application of passive seismic for exploration in the Palaeozoic basement underneath Tertiary basalts, western Tasmania: AEGC Online 2021, Abstract, 1p.

*Wells, T., Meffre, S., Cooke, D.R., Steadman, J.A., and Goemann, K., 2021, Apatite as an indicator of porphyry fertility in the Northparkes district: AESC Online 2021, Abstract, 1p.

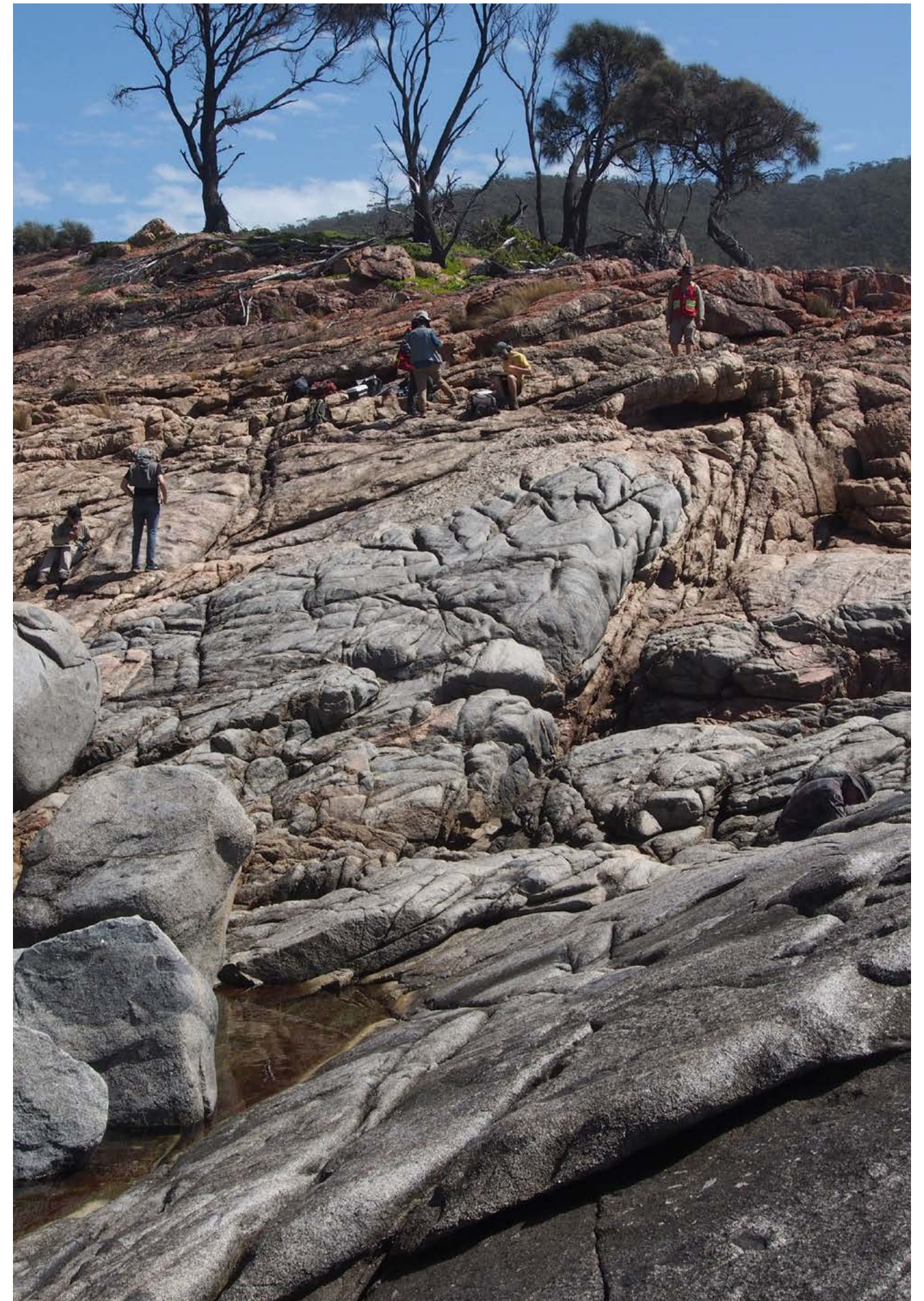
Zhang, L., Zhou, T., Fan, Y., White, N.C., Cooke, D., Chen, H., and Li, X., 2021, Advanced argillic alteration in the Lower Yangtze Metallogenic Belt: Porphyry-related or magnetite ($\pm$ apatite) deposit related?: AOGS 2021, Singapore, Abstract, 1p.

Zivkovic, Z., Danyushevsky, L., Baker, M., and Barker, S., 2021, “To fuse or not to fuse?” – whole-rock geochemistry method comparison for end-users: GESSS 2021, Abstract, 1p.

Invited keynote addresses (2)

Moore, H.C., 2021, The shallow conduit and vent processes during the 1886 basaltic Plinian eruption at Tarawera, New Zealand: AESC Online 2021.

Ostensen, T., 2021, Geoelectric structure of Tasmania from multi-scale magnetotelluric data: AESC Online 2021.



Participants of the Advanced Field Skills in Economic Geology short course, February 2021, at Bluestone Bay on the east coast of Tasmania (photo by Dr Rob Scott).

Research reports to industry/government agencies (219)

*Andrew, B., Brown, A., Rea, P., Shaw, T., Barker, S., Enkhbold, B., Baker, M., Cooke, D.R., and Halley, S., 2021, Mount Isa Copper Mine, Australia, Alteration of the Eastern Creek Volcanics (ECV): AMIRA P1202 Final Sponsors Meeting #1, 20 May 2021, p. 49–98.

*Baker, M., Belousov, I., Cracknell, M., Cooke, D.R., Danyushevsky, L., and Dreijing-Carroll, D., 2021, Aitik, Sweden: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 7–9.

*Baker, M., Belousov, I., Cracknell, M., Cooke, D.R., Danyushevsky, L., and Dreijing-Carroll, D., 2021, Laver, Sweden: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 21–22.

*Baker, M., Belousov, I., Cracknell, M., Danyushevsky, L., and Cooke, D.R., 2021, Laver and Aitik final report: AMIRA P1202 Final Sponsors Meeting #1, 20 May 2021, p. 13–48.

*Baker, M., Cooke, D.R., Barker, S., Cracknell, M., Hollings, P., Smyk, E., Jedemann, A., Arcos, C., Piquer, J., Enkhbold, B., Orovan, E., Belousov, I., Danyushevsky, L., and Marcelissen, M., 2021, Introduction to AMIRA P1202 final meeting #1 – Module 1: AMIRA P1202 Final Sponsors Meeting #1, 20 May 2021, p. 1–12.

*Baker, M., Cooke, D.R., Barker, S., Cracknell, M., Hollings, P., Smyk, E., Jedemann, A., Arcos, C., Piquer, J., Enkhbold, B., Orovan, E., Belousov, I., Danyushevsky, L., Marcelissen, M., and Cooke, S., 2021, AMIRA P1202 final meeting #4 – Module 1: AMIRA P1202 Final Sponsors Meeting #4, 30 June 2021, p. 24–57.

*Baker, M., and Orovan, E., 2021, Vermont greenstone belt, USA: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 29–30.

*Baker, M., Orovan, E., Cracknell, M., Belousov, I., and Bigelow, J., 2021, KCGM, Western Australia: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 19–20.

*Baker, M., and P1202 research team, 2021, Introduction to AMIRA P1202 final meeting for Modules 1–3: AMIRA P1202 Final Sponsors Meeting #4, 30 June 2021, p. 1–23.

*Baker, M., Zhang, L., Barker, S., Enkhbold, B., Belousov, I., and Kock, M., 2021, Potrerillos, Chile: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 27–28.

*Baker, M., Zhang, L., Danyushevsky, L., Morissette, M., and Ihlenfeld, C., 2021, West Wall, Chile: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 63–64.

*Barker, S., Enkhbold, B., Cooke, D.R., Baker, M., Andrew, B., Brown, A., Rea, P., and Shaw, T., 2021, Mount Isa Copper Deposits, Australia: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 23–26.

*Barker, S., Meffre, S., Cracknell, M., Danyushevsky, L., Cooke, D.R., Belousov, I., Baker, M., Zhang, L., Seow, X., and Merrill, J., 2021, New analytical approach: Sweep-by-Sweep LA-ICP-MS data processing and interpretation: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 32–33.

Belousov, I., 2021, P1048. Chlorite and epidote chemistry for 240 samples: Report to Codelco, 9 p.

*Belousov, I., Baker, M., Danyushevsky, L., Cooke, D.R., Testa, F., Zhang, L., Smyk, E., and Morissette, M., 2021, P1202 Newmont blind test – Module 3: AMIRA P1202 Final Sponsors Meeting #4, 30 June 2021, p. 105–149.

Belousov, I., Cooke, D., and Danyushevsky, L., 2021, P1083 Almaden Minerals fertility and vectoring report: Report to Almaden Minerals, 18 p.

Belousov, I., and Danyushevsky, L., 2021, P1048 Codelco fertility and vectoring report, Report to Codelco, 66 p.

Belousov, I., and Danyushevsky, L., 2021, P1083. Chlorite and epidote chemistry for 39 samples: Report to Almaden Minerals, 4 p.

Belousov, I., and Danyushevsky, L., 2021, P948. Tourmaline chemistry for 10 samples: Report to Codelco, 6 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P938 U-Pb apatite geochronology report: Report to Teck Vancouver, 6 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P938a U-Pb zircon geochronology report: Report to Teck Vancouver, 8 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P938b U-Pb zircon geochronology report: Report to Teck Turkey, 1 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P944 Report on U-Pb zircon geochronology and trace elements: Report to Anglo American (London), 7 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P944 U-Pb apatite geochronology report: Report to Anglo American (London), 6 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P944 U-Pb rutile geochronology report: Report to Anglo American (London), 6 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P945 U-Pb zircon geochronology report: Report to First Quantum, 7 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P947: U-Pb zircon geochronology report: Report to Kincora Copper, 7 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P956: Report on U-Pb zircon geochronology and trace elements: Report to Teck (Chile), 24 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P958 U-Pb zircon geochronology report: Report to ALS Brasil, 13 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P967. Chlorite and epidote chemistry for 17 samples: Report to Stavely Minerals, 5 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P969: U-Pb zircon geochronology report: Report to ALS Perth, 6 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P970 - U-Pb zircon geochronology report: Report to ALS Chile, 6 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P978 report No.

2-U-Pb zircon geochronology report: Report to Merdeka Copper Gold, 11 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P978 report No. 4-U-Pb zircon geochronology report: Report to Merdeka Copper Gold, 9 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P997 U-Pb apatite geochronology report: Report to Newmont Australia, 5 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P997 U-Pb zircon geochronology report: Report to Newmont Australia, 10 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1000 Pb apatite geochronology report: Report to Red River Resources, 4 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1000 U-Pb zircon geochronology report: Report to Red River Resources. 9 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1007 U-Pb zircon geochronology report: Report to AngloGold Ashanti, 6 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1014: U-Pb zircon geochronology report: Report to ALS Perth, 7 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1020: U-Pb zircon geochronology report: Report to Teck Chile, 7 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1025 U-Pb epidote geochronology report: Report to First Quantum Minerals, Chile, 5 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1034 U-Pb zircon geochronology report: Report to Red River Resources, 6 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1036 U-Pb zircon geochronology report: Report to Tehema Consultores Geológicos, 10 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1037: U-Pb zircon geochronology report: Report to Teck Chile, 11 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1043 U-Pb zircon geochronology report: Report to DGO Gold, 6 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1051, part 1 – U-Pb zircon geochronology report: Report to Antofagasta Peru, 13 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1051, part 2 – U-Pb zircon geochronology report: Report to Antofagasta Peru, 13 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1060 U-Pb zircon geochronology report: Report to Inflection Resources, 6 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1061: U-Pb zircon geochronology report: Report to ALS Perth, 6 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1069 Part 3: U-Pb zircon geochronology report: Report to BHP Peru, 8 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1069 Part 4: U-Pb zircon geochronology report: Report to BHP Peru, 8 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1069 Part 5: U-Pb zircon geochronology report: Report to BHP Peru, 7 p.

Belousov, I., Danyushevsky, L., and Morissette, M., 2021, P1080: U-Pb zircon geochronology report: Report to NTGS, 7 p.

Belousov, I., Goemann, K., and Danyushevsky, L., 2021, P940 – Gold deportment in mineral concentrates: Report to Merdeka/Sihayogold, 25 p.

Berry, R., 2021, Tandanyama, Ecuador: Calculation of mineralogy Preliminary Estimates: Report to SolGold, 10 p.

*Cloutier, J., Merrill, J., Eastman, K., Zhang, L., Escolme, A., Taube, R., and Bartlett, J., 2021, Resolving phyllosilicate mineralogy by Corescan, EMPA and FT-NIR: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 4, p. 24–25.

*Cloutier, J., Merrill Cifuentes, J., Escolme, A., Zhang, L., and Eastman, K., 2021, Tujuh Bukit – resolving phyllosilicate mineralogy using Corescan, FT-NIR microscopy and EPMA: AMIRA P1202 Final Sponsors Meeting #5, 1 July 2021, p. 166–191.

*Coaquira, T., Cooke, D.R., Zhang, L., Halley, S., and Escolme, A., 2021, Resolution, USA: AMIRA P1202 Final

Sponsors Meeting Executive Summary – Module 4, p. 14–15.

*Coaquira, T.X., Zhang, L., Escolme, A., Cooke, D.R., Halley, S., and Belousov, I., 2021, Hypogene upgrading at the giant Resolution Cu-Mo porphyry deposit: AMIRA P1202 Final Sponsors Meeting #3, 10 June 2021, p. 153–195.

*Coaquira, T.X., Zhang, L., Escolme, A., Cooke, D.R., Halley, S., and Belousov, I., 2021, Using spatial variations in white mica chemistry to locate giant high grade porphyry Cu-Mo deposits: Resolution case study: AMIRA P1202 Final Sponsors Meeting #3, 10 June 2021, p. 244–291.

*Cooke, D.R., Baker, M., Smyk, E., Cracknell, M., Zhang, L., Hollings, P., Orovan, E., White, N., Belousov, I., Gemmell, J.B., Thompson, J., Phillips, J., Garay, A., and Ahmed, A., 2021, The P1202 Explorer’s Toolbox; Workflow for green and white rock exploration: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 36–43.

*Cooke, D.R., Coaquira, T., Danyushevsky, L., Jones, R., Escolme, A., Osorio, J., Baker, M., Zhang, L., Orovan, E., Halley, S., Eastman, K., and Hamilton, P., 2021, White mica mineral chemistry synthesis: AMIRA P1202 Final Sponsors Meeting #5, 1 July 2021, p. 13–88.

*Cooke, D.R., Coaquira, T., Danyushevsky, L., Jones, R., Escolme, A., Osorio, J., Baker, M., Zhang, L., Testa, F., Orovan, E., Halley, S., Eastman, K., and Hamilton, P., 2021, White mica mineral chemistry synthesis: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 4, p. 22–23.

*Cooke, D.R., Cracknell, M., Belousov, I., Danyushevsky, L., Barker, S., Baker, M., Cooke, S., Chang, Z., Thompson, J., White, N., and Wilkinson, J., 2021, Batu Hijau, Indonesia: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 10–12.

*Cooke, D.R., Cracknell, M., Belousov, I., Danyushevsky, L., Barker, S., Baker, M., Cooke, S., Wilkinson, J., Chang, Z., Thompson, J., and White, N., 2021, New insights into chlorite from the Batu Hijau district, Indonesia: AMIRA P1202 Final Sponsors Meeting #1, 20 May 2021, p. 177–249.

*Cooke, D.R. and the P1202 Research Team, 2021, Performance review and major outcomes of P1202: AMIRA P1202 Final Sponsors Meeting #4, 30 June 2021, p. 216–235.

*Cracknell, M., Cooke, S., Cooke, D.R., Baker, M., Smyk, E., Danyushevsky, L., and Belousov, I., 2021, LocateOre v 2.0: AMIRA P1202 Final Sponsors Meeting #1, 20 May 2021, p. 99–110.

*Cracknell, M., Cooke, S., Cooke, D.R., Danyushevsky, L., Belousov, I., Baker, M., and Smyk, E., 2021, LocateOre Heat Source Vectoring: AMIRA P1202 Final Sponsors Meeting #1, 20 May 2021, p. 250–266.

*Cracknell, M., Cooke, S., Cooke, D.R., Danyushevsky, L., Belousov, I., Baker, M., Smyk, E., and Jedemann, A., 2021, LocatOre version 2: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 34–35.

*Danyushevsky, L., Baker, M., Belousov, I., Marcelissen, M., Smyk, E., Hollings, P., Cooke, D.R., Garay, A., Ahmed, A., Speakman, B., Torres, F., Thompson, J., and Morissette, M., 2021, Analysing magmatic minerals from the P765 – P1153 sample collections – Module 3 Synthesis: AMIRA P1202 Final Sponsors Meeting #4, 30 June 2021, p. 92–104.

Danyushevsky, L., and Belousov, I., 2021, P1156: Report on elemental concentrations of one quartz and one mica crystals: Report to Oritain, 8 p.

Danyushevsky, L., and Morissette, M., 2021, P950 U-Pb zircon geochronology report: Report to First Quantum Chile, 6 p.

Danyushevsky, L., and Morissette, M., 2021, P953: U-Pb zircon geochronology report: Report to Teck Vancouver, 7 p.

Danyushevsky, L., and Morissette, M., 2021, P963 Report on quartz trace element contents: Report to High Purity Quartz Ltd, 11 p.

Danyushevsky, L., and Morissette, M., 2021, P973: U-Pb zircon geochronology report: Report to ALS Brisbane, 6 p.

Danyushevsky, L., and Morissette, M., 2021, P974 U-Pb zircon geochronology report: Report to Tehema Consultores Geológicos, 14 p.

Danyushevsky, L., and Morissette, M., 2021, P975: U-Pb zircon geochronology report: Report to ALS Perth, 6 p.

Danyushevsky, L., and Morissette, M., 2021, P976: U-Pb zircon geochronology report: Report to ALS Perth, 5 p.

Danyushevsky, L., and Morissette, M., 2021, P978 report No. 1 – U-Pb zircon geochronology report: Report to Merdeka Copper Gold, 9 p.

Danyushevsky, L., and Morissette, M., 2021, P992: U-Pb zircon geochronology report: Report to ALS Perth, 6 p.

Danyushevsky, L., and Morissette, M., 2021, P993: U-Pb zircon geochronology report: Report to ALS Perth, 7 p.

Danyushevsky, L., and Morissette, M., 2021, P995 Report on quartz trace element contents: Report to High Purity Quartz Ltd, 13 p.

Danyushevsky, L., and Morissette, M., 2021, P996: U-Pb zircon geochronology report: Report to ALS Brisbane, 6 p.

Danyushevsky, L., and Morissette, M., 2021, P954: U-Pb zircon geochronology report: Report to BHP Peru, 8 p.

Danyushevsky, L., and Morissette, M., 2021, P959 U-Pb zircon geochronology report: Report to Anglo American Peru, 7 p.

Danyushevsky, L., and Morissette, M., 2021, P1001 U-Pb zircon geochronology report: Report to First Quantum Chile, 5 p.

Danyushevsky, L., and Morissette, M., 2021, P1005 Report on quartz trace element contents: Report to High Purity Quartz Ltd, 13 p.

Danyushevsky, L., and Morissette, M., 2021, P1015 Report on quartz trace element contents: Report to High Purity Quartz Ltd, 15 p.

Danyushevsky, L., and Morissette, M., 2021, P1032 U-Pb apatite geochronology report: Report to De Grey Mining, 6 p.

Danyushevsky, L., and Morissette, M., 2021, P1038 Part 1: U-Pb zircon

geochronology report: Report to BHP Peru, 7 p.

Danyushevsky, L., and Morissette, M., 2021, P1038 Part 2: U-Pb zircon geochronology report: Report to BHP Peru, 12 p.

Danyushevsky, L., and Morissette, M., 2021, P1048 U-Pb zircon geochronology report: Report to Codelco, 16 p.

Danyushevsky, L., and Morissette, M., 2021, P1049: U-Pb zircon geochronology report: Report to Teck Vancouver, 8 p.

Danyushevsky, L., and Morissette, M., 2021, P1054: U-Pb zircon geochronology report: Report to ALS Perth, 5 p.

Danyushevsky, L., and Morissette, M., 2021, P1055: U-Pb zircon geochronology report: Report to ALS Perth, 5 p.

Danyushevsky, L., and Morissette, M., 2021, P1062: U-Pb zircon geochronology report: Report to Amawta Geoconsultore, 12 p.

Danyushevsky, L., and Morissette, M., 2021, P1065 U-Pb zircon geochronology report: Report to Teck Chile, 12 p.

Danyushevsky, L., and Morissette, M., 2021, P1066: U-Pb zircon geochronology report: Report to First Quantum Chile, 6 p.

Danyushevsky, L., and Morissette, M., 2021, P1067: U-Pb zircon geochronology report: Report to First Quantum Chile, 6 p.

Danyushevsky, L., and Morissette, M., 2021, P1069 Part 1: U-Pb zircon geochronology report: Report to BHP Peru, 12 p.

Danyushevsky, L., and Morissette, M., 2021, P1069 Part 2: U-Pb zircon geochronology report: Report to BHP Peru, 9 p.

Danyushevsky, L., and Morissette, M., 2021, P1082 U-Pb zircon geochronology report: Report to First Quantum Zambia, 14 p.

Danyushevsky, L., and Morissette, M., 2021, P1084: U-Pb zircon geochronology report: Report to ALS Perth, 7 p.

Danyushevsky, L., and Morissette, M., 2021, P1090_Part1 U-Pb zircon geochronology report: Report to Teck Chile, 16 p.

Danyushevsky, L., and Morissette, M., 2021, P1090_Part2 U-Pb zircon geochronology report: Report to Teck Chile, 18 p.

Danyushevsky, L., and Morissette, M., 2021, P1090_Part3 U-Pb zircon geochronology report: Report to Teck Chile, 20 p.

Danyushevsky, L., and Morissette, M., 2021, P1092 U-Pb zircon geochronology report: Report to First Quantum Chile, 7 p.

Danyushevsky, L., and Morissette, M., 2021, P1105: U-Pb zircon geochronology report: Report to Teck Vancouver, 9 p.

Danyushevsky, L., and Morissette, M., 2021, P1109: U-Pb zircon geochronology report: Report to Anglo American USA, 9 p.

Danyushevsky, L., and Morissette, M., 2021, P1112: U-Pb zircon geochronology report: Report to Anglo American Chile, 9 p.

Danyushevsky, L., and Morissette, M., 2021, P1117: U-Pb zircon geochronology report: Report to Chilean Geological Survey, 11 p.

Danyushevsky, L., and Morissette, M., 2021, P1119. Part 1: U-Pb zircon geochronology report: Report to ALS, 12 p.

Danyushevsky, L., and Morissette, M., 2021, P1119. Part 2: U-Pb zircon geochronology report: Report to ALS, 13 p.

Danyushevsky, L., and Morissette, M., 2021, P1124: U-Pb zircon geochronology report: Report to ALS Perth, 6 p.

Danyushevsky, L., and Morissette, M., 2021, P1133 U-Pb zircon geochronology report: Report to Teck Chile, 6 p.

Danyushevsky, L., and Morissette, M., 2021, P1134: U-Pb zircon geochronology report: Report to Anglo American, 8 p.

Danyushevsky, L., and Morissette, M., 2021, P1137 U-Pb zircon

geochronology report: Report to First Quantum Chile, 5 p.

Danyushevsky, L., and Morissette, M., 2021, P1138 U-Pb zircon geochronology report: Report to Amawta Geoconsultore, 5 p.

Danyushevsky, L., and Morissette, M., 2021, P1145: U-Pb zircon geochronology report: Report to Anglo American Chile, 6 p.

Danyushevsky, L., Morissette, M., and Belousov, I., 2021, P978 report No. 3 – U-Pb zircon geochronology report: Report to Merdeka Copper Gold, 11 p.

Danyushevsky, L., Morissette, M., and Belousov, I., 2021, P984: U-Pb zircon geochronology report: Report to ALS Perth, 11 p.

Danyushevsky, L., Morissette, M., and Belousov, I., 2021, P1110: U-Pb zircon and apatite geochronology report: Report to Anglo American Chile, 9 p.

Danyushevsky, L., Morissette, M., and Belousov, I., 2021, P1113 U-Pb zircon and apatite geochronology report: Report to Amawta Geoconsultore, 11 p.

Danyushevsky, L., Morissette, M., and Belousov, I., 2021, P1115 U-Pb zircon and apatite geochronology report: Report to Chilean Geological Survey, 10 p.

*Escolme, A., and the P1202 Research Team, 2021, Introduction to AMIRA P1202 final meeting for Module 4: AMIRA P1202 Final Sponsors Meeting #5, 1 July 2021, p. 1–12.

*Escolme, A., Baker, M., Fabreschi, E., Merrill, J., Gaibor, A., and Avendaño M., 2021, Proximal white micas in the moderately phyllic overprinted Spence Cu-Mo porphyry, Chile: AMIRA P1202 Final Sponsors Meeting #3, 10 June 2021, p. 29–78.

*Escolme, A., Cooke, D.R., Zhang, L., Halley, S., Baker, M., Ailleres, L., Danyushevsky, L., Cracknell, M., Belousov, I., Cloutier, J., Barker, S., Armit, R., Piquer, J., Testa, F., Orovan, E., Eastman, K., Rodrigues, A., Merrill, J., Coaquira, T., Jones, R., Osorio, J., and Bozoglu, M., 2021, Introduction to AMIRA P1202 final meeting #3 – Module 4: AMIRA P1202 Final Sponsors Meeting #3, 10 June 2021, p. 1–14.

*Escolme, A., Fabreschi, E., Baker, M., Merrill, J., Gaibor, A., and Avendaño, M., 2021, Spence, Chile: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 4, p. 18–20.

*Escolme, A., Halley, S., Cooke, D.R., and P1202 Research Team, 2021, Revised geological models and new workflow for characterising porphyry transition zones from P1202 Module 4: AMIRA P1202 Final Sponsors Meeting #5, 1 July 2021, p. 261–301.

*Escolme, A., Halley, S., Jones, R., Coaquira, T., Osorio, J., Bozoglu, M., Zhang, L., and Cooke, D.R., 2021, Revised geological models for porphyry transition zones: AMIRA P1202 Final Sponsors Meeting #3, 10 June 2021, p. 292–299.

Farrar, A., 2021, Lithospheric architecture of the central Andes and the localization of giant porphyry copper deposits: Progress report to First Quantum Minerals, 20p.

*Fisher, E., 2021, Geochemical analysis of mine waste and pit lakes at Endurance Mine, northeast Tasmania: Final thesis provided to Mineral Resources Tasmania, 91p.

Goemann, K., and Danyushevsky, L., 2021, P1128 Mineralogical analysis of mineral concentrates: Report to Sihayogold, 17 p.

*Halley, S., Escolme, A., and Berry, R., 2021, Calculated Mineralogy using the Linear Programming Method: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 4, p. 26–28.

*Halley, S., Escolme, A., Berry, R., Jones, R., Coaquira T., and Osorio, J., 2021, Calculated Mineralogy Case Study: North Parkes: AMIRA P1202 Final Sponsors Meeting #5, 1 July 2021, p. 137–165.

Hunt, J., 2021, Geological controls on grade-by-size fractionation: CRC ORE Project P1-006: Final project snapshot report provided to CRC ORE, 1p.

Hunt, J., 2021, Geological controls on grade-by-size fractionation: CRC ORE Project P1-006: Final project summary report provided to CRC ORE, 16p.

Hunt, J., 2021, Geological controls on grade-by-size fractionation: CRC ORE Project P1-006: Final report provided to CRC ORE, 48p.



Advanced Field Skills in Economic Geology short course, Western Tharsis, February 2021. CODES staff member Dr Lejun Zhang (left) with students.

*Jedemann, A., Hamilton, P., Hollings, P., Zhang, L., Orovan, E., Belousov, I., Cracknell, M., Ailleres, L., Cooke, D.R., Smyk, E., Friedman, R., Olin, P., and Arellano, I., 2021, Pemberton Hills, Vancouver Island, Canada; An active exploration site test: AMIRA P1202 Final Sponsors Meeting #2, 27 May 2021, p. 60–116.

*Jedemann, A., Hamilton, P., Hollings, P., Zhang, L., Orovan, E., Cooke, D.R., Olin, P., Belousov, I., Barker, S., Arellano, I., and Ailleres, L., 2021, Pemberton Hills, Vancouver Island, Canada: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 44–47.

*Jones, R., Bozoglu, M., Halley, S., Escolme, A., Cooke, D.R., Zhang, L., and Hoyer, J., 2021, Northparkes, Australia: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 4, p. 10–13.

*Jones, R., Bozoglu, M., Hoyer, J., Halley, S., Escolme, A., Zhang, L., and Cooke, D.R., 2021, Spatial variations and geological controls on white mica compositions at Northparkes: E26 and

E20: AMIRA P1202 Final Sponsors Meeting #3, 10 June 2021, p. 79–152.

Lounejeva, E., 2021, P1140. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five samples: Report to BMTJV, 2 p.

Lounejeva, E., 2021, P1169. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five samples: Report to BMTJV, 2 p.

*Mah, F.R., 2021, Investigating remediation of acid and metalliferous drainage using *Baloskion tetraphyllum*, Western Tasmania: Final thesis provided to Mineral Resources Tasmania, 92p.

*Marcelissen, M., Hollings, P., Baker, M., Belousov, I., Maryono, A., Rompo, I., and Sweeney, J., 2021, Sunda arc, Indonesia: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 65–66.

*Marcelissen, M., Hollings, P., Vrzovski, J., Baker, M., Belousov, I., and Orovan, E., 2021, Mines Gaspé, Canada: AMIRA P1202 Final Sponsors Meeting

Executive Summary – Module 1–3, p. 18.

*Merrill J., Cracknell, M., and Escolme, A., 2021, Metallurgical parameter forecasting based on automated textural classification: AMIRA P1202 Final Sponsors Meeting #5, 1 July 2021, p. 229–260.

*Merrill-Cifuentes, J., Cracknell, M., and Escolme, A., 2021, Rock texture clustering: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 4, p. 33–35.

Morissette, M., Belousov, I., and Danyushevsky, L., 2021, P955. Chlorite and epidote chemistry for 4 samples: Report to BHP-Ecuador, 3 p.

Morissette, M., Belousov, I., and Danyushevsky, L., 2021, P986. Chlorite and epidote chemistry for 10 samples: Report to First Quantum Minerals Ltd., 4 p.

Morissette, M., Belousov, I., and Danyushevsky, L., 2021, P999. Epidote chemistry for 4 samples: Report to Newmont Australia, 4 p.

Morissette, M., Belousov, I., and Danyushevsky, L., 2021, P1154.

Chlorite and epidote chemistry for 6 samples: Report to Inflection Resources, 3 p.

Morissette, M., and Danyushevsky, L., 2021, P1100. Chlorite and epidote chemistry for 13 samples: Report to First Quantum Minerals Ltd., 3 p.

*Moyo, A., Parbhakar-Fox, A., Meffre, S., Miller, C.B., and Cooke D.R., 2021, Controlling acid and metalliferous drainage at legacy mine sites in Tasmania using industrial waste: Progress report to Mineral Resources Tasmania, September, 32p.

Olin, P., Belousov, I., and Danyushevsky, L., 2021, P951. Gold contents in pyrite in one sample: Report to ALS, 7 p.

Olin, P., Belousov, I., and Danyushevsky, L., 2021, P952. Mercury deportment in gold particles in two samples: Report to ALS, 10 p.

Olin, P., Belousov, I., Goemann, K., and Danyushevsky, L., 2021, P1098. Lithium contents in selected phases in five samples: Report to Yunnan Tin Australia, 7 p.

Olin, P., and Danyushevsky, L., 2021, P960. Seven pyrite images on six samples: Report to Vale, 1 p.

Olin, P., and Danyushevsky, L., 2021, P962. PGE contents in sulphides in two samples: Report to ALS, 10 p.

Olin, P., and Danyushevsky, L., 2021, P991. Vanadium contents in various minerals from sample: Report to ALS, 11 p.

Olin, P., and Danyushevsky, L., 2021, P998. Vanadium, titanium, and iron contents in various minerals: Report to ALS, 17 p.

Olin, P., and Danyushevsky, L., 2021, P1002. Gold contents in pyrite and arsenopyrite in one sample: Report to ALS, 7 p.

Olin, P., and Danyushevsky, L., 2021, P1004. Lithium contents in searlesite and zeolite/clay minerals in one sample: Report to ALS, 7 p.

Olin, P., and Danyushevsky, L., 2021, P1039. Lithium contents in various phases in one sample: Report to ALS, 12 p.

Olin, P., and Danyushevsky, L., 2021, P1045. Chromium in various oxide

minerals in two samples: Report to ALS, 10 p.

Olin, P., and Danyushevsky, L., 2021, P1047. Gold contents in pyrite and arsenopyrite in three samples: Report to ALS, 12 p.

Olin, P., and Danyushevsky, L., 2021, P1056. Selenium contents in sulfides in two samples: Report to Reid Keays, 2 p.

Olin, P., and Danyushevsky, L., 2021, P1068. Silver contents in sulfide and sulfate minerals in two samples: Report to University of Queensland, 9 p.

Olin, P., and Danyushevsky, L., 2021, P1070. Nickel contents in pyrrhotite in one sample: Report to ALS, 6 p.

Olin, P., and Danyushevsky, L., 2021, P1077. PGE contents in selected minerals in two samples: Report to ALS, 9 p.

Olin, P., and Danyushevsky, L., 2021, P1102. Gold contents in pyrite in one sample: Report to ALS, 7 p.

Olin, P., and Danyushevsky, L., 2021, P1103. Gold contents in pyrite and arsenopyrite in three samples: Report to ALS, 13 p.

Olin, P., and Danyushevsky, L., 2021, P1104. Gold contents in pyrite in five samples: Report to MODA, 12 p.

Olin, P., and Danyushevsky, L., 2021, P1120. PGE contents in sulphides in one sample: Report to ALS, 9 p.

Olin, P., and Danyushevsky, L., 2021, P1127. Gold contents in pyrite and arsenopyrite in two samples: Report to ALS, 7 p.

Olin, P., Goemann, K., and Danyushevsky, L., 2021, P1063. Gold and tellurium contents in pyrite and chalcopyrite in three samples: Report to ALS, 11 p.

Olin, P., Goemann, K., and Danyushevsky, L., 2021, P1135. Assessment of germanium deportment in three samples: Report to Mount Burgess Mining, 5 p.

*Osorio, J., Testa, F., Zhang, L., Belousov, I., Orovan, E., Eastman, K., Hamilton, P., and Olin, P., 2021, White mica and pyrite chemistry at Rincones de Araya and Encuentro porphyry copper systems: AMIRA P1202 Final

Sponsors Meeting #3, 10 June 2021, p. 196–243.

*Osorio, J., Zhang, L., Eastman, K., Testa, F., Quinn, C., and Olafson, D., 2021, Rincones de Araya, Argentina: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 4, p. 16–17.

*Osorio, J., Zhang, L., and Testa, F., 2021, Encuentro, Chile: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 4, p. 6–7.

*Orovan, E., Rodrigues, A., Harris, A., Harris, M., and Ackerman, B., 2021, Namosi District, Fiji: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 4, p. 8–9.

*P1202 Research Team, 2021, Outcomes of P1202 Module 1: AMIRA P1202 Final Sponsors Meeting #1, 20 May 2021, p. 267–273.

*P1202 Research Team, 2021, Outcomes of P1202 Module 2: AMIRA P1202 Final Sponsors Meeting #2, 27 May 2021, p. 232–241.

*Piquer, J., Arcos, C., Cooke, D.R., Belousov, I. Baker, M., and Hollings, P., 2021, Yeso Valley, central Chile: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 31.

*Rodrigues, A., Ailleres, L., Harandi, M., Grose, L., Armit, R., Escolme, A., Cracknell, M., Cooke, D.R., Harris, A., Harris, M., and Haraden, C., 2021, Automated mineral classification of hyperspectral data: AMIRA P1202 Final Sponsors Meeting #5, 1 July 2021, p. 192–228.

*Rodrigues, A., Grose, L., Ailleres, L., Armit, R., Harandi, M., Escolme, A., Cracknell, M., Cooke, D.R., Harraden, C., Harris, A., and Harris, M., 2021, Classification of hyperspectral data: towards automated mineralogical and textural characterization: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 4, p. 31–32.

*–Rodrigues, A., Grose, L., Ailleres, L., Armit, R., Harandi, M., Escolme, A., Coaquira, T., Cracknell, M., Berry, R., and Halley, S., 2021, Modal mineralogy approximations via Bayesian Inference: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 4, p. 29–30.



A CODES SEG Student Chapter member enjoying the sunset BBQ at Currie Harbour, King Island, during the SEG field trip to the island in April 2021. This photo, taken by CODES PhD student Zeb Zivkovic, won the ‘Scenic’ category of the CODES 2021 Photo Competition.

*Rodrigues, A., Grose, L., Ailleres, L., Halley, S., Escolme, A., Armit, R., Harandi, M., Coaquira, T., Cracknell, M., and Berry, R., 2021, Modal mineralogy approximations via Bayesian Inference: AMIRA P1202 Final Sponsors Meeting #5, 1 July 2021, p. 89–136.

Sawyer, T., 2021, P946. Identification and quantification of mineral phases by X-ray diffraction (XRD) in six samples: Report to BMTJV, 2 p.

Sawyer, T., 2021, P965. Identification and quantification of mineral phases by X-ray diffraction (XRD) in six samples: Report to BMTJV, 3 p.

Sawyer, T., 2021, P971. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five samples: Report to BMTJV, 3 p.

Sawyer, T., 2021, P987. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five samples: Report to BMTJV, 2 p.

Sawyer, T., 2021, P1003. Identification and quantification of mineral phases by X-ray diffraction (XRD) in six samples: Report to BMTJV, 2 p.

Sawyer, T., 2021, P1023. Identification and quantification of mineral phases by X-ray diffraction (XRD) in six samples: Report to BMTJV, 2 p.

Sawyer, T., 2021, P1042. Identification and quantification of mineral phases by X-ray diffraction (XRD) in six samples: Report to BMTJV, 2 p.

Sawyer, T., 2021, P1053. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five samples: Report to BMTJV, 2 p.

Sawyer, T., 2021, P1081. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five samples: Report to BMTJV, 2 p.

Sawyer, T., 2021, P1086. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five samples: Report to BMTJV, 2 p.

Sawyer, T., 2021, P1094. Identification and quantification of mineral phases by X-ray diffraction (XRD) in one extra samples: Report to BMTJV, 3 p.

Sawyer, T., 2021, P1111. Identification and quantification of mineral phases by X-ray diffraction (XRD) in five samples: Report to BMTJV, 2 p.

Sawyer, T., 2021, P1130. Identification and quantification of mineral phases by X-ray diffraction (XRD) in two samples: Report to BMTJV, 2 p.

*Seow, X., Zhang, L., Orovan, E., Cooke, D.R., White, N., and Kim, E., 2021, Seongsan district, South Korea: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 56–57.

*Seow, X., Zhang, L., Rodemann, T., Sun, Y., Eastman, K., Coaquira, T., Goeman, K., Feig, S., and White, N., 2021, Aluminium phosphate-sulfate (APS) minerals: Occurrence, chemistry, spectra and exploration implications: AMIRA P1202 Final Sponsors Meeting #2, 27 May 2021, p. 198–231.

*Seow, X., Zhang, L., Sun, Y., Eastman, K., Coaquira, T., White, N., and Rodemann, T., 2021, Aluminium phosphate-sulfate (APS) minerals: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 48–50.

*Smyk, E., Belousov, I., Cracknell, M., Baker, M., Cooke, D.R., Danyushevsky, L., Hollings, P., Lewis, K., Wetzel, M., and Creaser, R., 2021, Christmas, USA: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 13–17.

*Smyk, E., Belousov, I., Thompson, J., Cracknell, M., Wetzel, M., Lewis, K., Baker, M., Cooke, D.R., Hollings, P., and Danyushevsky, L., 2021, Mineral chemistry at Christmas, USA: Screening, fertility-assessment and heat source modelling: AMIRA P1202 Final Sponsors Meeting #1, 20 May 2021, p. 111–176.

*Sun, Y., Zhang, L., Escolme, A., and Cooke, D.R., 2021, Mankayan district, Philippines: Multiple episodes of porphyry – epithermal mineralization: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 54–55.

*Sun, Y., Zhang, L., Escolme, A., and Cooke, D.R., 2021, New geological model for the Mankayan district and mineral vectoring results: AMIRA P1202 Final Sponsors Meeting #2, 27 May 2021, p. 117–159.



Sunset view of the Strahan foreshore, west coast of Tasmania, taken during the Ores in Magmatic Arcs short course in November 2021 (photo by PhD student Richard Hill).

*Testa, F., Zhang, L., Cooke, D.R., Escolme, A., Eastman, K., White, N., Sun, Y., and Belousov, I., 2021, Textural variations in pyrite from Tujuh Bukit: A potential field vectoring tool in lithocaps: AMIRA P1202 Final Sponsors Meeting #4, 30 June 2021, p. 58–91.

*Testa, F., Zhang, L., Cooke, D.R., Escolme, A., Eastman, K., White, N., Sun, Y., and Belousov, I., 2021, Tujuh Bukit, Indonesia – pyrite morphology: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 61–62.

*Zhang, L., Escolme, A., Cloutier, J., Halley, S., Cooke, D.R., Jones, R., Coaquira, T., Osorio, J., Bozoglu, M., Testa, F., Baker, M., and Orovan E., 2021, Introduction to white mica: AMIRA P1202 Final Sponsors Meeting #3, 10 June 2021, p. 15–28.

*Zhang, L., Escolme, A., Eastman, K., Seow, X., Cooke, D.R., White, N., Sun, Y., and Smyk, E., 2021, Tujuh Bukit, East Java, Indonesia: AMIRA P1202 Final Sponsors Meeting #2, 27 May 2021, p. 160–197.

*Zhang, L., Escolme, A., Eastman, K., Seow, X., Cooke, D.R., White, N., Sun, Y., and Smyk, E., 2021, Tujuh Bukit, Indonesia: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 58–60.

*Zhang, L., Seow, X., Orovan, E., Testa, F., White, N., Cooke, D.R., Danyushevsky, L., Eastman, K., Cooke, S., Sun, Y., Cracknell, M., and Barker, S., 2021, Buckskin Lithocap, Yerington, Nevada: AMIRA P1202 Final Sponsors Meeting #2, 27 May 2021, p. 14–59.

*Zhang, L., Seow, X., Orovan, E., White, N., and Cooke, D.R., 2021, Buckskin lithocap, Yerington district, USA: AMIRA P1202 Final Sponsors Meeting Executive Summary – Module 1–3, p. 51–53.

*Zhang, L., White, N., Cooke, D.R., Seow, X., Sun, Y., Hamilton, P., Orovan, E., Testa, F., Danyushevsky, L., Rodemann, T., Escolme, A., Eastman, K., Merrill Cifuentes, J., Cracknell, M., Belousov, I., Morissette, M., Olin, P., Barker, S., Cooke, S., Hollings, P.,

Halley, S., Gonzalez, R., and Piquer, J., 2021, P1202 Final Report – Module 2 Synthesis: Refined lithocap model and workflow for exploring lithocaps: AMIRA P1202 Final Sponsors Meeting #4, 30 June 2021, p. 150–215.

*Zhang, L., White, N., Seow, X., Sun, Y., Hamilton, P., Orovan, E., Cooke, D.R., Danyushevsky, L., Rodemann, T., Escolme, A., Eastman, K., Belousov, I., Morissette, M., Olin, P., Barker, S., Cracknell, M., Cooke, S., Halley, S., Gonzalez, R., and Piquer, J., 2021, Introduction to AMIRA P1202 final meeting #2 – Module 2: AMIRA P1202 Final Sponsors Meeting #2, 27 May 2021, p. 1–13.

Appendices

CODES postgraduate students 2021

Bachelor of Science (Honours) (11)

Student	Supervisors	Research Program	Project	Support
Kate Cheesman ^	Miller, Barmuta (Biological Sciences), Cracknell	2	Invertebrate biomonitoring: A geoscience tool for AMD remediation, north-west Tasmania	MRT, Bluestone Mines
Dina Chu ^	Roach	1, 6	Geophysical characteristics of the Pine Creek Deposit through petrophysical properties	Kirkland Lake Gold
Erik Fabreschi *^	Escolme, Baker	1, 2	Pyrite trace element geochemistry at the Spence Cu Mo porphyry deposit, Chile	Amira P1202, ARC TMVC
Eliza Fisher *^	Miller, Cracknell, Cooke	2	Geochemical analysis of mine waste and pit lakes at Endurance Mine, northeast Tasmania	MRT, ARC TMVC
Till Gallagher	Orth, Carey, Cumming (MRT), Bottrill (MRT)	3, 4	Nature, structure and origin of the St Marys Porphyrite, northeastern Tasmania	MRT, UTAS Foundation
Kate Jenkins ^	Danyushevsky, Belousov, Meffre	5	Characterisation of elemental fractionation in U-Pb dating by LA-ICP-MS analysis of rutile and garnet	AusIMM, CODES
Fu Rong Mah *^	Miller, Meffre, Prahalad (Geography)	2	Investigating passive remediation of copper and acid mine drainage using <i>Baloskion tetraphyllum</i> , Western Tasmania	MRT, ARC TMVC
Stephanie Morrish ^	Carey, Whittaker (IMAS)	4	The geological evolution of Frederick and Sula Seamounts, Coral Sea	
Hugh Sayers ^	Meffre	2, 3	Understanding framboidal pyrite formation mechanisms and their potential environmental implications	Earth Sciences
Zak Weidinger ^	Cracknell, Roach, Miller	2, 6	Time-lapse geophysical investigation of the Royal George tailings repository, northeast Tasmania	MRT, GHD, UTAS
Riley Winter *^	Zhang, Baker, White	1	Geology, geochemistry and genesis of advanced argillic alteration at Kurrajong Hills, Wirrinya District, NSW, Australia	ARC TMVC

Graduate Certificate in Economic Geology (3)

Student	Supervisors	Research Program	Project	Support
Caitlin Brown			coursework only	
Rebecca Lowndes ^			coursework only	
Kristy O'Connor			coursework only	

Master of Economic Geology (81)

Student	Supervisors	Research Program	Project	Support
Michael Adams			coursework only	
Greg Amalric			coursework only	
Jessica Askew			coursework only	
Robert Ayres			coursework only	
Stuart Badock			coursework only	
Grace Barber			coursework only	
Emma Beattie			coursework only	
Joel Blake			coursework only	
Christopher Booth ^			coursework only	
Ian Borg #			coursework only	
Kim Boundy *	Baker, Zhang	1	Geochemistry and geochronology of lithium-enriched pegmatites in the Bynoe pegmatite field, Northern Territory	Core Lithium
Mertkan Bozoglu *#	Cooke, Zhang, Escolme	1	Phyllic alteration at Northparkes	Turkish Government, ARC TMVC, Amira P1202
James Bresnahan			coursework only	
Matt Brown			coursework only	
Dale Cameron			coursework only	
Jimmy Carranza Meza ^			coursework only	
Nicole Casilla			coursework only	
Kaitlin Catalano			coursework only	
Glen Cathers #			coursework only	
Duncan Chessell			coursework only	
Brianna Clark			coursework only	
Sarah Cochrane			coursework only	
Jamin Cristall			coursework only	
Roseanna Dale			coursework only	
Oliver Davies			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
Luziane de Souza Castell			coursework only	
Jaime Carlos Diaz Castro ^	Cooke	1	The Cascabel Cu-Au-Ag porphyry cluster in northern Ecuador	SolGold
Laura Dowling			coursework only	
Mark Eastlake			coursework only	
David Eddy			coursework only	
Paul Edmonds			coursework only	
Lauren Elliott			coursework only	
Batbayar (Baggy) Enkhbold *^	Barker, Baker	1, 3	Alteration sequence of Eastern Creek Volcanics of Mount Isa	DFAT, Amira P1202
Benjamin Ferguson			coursework only	
Michael Fisher			coursework only	

Student	Supervisors	Research Program	Project	Support
Daniel Foulds ^			coursework only	
Emma Haley			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	
Jonathan Higgins			coursework only	
Kyle Hodges #			coursework only	
Kyle Hughes	Meffre	1, 3	Paragenesis of the Dobroyde Deposit, central NSW	ARC Linkage
Carl Jackman			coursework only	
Corey Jago ^	Meffre, Cooke	1, 3	Spectral analysis of hydrothermal alteration associated with the Northparkes porphyry Cu-Au deposits, New South Wales	ARC Linkage
Fungai (Grace) Jaravani			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
Pascal Kabilo #			coursework only	
Sitthinon (Gun) Kultaksayos ^	Meffre	3	Provenance of early to mid-Paleozoic sediments in Tasmania: When did Tasmania join with Australia?	ARC Linkage
Greer Lane			coursework only	
Esther Little			coursework only	
Karen MacQueen			coursework only	
David Mallon			coursework only	
George Maroa ^	Scott	1, 3	Characterization of the geology, mineralization and genesis of the Bumbo polymetallic sulphide deposit within the Busia-Kakamega Greenstone Belt, Western Kenya	DFAT, Acacia Mining
Francisco Maturana			coursework only	
Todd McGilvray			coursework only	
Karl McNamara			coursework only	
Dominic Murphy			coursework only	
Menford Ngara			coursework only	
Ana Nichols			coursework only	
Alister Orton #			coursework only	
Christian Oviawe			coursework only	
Robbie Parr			coursework only	
Jose Pascual			coursework only	
Thomas Pearson			coursework only	
Luke Pickering			coursework only	
Chris Piggott			coursework only	
David Gerardo Portocarrero Ccaccya	TBC		TBC	
Steven Rennick			coursework only	

Student	Supervisors	Research Program	Project	Support
Alex Richards			coursework only	
Hugo Rios Mansilla ^			coursework only	
Torrin Rowe			coursework only	
Henry Schaumburg			coursework only	
Markus Staubmann ^			coursework only	
James Taylor			coursework only	
Victor Torres Pacheco ^			coursework only	
Madeline Wallace			coursework only	
Megan Weatherman			coursework only	

Master of Science (2)

Student	Supervisors	Research Program	Project	Support
Nathaly Guerrero Ramirez #	Cracknell, Hunt, Escolme	2	Geological controls on grade-by-size fractionation in gold systems	CRC ORE, UTAS
Karla Morales	Hunt, Cracknell, Roach	2	Geological predictors for pre-concentration	CRC ORE, UTAS

Doctor of Philosophy (41)

Student	Supervisors	Research Program	Project	Support
Peter Berger	Barker, Cooke	1	Understanding and predicting hypogene and supergene footprints of Carlin-type gold deposits using a hydrochemical modelling approach	UTAS
Acacia Clark	Carey, Jutzeler, Fox (IMAS)	4	Silicic explosive volcanism: Understanding the conditions of steady and unsteady eruptive behaviour of silicic magma - the Kaharoa 1315 eruption	UTAS
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, Danyushevsky	6	Pathways to mineral discoveries through computer-based modelling of geochemical data	UTAS, Amira P1249
Rob Davidson #	Gemmell, Cooke	1	Geology and genesis of the San Sebastian vein system, Durango, Mexico	Hecla Mining, UTAS
Alex Farrar	Cracknell, Cooke	1, 3, 6	Spatial and temporal controls on the formation of giant porphyry Cu Au 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
Umer Habib	Meffre, Roach, Musgrave (GSNSW)	3, 6	Tectonic evolution of the Paleozoic rocks in southeast Australia using geophysical, geochronological, geochemical and Hf isotope systematics	ARC Linkage, Geological Survey of NSW
Jacob Heathcote	Scott, Barker	1, 3	Gold distribution and association at the Kansanshi copper-gold deposit Zambia: Processes responsible for gold precipitation and implications for ore zone delineation and recovery	First Quantum Minerals

Student	Supervisors	Research Program	Project	Support
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 IOCG deposits in northwest Queensland	UTAS, GSQ
Fumihiko Ikegami	Carey, McPhie	4	2012 submarine silicic eruption of Havre volcano and implications for ancient submarine successions in Australia	UTAS, ARC, US National Science Foundation
Malai Ila'ava	Jutzeler, Carey, Cas	4	Volcanic architecture of the Cowal Igneous Complex	ARC Linkage, UTAS, Evolution Mining
Stewart Jackson §	Roach, Olivier (IMS)	6	Integrating passive and active methods of seismic imaging for structural stability of tailings dams	UTAS, GHD, IMS
Colin Jones *	Meffre, Orovan, Cooke	3, 4	Petrogenesis of northeast Tasmanian granites	MRT, ARC TMVC, UTAS
Rhiannon Jones *	Cooke, Escolme, Zhang	1, 2	The significance of phyllic alteration at the E26 porphyry Cu-Au deposit, Northparkes district, NSW, Australia	Amira P1202, ARC TMVC, UTAS
Joseph Knight #	Orovan, Zhang, Cooke	1	The geodynamic and metallogenic setting of base- and precious-metal mineralisation in Myanmar: Implications for Cu and Au exploration	Anglo American
Stephen Kuhn **^	Reading (Physics), Cracknell	6	Machine learning for mineral exploration: prediction and quantified uncertainty at multiple exploration stages	UTAS, CODES, ARC TMVC, First Quantum Minerals, Gold Fields, ASEG, AIG
Bridie Le'Gallais	Danyushevsky, Olin	4	The tectonic significance of mafic/ultra mafic igneous rocks in western Tasmania	UTAS, MRT
Christopher Leslie ^	Meffre, Cooke, Steadman	1, 3	Metallogeny of the Cowal district, New South Wales, Australia	ARC Linkage, UTAS, Evolution Mining
Elena Lounejeva	Steadman, Large	3	Geochemical signature of syngenetic and diagenetic pyrite from marine sediments as a paleo-environmental tool	ARC Discovery, CODES
Javier Merrill *	Cracknell, Escolme	2	Evaluating applications of hyperspectral data for predicting mineral processing attributes and waste characteristics of slurries	Amira P1202, Minerals Council of Australia, BECAS Chile, ARC TMVC
Hannah Moore	Carey, Jutzeler	4	Investigation of the shallow conduit processes involved in the 1886 basaltic Plinian eruption at Tarawera Volcano, New Zealand	UTAS
Peter Morse ^	Reading (Physics), Walters (Physics)	6	Interactive visualisation for data inference in the geosciences	UTAS, CODES, ARC TMVC
Annah Moyo *	Cooke, Meffre, Miller, Parbhakar-Fox (UQ)	2	Controlling acid and metalliferous drainage at legacy sites in Tasmania using industrial wastes	UTAS, Mineral Resources Tasmania, ARC TMVC
Nanda Yusentri Mrabawani *§	Danyushevsky, Meffre	5	Method development for laser-ablation ICP-MS applied to complex matrices	ARC TMVC, UTAS
Sibele Cristina do Nascimento *	Cracknell, Cooke, Meffre, Parbhakar-Fox (UQ)	2	Geoenvironmental characterisation of historic mine tailings: Evaluating opportunities for reprocessing	ARC TMVC, UTAS
Gilles Ngoran §	Carey, Jutzeler	4	Exploration targeting from next-generation volcanic facies reconstruction, Cowal District	UTAS, ARC Linkage

Student	Supervisors	Research Program	Project	Support
Jaime Osorio *	Zhang, Cooke, Escolme, Piquer (UACH)	1	Porphyry to epithermal transition in the Valeriano Cu-Mo-Au deposit, Chile	ARC TMVC, UTAS, Amira P1202, SEG, Fortescue
Thomas Ostersen ^	Reading (Physics), Cracknell	6	Geoelectric structure of the Tasmanian lithosphere	UTAS, CODES, MRT, U Adelaide, Geoscience Australia, GSSA
Thomas Schaap #	Meffre, Whittaker (IMAS), Cracknell, Roach	3, 6	Tectonic evolution of the Palaeozoic Lachlan Orogen	ARC Linkage, UTAS
Xin Ni Seow *	Zhang, Orovan, Cooke, Danyushevsky	1, 5	Geochemistry, mechanism of formation and exploration implications of alunite supergroup minerals	ARC TMVC, UTAS, Amira P1202, SEG
Emily Smyk *	Cooke, Baker, Barker, Meffre	1	A characterisation of the intrusive rocks and magmatic minerals and their related propylitic and skarn alteration at the Christmas porphyry Cu deposit, Arizona, USA: assessing the potential for mineral chemistry vectoring to mineralisation	Amira P1202, ARC TMVC, UTAS
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
Tobias Stål ^	Reading (Physics), Halpin (IMAS), Whittaker (IMAS)	6	The Antarctic lithosphere revealed by multivariate analysis	Antarctic Gateway Partnership, Australian Antarctic Division
Yi Sun *	Zhang, Escolme, Cooke	1, 2	Mineralogical, textural, geochemical characterisation and geometallurgical models of Lepanto Quartz – Pyrite – Gold vein and breccia system, Philippines	ARC TMVC, Amira P1202, UTAS, SEG, Lepanto Consolidated
Jay Thompson ^	Danyushevsky, Meffre	5	Understanding the specifics of H ₂ O-free aerosol behaviour in the inductively-coupled plasma in geochemical LA-ICPMS applications involving U/Pb dating and accurate trace element analysis in silicate minerals and glasses	CODES
Jennifer Thompson *#	Cooke, Danyushevsky	1, 5	Carbonate mineral chemistry in epithermal and porphyry hydrothermal systems	UTAS, Amira P1153, ARC TMVC, SEG
Chuang Wang	Jutzeler, Olivier (IMS), Roach, Carey	4	Application of seismic techniques to reconstruct volcanic architecture	MRT, UTAS, IMS
Tristan Wells	Meffre, Cooke, Steadman	1, 3	Magmatic fertility in the Macquarie Arc	ARC Linkage, UTAS, CODES, NorthParkes
Zebedee Zivkovic	Baker, Barker, Danyushevsky	1, 4	Lithogeochemical and mineral analysis of magmatic-hydrothermal mineralisation systems: Implications on mineralisation and exploration	Mineral Resources Tasmania, Mineral Mapping, Dreadnought Resources

* Affiliated with the ARC TMVC Research Hub # Degree completed, not yet graduated ^ Graduated § Withdrawn

Major externally funded research projects^

ARC Industrial Transformation Research Hub Grants 2021

Investigators	Project	Funding Body	Period	ARC Funding for 2021	Partner Funding for 2021	UTAS Funding for 2021	Misc Funding for 2021
Cooke, Danyushevsky, Jiang, Gemmell, Large, Meffre, Reading, Harris (Newcrest), Seymon (AMIRA), Ehrig (BHP), Goodey (Corescan), Lottermoser (Aachen), Shelley (Laurin Technic)	Transforming the mining value chain	ARC, Amira Global, BHP, Newcrest Mining, UTAS	2015–2021	**	\$860,139	**	\$51,053

Additional Funder Projects within the ARC TMVC Research Hub 2021

Investigators	Project	Funding Body	Period	Funding for 2021
Miller, Meffre, Prahalad (Geography), Mah (student)	Investigating passive remediation of copper and acid mine drainage using <i>Baloskion tetraphyllum</i> , Western Tasmania	Mineral Resources Tasmania	2020–2021	\$10,082
Cooke, Zhang, Escolme, Coaquira (student)	Resolving multiple generations of white mica and clay alteration at the Resolution porphyry Cu-Mo deposit, Arizona	Society of Economic Geologists	2021–2022	\$6,363
Zhang, Orovan, Cooke, Danyushevsky, Seow (student)	Geochemistry, mechanism of formation and exploration implications of alunite supergroup minerals	Society of Economic Geologists	2021–2022	\$5,649
Zhang, Cooke, Escolme, Piquer (UACH), Osorio (student)	Porphyry to epithermal transition in the Valeriano Cu-Mo-Au deposit, Chile	Society of Economic Geologists	2021–2022	\$5,150
Zhang	Alteration minerals chemistry at Yaojialing Zn-Au-W skarn deposit, China: implications for ore genesis and exploration	Hefei University of Technology	2019–2021	\$24,000
Orovan, Cooke, Jones (student)	Petrogenesis of northeast Tasmanian granites	Mineral Resources Tasmania	2018–2021	**
Baker, Orovan, Zhang, Lane (student)	Genesis of the Four Mile Diamictite and implications for Uranium mineralisation, South Australia	Heathgate Resources	2020–2021	#
Cooke, Meffre, Parbhakar-Fox, Moyo (student)	Controlling acid and metalliferous drainage at legacy sites in Tasmania using industrial waste materials	Mineral Resources Tasmania	2017–2022	**

ARC Discovery Grants 2021

Investigators	Project	Funding Body	Period	ARC Funding for 2021
King (ANU), V Kamenetsky	Impact of hot gas on volcanic rocks and ore-forming processes	ARC	2020–2023	\$35,669
Seton (USyd), Carey, Williams (IMAS), Coltice (ENS Lyon), Duncan (Oregon)	How Earth’s deep interior communicates with the surface	ARC	2020–2023	\$96,674

ARC Linkage Grants 2021

Investigators	Project	Funding Body	Period	ARC Funding for 2021	Partner Funding for 2021
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	2020–2022	\$176,519	\$42,000

CRC Projects 2021

Investigators	Project	Period	CRC Funding for 2021	UTAS Funding for 2021
Cooke, Gemmell	CRC ORE II Participant funding	2015–2021	\$0	\$100,000
Hunt, Cooke	CRC ORE II- Predictive geometallurgy controls on grade by size	2016–2021	\$438,025	\$0

Industry and other externally funded research grants 2021

Investigators	Project	Funding Body	Period	Funding for 2021
M Kamenetsky	Olympic Dam fluid/melt inclusion project	BHP	2021–2023	\$302,322
Cooke, Cloutier	Exploring for the future: uncovering Australia's exploration potential	Geoscience Australia	2021–2024	\$184,823
Barker, Zivkovic (student)	Investigating mineralisation in the Tarraji-Yampi (West Kimberley) and Illaara (Yilgarn) project areas	Dept of Industry, Innovation and Science	2020–2022	\$25,000
		Dreadnought Resources	2020–2022	\$12,500
Zhang	Mineral chemistry vectors at Mount Gilmore Cu-Co-Au Trend, NSW	Dept of Industry, Innovation and Science	2020–2022	\$24,983
		Corazon Mining	2020–2022	\$12,492
Zhang, Cooke, Rodemann, Brown (student)	Geology, geochemistry and genesis of the Havieron gold-copper deposit, Paterson Province, Western Australia	Newcrest Mining	2021–2025	\$31,062
Mukherjee, Steadman, Large, Olin	Application of pyrite chemistry to exploration and deep-time geology	Ian Potter Foundation	2019	**
		Teck, Rio Tinto, Anglo American, First Quantum Minerals, Mt Isa Mines, Red Metal, Geological Survey of Queensland, Geological Survey of South Australia, Sandfire Resources	2019–2021	\$30,000
Barker, Steadman, Cooke	Mineral geochemistry vectoring uncovering North West Queensland’s hidden potential	Geological Survey of Queensland	2018–2021	\$30,000
Roach, Olivier, Jackson (student)	Integrating passive and active methods of seismic imaging for structural stability of tailings dams	Institute of Mine Seismology	2020–2021	\$27,339

Investigators	Project	Funding Body	Period	Funding for 2021
Roach, Chu (student)	Geophysical characteristics of the Pine Creek Deposit through petrophysical properties	Kirkland Lake Gold	2021	\$15,000
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	\$14,422
Danyushevsky, Olin, Le’Gallais (student)	The tectonic significant of mafic/ultramafic igneous rocks in western Tasmania	Mineral Resources Tasmania	2019–2023	\$14,000
Steadman	Evaluating epidote and chlorite mineral chemistry in the Temora area, NSW	Dept of Industry, Innovation and Science	2019–2021	\$5,526
		Argent Minerals	2019–2021	**
Meffre	Mineral chemistry research for Emmerson Resources	Emmerson Resources	2021–2022	\$4,500
Orth, Carey, Cumming (MRT), Bottrill (MRT), Gallagher (student)	Nature, structure and origin of the St Marys Porphyryite, northeastern Tasmania	Mineral Resources Tasmania	2020–2022	\$4,239
Carey, Whittaker (IMAS), Duncan (Oregon), Seton (USyd)	Seamounts in the Tasman Sea and Southwest Pacific: Deep seated Balleny plume vs. Pacific Superswell	Australian Antarctic Division	2020–2022	\$4,000
Cracknell, Cooke, Farrar (student)	The geodynamic and tectonic influence on giant porphyry copper deposit architectural controls	First Quantum Minerals	2020–2023	\$0
Orovan, Zhang, Cooke, Knight (student)	The geodynamic and metallogenic setting of base- and precious-metal mineralisation in Myanmar: Implications for Cu and Au exploration	Anglo American	2015–2021	**
Cooke, Torres (student)	Geology, genesis and exploration implications of Cu-Au mineralised tourmaline breccia pipes at Soledad, central Peru	Chakana Copper	2017–2021	**
Cooke, Meffre, Jutzeler, Carey	4D geological modelling of the Cowal district, NSW	Evolution Mining	2018–2021	**
Carey, Falloon, Coffin (IMAS), Barling (Oxford), Duncan (Oregon), Fox (IMAS)	The re-awakening of a mantle plume – the nature and petrogenesis of Neogene volcanism on the Central Kerguelen Plateau	Australian Antarctic Division	2020–2022	**

^ projects with greater than \$2,000 external funding per year

** all project funding received, project still active

funding milestones delayed

Visitors 2021

INDUSTRY VISITORS TO CODES IN 2021

NAME	COMPANY
Rachid Ait Maamar	MNI Partners
Jeff Bigelow	Newmont
John Bishop	Mitre Geophysics
Mary Harris	Newcrest
Wei Xuen Heng	GHD
Michael Hughes	Embrio
Simon Marshall	Newmont
Robert May	Golder Associates
Jon McLoughlin	St Barbara
Ashley Norris	Norris Scientific
Dana Olafson	Fortescue Metals Group
Josh Phillips	Fortescue Metals Group
Cameron Quinn	Fortescue Metals Group
Geoff Webb	GR Webb Consulting
John Webber	MNI Partners
Olivia Wilson	Entura
Jamal Zaidi	Peak Scientific

NATIONAL ACADEMIC AND GOVERNMENT VISITORS TO CODES IN 2021

NAME	INSTITUTION
Ralph Bottrill	Mineral Resources Tasmania
Clive Calver	Mineral Resources Tasmania
Andrew Cross	Geoscience Australia
Grace Cumming	Mineral Resources Tasmania
John Everard	Mineral Resources Tasmania
Barbara Frankel	Australian Antarctic Division
Dave Huston	Geoscience Australia
Claire Kain	Mineral Resources Tasmania
Colin Mazengarb	Mineral Resources Tasmania
Andrew McNeill	Mineral Resources Tasmania
Eric Roberts	James Cook University
Nick Roberts	Mineral Resources Tasmania
Kevin Robinson	Mineral Resources Tasmania
Elspeth Wishart	Tasmanian Museum and Art Gallery



Dr Lejun Zhang pictured during the CODES SEG Student Chapter field trip to King Island in April 2021. He is examining the granite dyke in the open pit of Dolphin W skarn mine.

CODES

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