





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: Dr Michael Roach at City of Melbourne Bay on King Island collecting data for his 'Geological visualisation' project, which sits within CODES' Program 6. BELOW LEFT: 2020 CODES Honours student Ben Speakman looking at titanite and apatite occurrences from the Yerington district, Nevada, in the lab at CODES. BELOW RIGHT: Dr Clare Miller measuring the concentrations of redox-sensitive elements in surface at porewaters to better understand the geochemical and mineralogical controls on the mobility of metal(loid)s in mine waste and environmental systems (i.e., wetlands and soils) in October 2020.



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FRONT COVER: Dr Martin Jutzeler and Professor David Cooke pointing out Surtseyan-style shallow marine volcanoclastic breccias associated with a Miocene basaltic volcanic centre at Aireys Inlet in southwest Victoria to Master of Economic Geology students and industry participants during the 'Volcanology and Mineralisation in Volcanic Terrains' short course, which took place in March 2020 prior to the COVID-19 lockdown.

BACK COVER (clockwise from top left): Second-year KEA208 Earth Materials and Interior students carrying out detailed mapping at Piccaninny Point, eastern Tasmania, in February 2020. CODES-TMVC Honours student Olivia Wilson undertaking fieldwork at the legacy Endurance Mine in northeast Tasmania in September 2020. She is examining mine wastes brought up by a drill rig during the installation of groundwater wells. Professor David Cooke with Senior Geologist Jacqui Rush from PYBAR Mining Services examining drill core at the Henty Gold Mine core shed on Tasmania's west coast. CODES-TMVC Honours student Erik Fabreschi in the lab undertaking sulfide mineral identification and analysis of HCl etched pyrite using reflected microscopy in November 2020. Professor David Cooke (left) and Associate Professor Sebastien Meffre at the disused Mt Bischoff tin mine looking at the main face of the pit during a trip to the west coast of Tasmania in 2020 to discuss possible collaborations with mining companies. CODES-TMVC Honours student Eliza Fisher (left) with fieldwork volunteer Frank Bird at Blue Lake at the legacy Endurance Mine, northeast Tasmania, preparing to take water samples in June 2020.

RIGHT: Chlorite – calcite – quartz vein in chlorite – epidote – hematite-altered Cadia Hill monzonite, Cadia Hill porphyry Cu-Au deposit, NSW. This high-resolution photograph was taken by Dr Michael Roach.





2020 Director's report

2020 is a year that no one will soon forget. The global disruption caused by the COVID-19 pandemic created unprecedented challenges in all aspects of our lives, both private and professional. The ability of CODES staff and students to adapt rapidly and effectively throughout 2020 to an uncertain, ever-changing, highly stressful and confronting situation has been truly impressive, whether it be our professional staff working in isolation to keep our analytical laboratories fully functional throughout lockdown, our academic staff rapidly flipping to online delivery of teaching and research sponsors' meetings and training workshops, or our research staff and students adapting to a lab-based research focus while lockdown persisted.

We also all somehow managed to survive an endless stream of Zoom meetings whilst learning how to remain connected while working remotely. Unfortunately, our Annual Review and planning meeting in 2020 was cancelled due to COVID, and our CODES Advisory Board meeting was online. I thank everyone at CODES for their outstanding efforts under the incredibly difficult and stressful circumstances that 2020 presented – your collective efforts ensured that our research stayed on-track, our Masters courses achieved larger numbers of attendees than any previous year, and our student cohort continued to advance their research effectively.

Those of us based in the island state of Tasmania have been fortunate in our geographic location to have escaped the worst travails of the pandemic. We do, however, have a large cohort of international staff and students, and so many members of the CODES family suffered considerable distress throughout the year with regards to being separated from their loved ones during these trying times, and worrying for their safety and well-being. Our thoughts go out to all our friends, colleagues and family members around

I thank everyone at CODES for their outstanding efforts under the incredibly difficult and stressful circumstances that 2020 presented...

the world through these difficult times – we hope that circumstances improve in 2021 and that we can meet with you again soon.

Possibly the largest impact of the global pandemic on CODES' operations in 2020 related to recruitment and retention of personnel. Several of our international PhD students returned to their home countries to be close to loved ones – some have completed their theses and others continue to work on their theses remotely. We have also had the unfortunate situation whereby some newly recruited PhD students (Jamie Osorio, Gilles Ngoran) missed the opportunity to travel to CODES before

the international borders closed – consequently, they have been working remotely on their PhDs since the start of the pandemic, which has been a very challenging and difficult situation for them. Their patience, understanding and hard work during these trying times is greatly appreciated – unfortunately, at the time of writing, there is still no clear pathway for our overseas students to travel to CODES.

Research highlights

For several years, Dr Michael Roach and colleagues have been developing a 3D virtual library of key Australian geological field locations, which now has over 3,800 field sites visualised at <https://www.ausgeol.org/>. Mike's work in developing a 3D visualisation laboratory proved a huge boon to CODES researchers, and teaching staff in Earth Sciences and other disciplines at the University of Tasmania: the high-resolution visualisations Mike generated proved to be vital resources that facilitated the transition to online teaching and research delivery. The University of Tasmania recognised the importance of Mike's work by granting him \$90,000 in funding through UTAS' Digital Futures Program. The bulk of

this funding was used in the 'Virtual Tasmania' project that Mike initiated in 2020, with the remainder used to digitise the UTAS cultural collections, including artworks and items in the John Elliott Classics Museum. Any of the participants in the 2020 'Ore Deposit Models and Exploration Strategies' Masters short course can testify to the quality of Mike's 3D visualisations and their applications for education.

Associate Professor Sebastien Meffre's team brought the three-year ARC Linkage Project 'Ore deposits and tectonic evolution of the Lachlan Orogen, southeast Australia' to a successful conclusion in early March 2020, with a two-day final sponsors' meeting at CODES involving industry sponsors and government and academic research partners. This project made significant advances in our understanding of the Lachlan Orogen in several ways, including a new model for the geodynamic evolution of the region, generation of a large database of green rock mineral chemistry and pyrite data, new fertility maps for porphyry deposits in NSW and discovery of Cambrian rocks beneath the Ordovician Macquarie arc rocks. Although the main project concluded in early 2020, PhD students Chris Leslie, Tom Schaap, Umer Habib and Tristan Wells continued their research throughout 2020, adding considerable additional value to the outcomes of the project.

The P1202 research team modified its mode of delivery for sponsors' review meetings from in-person to online... that achieved strong engagement with industry representatives globally.

Dr Clare Miller and Dr Matt Cracknell initiated a series of environmental geochemistry, geophysics and hydrology Honours projects at the abandoned Endurance Sn mine in NE Tasmania in 2020, supported strongly by Mineral Resources Tasmania. Honours students Olivia Wilson, Eliza Fisher and Wei Xuen Heng were fortunate to have the opportunity to conduct fieldwork during the period when lockdown restrictions were widespread. Their work has provided considerable insights into acid generation from waste materials at this site that will be beneficial in future remediation activities.

The AMIRA P1202 project 'Far-field and near-mine footprints: Finding and defining the next generation of Tier 1 ore deposits' entered its third and final

year of research activity in 2020. The team were fortunate in that most of the field-based research campaigns had already been completed prior to the onset of the pandemic, and so research was able to continue without significant interruption for most of the team members. For the new students recruited to the project in 2020 (Rhiannon Jones, Jaime Osorio, Erik Fabreschi, Mitch Marcelissen, Ben Speakman, Mertkan Bozoglu), the pandemic prevented them from undertaking fieldwork, but they were able to conduct lab-based research using the CODES sample archive, or samples that were shipped to CODES by the industry sponsors. The P1202 research team modified its mode of delivery for sponsors' review meetings from in-person to online and facilitated effective technology transfer by providing a series of additional online workshops that achieved strong engagement with industry representatives globally.

CRC-ORE entered its final year of operation in mid-2020. Dr Julie Hunt has been leading CRC-ORE's project P1:006 ('Geological controls on grade-by-size deportment') which has

In March 2020 the 'Volcanology and Mineralisation in Volcanic Terrains' Masters short course included field trips to southwest Victoria (the original itinerary was changed from New Zealand due to COVID-19 restrictions). Professor David Cooke is seen here talking about Oligocene shallow marine volcanoclastic rocks at Aireys Inlet.





The Strahan Geoscience Forum in December 2020 provided a chance for researchers, academics and industry geologists to meet in person after a long year interrupted by COVID restrictions. Here Professor David Cooke (left) and Dr Andrew McNeill (Mineral Resources Tasmania) prepare to lead a field trip in the Mt Read Volcanics area as part of the Forum.



Students were finally able to graduate in person during December 2020. Here CODES PhD student Erin Lawlis poses with her supervisor Professor David Cooke during a graduation ceremony at the Grand Chancellor Hotel in Hobart.

involved CODES MSc students Nathaly Guerrero and Karla Morales. The team has evaluated geological controls on rock breakage and the natural fractionation of minerals at a range of scales, including mineralogy, texture, paragenesis, metal deportment and rock hardness. They have assessed mineralisation styles in different rock types to better understand which geological features are related to the propensity of metal to fractionate into certain size fractions, so as to facilitate early predictions of the variability in grade-by-size response from intact drill core, which is key to identifying deposits that have a strong potential for pre-concentration via screening and are viable for larger-scale testing. Work progressed without interruptions throughout 2020, setting up the team for a successful completion of the project in mid-2021.

The Australian Research Council Linkage project 'Exploration targeting from next-generation volcanic facies reconstruction', led by Associate Professor Rebecca Carey, commenced in 2020 with the appointment of Dr Martin Jutzeler as the project's postdoctoral research fellow. Lockdown prevented fieldwork getting underway, but Martin was able to initiate textural analyses of volcanic facies from the Cowal district of NSW using the results of two pilot studies conducted by CODES Honours students in collaboration with Evolution Mining. Work on this project will ramp up in 2021 with PhD student recruitment and field campaigns planned for NSW and New Zealand.

Awards and accolades

Associate Professor Rebecca Carey was honoured by the Australian Academy of Science in 2020, which awarded her the prestigious 2020 Dorothy Hill Medal for her internationally recognised volcanological research. The Dorothy Hill Medal recognises significant research contributions by women in Earth Sciences up to 10 years post their PhD. Bec's career has certainly made profound impacts across the volcanology field. She has profoundly influenced the understanding of submarine silicic volcanism, and how water depths modify eruption styles in submarine settings. Her work on

basaltic magmatism has revealed a previously unrecognised mechanism that can trigger explosive eruptions involving volatile supersaturation, bubble nucleation and explosive fragmentation triggered by a compression-decompression wave in the shallow magma conduit. She has also provided innovative new methods for quantifying the duration of magma convection using microtextures in erupted clasts. Congratulations Bec for a well-deserved recognition of your great work!

Congratulations also to CODES staff members who were recognised with awards for their contributions to the College of Sciences and Engineering (CoSE) at the University of Tasmania in 2020. The CODES Analytical Laboratory Staff collectively received a Commendation for Service Excellence in Response to COVID-19. Dr Indrani Mukherjee received an individual commendation for an Early Career Researcher for Service Excellence to CoSE, CODES PhD student Tristan Wells was part of the 2020 Young Tassie Scientists' team that also received a Commendation for Service Excellence in Response to COVID-19, and Trish McKay was part of the Diploma of Sustainable Living team who were also recognised for their response to COVID-19.

Graduations in 2020 were mostly virtual events, although students and a small cohort of staff were able to attend the December 2020 graduation. Congratulations to all of our Honours, MEconGeol and PhD students who graduated in 2020. The following eight students graduated with a PhD: Adam Abersteiner, Nathan Chapman, David Douth, Matthew Ferguson, Amos Garay, Laura Jackson, Erin Lawlis and Francisco Testa.

Masters program short courses

Our Masters program was transformed in 2020, in large part due to the pandemic, but also due to an expansion in our course offerings that had been in the works since 2019. Our Volcanology short course was set to start in New Zealand in mid-March 2020, but the University of Tasmania banned international travel three days before the course started. A very

Our Masters program was transformed in 2020, in large part due to the pandemic, but also due to an expansion in our course offerings that had been in the works since 2019.

rapid transition from New Zealand to Victoria for the first part of the course was initiated, with Dr Martin Jutzeler and Professor David Cooke leading a group of 19 participants on a seven-day field trip through the Older and Younger volcanics of western Victoria, examining spectacular exposures of basaltic volcanism including scoria cones, maars, and lava field and Surtesyan-style eruptive products. The course continued in western Tasmania for several days before ending a few days early as widespread lockdowns were initiated. Our next two short courses, 'Ore Deposit Models' and 'Exploration in Brownfield Terrains', were moved entirely online, which allowed for global participation. Ore Deposit Models achieved its largest-ever number of participants (229) in early June, and Brownfields also achieved strong registrations (47) in October, although numbers needed to be capped in order to manage the online practicals. We also initiated our first new Masters course, 'Geodata Analytics', late in 2020, which proved so popular (over-subscribed with a cap of 30 participants) that it will be repeated early in 2021.

Conferences and trips

Field trip participation was limited in 2020 for obvious reasons. An early

Participants in the AUGEN field trip in January 2020 are seen here at Picaninny Point on Tasmania's East Coast comparing maps they had made with images taken from a drone. The AUGEN field trip, run by Dr Michael Roach, introduced geoscience educators from universities across Australia and New Zealand to new technologies for use in the teaching of Earth Sciences.

highlight was Dr Mike Roach leading a cohort of 26 Australian geoscience educators on the AUGEN 'Field Geology in the 21st Century' excursion in eastern Tasmania, 29–31 January 2020. Fieldwork was mostly restricted to intra-state travel for CODES staff and students in the second half of 2020, with Dr Mike Roach and Dr Rob Scott

conducting a trip to King Island late in 2020 to build a virtual guide for King Island geology. Several of our staff and students participated in online conferences throughout the year, including Goldschmidt 2020, and CODES staff and students organised the Tasmania session of GESSS.

STATISTICS AT A GLANCE 2020

Academic research staff	59
Postgraduate Students	127
Major research projects	58
Countries involved	25
Publications in refereed journals	92
Research reports to industry	188
Workshops and short courses	
Number	20
Countries	Delivered online
Attendees	1,000+
Funding	
Industry	\$1.40 million
UTAS	\$1.94 million
TMVC	\$1.66 million
Worldwide collaborations	
Industry	43
Institutes and universities	139





Associate Professor Rebecca Carey was awarded the prestigious Dorothy Hill Medal by the Australian Academy of Science in 2020. Here she is seen speaking about her research into the eruption and hydrothermal processes of volcanoes on a video produced by the Academy.

an active and popular supervisor of several PhD and Honours students, and an engaging teacher in several undergraduate courses. Evan remains an adjunct of CODES and is maintaining a supervisory role for his ongoing PhD students.

After eight years of working as part of the CODES Analytical Laboratories team, Elena Lounejeva moved on at the end of 2020 to take up a position with Mineral Resources Tasmania. We wish Elena every success with her new role at MRT. Elena does remain part of the CODES team, however, as she is still completing her PhD thesis part time while working at MRT.

Several other staff members departed CODES during 2020 – I would like to thank Troy Finearty, Deborah Macklin, James Tolley, Margaret Hawke and Adam Abersteiner for their efforts and wish them all well with their future careers.

Dr Clare Miller joined CODES and the Discipline of Earth Sciences as a lecturer in Environmental Geochemistry in February 2020 after completing

her PhD dissertation at Queen's - University in Canada. Clare instantly proved to be a highly popular and engaging staff member, building collaborations with staff within CODES and other disciplines across UTAS, and recruiting an active and productive cohort of environmental geology students who have been researching mine wastes across Tasmania. A statewide lockdown caused by the pandemic was not the ideal welcome for Clare, but once intrastate travel restrictions were lifted in June, Clare had the opportunity to begin to explore Tasmania's beautiful wilderness and get her students into the field, providing UTAS with one of the few active field programs conducted in 2020.

Other new staff members who arrived during 2020 include Maxwell Morissette, who joined CODES Analytical Laboratories in March, adapting quickly to the changing COVID-safe work practices that were implemented in late March to keep the laboratories fully operational throughout lockdown. Asher Riaz joined in early 2020 to collaborate with Dr Indrani Mukherjee and Professor Ross Large on the PY005 project, and Meagan Porter joined us for a short stint as safety officer late in 2020.

Publications

CODES staff and students were significant contributors to several special issues of journals in 2020, with the June–July Special issue of *Economic Geology* on 'The green



rock environment' edited by Dr Evan Orovan and Dr Pete Hollings containing seven articles co-authored by CODES staff and students that highlighted significant outcomes of the AMIRA porphyry footprints research program. Professor Khin Zaw also edited and contributed to special issues of the *Journal of Asian Earth Sciences*, *Ore Geology Reviews* and *Minerals* relating to mineral deposits of SE Asia. During 2020 CODES staff and researchers contributed to 92 academic publications and 188 industry reports.

The year ahead: what does 2021 hold?

We look forward to a gradual return towards normalcy in 2021, although Australia's border closures will continue to impact on our ability to recruit and travel internationally. We are adding two new Masters short courses to

In October 2020 the CODES Masters short course 'Exploration in Brownfield Terrains' was delivered online for the first time – due to COVID restrictions. All sessions were hosted on the Zoom platform, a technology with which everyone at CODES was extremely familiar by the latter half of 2020. CODES had a record number of participants in the four Masters short courses that ran during the year.

our program – 'Advanced Field Skills in Economic Geology' (February) and 'Fundamentals of Economic Geology' (September) – and aim to run 'Ore Deposit Geochemistry, Hydrology and Geochronology' online in June–July, 'Geometallurgy' online in October and 'Ores in Magmatic Arcs' in person in late November in eastern Australia. We will see the completion of several major CODES projects in 2021, including P1202, the TMVC (ARC Industrial Transformation Research Hub), CRC-ORE, the NW Queensland project and the PY005 pyrite project. We have new projects in development and will be working with our industry partners and academic collaborators to move them into active project status. A number of CODES staff and students will be involved in running the Australian Earth Sciences Convention in February 2021, and we will be participating in the SEG 100 conference and other online meetings throughout the year. We look forward to another successful year in unusual circumstances.

David Cooke
Director of CODES

Staff changes

Associate Professor Shaun Barker departed CODES in November 2020 to take up the role of Director of the Mineral Deposits Research Unit at the University of British Columbia. Shaun made profound contributions to CODES' research and teaching during his short (< 3 year) stint with us. He helped to expand the Master of Economic Geology program, initiated and led a major new AMIRA collaborative research initiative (P1206), provided critical insights and innovations to AMIRA P1202, and helped to mentor and train junior staff and graduate students, amongst many other significant activities. Although he is keenly missed, Shaun has continued to collaborate on CODES research projects since his departure, and we hope that this foreshadows a new phase of research collaborations between CODES and MDRU. We wish him every success in his role as MDRU Director.

One of our most popular staff members, Dr Karin Orth, accepted an early retirement package at the end of 2020. Since completing her PhD in 2002, Karin has worked collaboratively on several CODES research projects and in CODES Analytical Laboratories. In more recent times, Karin took on an undergraduate teaching role in the Discipline of Earth Sciences, where she proved to be a highly popular and engaging unit coordinator and lecturer. Post-retirement, Karin is still active as an adjunct, supervising students, and in the broader Tasmanian geological community as Chair of the Tasmanian Division of the Geological Society of



The CODES Christmas BBQ, which was held in the CODES Rock Garden, was an opportunity for a friendly and informal catch-up with colleagues and friends. Head of the Discipline of Earth Sciences Associate Professor Sebastien Meffre (left) and Professor David Cooke on the tools during a sunny day in mid-December 2020.



Professor David Cooke lecturing in the field near Mount Lyell in western Tasmania during the KEA348 field trip for third-year Earth Sciences students, September 2020.

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

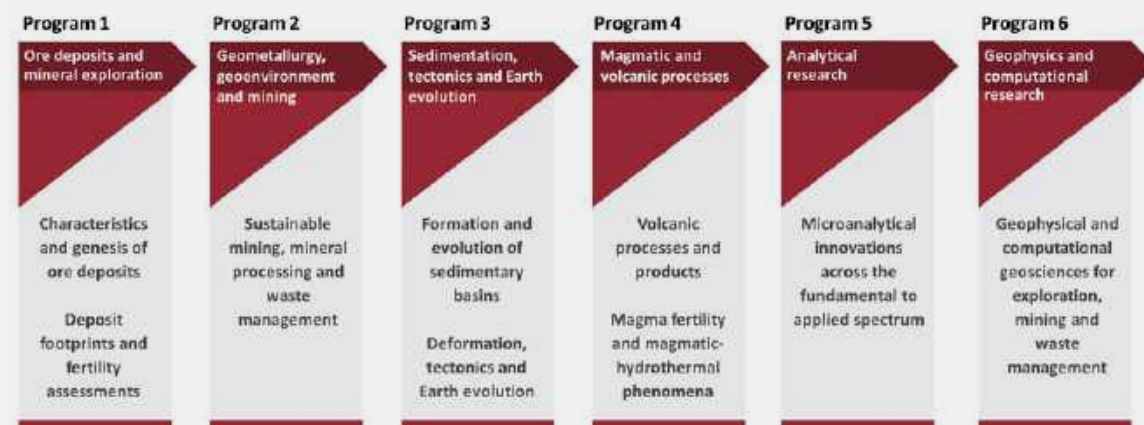
deposit research and postgraduate training. With 59 highly qualified research staff and 127 postgraduate students, CODES is one of the largest university-based teams of ore deposit researchers in the world.

Highly productive worldwide collaborations have been developed with over 43 industry companies, plus a host of joint research initiatives with 139 institutions and universities – 22 in Australia and 117 overseas. It currently has 58 major research projects spanning 25 countries, and all

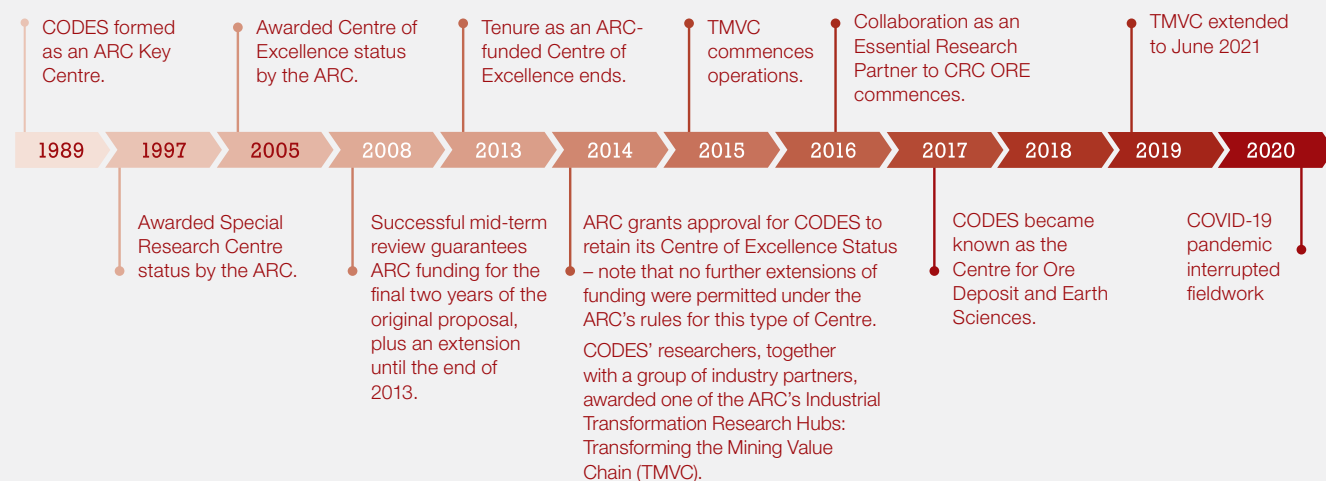
seven continents. It is also one of the leading groups to publish in *Economic Geology*. In the past year, despite the restrictions brought about by COVID-19, it maintained its reputation for delivering excellence in technology transfer by producing 188 reports to industry and conducting 20 short courses, 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 to join these courses and workshops.

Codes Program Structure

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



Timeline



Participants of the 'Volcanology and Mineralisation in Volcanic Terrains' Masters short course with course leaders Dr Martin Jutzeler (holding whiteboard) and Professor David Cooke during a teaching session at Aireys Inlet in Victoria in early 2020. This short course is one of an increased number of Master of Economic Geology short courses being offered by CODES.



Industry-focused research and training

CODES' research is conducted within and across six research programs. 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, 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 program.

Training and education

Training and education at CODES provides an ongoing supply of world-class 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 and Geochemistry.

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. In 2020 an entirely new MEconGeol short course – 'Geodata Analytics' – was offered in response to demand from both students and minerals industry professionals. This course was run online as were most other MEconGeol courses in order to adapt to COVID-19 restrictions.

PhD and MSc

These higher degree by research 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 five 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) is based at CODES. The Hub encompasses a wide array of activities from exploration, discovery, ore deposit characterisation and mineral processing to environmental management. The main objective of the TMVC is 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 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, UTAS Engineering and RWTH Aachen University in Germany.

In 2019 the tenure of the TMVC Research Hub was extended to June 2021, so in 2020 researchers in lockdown were concentrating on finalising and refining their research outcomes.

TMVC activities are covered later in this annual report.

Staff and management 2020

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. Assisting them in these roles are the Advisory Board and the Executive Committee.

ARC TMVC Research Hub Director

Professor David Cooke is Director of the ARC Research Hub for Transforming the Mining Value Chain. He is 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.



Professor Leonid Danyushevsky, Leader of the CODES Analytical Laboratories and Deputy Director of CODES, in one of the labs at CODES.

The Advisory Board met online during 2020 due to COVID-19 restrictions.

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 2020.

Staff movements 2020

Appointments

Academic/research staff

Dr Clare Miller joined the CODES and TMVC team in mid-February after completing her PhD in environmental geochemistry at Queen's University in Ontario, Canada. As a lecturer in geoenvironment and geometallurgy, and a researcher, she will be teaching and supervising students in addition to leading the growth and development of the environmental geochemistry lab at CODES.

Dr Adam Abersteiner, who completed his PhD at CODES in 2020, took up a short-term position (April to August) working within the TMVC. He left later in the year to do further research at the University of Helsinki in Finland.

Dr Angela Escolme was appointed as a Lecturer in Geology and Geometallurgy.

Professional/technical staff

Maxwell Morissette joined the CODES team in March as a Laboratory Technician for LA-ICP-MS. He completed his undergraduate degree in chemistry at McGill University in Montreal, Canada. With a background in chemistry and having worked in the mining industry for several years, Maxwell operates one of the laser ablation laboratories at CODES.

Asher Riaz, who hails from Pakistan, joined the PY005 project 'Characterizing pyrite chemistry of black shales hosting stratiform Zn-Pb-Ag and stratiform Cu deposits: Application to mineral exploration' as a database officer in early 2020.

Departures

Academic/research staff

Dr James Tolley resigned from his position as a Research Fellow in LA-ICP-MS in early March and moved to the UK. James had worked in the CODES Analytical Laboratories for almost two years.

Dr Margy Hawke came to the end of her six-month assignment working with Professor Ross Large on 'Pyrite vectors for the Cobar Basin', and in July moved to Western Australia to work for Kalamazoo Resources. She was appointed as an adjunct researcher to CODES after leaving.

Dr Evan Orovan resigned from his position as Research Fellow in Ore Deposit Footprints within the ARC TMVC Research Hub in July and took up a position with the British Columbia Geological Survey.

Associate Professor in Economic Geology Shaun Barker left CODES in November to take up the position of Director of the Mineral Deposit Research Unit (MDRU) at the University of British Columbia in Canada. He plans to strengthen ties and future research collaborations between MDRU and CODES.

Dr Karin Orth retired and left her role as Lecturer and Research Fellow in the Discipline of Earth Sciences at the end of 2020. Karin had been with Earth Sciences and CODES for 25 years.

Professional/technical staff

Troy Finearty left his role as Maintenance, Field Equipment and Safety Officer at CODES to take up a secondment position as Facilities Services Officer – Electrical at UTAS in late September.

Elena Lounejeva left her role as a Laboratory Analyst in the CODES Analytical Laboratories, at the end of the year. She had worked at the CAL for eight years. Elena then took up a role as a Senior Laboratory Technician at Mineral Resources Tasmania, and will continue to work on her PhD at CODES.

RIGHT (TOP): Professor David Cooke (left) and Dr Martin Jutzeler pictured in Victoria, in March 2020, during the 'Volcanology and Mineralisation in Volcanic Terrains' Masters short course. (2ND ROW) LEFT: Dr Karin Orth, Associate Professor Sebastien Meffre and Dr Rob Scott at a CODES Halloween event organised by the CODES SEG Student Chapter, 30 October 2020. 2ND ROW (RIGHT): Earth Sciences/CODES Rock Library Curator Izzy von Lichtan (left) chats with Dr Indrani Mukherjee at the CODES 2020 Christmas BBQ in December. 3RD ROW: CODES Administrative Assistant Karen Huizing (left) with Dr Julie Hunt preparing to tuck in at the CODES 2020 Christmas BBQ. BOTTOM ROW (LEFT): Dr Michael Roach (left) and Associate Professor Sebastien Meffre (right) with participants of the Australasian Universities Geoscience Educators Network (AUGEN) course, January 2020. This course was led by Dr Roach, and was titled 'Field Geology in the 21st Century'. BOTTOM ROW (RIGHT): Dr Clare Miller collecting tailings and Baloskion tetraphyllum samples as part of Fu Rong Mah's Honours study examining wetlands as passive remediation strategies for treatment of acid and metalliferous drainage across mining-impacted Tasmanian landscapes (taken at Copper Mines of Tasmania's Mount Lyell mine).



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 Mike Baker, BSc Hons (Sydney), PhD (UTAS)	Igneous petrology, mineral chemistry	100	✓
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	100	✓
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	100	✓
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 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	100	
Dr Michael Roach, BSc Hons (Newcastle), PhD (UTAS)	Geophysical responses of ore deposits	20	
Dr Robert Scott, BSc Hons, PhD (Monash)	Structural geology, gold deposits/MTEC Senior Lecturer and Masters Program Coordinator	70	
Dr David Selley, BSc Hons (Adelaide), PhD (UTAS)	Structural geology, basin analysis, ore deposit modelling	Hon	

*Research percentage † TMVC affiliated

Dr Jeff Steadman, BSc (Central Missouri), MSc (Iowa), PhD (UTAS)	Ore and sedimentary pyrite geochemistry; seawater composition through geologic time	100	
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	
Mr Ralph Bottrill	Mineral Resources Tasmania	Hon	
Dr Tony Brown	Consultant	Hon	
Dr Kathy Ehrig	BHP	Hon	✓
Professor Andrea Gerson	Blue Minerals Consultancy	Hon	
Neil Goodey	Corescan		✓
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 Evan Orovan	British Columbia Geological Survey	Hon	✓
Dr Anita Parbhakar-Fox	SMI, University of Queensland	Hon	✓
Adele Seymon	Amira Global		✓
Michael Shelley	Laurin Technic		✓
Professor Roger Smart	Blue Minerals Consultancy	Hon	
Dr Steve Walters	MINOREvation	Hon	
Professor Noel White	Consultant	Hon	
Professor Jamie Wilkinson	Natural History Museum/Imperial College London	Hon	

TECHNICAL/ADMINISTRATIVE STAFF

NAME		%*	TMVC†
Dr Ivan Belousov, BSc, MSc (Moscow), PhD (Vernadsky Inst.)	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	
Ms Elena Lounejeva, MSc (UNAM)	Laboratory Analyst	100	

TECHNICAL/ADMINISTRATIVE STAFF

NAME		%*	TMVC†
Mrs Michelle Makoundi, B Acc (U Marien Ngouabi)	Laboratory Assistant	60	
Ms Caroline Mordaunt, BA Hons (King's London)	Administrative Assistant	60	
Mr Maxwell Morissette, BSc (McGill)	Laboratory Analyst	100	
Dr Paul Olin, BA (SOU), MSc, PhD (WSU)	Deputy Leader – CODES Analytical Laboratories	100	
Mr Asher Riaz, BSc Hons (FC College), MSc (U Bremen)	Research Assistant	70	
Mrs Claire Rutherford, BBus (Acc) (RMIT)	Administrative Assistant	60	
Ms Terrie Sawyer, BSc Hons (UH)	Laboratory Analyst	100	
Ms Helen Scott, BSc Hons (UTAS), BEd (QUT)	Hub Manager – ARC TMVC Research Hub	100	✓
Ms Isabella von Lichten, BSc Hons (UTAS)	Curator	25	

ADVISORY BOARD

Chair: Paul Heithersay	Department for Energy and Mining, South Australia
Deputy Chair: Paul Agnew	Rio Tinto Exploration
Rufus Black	Vice Chancellor, UTAS
Dave Braxton	Anglo American
David Cooke	CODES, UTAS
Leonid Danyushevsky	CODES, UTAS
Andrew Davies	Teck
Mark Doyle	AngloGold Ashanti
Simon Ellingsen	School of Natural Sciences, UTAS
Angela Escolme	Earth Sciences and CODES, UTAS (observer)
Anthony Harris	Newcrest Mining
Ned Howard	Evolution Mining
Julie Hunt	CODES, UTAS (observer)
Anthony Koutoulis	Research, UTAS
Ben Maynard	Tasmanian Minerals, Manufacturing and Energy Council
Andrew McNeill	Mineral Resources Tasmania
Sebastien Meffre	Earth Sciences, UTAS
Brett Paull	College of Sciences and Engineering, UTAS
Kevin Robinson	Mineral Resources Tasmania
Helen Scott	CODES, UTAS (observer)
Adele Seymon	Amira Global
Trevor Shaw	Mt Isa Mines (Glencore)
Miles Smith	School of Natural Sciences, UTAS
Noel White	CODES, UTAS
Chris Wijns	First Quantum Minerals
Andy Wurst	Barrick
Brian Yates	College of Sciences and Engineering, UTAS

Note: In 2020 there was no Annual Review at CODES due to COVID-19 restrictions.

EXECUTIVE COMMITTEE

Chair: David Cooke	Director, CODES and ARC TMVC Research Hub
Shaun Barker	Applied Research (part year)
Rebecca Carey	Fundamental Research
Leonid Danyushevsky	Deputy Director, CODES
Sebastien Meffre	Head, Discipline of Earth Sciences
Helen Scott	Administration
Robert Scott	Education



OPPOSITE PAGE: The contact between Proterozoic sedimentary rocks of the Fraser Formation and the Early Carboniferous Sandblow Granite, Red Hut Point, King Island (photo by Rob Scott).

Program One

Ore deposits and mineral exploration

Objectives

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 six 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

Despite the challenges faced in 2020 due to the COVID-19 pandemic, Program 1 within CODES has continued to retain a critical mass of projects, spread across a diverse range of geological fields, deposit types and locations. 2020 has seen Program 1 continue with the carry-over of several major projects from previous years, with the current list of projects and research continuing to have a significant impact 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. In 2020 Yi continued analytical work on these newly discovered epithermal vein systems, located underneath and beside the Lepanto high sulfidation orebody. This work has helped to unravel the complex overlapping stages of copper and gold mineralisation that led to significant grade enhancement at Lepanto. (See the TMVC section of this report for further details about Yi Sun's research.)

OPPOSITE PAGE (TOP): CODES Master of Economic Geology student Victor Torres, now based in South America, pictured while undertaking fieldwork at Soledad, central Peru. Victor's research is looking at the geology, genesis and exploration implications of Cu-Au mineralised tourmaline breccia pipes at Soledad. He is holding core of semi-massive chalcopyrite from the current 25,000-m drilling program in Cu-Au-Ag tourmaline breccias. (BOTTOM): CODES PhD student Rob Davidson undertaking fieldwork while researching the San Sebastian vein system in 2018. He is examining an outcrop of silicified volcanics, which is indicative of a major graben bounding structure, La Roca prospect, Saladillo District, Durango, Mexico. Due to COVID-19, Rob's third field season in Mexico, scheduled for 2020, was cancelled. However, he had sufficient material from his two previous field seasons to complete all the analyses to support the aims of his thesis.

SE Asia

The 'Power of pyrite' sub-project focusing on the study of bio-essential and redox-sensitive trace element concentrations in sedimentary pyrites in three black shale sequences in the Yanliao area in the northern North China Craton, and Australian black shales (particularly Middle Proterozoic), continued in 2020. This sub-project will build upon work undertaken by the 'Power of pyrite' research team over the past decade.

A new research project focusing on the tectonic and mineral resources of sections of the Indochina Terrane in Thailand and Laos has been under development by Professor Khin Zaw and the SE Asia research team at CODES. This replaces the project under development in 2019 that focused on Myanmar terranes, due to feasibility and access issues. This new project is linked with collaborator-led projects on the Indochina Terrane funded by Chulalongkorn University and Universiti Brunei Darussalam.

North America

Brian McNulty and team members published a scientific communication in *Economic Geology* based on the results of his PhD study into the assessment of hydrothermal alteration intensity in VHMS systems using pXRF analysis at Myra Falls, Canada. This study highlights the application of new proxies to commonly used alteration indices in hydrothermal systems.

Rob Davidson has also continued his PhD research on the sediment-hosted San Sebastian intermediate sulfidation epithermal vein system in Durango, Mexico. Despite the cancellation of a third field campaign in 2020 due to COVID-19, Rob is on track to complete his thesis and is now in the process of writing up his results in expectation of submission in 2021.

South America

Carlos Diaz has completed the first draft of his Master of Economic Geology thesis on the Cascabel porphyry deposit cluster in Ecuador. This thesis is scheduled for completion in early 2021, and a draft *Economic Geology* manuscript is in preparation.

Victor Torres' Master of Economic Geology project on the Soledad tourmaline breccia complex in the Cordillera Negra of central Peru has also continued throughout 2020. Discussions are currently underway in regard to upgrading Victor's project into a PhD study.

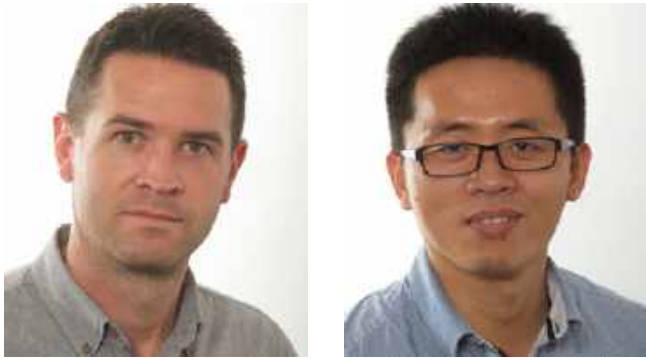
Australia

The 'Power of pyrite' project has also 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. In 2020, Ben Johnson commenced a Masters research project on pyrite chemistry from the Century stratabound Zn-Pb-Ag deposit in northwest Queensland.

In 2020, Dr Wei Hong published an article in *Mineralium Deposita* summarising the boron and oxygen isotope systematics of tourmaline and quartz from the Tasmanian tin granites study (previously published online in late 2019). A manuscript documenting fluid inclusion and quartz cathodoluminescence characteristics of the magmatic-hydrothermal features in Western Tasmanian tin granites was submitted to *Economic Geology* in 2020 and is scheduled for publication in 2021.

The
program
team

LEADER MIKE BAKER
DEPUTY LEADER LEJUN ZHANG



TEAM MEMBERS:

Shaun Barker, Ron Berry, Stuart Bull, David Cooke, Matthew Cracknell, Leonid Danyushevsky, Angela Escolme, Bruce Gemmell, Margaret Hawke, Ross Large, Charles Makoundi, Adi Maryono, Sebastien Meffre, Brian McNulty, Indrani Mukherjee, Evan Orovan, Asher Riaz, Robert Scott, David Selley, Jeff Steadman, Jay Thompson, Khin Zaw

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Akira Imai

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Lin Sutherland

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Xue Gao, Bin Lin

**CHINA UNIVERSITY OF
GEOSCIENCES, WUHAN, CHINA**
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Cho Cho Aye

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Mike Gadd

**GEOLOGICAL SURVEY OF
SOUTH AUSTRALIA**
Adrian Fabris, Anthony Reid

**GEOLOGICAL SURVEY OF
QUEENSLAND**
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Peter Hollings

MACQUARIE UNIVERSITY
Nathan Daczko

**MAHASARAKHAM UNIVERSITY,
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Clive Burrett

**MANDALAY UNIVERSITY,
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**MINERAL RESOURCES
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MONASH UNIVERSITY
Ray Cas

**NANYANG TECHNOLOGY
UNIVERSITY, SINGAPORE**
Lin Thu Aung

NEWCREST MINING
Karyn Gardner, Anthony Harris

NYRSTAR
Rick Sawyer, Armond Stansell

**ROYAL HOLLOWAY UNIVERSITY
OF LONDON, UK**
Tony Barber, Ian Watkinson

SANDFIRE RESOURCES
Bruce Hooper, 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

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DARRUSALAM, BRUNEI**
Chun-Kit Lai

**UNIVERSITI KEBANGSAAN,
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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

**YANGON UNIVERSITY,
MYANMAR**
Nyein Nyein Sint

The core shed at the Century Mine, 250km northwest of Mount Isa in the Lower Gulf of Carpentaria, Queensland; CODES Masters student Ben Johnson is completing a deposit case study of samples from this zinc mine as part of the sub-project PY005 within the 'Power of pyrite' project.



Projects
Geology of the West Block area of the late Devonian Myra Falls VHMS district, BC, Canada
The power of pyrite: Application in ore deposit and deep time geology
Tectonics, mineral resources and magma fertility of the Indochina Terrane
Epithermal research
Porphyry research
Tasmanian tin granites

Project summaries

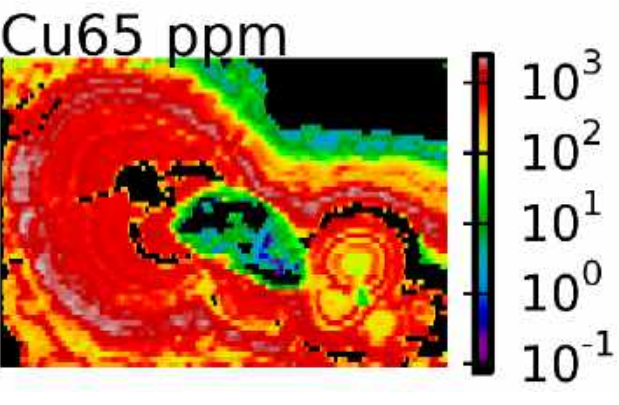
GEOLOGY OF THE WEST BLOCK AREA OF THE LATE DEVONIAN MYRA FALLS VHMS DISTRICT, BC, CANADA

Leader: Bruce Gemmell

Team member: Brian McNulty

Collaborators: Nathan Fox, Rick Sawyer, Armond Stansell

In 2020, Dr Brian McNulty published a scientific communication in *Economic Geology*, co-authored with Dr Nathan Fox and Professor Bruce Gemmell, entitled ‘Assessing hydrothermal alteration intensity in VHMS systems using pXRF analysis of drill core: An example from Myra Falls, Canada’. Current portable X-ray fluorescence (pXRF) technology can rapidly and inexpensively yield concentrations of geologically significant elements, typically with instrument detection limits below several 10’s of ppm. Based on conventional XRF whole-rock geochemical data, both the Ishikawa Alteration Index and the Chlorite-Carbonate-Pyrite Index increase with proximity to sulfide mineralisation at Myra Falls. However, available pXRF technology is typically



The ‘Power of pyrite’ project research findings: This image shows a laser ablation image of a large banded pyrite crystal from the Black Butte sediment-hosted Cu district, Montana, USA, showing the distribution and amount of copper that is present in the pyrite. Each ring of the pyrite crystal represents a growth event, similar to tree rings. As this pyrite grew, more rings were added, and each ring contains a different amount of copper. This pyrite probably grew during the formation of the copper orebodies at Black Butte, so the image provides important geological information relative to the genesis of the copper mineralisation in the Black Butte area.

unable to detect all of the elements required to calculate these alteration indices. As a result, there is a need to utilise the elements that are readily detectable using pXRF and apply these to hydrothermal alteration assessment. Brian proposed that Rb/Sr ratios provide a robust proxy for the Ishikawa Alteration Index and demonstrate that conventional whole-rock XRF analytical results for Rb and Sr can be reproduced using pXRF analysis from drill core surfaces. At Myra Falls, the Rb/Sr ratios range from 2.0 for intensely altered rocks. Down-hole profiles of alteration intensity generated from systematic pXRF analysis of drill core surfaces can be used to inform drilling and targeting decisions. The application of the Rb/Sr ratio as a proxy for alteration intensity extends beyond this case study and can be applied to other hydrothermal systems that produce phyllosilicate minerals as alteration products of feldspar.

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

Leaders: Indrani Mukherjee, Ross Large

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

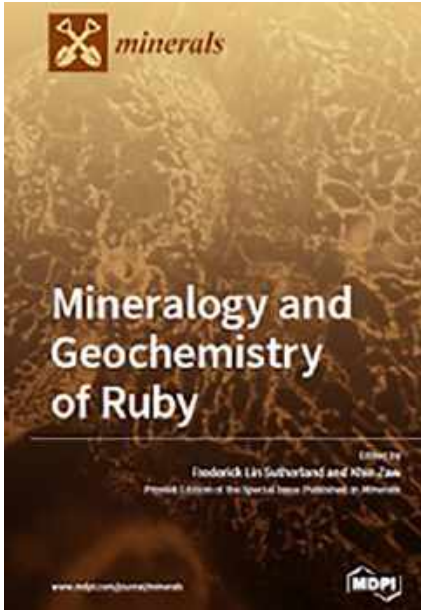
Student: Ben Johnson

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 of these sub-projects is funded by the Ian Potter Foundation and a collaboration with Professor Shuanhong Zhang at the Institute of Geomechanics, Chinese Academy of Sciences. The objectives are to provide key insights into the evolution of the first complex cell and subsequent macroscopic life. We aim to undertake a detailed comparison between Chinese and Australian black shales (particularly Middle Proterozoic) to advance our understanding of the geochemical conditions of the two sedimentary basins (McArthur Basin in north Australia and Yanliao Basin in north China). We propose to analyse a suite of bio-essential and redox-sensitive trace element concentrations in sedimentary pyrites, using laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) in the three black shale sequences in



Cover of the Minerals Special Issue on rubies, which was published in 2020 and was jointly edited by Professor Khin Zaw, who is now working on a new southeast Asia project in Program 1 called ‘Tectonics, mineral resources and magma fertility of the Indochina Terrane’.

the Yanliao area in the northern North China Craton. They are located in the Xiamaling, Hongshuizhuang and Chuanlinggou Formations, respectively. The peak age of black shales within the Xiamaling Formation is around 1380 Ma, similar to the Upper Velkerri Formation in northern Australia. The peak age of the black shales within the Hongshuizhuang Formation is around 1450 Ma. The peak age of the black shales within the Chuanlinggou Formation is around 1650 Ma, similar to the Barney Creek Formation in Australia.

The second of these sub-projects (PY005), which commenced in mid-2019, is currently funded by eight mining companies and two state geological surveys (Teck, Sandfire Resources, First Quantum, Anglo American, Glencore, Rio Tinto, Red Metal, DGO Ltd., the Geological Survey of South Australia and the Geological Survey of Queensland). The main aims of this sub-project are to:

- focus sampling in ore deposit districts to determine pyrite chemical trace element and isotopic halos (footprints) around major ore deposit types of stratiform Zn-Pb-Ag and stratiform Cu;

- study sedimentary pyrite in other high-priority black shale formations, principally in Australia, to determine their potential to host stratiform Zn-Pb-Ag and stratiform Cu deposits; and

- assess the pyrite 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.

Despite delays in sample collection and analyses due to COVID-19 during 2020, the team met its deliverable deadlines that included sponsor updates, reporting and deliverables. The team reported on results and analyses of the various case studies for the sub-project PY005 via two online sponsors’ meetings in 2020.

Ben Johnson commenced his Masters research as part of sub-project PY005 and is on track to complete his Century deposit case study by the end of 2021.

A database comprising more than 10,000 legacy LA-ICP-MS pyrite analyses, including all metadata, was delivered to the sponsors in mid-2020. The database was updated with newly generated data as part of the PY005 project at the end of 2020. Database compilation was managed by Asher Riaz, who joined CODES in early 2020 specifically to carry out this work.

The first sub-project (funded by the Ian Potter Foundation) was completed during 2020, including submission of the final report to the Foundation. The project generated seven manuscripts of which five are published and two are under review. These also include an invited contribution to the *Encyclopedia of the UN Sustainable Development Goals – Life on Land* (published by Springer Nature). There are five further manuscripts under preparation. The results of the project provide insights into past ocean chemistry and evolution of early complex life. Trace element concentrations in sedimentary pyrite were utilised to construct trends of bio essential elements through time. These trends, in combination with other direct oxygenation proxies, provided robust atmospheric oxygenation trends through time. Results also provided valuable insights into patterns of trace element utilisation strategies by early

life. The results of this sub-project were also presented at the Goldschmidt Online conference in 2020: two oral presentations were given by Indrani Mukherjee and Ross Large.

TECTONICS, MINERAL RESOURCES AND MAGMA FERTILITY OF THE INDOCHINA TERRANE

Leaders: Khin Zaw, Sebastien Meffre

Team members: David Cooke, Charles Makoundi, Lejun Zhang

Student: Peerapong Sritangsirikul

Collaborators: Mohd Basril Iswadi Bin Basori, Clive Burrett, Punya Charusiri, Mike Crow, Htet Sandar Aung, Akira Imai, Chun-Kit Lai, Nyein Nyein Sint, Abhisit Salam, Sokha Seang, Meifeng Shi, Chakkaphan Sutthirat, Zaw Htet

The Indochina Terrane is the largest tectonic unit in mainland SE Asia consisting of the highly mineralised Troung Son, Loei, Dalat–Kratie and east Malaysia Fold Belts and 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.

This new project will be focused on tectonic development, metallogenesis and timing of mineralisation of the diverse deposit types and will look mainly at the 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. 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 promising patterns and trends to discriminate pre-mineralisation magmas from mineralised fertile magmas, and insights into a complex petrogenesis. This project is also linked with ‘Tectonic evolution and mineralization along the Loei Belt’ led by Professor Punya Charusiri and funded by Chulalongkorn University and the

‘Gold deposits of Borneo’ project led by Professor Chun-Kit Lai and funded by Universiti Brunei Darussalam as well as ‘IGCP 668: Equatorial Gondwanan History and Early Palaeozoic Evolutionary Dynamics’.

EPITHERMAL RESEARCH

Leaders: Bruce Gemmell, David Cooke

Student: Rob Davidson

Collaborators: Kurt Allen, Stephen Redak

Rob Davidson continued his PhD research on the sediment-hosted San Sebastian intermediate sulfidation epithermal vein system in Durango, Mexico, in 2020 with support from Hecla Mining. His research aims were to: determine the relationship between the vein systems and occurrences within the San Sebastian district; characterise the Mesozoic sedimentary host rock lithologies; understand the structural controls on vein formation; characterise whole-rock and trace element geochemistry of veins, vein stages, host rock, volcanic rocks and alteration in order to develop potential vectors towards mineralisation; and date, using a range of geochronological methods, the veins, host rocks and alteration.

His research methods include hand sample descriptions, polished thin section descriptions, SEM analyses of mineralisation, potassium feldspar staining, SWIR (TerraSpec) data collection, pXRF (Olympus Vanta) data collection, a carbon and oxygen (in carbonates) isotope study, a pilot Raman geo-thermometry study of the host rocks, and age dating of the regional volcanic rocks and hydrothermal alteration.

Due to COVID-19, Rob’s third field season in Mexico was cancelled. However, Rob had sufficient material from his two previous field seasons to complete all the analyses to support the aims of his thesis. Rob is in the process of writing his thesis and he should be submitting it for examination in 2021.

PORPHYRY RESEARCH

Leader: David Cooke

Team members: Michael Baker, Evan Orovan, Lejun Zhang

Students: Carlos Diaz, Victor Torres

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

In 2020 Carlos Diaz completed the first draft of 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 has documented the characteristics, genesis and exploration significance of porphyry Cu-Au-Ag mineralisation in the Cascabel district and has 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 (Aguinaga and Tandayama – America). This thesis is scheduled for completion early in 2021, and a draft *Economic Geology* manuscript is in preparation.

Master of Economic Geology student Victor Torres continued his research into Cu-Au mineralisation in the Soledad tourmaline breccia complex, central Peru, supported by Chakana Copper Corp. Significant new geological understanding has arisen from the ongoing drilling program by Chakana, and discussions are underway with regards to upgrading Victor’s study to a PhD investigation.



Dr Indrani Mukherjee at work in her office on the ‘Power of pyrite’ project.

TASMANIAN TIN GRANITES

Leader: David Cooke

Team member: Lejun Zhang

Collaborators: Mostafa Fayek, Nathan Fox, Wei Hong, Jay Thompson

Western Tasmania is a major Sn-W mineral province where post-orogenic Sn granites intruded between 370 and 355 Ma and produced a spectrum of Sn, W and base mineralisation in large zoned mineral districts. To better understand controls on mineralisation in the region, Wei Hong investigated magmatic-hydrothermal textural features (unidirectional solidification textures, miarolitic cavities, tourmaline orbicules, alteration patches and veins) in the strongly mineralised Heemskirk Granite and the unmineralised Pieman Heads Granite. In 2020, Wei published an article in *Mineralium Deposita*, that summarises the boron and oxygen isotope systematics of tourmaline and quartz from both granites and discusses their implications for fluid exsolution and mineralisation crust. This study demonstrated that high degrees of fractional crystallisation of the melt caused exsolution of boron-rich hypersaline fluids from which

tourmaline orbicules and miarolitic cavities formed. Bimodal ^{11}B populations (– 21.7 to – 12.7‰ and – 3.9 to +4.0‰) imply that the granitic melts were mostly sourced from ^{10}B -rich meta-pelitic rocks. Extensive fluid exsolution occurred late during granite crystallisation and contributed to the widespread development of tourmaline-rich features in the granites, and to the formation of tin and base metal sulfide deposits within and above the Heemskirk Granite.

A final manuscript documenting fluid inclusion and quartz cathodoluminescence characteristics of the magmatic-hydrothermal features in Western Tasmanian Sn granites was submitted to *Economic Geology* in 2020 and is scheduled for publication in 2021.

Looking forward

Despite the upheaval caused by the COVID-19 pandemic in 2020, Program 1 will continue to deliver a diverse range of projects into 2021. Importantly, several Program 1 projects that are driven by graduate student research have entered critical stages in data acquisition, interpretation and thesis writing, and have consequently been largely unaffected by the current inability to travel to field sites. These projects, and the students who drive them, continue to be the lifeblood of this Program, as they will generate quality research outcomes including theses, peer-reviewed publications, and models for the development of mineralised hydrothermal systems in a diverse range of environments.

Postgraduate research projects continuing into 2021 include Rob Davidson’s work on the San Sebastian epithermal deposit in Mexico; Yi Sun’s project on the Lepanto QPG veins in the Philippines; Carlos Diaz’s project on the Cascabel porphyry deposit in Ecuador; Victor Torres’ project on the Soledad tourmaline breccia complex in central Peru; and Ben Johnson’s ‘Power of pyrite’ project on the Century deposit in Queensland.

Several journal articles from across the Program have also neared completion or have been submitted for review for future publication. This, in addition to the expected completion of several graduate student theses, indicates that 2021 will once again be an excellent year for scientific reporting of Program 1 outcomes to the wider academic community and industry.



Another view of the core shed at the Century Mine, where CODES Masters student Ben Johnson is completing a deposit case study.

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

OPPOSITE PAGE (TOP): The legacy Endurance Mine, northeast Tasmania: an erosional gully in the mine wastes where AMD-impacted waters flow from Blue Lake to the downstream environment. One of the aims of TMVC Honours students' Olivia Wilson, Wei Xuen Heng and Eliza Fisher's projects was to understand the hydrological and mineralogical factors influencing the generation and migration of AMD along this pathway to inform remediation at the site. (BOTTOM): CODES Master of Science student Nathaly Guerrero pictured selecting samples from Telfer drill core while at the CRC ORE facility in Brisbane during early 2020.

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 is active both within the current 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 is an Essential Research Participant.

CRC ORE aims to support mining sector growth through implementation of technological innovations in minerals characterisation, extraction and processing. Fundamental to CRC ORE's research is 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 is organised into five programs: Define, Separate, Extract, Control and Operate. Project P1-006 ('Geological controls on grade-by-size deportment'), which operates at CODES, sits within Program 1 – Define.

The P1-006 project aims to evaluate 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, is fundamental to effective Grade Engineering® levers that upgrade ores by size-based screening. Using a range of deposit and mineralisation styles, P1-006 is evaluating the geometallurgical drivers that influence natural grade by size deportment. The workflow integrates 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.

Additional geometallurgical research activities at CODES are being 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). The largest of these projects is the major AMIRA P1202 Module 4 sub-project which includes five PhD projects, one Economic Geology Masters project and one Honours project across six study sites. The project is developing 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.

Highlights

- New appointments to the Program's senior team members in 2020 include Dr Clare Miller as Researcher and Lecturer in Geology and Geoenvironment. She has been generating new geoenvironmental research initiatives in 2020, including three collaborative and multidisciplinary Honours projects to characterise and remediate acid and metalliferous drainage at legacy mine sites in Tasmania.
- An online short course on 'Geology for gold metallurgists' was held for the first time in October 2020 in collaboration with Teresa McGrath (Curtin University) and attended by a high turnout of ~50 students from the AMIRA P420 sponsor group. The course was coordinated and presented by Dr Hunt and Dr Escolme and included a number of guest speakers.
- Dr Hunt and MSc students Nathaly Guerrero and Karla Morales attended the Preconcentration 2020 conference where Nathaly Guerrero gave an oral presentation entitled



Tasmanian fieldwork in 2020: L–R: Dr Clare Miller, TMVC Honours students Eliza Fisher and Wei Xuen Heng, Dr Matthew Cracknell and TMVC Honours student Olivia Wilson. The three Honours students all completed their theses on aspects of acid and metalliferous drainage at legacy Endurance Mine, northeast Tasmania, where this photo was taken.

‘Grade Engineering at Gramalote gold deposit’, describing part of her research on geological controls of grade-by-size fractionation in gold systems.

- Publication of two papers in the Preconcentration 2020 conference Proceedings: Grade Engineering at Gramalote gold deposit, Colombia: an example of industry-research collaboration, part 1 and part 2.
- Dr Miller and TMVC PhD student, Annah Moyo, attended the Goldschmidt Virtual conference where both gave oral presentations. Annah presented a talk entitled ‘Potential use of industrial wastes in the treatment of mine wastes: A case study of legacy mine sites in Tasmania’.
- Completion of PhD thesis by Laura Jackson titled ‘Mineralogical domaining of low and no grade zones using automated drill coring’.
- Completion of Honours thesis by Olivia Wilson titled ‘Hydrogeological studies of acid mine drainage at the legacy Endurance Mine Site, northeast Tasmania’.

- Olivia Wilson received the 2020 GSA Endowment Fund Honours/Masters award and was invited to speak at the AusIMM/AIG/GSA Geoscience Forum in Strahan, Tasmania, in December 2020.

- Completion of Honours by Eliza Fisher titled ‘Geochemical analysis of mine waste and pit lakes at Endurance Mine, NE Tasmania’.
- Completion of Honours thesis by Wei Xuen Heng titled ‘Geophysical investigation of the Endurance legacy mine site, northeast Tasmania’.

Technology transfer

Dr Hunt participated in project development meetings and CRC ORE Implementation Council meetings.

Dr Hunt gave an oral presentation at the 2020 Geoscience Forum, Strahan, Tasmania, covering geological contributions to geometallurgy.

TMVC PhD student Annah Moyo has continued to present the ongoing results of her experiments to government sponsors. She successfully sought approval and continued her long-duration experiments during COVID-19 lockdowns in 2020.

Short courses

Dr Hunt and Dr Escolme coordinated and presented a short course entitled ‘Geology for gold metallurgists’ in October 2020. The course was held online and included sessions on:

- geology for metallurgists;
- gold deposit models for metallurgists; and
- geological characterisation and geometallurgy.

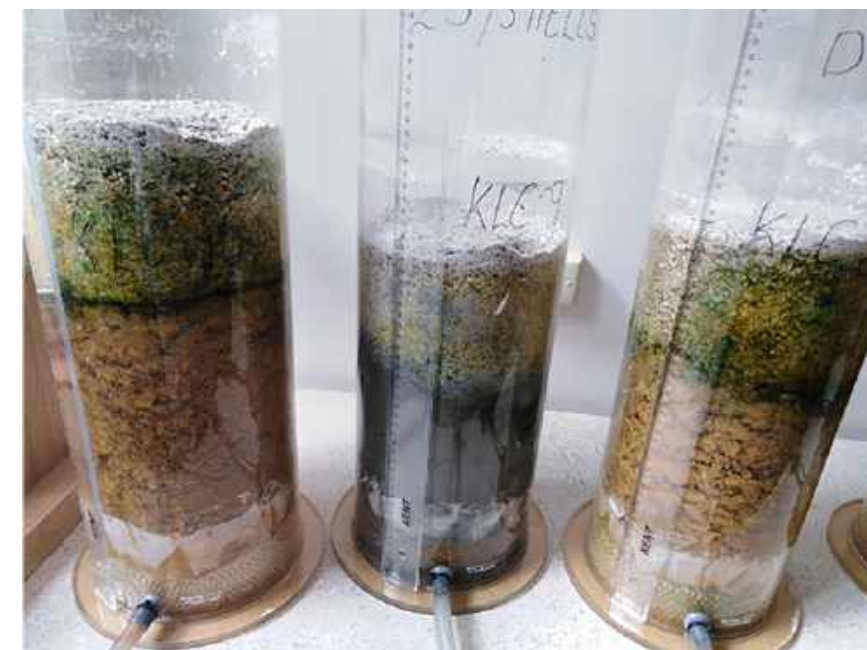
Conferences

In 2020 research outcomes were presented by staff and students at several conferences and geological society meetings, including:

- CODES Masters student Nathaly Guerrero and Dr Hunt were co-authors on two presentations at ‘Preconcentration 2020’ (Grade Engineering at Gramalote gold deposit, Colombia: an example of industry-research collaboration, parts 1 and 2).
- Dr Hunt gave an oral presentation at the 2020 Geoscience Forum, Strahan, Tasmania (Geological contributions to geometallurgy: Rocks first).
- TMVC Honours student Olivia Wilson was invited to present the findings of her collaborative research project (collaborating TMVC Honours students Wei Xuen Heng and Eliza Fisher) at the 2020 Geoscience Forum, Strahan, Tasmania (‘An enduring problem: A multidisciplinary approach to characterise acid and metalliferous drainage at Endurance Mine, NE Tasmania’).
- Wei Xuen Heng, Olivia Wilson and Eliza Fisher, TMVC Honours students, co-presented the findings of their collaborative research at the GSA Earth Science Student Symposium, 2020 (‘An enduring problem: A multidisciplinary approach to characterise acid and metalliferous drainage at Endurance Mine, NE Tasmania’).
- Dr Miller co-chaired a session at the 2020 Goldschmidt Conference (‘Mining environments: Dynamic biogeochemical hotspots

understanding geochemical processes related to mined, milled, or natural metal deposits in a changing climate’).

- Dr Miller gave an oral presentation at the 2020 Goldschmidt Virtual conference (‘The development of a national water quality database to assess shifting baselines in a changing climate’).
- Dr Miller was lead author on a poster presented at SETAC Europe 2020 (‘The development of a national water quality database to assess shifting baselines in a changing climate’).
- TMVC PhD student Annah Moyo gave an oral presentation at the 2020 Goldschmidt Virtual conference (‘Potential use of industrial wastes in the treatment of mine wastes: A case study of legacy mine sites in Tasmania’).
- Dr Miller was invited to present at a GSA Tasmanian Division Meeting in October (‘Impact of climate warming on the speciation and long-term stability of arsenic in sub-Arctic lakes: Implications for environmental monitoring of mining impacted sites’).
- Dr Miller was invited to present at the Tasmanian Minerals, Manufacturing and Energy Council (TMEC) Environment Committee Meeting to address forward progression of research/innovation for industry (CODES Environmental Geology Research Overview).
- Dr Escolme was invited to participate in an online panel discussion titled ‘Geology to mineral - The holistic perspective challenge in processing’ during the ‘AMIRA 24-hour Global Muster for Future Processing’
- Dr Escolme was invited to participate in a webinar titled ‘Early data collection for geometallurgy’ as part of a webinar series facilitated by Geological Survey of Queensland.



TOP: TMVC PhD student Annah Moyo's work in progress in the lab at CODES: growth of algae on shells, week 23. This research is looking at how to control acid and metalliferous drainage legacy at mine sites in Tasmania using industrial wastes. MIDDLE: CODES Master of Science students Nathaly Guerrero and Karla Morales with supervisor Dr Julie Hunt in the core shed at the Mornington Core Library. They are collecting rebound hardness and petrophysical data from drill core (photo courtesy of CRC ORE). RIGHT: View of one of the tanks in the flotation circuit process inside the Hellyer Gold Mine Processing Plant in Tasmania, taken by CODES Master of Science student Nathaly Guerrero. During the flotation process, the ore minerals are attached to the bubbles and float to the surface.



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, Laura Jackson, Rhiannon Jones, Javier Merrill, Annah Moyo, Sibebe Nascimento, Angela Rodrigues (Monash), Yi Sun

MASTERS STUDENTS:

Roseanna Dale, Nathaly Guerrero, Lucy Jones, Karla Morales

HONOURS STUDENTS:

Erik Fabreschi, Eliza Fisher, Wei Xuen Heng, Fu Rong Mah, Hugh Sayers, Olivia Wilson

COLLABORATORS:

ALS GLOBAL
Shengli Zhao

ANGLOGOLD ASHANTI
Vaughan Chamberlain

BHP
Mario Avendaño, Alina Gaibor, Simon Gatehouse

CARL ZEISS MICROSCOPY
Shaun Graham, Matthew Andrew

CENTRAL SCIENCE LABORATORY (UTAS)
Sandrin Feig, Karsten Goemann

COPPER MINES OF TASMANIA
Geoff Cordery

CORESCAN
Neil Goodey, Cassady Harraden



CRC ORE
Luke Keeney, Paul Revell, Greg Wilkie

CSIRO
Louise Fisher, Carsten Laukamp, Mark Pearce, Steven Peacock

CURTIN UNIVERSITY
Teresa McGrath

FORTESCUE METALS 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

OLYMPUS AUSTRALIA
Dane Burkett, Jake Jarvinen

OREXPLORE
Rob Downard, Russell McChesney

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

TERRACORE
Paul Linton

TRUSCAN
Rod Fowler, Shaun O'Brien

Project

Geological controls on grade-by-size deportment (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 DEPORTMENT (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

This is a CODES–CRC ORE (Cooperative Research Centre for Optimising Resource Extraction) collaborative project and is focused on understanding the geological controls on grade by size deportment. 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. The project began in 2016 but had a change of staff and students at CODES in 2019 with the departure of researcher Dr Nathan Fox and two students, and the appointment of researcher Dr Julie Hunt and the arrival of new Masters student Nathaly Guerrero. Karla

Morales joined as a Masters student in February 2020.

Research within this project is directed towards identifying predictors for preconcentration from intact rocks and drill core and is divided into an over-arching research stream and two Masters projects. One Masters project is focused on grade by size deportment of gold systems using the Gramalote and Telfer deposits as examples; this is being undertaken by Nathaly Guerrero. The second is directed towards establishing a library of mineralisation styles that show a tendency for pre-concentration in early comminution stages and is being carried out by Karla Morales. Within the main research stream there are several projects:

- A project on grade-by-size fractionation of gold at the Carosue Dam project, WA, which was completed in 2019.
- Grade-by-size fractionation of copper and gold at a Chilean porphyry deposit is ongoing.
- A library of grade-by-size fractionation 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.

As part of the project, researchers and students are testing equipment for its suitability to assist with predicting grade by size response. This includes 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 is being done in conjunction with a range of equipment suppliers and labs (e.g., CSIRO, Minalyze, Oreplore, Hylogger, TerraCore, Corescan, TruScan, Zeiss).

TMVC Honours student Olivia Wilson installed and sampled groundwater monitoring wells to improve the understanding of how groundwater may be transporting contaminants and impacting water quality at the former Endurance Mine site in northeast Tasmania.

Looking forward

The year ahead will see the major projects under Program 2 and the TMVC (CRC ORE P1-006 and AMIRA P1202 Module 4) move towards their completion in mid-2021. Results from P1-006 are planned to be presented at several conferences (e.g., Sustainable Minerals '21; 16th SGA Meeting; SEG 100; Integrated Min Pro '22) with publications to follow. Dr Miller and Dr Cracknell will also be working closely with Mineral Resources Tasmania in 2021 as part of the Mining Sector Innovation Initiative Program (MSIIP) that will include two Honours projects and one PhD at legacy mine sites around Tasmania. As part of this innovation funding, Dr Miller and Dr Escolme will also be conducting a pilot study in collaboration with MRT and the Tasmanian mining industry.

CODES Masters student Karla Morales with Professor David Cooke and Dr Julie Hunt in the UTAS Engineering workshop watching a rock sample in a MATEST compression machine. High resolution video of rock breakage is being recorded (photo courtesy of CRC ORE).

INSET: An example of how a rock sample reacts in a MATEST compression machine with the direction of compression marked by red arrows.



Program Three

Sedimentation, tectonics and Earth evolution

Objectives

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

2020 saw the successful conclusion of the ARC Linkage project 'Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia', culminating in a final sponsors' meeting held at CODES in March (just before the COVID-19 lockdowns). The project produced significant advancements in the geological understanding of the Lachlan Orogen, and follow-on research is underway at several locations in the area.

In October, Associate Professor (and Program 3 Leader) Shaun Barker said farewell to CODES and moved to Vancouver to begin his tenure as Director of the Mineral Deposit Research Unit (MDRU) at the University of British Columbia, Canada. Dr Jonathan Cloutier assumed the role of Program 3 Leader in November. As with all the other research programs at CODES, the COVID-19 pandemic curtailed planned fieldwork for several Program 3 projects, as well as travel to conferences. However, Program 3 researchers gave presentations at several online webinars, conferences and workshops via Zoom, including the virtual Goldschmidt2020 conference.

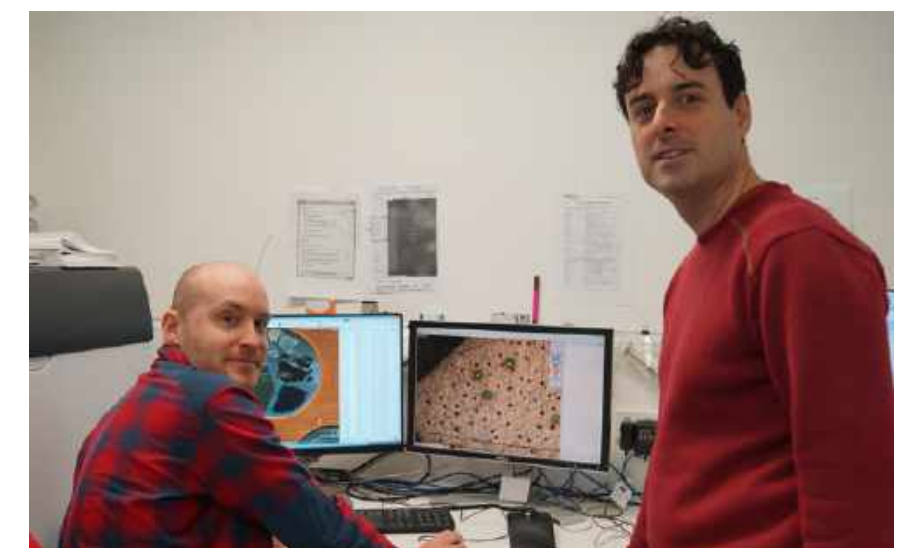
Ongoing projects within Program 3 include the Kansanshi gold project, funded by Kansanshi Mining, and 'Mineral chemistry vectoring: uncovering Northwest Queensland's hidden potential' supported by the Geological Survey of Queensland as part of the Strategic Resources Exploration Program.

Dr Martin Jutzeler is part of two RV *Investigator* voyages that will target landslides off the Australian shelf in 2022, totalling an investment of \$8 million in-kind from the Marine National Facilities (CSIRO). Martin Jutzeler is lead CI on the voyage to the western coast of Tasmania to study a gigantic (~50-km-wide) submarine landslide, and will be an onshore participant to a voyage off Queensland and New South Wales.

Publications in 2020

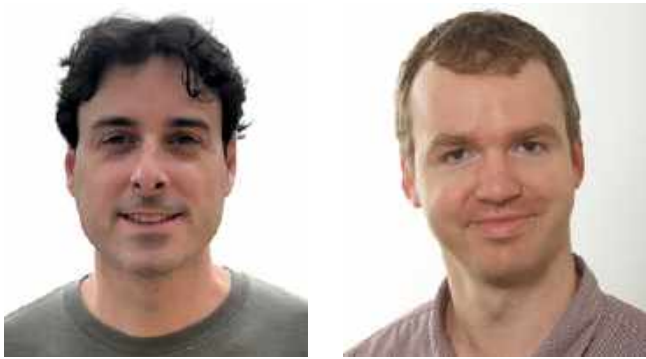
During 2020, Program 3 researchers published numerous papers, including a review paper on the trace element chemistry of pyrite in magmatic-hydrothermal environments, co-authored by Dr Jeff Steadman, Professor Ross Large, Associate Professor Sebastien Meffre, Dr Paul Olin and Professor Leonid Danyushevsky. Dr Indrani Mukherjee and Professor Ross Large also published a paper in *Geology* detailing the co-evolution of trace elements and life during the Proterozoic Eon. Dr Jeff Steadman, Professor Ross Large, Dr Indrani Mukherjee, Dr Ross Corkrey and Professor Leonid Danyushevsky published a major paper in *Precambrian Research* on the oxygenation history of the terrestrial ocean-atmosphere system throughout the Precambrian Eon, indicating that oxygen concentrations varied significantly during this time, contrary to nearly all previous research on this topic.

RIGHT: Dr Jonathan Cloutier (right), leader of the northwest Queensland project, with CODES PhD student Max Hohl, programming points for laser ablation ICP-MS analysis. OPPOSITE PAGE (TOP): Dean's Summer Research Scholarship student Eva Knight pleased as punch after having bagged her first sample at Scamander Quarry in 2020 as part of research for the 'Building Tasmania' project headed by Associate Professor Sebastien Meffre and Dr Robert Scott. OPPOSITE PAGE (BOTTOM): Schistose blocks (Keith Schist) exposed along Savage River near the Savage River Mine, in northwest Tasmania, photographed by collaborator Grace Cumming (Mineral Resources Tasmania) during fieldwork on the 'Building Tasmania' project.



The program team

LEADER JONATHAN CLOUTIER
DEPUTY LEADER JEFF STEADMAN



TEAM MEMBERS:

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

PHD STUDENTS:

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

MASTERS STUDENTS:

Chloe Cavill, Batbayar Enkhbold, Brendan Hardwick, Corey Jago, Benjamin Johnson, Sitthinon Kultaksayos, Greer Lane, George Maroa, Peerapong Sritangsirikul

HONOURS STUDENTS:

Till Gallagher, Verity Kameniar-Sandery, Hugh Sayers

DEAN’S SUMMER RESEARCH SCHOLARSHIP STUDENT:

Eva Knight

COLLABORATORS:

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Janaina Avila, Trevor Ireland, Marc Norman

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Sandrin Feig, Karsten Goemann

CHINA UNIVERSITY OF GEOSCIENCES, WUHAN, CHINA

Aleksandr (Sasha) Stepanov, Irina Zhukova

CSIRO

James Austin

CURTIN UNIVERSITY

William Collins

FIRST QUANTUM MINERALS

Tim Ireland, Louis van Heerden

FLINDERS UNIVERSITY

John Long

GEOLOGICAL SURVEY OF NSW

John Greenfield, Robert Musgrave

GEOLOGICAL SURVEY OF QUEENSLAND (DEPARTMENT OF NATURAL RESOURCES, MINES AND ENERGY)

Helen Degeling, Courteney Dhnaram, Tony Knight, Vladimir Lisitsin

GEOSCIENCE AUSTRALIA

David Huston, Scott Nichol

IMEX CONSULTING

Mark Arundell

INSTITUTE FOR MARINE AND ANTARCTIC STUDIES (IMAS)

Jacqui Halpin, Vanessa Lucieer, Joanne Whittaker

IRISH CENTRE FOR RESEARCH IN APPLIED GEOSCIENCE (iCRAG)

Sean Johnson

MACQUARIE UNIVERSITY

Elena Belousova

MINERAL RESOURCES TASMANIA

Ralph Bottrill, Clive Calver, Grace Cumming, John Everard, Claire Kain, Andrew McNeill, Mike Vicary

MONASH UNIVERSITY

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Michael Clare

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Valeriy Maslennikov

TASMANIAN INSTITUTE OF AGRICULTURE (UTAS)

Ross Corkrey

UNIVERSITY OF DELHI, INDIA

Mihir Deb

UNIVERSITY OF MELBOURNE

Roland Maas

UNIVERSITY OF MISSOURI-KANSAS CITY, USA

Ray Coveney

UNIVERSITY OF NEWCASTLE, NSW

Hannah Power

UNIVERSITY OF PORTSMOUTH, UK

David Loydell

UNIVERSITY OF QUEENSLAND

Rick Valenta

UNIVERSITY OF TORONTO, CANADA

Dan Gregory

UNIVERSITY OF SYDNEY

David Airey, Samantha Clarke, Tom Hubble, Michael Kinsela, Maria Seton

UNIVERSITY OF WESTERN ONTARIO, CANADA

Nigel Blamey

US GEOLOGICAL SURVEY, USA

Karen Kelley, John Slack

YUKON GEOLOGICAL SURVEY, CANADA

Patrick Sack

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 summaries

TRACE ELEMENTS IN ANCIENT OCEANS

Leader: Ross Large

Team members: Leonid Danyushevsky, Indrani Mukherjee, Jeff Steadman

Collaborators: Ross Corkrey, Trevor Ireland, John Long, David Loydell, Valeriy Maslennikov, Aleksandr (Sasha) Stepanov, Irina Zhukova

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.

The sampling and LA-ICP-MS analysis of pyrite in black shales slowed in 2020 due to lack of funding. However,



Dr Jeff Steadman studying a trace element image of pyrite from the Ernest Henry copper-gold deposit, Cloncurry District, northwest Queensland. This work was done as part of Program 3's flagship project, 'Mineral geochemistry vectoring – Uncovering Northwest Queensland's hidden potential'. This project aims to help mineral explorers identify new target areas for copper-gold mineralisation in the Eastern Succession of the Mount Isa Inlier. Mineral trace element imaging using the laser ablation facilities at CODES is the backbone of the project.

the TEO team focused on writing up previous research for publication. A joint paper by Dr Indrani Mukherjee and Professor Ross Large used the extensive sedimentary pyrite database to investigate trace element ocean trends through the Archean and Proterozoic and their influence on the evolution of organisms. A decline in trace elements in the middle Proterozoic prompted alternative utilisation strategies by organisms whereas an overall increase in elements, including Ni, Co, Cu, Cr, Mo Se and P, in the Neoproterozoic and early Cambrian was probably critical for the explosion of various micro- and macro-life forms. The work was followed by publication of a chapter in the *Encyclopedia of the UN Sustainable Development Goals* by Dr Indrani Mukherjee and Dr Ross Corkrey on 'Abiotic Influences on the Early Evolution of Life'. In a methods paper, Dr Sasha Stepanov and co-workers published in *American Mineralogist* the technique used routinely to obtain LA-ICP-MS analyses of fine-grained sedimentary pyrite intimately intergrown with sediment matrix.

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.



Dr Paul Olin, Deputy Leader of the CODES Analytical Laboratories, performing a laser gas exchange in the Newcrest lab at CODES.

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. Two of these students have now submitted their theses and the others are expected to submit in 2021. Highlights from this work include:

- 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 Lesley using information from the chemistry of zircons, molybdenite and pyrite.
- 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.
- The new constraints on age and provenance of Cambrian to Ordovician igneous and sedimentary rocks in Victoria and Tasmania acquired by Umer Habib. This includes new Hf isotope data on the Mt Read Volcanics and the mafic and ultramafic complexes in Tasmania and Victoria.
- Peerapong Sritangsirikul submitted his thesis on the geological evolution of the Oberon area in NSW.

The data sets and results from these studies are being prepared for publication in peer-reviewed journal articles.

BUILDING TASMANIA: THE CAMBRIAN AND BEYOND

Leaders: Sebastien Meffre, Robert Scott

Team members: Ron Berry, Karin Orth

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 2020 the main areas of focus were in northern Tasmania and included:

- New detrital zircons data from northwestern Tasmania was compiled and a manuscript documenting these results was prepared by Grace Cumming from MRT. These data were primarily acquired to help with correlating the stratigraphy around the Savage River Mine area but also provides insights into the tectonic processes that formed that part of Tasmania in the Proterozoic.
- New zircons data from the Devonian magmatic and sedimentary rocks from eastern and northeastern Tasmania was acquired by Colin Jones (PhD), Till Gallagher (Honours) and Eva Knight (undergraduate research). This data will be used to constrain the age and tectonic and magmatic evolution of this area.

ORE DEPOSIT CYCLES AND OCEAN/ATMOSPHERE CONDITIONS

Leader: Ross Large

Team members: Sebastien Meffre, Indrani Mukherjee, Jeff Steadman

Collaborators: Janaina Avila, Nigel Blamey, Ross Corkrey, Ray Coveney, Mihir Deb, Dan Gregory, Sean Johnson, Karen Kelley, Valeriy Maslennikov, Patrick Sack, John Slack

Professor Ross Large and Dr Jeff Steadman (CODES) joined forces with Dr Nigel Blamey from the University of Western Ontario in Canada to publish the first paper to attempt a full quantification of atmosphere oxygen through the Precambrian, based on the Se/Co ratio in marine pyrite and the oxygen concentration in marine halite fluid inclusion gases. The resultant oxygen profile is very different to that currently accepted by most scientists and has caused a significant controversy. The team has written follow-up papers on their controversial ideas but has been rejected from publication to date, due to the current 'group think' on this topic.

MINERAL GEOCHEMISTRY VECTORING: UNCOVERING NORTHWEST QUEENSLAND'S HIDDEN POTENTIAL

Leader: Jonathan Cloutier

Team members: Shaun Barker, David Cooke, Jeff Steadman

Student: Max Hohl

Collaborators: James Austin, Vladimir Lisitsin, Courteney Dhnaram, Rick Valenta

Throughout 2020, the project team focused on analytical work at the Ernest Henry, SWAN Starra, and Capricorn deposits as part of the mineral chemistry 'footprint' studies being carried out to identify mineral chemistry vectors towards ore.

At Ernest Henry, petrographic and mineral chemistry analyses were focused on amphibole and epidote from both proximal and distal samples. The new epidote analyses confirmed the previous pattern of enrichment and depletion in a suite of trace elements that correlate with distance from the mine, whereas the amphibole analyses – though more complex than the epidote profiles – nonetheless demonstrate similar distance-correlated behaviour.

At SWAN, a major laser ablation analytical campaign on amphibole, apatite, carbonate, chlorite, epidote, magnetite, pyrite and pyroxene was undertaken to characterise the

fingerprint and footprint associated with the deposit. The campaign was supported by the creation of a 3D geological model and grade shells to approximate distance to the mineralisation halo. Results show that most minerals are associated with a chemical gradient with distance to the deposit.

At Starra, a detailed paragenetic study shows several stages of Cu mineralisation are present with the onset of mineralisation paragenetically associated with mafic intrusions in the region. Trace element data for calcite, chlorite, pyrite and magnetite were created, with a focus on magnetite. Based on magnetite trace element chemistry, a redox gradient between the Southern deposits and the Northern deposits was identified. At the south Starra 222 deposit, hematite is the dominant iron oxide, while at north Starra 276 deposit, magnetite becomes more abundant and shows a potential application as a vectoring tool towards mineralisation in future work.

At Capricorn, pyrite-, hematite-, and carbonate-bearing samples from the Esperanza South and Mammoth Cu deposits were analysed for trace element contents and deportments. Pyrite from Mammoth displays a

consistent trace element signature of high Sb-Tl-As-Pb-Mo±Bi±Co. Carbonate composition varies from dolomitic to sideritic with increasing proximity to the ore zone. Hematite is intimately intergrown with goethite and exhibits multiple generations of growth, each with its own unique trace element signature.

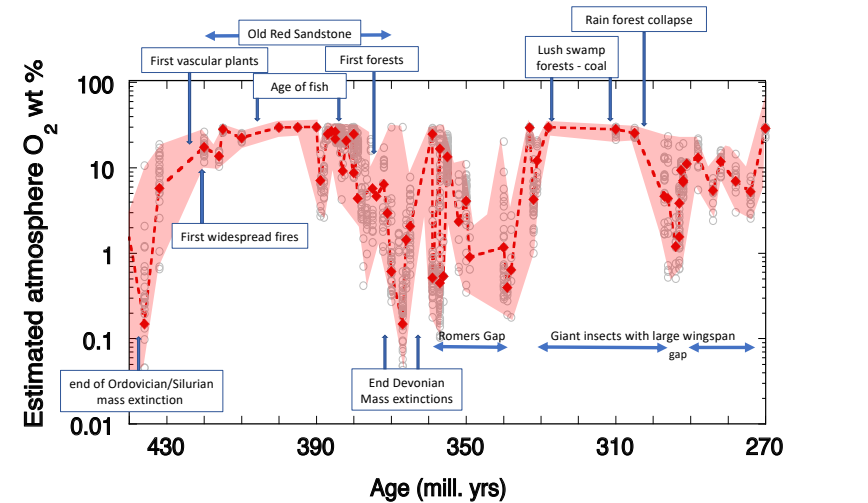
Together, the results to date show promises for mineral chemistry vectoring using silicates, magnetite and pyrite for IOCG deposits of the Cloncurry region. The project is scheduled to end in June 2021.

STABILITY OF THE AUSTRALIAN CONTINENTAL SHELF

Leader: Martin Jutzeler

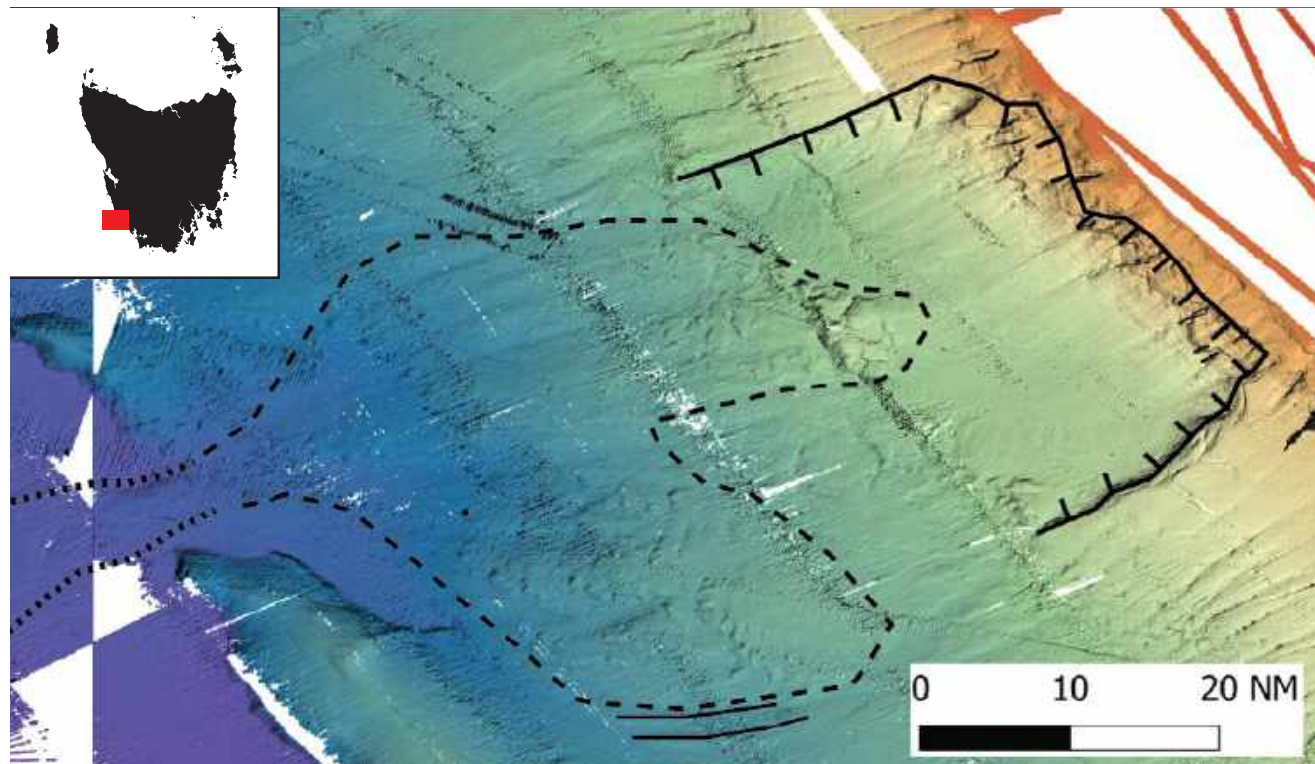
Team member: Stuart Bull

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



The pyrite Se/Co proxy oxygen curve with major bio-evolutionary events : Silurian to Lower Permian.

This diagram from Professor Ross Large's 'Trace elements in ancient oceans' project shows the variation in atmospheric oxygen content from Silurian to Lower Permian (~440 Ma – 270 Ma) along with major bio-evolutionary events.



Dr Martin Jutzeler is carrying out research into the stability of the Australian continental shelf. This diagram shows preliminary geomorphologic interpretation of the targeted submarine landslide off the continental shelf of western Tasmania. Solid lines for headscarps; dashed lines for landslide deposit event; thin solid lines for compression ridges (bottom right).

Western Tasmania submarine slide

In 2019 Dr Martin Jutzeler and IMAS colleagues were successful in an application for a 42-day voyage in late 2022 on board the RV *Investigator*. The team will investigate the submarine 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).

Qld and NSW neogene slides

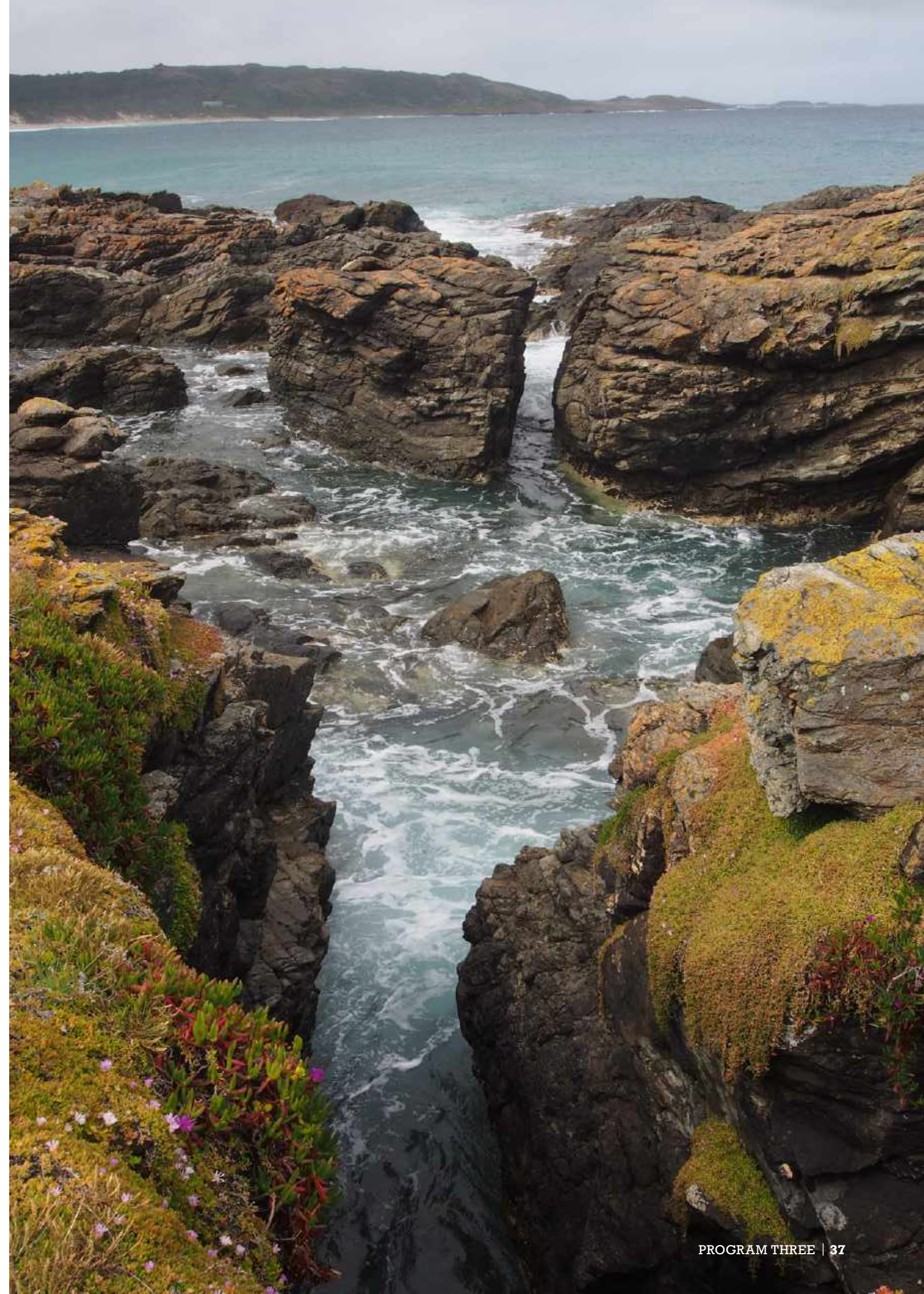
Numerous Neogene landslides are spread along the passive margin of the eastern Australian seaboard. Dr Martin Jutzeler is part of the team led by Tom Hubble (University of Sydney) to characterise the architecture of the landslides and canyons that dissect the continental shelf. This study is based on a future voyage on the RV *Investigator* in 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.

Looking forward

2021 will see the conclusion of the northwest Queensland mineral chemistry project and PY005 (Characterising pyrite chemistry of black shales hosting stratiform Zn-Pb-Ag: Application to mineral exploration), with exciting results anticipated from both of these projects. PhD student Max Hohl will continue his research on the Starra Cu-Au deposits throughout 2021.

The preparation for the two 2022 voyages with the RV *Investigator* for the 'Stability of the Australian continental shelf' project is currently ongoing. Watch this space for future news on this topic.

OPPOSITE PAGE: West coast of King Island taken on a reconnaissance trip in December 2020 (photo by Rob Scott).



Program Four

Magmatic and volcanic processes

Objectives

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, ascent and eruptions in a range of tectonic settings, and subaerial and submarine environments. The fundamental research 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

Student achievements

Congratulations to Dr Jodi Fox, who in 2020 began a postdoctoral position with the Institute for Marine and Antarctic Science to understand the volcanic history of the East Antarctica ice sheet, together with Dr Jacqueline Halpin and Associate Professor Joanne Whittaker.

In 2020 we celebrated three student PhD graduations in Program 4: David Douth, Matt Ferguson and Adam Abersteiner. We wish these students the very best in their future careers.

David Douth's thesis is titled 'Origin, geochemistry, stratigraphic and structural setting of the Archean Invincible gold deposit, St Ives gold camp, Yilgarn Craton, Western

Australia'. The thesis has shed new light on the stratigraphic and structural controls on vein and shear hosted gold mineralisation at a stratigraphic level in the stratigraphy of the Kalgoorlie Terrane traditionally not considered to be prospective for gold. After submitting his PhD in 2019, David recommenced a position as mine geologist at the St Ives gold mine, Kamalda, Western Australia, operated by Gold Fields. In April 2020, David commenced a new position as Senior Mine Geologist at the Carosue Dam Gold Mine northeast of Kalgoorlie, operated by Saracen Mineral Holdings Limited. Several publications resulting from David's PhD thesis are planned.

Matt Ferguson's PhD thesis is titled 'Late-stage magmatic evolution of A-type rocks around and to the southeast of Olympic Dam, South Australia'. Matt's recent publication 'Associations between zircon and Fe-Ti oxides in Hiltaba event magmatic rocks, South Australia: atomic- or pluton-scale processes?' was published in 2020 in the *Australian Journal of Earth Sciences* with collaborator Kathy Ehrig from BHP. Matt is now employed at Entura as a Senior Geologist in Hobart, Tasmania, and we see him regularly at meetings of the Geological Society of Australia Tasmania Chapter.

Adam Abersteiner received a prestigious APR Internship (Australian Institute of Mathematics & Science and BHP Olympic Dam) to work on sulfur isotopes in Olympic Dam. His project aims to elucidate isotopic variations in sulfur and lead in sulfate and sulfide minerals across the Olympic Dam U-Cu-Au-Ag super giant deposit in South Australia. Subsequently, Adam has moved to Finland to undertake another postdoctoral position at the University of Helsinki where he is doing – among other things – studies on the origin and evolution of chromite in mafic-ultramafic lithologies and their links to ore-forming processes. We wish him all the best.

Awards

Associate Professor Rebecca Carey was awarded the Australian Academy of Science's 2020 Dorothy Hill Medal for research in the Earth Sciences. She received the award for her internationally recognised research into volcanology, and is one of only

18 of Australia's top scientists to receive an honorific award in 2020 from the Academy. The Dorothy Hill Medal supports research in the Earth Sciences by women researchers up to ten years post their PhDs.

2020 kicked off for four major research programs in Program 4

After a highly successful year in 2019 acquiring over \$1.1 million for fundamental and applied research, 2020 was the year when the science kicked-off.

Australian Research Council

Linkage: This project is led by Associate Professor Rebecca Carey, along with CIs Professor Ray Cas, Professor David Cooke, Associate Professor Sebastien Meffre and Associate Professor Shaun Barker, with Dr Martin Jutzeler as Senior Research Fellow, and includes active collaboration with Evolution Mining, Mineral Resources Tasmania, the Geological Survey of NSW, the University of Auckland (NZ), the University of Waikato (NZ) and Oceanagold (NZ). This project aims at reconstructing the architecture of volcanic host rocks at various mineralised sites in Australia and New Zealand, using traditional and image analysis-based techniques to aid exploration.

Australian Research Council

Discovery Grant: Dr Rebecca Carey with colleagues Associate Professor Jo Whittaker (IMAS), Dr Maria Seton (University of Sydney), Dr Simon Williams (Northwest University, Xi'an, China) and Professor Nico Coltice (Laboratoire de Geologie de Lyon: Terre, Planetes, Environnement, France) began their ARC Discovery grant for a project associated with how Earth's deep interior and surface communicate. This project utilises igneous samples from volcanic seamounts in the Coral and Tasman seas that were sampled by us and our collaborators using the RV *Southern Surveyor* and RV *Investigator* over the past five years. The project kicked off in 2020 with a full program of analytical work conducted at UTAS. Honours student Stephanie Morrish will begin her project in 2021 associated with this research theme.



CODES Director Professor David Cooke (right) with Dr Martin Jutzeler at Aireys Inlet, southwestern Victoria, during the 2020 Master of Economic Geology short course 'Volcanology and Mineralisation in Volcanic Terrains'.

Australian Antarctic Science

Program: Research on the opening of the Tasman Sea and the separation of Australia and Antarctica began in June 2020. This project is led by Associate Professors Jo Whittaker and Rebecca Carey at UTAS. The project aims are to understand the genesis of an age-progressive track of volcanic seamounts offshore of eastern Tasmania, to test plume models for magma genesis in this region, and to use the absolute ages of volcanic seamounts in the Tasman Sea to refine plate tectonic models on the separation of Australia with Antarctica.

A second project funded by the Australian Antarctic Science Program on the nature and petrogenesis of Neogene volcanism on the Central Kerguelen Plateau also kicked off in 2020. Collaborator Dr Jane Barling from Oxford University is one of a few people globally who has spent significant time as a geologist on Heard Island. Jane is collaborating with us on this project, where we will use her sample collection to further understand the tempo of volcanism on the Central Kerguelen Plateau. Further, Jane will co-lead a geochemistry program with Dr Trevor Falloon and Dr Jodi Fox on understanding magma petrogenesis

and storage dynamics for magmas erupted on the Kerguelen Plateau.

Miocene submarine volcanism in the Izu-Bonin rear arc: In 2019 Dr Martin Jutzeler and co-PI Dr Rebecca Carey obtained a grant from the Australia and New Zealand Consortium to the International Ocean Discovery Program (ANZIC) to carry out geochemical analyses on pumice-rich deposits drilled in the Izu-Bonin rear-arc. This study follows on from Martin's participation in the deep-sea drilling IODP expedition 350 in 2014. PhD student Gilles Ngoran will reconstruct the volcanic architecture of a deep-water submarine succession ranging from the Miocene to Pliocene using a stratigraphically continuous sequence of sedimentary facies. Further, a 30-m thick pumiceous succession will be analysed for its volcanic micro-texture, glass composition and volatile content to infer the style of submarine eruption and transport processes involved.

International workshops/ presentations

Due to the COVID-19 pandemic there were no international presentations or workshops involving Program 4 research held at CODES during 2020.

Voyages

COVID-19 has significantly affected the schedule of the CSIRO's Marine National Facilities research ship, the RV *Investigator*, where voyages have had to be rescheduled ~1–2 years after they were originally planned. Two month-long voyages are planned for 2022 with CODES staff and students on board leading the research, for a total in-kind investment of \$8.4 million from the Marine National Facilities. Next year we will bring you more information on our participation in these voyages.

Publications in 2020

During 2020, 30 papers were published in international peer-reviewed journals by researchers within Program 4; a stunning 22 of those by Professor Vadim Kamenetsky and Leonid Danyushevsky in igneous petrology and geochemistry, and eight by the volcanology group led by Associate Professor Rebecca Carey. The majority of these articles were published in A* and A journals. See the 2020 Publications section of this report for further details.

The program team

LEADER REBECCA CAREY

DEPUTY LEADER VADIM KAMENETSKY



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Sharon Allen, Shaun Barker, Ron Berry, Stuart Bull, Jonathan Cloutier, Leonid Danyushevsky, Paul Davidson, Trevor Falloon, Jodi Fox, Bruce Gemmell, David Green, Martin Jutzeler, Maya Kamenetsky, Ross Large, Charles Makoundi, Jocelyn McPhie, Sebastien Meffre, Paul Olin, Karin Orth, Naomi Potter, Robert Scott, David Selley, Jeff Steadman, Khin Zaw

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UNIVERSITY OF HEIDELBERG, GERMANY

Alex Schmidt

UNIVERSITY OF ICELAND, ICELAND

Maria Janebo, Thor Thordarson

UNIVERSITY OF MANITOBA, CANADA

Anton Chakhmouradian

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 Sebillie

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



In the thick of it: Professor Leonid Danyushevsky (right) and Grace Cumming (Mineral Resources Tasmania) examining an outcrop and collecting ultramafic rock samples for Bridie LeGallais’ PhD project. The outcrop is in a tributary to the Whyte River, in the Whyte River Complex, northwest Tasmania.

Projects

Volcanology research related to ore deposits

Subaerial and submarine volcanology and natural hazards

Sedimentary volcanology

Pegmatites and pegmatite-related ores

Kimberlites and flood basalts: Linking primary melts with mantle and crustal sources

A melt inclusions pursuit into identity of carbonatite magmas and their economic potential

Melt-fluid evolution, magmatic immiscibility and budget of chalcophile and noble metals in basaltic magmas

Olympic Dam

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

Mantle characteristics of the East Antarctic margin

VHMS research – ancient

OPPOSITE PAGE: In 2020 Associate Professor Rebecca Carey, leader of Program 4 was awarded the Australian Academy of Science’s Dorothy Hill Medal for her research into the Earth Sciences. She received the award for her internationally recognised research into volcanology, and was one of only 18 of Australia’s top scientists to receive an honorific award in 2020 from the Academy.

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, Karin Orth, Robert Scott, David Selley, Gerrit Olivier, Michael Roach, Jeff Steadman

Students: David Doutch, Matt Ferguson, 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

Our group have active projects to study the facies architecture of volcanic centres across a range of tectonic settings, both on the modern seafloor and in terrestrial settings. Several projects include volcanic architecture reconstruction using traditional and new automated methods to characterise volcanic facies. A novel side of our research is to combine passive seismic, active seismic and physical properties datasets with volcanic facies analysis to improve on 3D volcanic architecture reconstruction. In addition to this research on understanding the paleoenvironment setting of ancient volcanic-hosted mineralised deposits, some of our recent research is focused on understanding fluid, vapour and metal transport during magma degassing in the shallowest conduit environment, and the physical properties of volcanic lithologies that may favour high-grade mineralisation.

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

This collaborative project with the mining industry and state geological surveys aims at providing new

tools for exploration in volcanic-hosted mineralised terrains. The traditional facies analysis and volcanic architecture reconstruction will be augmented with modern image analysis based on core photos to permit stratigraphic reconstructions based on phenocryst fingerprinting in igneous and volcanoclastic rocks. Crystal shape, abundance and size distribution will allow correlation of volcanic units despite structural complexities in weak to moderately altered successions. Delays in accessing the field in 2020 led to the focus on a machine learning-based image analysis technique through collaboration with the company Datarock. The technique is currently tested by Dr Martin Jutzeler in the Mount Read Volcanics in Tasmania, the Cowal gold mine in NSW and the Waihi gold mine in New Zealand. Expected outcomes of this project include next-generation techniques for volcanic facies analysis, and predictions of where hydrothermal alteration is most prospective for mineralisation.

In December 2020, CODES student Malai Ila’ava started his PhD and he will focus on the reconstruction of the volcanic architecture of the Cowal Igneous Complex at basin scale, and will spend several months on-site in early 2021.

A second component of this ARC Linkage project is in collaboration with Dr Michael Heap from the University of Strasbourg. Rebecca, Shaun and Michael are investigating the physical properties of intermediate-felsic rocks that favour high-grade mineralisation. During the course of this project, we will be selecting key volcanic samples from the Waihi mine, NZ, to conduct various rock stress tests in world-class facilities in Michael’s rock properties laboratory.

Bathymetric mapping west of Tasmania

Martin Jutzeler is the lead CI on a 42-day voyage west of Tasmania on the RV Investigator planned for 2022. Using active seismic reflection the team will investigate the possible 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, Martin Jutzeler, Jocelyn McPhie, Paul Olin, Karin Orth

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

Collaborators: Daniele Andronico, Costanza Bonadonna, Cathy Busby, Fabio Caratori-Tontini, Ray Cas, Maya Coussens, Grace Cumming, Nathan Daczko, Robert Duncan, John Everard, Richard Fiske, Daniel Fornari, Bruce Houghton, Michael Manga, Gerrit Olivier, Tim Orr, Matthew Patrick, Christopher Phillips, Ryan Portner, Michael Rosenberg,

Maria Seton, Jack Simmons, Adam Soule, Kenichiro Tani, Rex Taylor, James White, Joanne Whittaker, Simon Williams, Richard Wysoczanski

The 2020 highlights in this research theme include two high-impact research papers on understanding submarine eruption and transport processes. Associate Professor Rebecca Carey was an author on a paper titled ‘Deep-sea eruptions boosted by induced fuel-coolant explosions’ in *Nature Geoscience* which describes a new understanding about deep submarine explosive eruptions. This research was supported by ARC and New Zealand Marsden grants to Rebecca and co-authors. A second paper was published by Dr Martin Jutzeler, and uses satellite and oceanographic modelling to predict the fate of pumice rafts in the pacific ocean which were produced in 2019 from a volcano in the Tonga Arc. This paper was published in *Geophysiscal Research Letters*.

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 on four key powerful endmembers of basaltic eruptions globally. CODES PhD student Hannah Moore has used crystallinity of the erupted products to further elucidate those drivers for the Tarawera 1886 eruption, New Zealand. She is currently preparing a shallow conduit model to understand the timing of crystal nucleation and growth during final stages of magma ascent at Tarawera.

Cenozoic volcanism in Tasmania

CODES PhD student Chuang Wang has deployed a passive seismic survey in western Tasmania through collaboration with the Institute of Mine Seismology and MRT. Ninety seismometers were deployed for one month over 30km² north of the Hellyer mine, where Tertiary basalts cover the highly prospective Mount Read Volcanics. Corroborated with a few drill holes in the area, this passive seismic survey will inform on the depth of the Tertiary basalts that were emplaced over complex paleotopography, and on the nature of the Palaeozoic basement.



CODES collaborator Grace Cumming from Mineral Resources Tasmania examining a large ultramafic outcrop at Lost Creek, in the Whyte River Complex, northwest Tasmania. Grace was the guide for this 2020 field excursion, having visited this remote site previously. Rock samples were collected for CODES PhD student Bridie Le'Gallais' project for further investigation in the lab.

Surtsey International Continental Scientific Drilling Program

Surtsey volcano is a small island that grew from the sea floor during basaltic eruptions from 1963 to 1967 off the southern coast of mainland Iceland. In a project sponsored by the International Continental Scientific Drilling Program, Surtsey was drilled during the Icelandic summer of 2017. The drill core recovered is a source of unique information on the characteristics and origin of the volcanic products, the colonisation of submarine tephra by organisms, the products of hydrothermal alteration, and interactions between biological and hydrothermal processes. A paper on the characteristics of the 2017 drill cores has been published: McPhie, J., White, J.D.L., Gorny, C., Jackson, M.D. and Gundmundsson, M.T. 2020. Lithofacies from the 1963-1967 Surtsey eruption in SUSTAIN drill cores SE-2a, SE-2b and SE-03, *Surtsey Research 14*: 19–32 <https://doi.org/10.33112/surtsey.14.2>.

SEDIMENTARY VOLCANOLOGY

Leader: Martin Jutzeler

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

Collaborators: Mirzam Abdurrachman, Cathy Busby, Ray Cas, Michael Cassidy, Cornel de Ronde, Sue DeBari, Raymond Duraiswami, James Gill, Jens Karstens, Steffen Kutterolf, Emily Lane, Michael Manga, Robert Marsh, Adam Soule, David Tappin, Christian Timm, Erik van Sebille, Sebastien Watt, James White, Joanne Whittaker, 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 volcanism

In 2019 Dr Martin Jutzeler and co-PI Dr Rebecca Carey were successful in obtaining time on the RV *Investigator* for a 39-day voyage they will lead in March 2022 at five 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 aprons, which are voluminous dune-like deposits formed during caldera-forming eruptions. 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.

Tonga submarine eruption

On 7 August 2019, a 195 km² raft of andesitic pumice was produced at 200 m below sea level at an unnamed submarine volcano in the Tonga Islands (Southwest Pacific Ocean). This eruption and the pumice raft made headline news, not because it was a particularly large eruption but because there were a number of yachts that intersected the raft and filmed what looked like a vast moonscape – but on the surface of the ocean. Dr Martin Jutzeler, Associate Professor Rebecca Carey, Professor Jocelyn McPhie and collaborators from the National Oceanography Centre, UK, and the University of Utrecht, Netherlands, tracked the dispersed raft with satellite imagery and then modelled the predicted path of the raft including its future arrival in Australia. This research was published in 2020 in a highly prestigious journal, *Geophysical Research Letters*.

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 2014, where hundreds of metres thick of contourite were drilled.

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.

In 2020 a paper was published, titled 'Emerald from the Habachtal: New observations', by Rainer Thomas, Paul Davidson and Adolf Rericha, in *Mineralogy and Petrology*.

KIMBERLITES AND FLOOD BASALTS: LINKING PRIMARY MELTS WITH MANTLE AND CRUSTAL SOURCES

Leader: Vadim Kamenetsky

Team member: Maya Kamenetsky

Student: Adam Abersteiner

Collaborators: Elena Demonerova, Kathy Ehrig, Karsten Goemann, Alexander Golovin, Alexei Ivanov, Graham Pearson, Thomas Rodemann, Igor Sharygin, Zdislav Spetsius, Jay Thompson

This project is aimed at understanding the relationship between kimberlites and diamonds, flood basalts and magmatic sulfides, and chromitites and related PGE mineralisation, by linking mantle structure, phase and chemical composition, isotope evolution and temperature to the melting processes.

In 2020 the team published five papers associated with the characterisation of kimberlite magmas and rocks in a number of continental magmatic provinces (South Africa, Siberia and NW Canada). Two of these publications were led by CODES PhD student Adam Abersteiner. Adam's papers utilised the well-preserved Mark kimberlite in NW Canada; a small hypabyssal coherent body that is diamondiferous. His research was focused on reconstructing kimberlite petrogenesis in order to reveal

insights into these magmas. Adam's are derived from significant depth (>150km). Adam's research published in *Lithos* revealed:

- the crystallisation history of kimberlite groundmass for the Mark kimberlite, concluding that alkalic and halogen- rich groundmass minerals likely formed, but were unstable water-soluble carbonates that were removed from the groundmass by late-stage magmatic or post-magmatic alteration; and
- that the olivine present in the Mark kimberlite was derived from different pulses of variably differentiated silica-poor, halogen-bearing, alkali-dolomitic melt.

A MELT INCLUSIONS PURSUIT INTO IDENTITY OF CARBONATITE MAGMAS AND THEIR ECONOMIC POTENTIAL

Leader: Vadim Kamenetsky

Team members: Maya Kamenetsky, Naomi Potter

Collaborators: Anton Chakhmouradian, Karsten Goemann, Thomas Rodemann, Victor Sharygin, Jay Thompson

This project aims to understand primary compositions of mantle-derived carbonatite magmas and carbonate-rich components in association with alkali silicate magmas. The study is based on a set of representative samples from renowned occurrences of carbonatites.

CODES PhD graduate Dr Naomi Potter published her paper on the Afrikanda alkalic-ultramafic complex in 2020. Naomi's research has demonstrated that the material in melt inclusions is not *a priori* inclusions of melt but can be a result of annealing of individual disseminated grains.



CODES Honours student Till Gallagher (right) pictured at Hughes Point, northeastern Tasmania, during a reconnaissance fieldwork trip for his research into St Marys Porphyrite during 2020. With him are CODES collaborators Grace Cumming and Ralph Bottrill, both from Mineral Resources Tasmania.

MELT-FLUID EVOLUTION, MAGMATIC IMMISCIBILITY AND BUDGET OF CHALCOPHILE AND NOBLE METALS IN BASALTIC MAGMAS

Leader: Vadim Kamenetsky

Team member: Maya Kamenetsky

Student: Adam Abersteiner

Collaborators: Alexander Belousov, Ilya Chaplygin, Kathy Ehrig, Pavel Nesterenko, Victor Sharygin, Michael Zelenski, Liudmila Zhitova

This research aims to establish the initial metal abundances in common primitive magmas, and the mechanisms of separation of immiscible liquids and fluids from the silicate melt, through studies of melt and fluid inclusions in minerals.

In 2020 we published eight papers in this research theme, including a paper in the prestigious journal *Geology* with lead author Dima Kamenetsky. This paper has highlighted another mechanism for the platinum group element minerals – crystallisation in primitive basaltic melts undergoing sulfide unmixing and possibly breakdown due to oxidation.

Please see the 2020 Publications section of this report for all articles published by Dima Kamenetsky and his team.

OLYMPIC DAM

Leader: Vadim Kamenetsky

Team members: Maya Kamenetsky, Jocelyn McPhie

Student: Adam Abersteiner

Collaborators: Cristiana Ciobanu, Nigel Cook, Christian Dietz, Kathy Ehrig, Karsten Goemann, Roland Maas, Danielle Schmandt

This project is building on existing knowledge related to economic geology at Olympic Dam through a combination of petrological, geochemical and geochronological research initiatives.

In 2020 we published five papers in this research theme, including a paper by CODES PhD student Matthew Ferguson, two papers by former PhD student Olga Apukhtina, and a paper on the geology of the Acropolis prospect, South Australia, led by Professor Jocelyn McPhie.

The Acropolis iron oxide-copper-gold (IOCG) prospect ~20 km south of Olympic Dam in South Australia was discovered in 1975 during regional IOCG exploration. The mineralised succession comprises Mesoproterozoic Gawler Range Volcanics and Hiltaba Suite granite, and Paleoproterozoic Donington Suite granite, all of which are covered by 400–800-m-thick sedimentary formations, so the geology of the prospect is known only from drilling and geophysical data. This paper presented a geological map of the mineralised succession based on logging 16 drill cores and also reconstructed the paleotopography beneath the sedimentary formations. New LA-ICP-MS and high-precision CA-TIMS on syn- and post-mineralisation units showed that the main hydrothermal event at Acropolis happened at ~1594 Ma and pre-dated the main hydrothermal event at Olympic Dam by as much as 3 my. These results require revision of genetic models that assume Olympic Dam and other IOCG prospects and deposits in the district are the same age.

SUBDUCTION MAGMATISM IN THE SOUTHWEST PACIFIC

Leaders: Trevor Falloon, Leonid Danyushevsky

Collaborators: Julien Collot, Roland Maas, Anders McCarthy, Martin Patriat

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 2020, a manuscript aimed at understanding the processes leading to the formation of adakite magmas in the modern subduction zones was prepared for publication. This study is based on samples from active adakite volcanoes within the underwater section of the Hunter Ridge. The manuscript will be submitted for publication in 2021.

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 2020, 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. New fieldwork is planned for 2021 to collect more samples and continue work to determine the likely tectonic setting for the formation of the Whyte River Complex

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

Leader: Karin Orth

Team members: Rebecca Carey, Sebastien Meffre

Student: Till Gallagher

Collaborators: Ralph Bottrill, Grace Cumming

This Honours project aims to re-appraise the volcanic architecture of the St Marys Porphyry 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 Porphyry. 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 Porphyry. Some zircon dating has been completed on the St Marys Porphyry, underlying Mathinna Supergroup and proposed feeder dyke. The new dates will help to constrain the connections of the St Marys Porphyry with the crustal architecture and development of NE Tasmania, and compare it with similar units in Victoria.



CODES PhD student Zebedee Zivkovic is researching lithogeochemical fertility indicators for VHMS deposits within the ‘VHMS research – ancient’ project in Program 4. Pictured are samples of Mount Read Volcanics rocks from his project (L–R): Sth Darwin - CVC – highly altered rhyolite with dominant hematite-magnetite-tourmaline; Whitespur Formation – feldspar-phyric andesitic volcanoclastic; Murchison Granite; West Sedgwick – chlorite/sericite altered, foliated dacite.

MANTLE CHARACTERISTICS OF THE EAST ANTARCTIC MARGIN

Leaders: Trevor Falloon, David Green

Collaborator: Anders McCarthy

CODES academics Dr Trevor Falloon and Professor David Green co-authored a paper focused on Seamount B along the East Antarctic Margin that reveals a 50–100-km-wide domain of exhumed subcontinental mantle at the transition between thinned continental crust and oceanic lithosphere. This represents only the second locality where the combination of petrological and seismic data can clearly outline an ocean-continent transition dominated by exhumed mantle domains and sparse volcanism. These exhumed mantle rocks (peridotites) are similar in composition to mantle xenoliths sampled during more recent volcanism along southern Australia and Tasmania. Additional melt percolation at high pressure is interpreted to occur during mantle exhumation likely to lead to the formation of highly deformed plagioclase-bearing pyroxenites. They argued that initial magnetic anomalies close to passive margins are likely formed by sparse volcanism along an ocean-continent transition zone dominated by exhumed mantle in (ultra-)slow spreading systems. The paper is titled ‘Revisiting the Australian-Antarctic ocean-continent transition zone using petrological and geophysical characterization of exhumed subcontinental mantle’.

VHMS RESEARCH – ANCIENT

Leader: Jonathan Cloutier

Team members: Shaun Barker, Leonid Danyushevsky, Ross Large, Charles Makoundi, Sebastien Meffre, Khin Zaw

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

SE Asia Although no fieldwork was possible in 2020 due to the COVID-19 pandemic, research on the Cambro-Ordovician Bawdwin VHMS deposit in Myanmar was continued in the laboratory. The sulfur isotopes of galena from the Bawdwin deposit gave restricted $\delta^{34}\text{S}$ values of 1.0–3.9 ‰ and one mixed galena-sphalerite-pyrite sample yielded $\delta^{34}\text{S}$ values of 2.8 ‰, whereas $\delta^{34}\text{S}$ values of sulphate sulfur (barite) range from 21.39 to 30.11 ‰. The sulfide sulfur isotope values of the Bawdwin deposit are significantly lower than those of the Kuroko deposits but comparable to those of the VHMS deposits in western Tasmania. It is also interesting to note that sulfate sulfur isotopic compositions of the Bawdwin deposit are close to the Cambrian seawater values. The sulfur isotopes of the Bawdwin ores are similar to a number of available $\delta^{34}\text{S}$ values from Cambrian evaporites and the anhydrite from the Lower Middle Cambrian in the Amadeus Basin (Australia) averaged +27.3 ‰. Further work on Pb isotopes and LA-ICP-MS U-Pb zircon age dating of the host volcanic rocks of the Bawdwin deposit are in progress.

Tasmania Shaun Barker, Jonathan Cloutier, Leonid Danyushevsky and Sebastien Meffre 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 during 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 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 interpretation, a multi-method study was initiated to analyse how the different geochemical analysis methods might provide different results. 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. By applying whole rock lithogeochemical and fractionation interpretations to a variety of deposits, we can test the robustness of the method 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 datasets 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) and Rosebery VHMS deposits 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 and Professor Khin Zaw (CODES) and David Green and Dr Andrew McNeill (Mineral Resources Tasmania). This project has the support of two mining companies, namely

MMG and Diversified Minerals Pty Ltd. The project will further look at thermal-infrared mineralogy focusing on plagioclase and quartz alteration and how wavelengths play out across the two deposits. The findings of this project will be published in a well-known journal.

Looking forward

In 2020 we kickstarted many of the Program 4 research projects funded by the ARC and industry partners albeit without our beloved fieldwork campaigns, which was frustrating for all. In place of the field campaigns we have focused on the analytical programs for these projects with some exciting results to set the foundation for fieldwork and hypothesis testing in 2021. We are excited to announce that two new PhD students with UTAS scholarships will be joining us in 2021, focused on projects in volcanology and sedimentology. COVID-19 has disrupted our voyage plans to New Zealand and western Tasmania on the RV *Investigator* with the Marine National Facility, but we are expecting to lead our two voyages in 2022 with staff and students from UTAS and other Australian universities. CODES will also send Honours student Stephanie Morrish on the RV *Investigator* in mid-2021 to participate in geoscience around the Cocos and Christmas islands where they will undoubtedly discover new volcanoes and collect rocks from the seafloor to understand this enigmatic region of Cretaceous to ~4 Ma magmatism.

CODES-TMVC Honours student Olivia Wilson at Aireys Inlet in southwestern Victoria looking at shallow marine volcanoclastic rocks during the 2020 Master of Economic Geology short course ‘Volcanology and Mineralisation in Volcanic Terrains’.



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 and advanced data-reduction algorithms. 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 2020, 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 and Pb isotope measurements; 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 method for U/Pb dating of ilmenite has been developed and a publication will be prepared in 2021.

Equipment

A collaborative agreement has been signed with Agilent to instal a triple-quad 8900 ICP-MS instrument at the CODES Analytical Laboratories. The installation is scheduled for January 2021.

Software

A new version of LADR, the data reduction software for LA-ICP-MS, has been released. This version includes support for a wide range of laser microprobes and mass-spectrometers.

Staff

The team welcomed Maxwell Morissette as a Laboratory Analyst operating one of our LA-ICP-MS units. Prior to joining CODES Analytical Laboratories Maxwell worked in analytical laboratories around Australia.

In February 2020 James Tolley decided to return to England, and in December 2020 Elena Lounejeva left and took up a position with Mineral Resources Tasmania

Conferences

No conference participation in 2020 due to COVID-19 restrictions.



LEFT: Laboratory Analyst Maxwell Morissette, who joined CODES in 2020, is seen here setting up an LA-ICP-MS U/Pb dating run.

OPPOSITE PAGE: (TOP) Laboratory Analyst Terrie Sawyer is setting up an ICP-MS run for the quantitative analysis of trace elements in dissolved rock samples and certified reference materials. These data are cross-referenced with the concentrations determined by LA-ICP-MS, XRF and EPMA for the purposes of developing quantitative methods for in-situ analyses of different minerals. (BOTTOM) Program 5 collaborator Dr Ashley Norris from Norris Scientific working on the laser ablation data reduction software package LADR, which has been developed with his input.

The program team

LEADER LEONID DANYUSHEVSKY
DEPUTY LEADER IVAN BELOUSOV



TEAM MEMBERS:

Shaun Barker, Matthew Cracknell, Elena Lounejeva, Sebastien Meffre, Maxwell Morissette, Paul Olin, Terrie Sawyer

PHD STUDENTS:

Nanda Mrabawani, Xin Ni Seow, Jay Thompson, Jennifer Thompson

HONOURS STUDENT:

Kate Jenkins

COLLABORATORS:

AGILENT TECHNOLOGIES
Fred Fryer

CENTRAL SCIENCE LABORATORY, UTAS
Karsten Goemann

IOWA STATE UNIVERSITY, USA
Sam Houk

LAURIN TECHNIC
Michael Shelley

MOSCOW STATE UNIVERSITY, RUSSIA
Pavel Plechov

NORRIS SCIENTIFIC
Ashley Norris

UNIVERSITÉ DU QUEBEC À CHICOUTIMI, CANADA
Dany Savard

UNIVERSITY OF BRISTOL, UK
Jon Blundy

UNIVERSITY OF KIEL, GERMANY
Dieter Garbe-Schönberg

INSTITUT DES SCIENCES DE LA TERRE, UNIVERSITÉ GRENOBLE ALPES, CNRS, FRANCE
Valentina Batanova, Alexander Sobolev

UNIVERSITY OF MELBOURNE
Roland Maas



The CODES Analytical Laboratories team photographed in December 2020 in the CODES Rock Garden: (L–R): Maxwell Morissette (Laboratory Analyst), Terrie Sawyer (Laboratory Analyst), Dr Paul Olin (Deputy Leader), Michelle Makoundi (Technical Officer), Professor Leonid Danyushevsky (Leader), Al Cuisson (Lapidary Manager), Michele Chapple-Smith (front, Lapidary Technician), Claire Rutherford (Administrative Support Officer), Elena Lounejeva (Laboratory Analyst) and Dr Ivan Belousov (TMVC Research Associate).

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

A paper was published in *Spectrochimica Acta Part B* describing the effects of H₂O, He, N₂ and H₂ on ion kinetic energies in inductively-coupled plasma mass spectrometry.

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 2020, research within this project has focused on understanding the relationship between matrix composition, ablation rate and elemental fractionation. A publication describing these results is in preparation with submission planned for 2021.

Work continued on developing algorithms for mineral identification within time-resolved LA-ICP-MS data.

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, Dany Savard

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 is being distributed to several analytical laboratories worldwide. A manuscript describing this new reference material is in preparation.

in 2020 collaboration continued with the University of Kiel, the University of Bristol, Moscow State University and the Université du Québec à Chicoutimi on characterising pressed nanoparticle pellets of sulfide minerals and plagioclase reference materials.

LA-ICP-MS INSTRUMENTATION DEVELOPMENT

Leader: Leonid Danyushevsky

Team member: Paul Olin

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 2020, in collaboration with Norris Scientific, a synchronisation device has been tested 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. A publication describing the approach has been submitted for publication in the *Journal of Analytical Atomic Spectrometry*.

U/PB DATING

Leaders: Leonid Danyushevsky, Ivan Belousov

Team member: Maxwell Morissette

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. Zircon is the primary mineral investigated; however, ongoing investigations for apatite, garnet, rutile and monazite are currently underway.

Throughout the year the focus was on understanding ablation behaviour of garnet and rutile and its impact on the accuracy and precision of U/Pb dating of these minerals.

A paper describing development of a method for U-Pb dating of ilmenite has been submitted for publication

A paper describing the application of time-of-flight mass-spectrometer to U/Pb has been published in the *Journal of Analytical Atomic Spectroscopy*.

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

Activities in 2020 were directed towards developing algorithms for imaging elemental distributions in minerals and adding support for a range of laser microprobes and mass-spectrometers. A new version of the software capable of processing images of elemental distributions will be released in 2021.

INTERPRETATION OF LA-ICP-MS TIME-RESOLVED SIGNALS

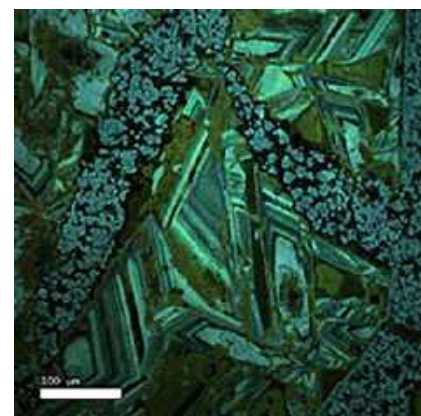
Leader: Shaun Barker

Team members: Matthew Cracknell, Sebastien Meffre

This project is evaluating the use of changes in signals during single LA-ICP-MS analyses to identify inclusions within minerals, and the potential to improve the speed and consistency of LA-ICP-MS signal interpretation and processing. Each laser ablation ICP-MS point or line analysis contains an enormous amount of information, typically 30–40 elemental masses collected every 0.5 to 1 second during a single “sweep” over the mass spectrometer, over a 60-second interval. This means that every analysis yields between 1800 and 2500 data points. With hundreds of analyses collected on a daily basis, this data-rich environment presents an opportunity to apply new approaches including data analytics and machine learning to obtain more information from the data sets that the CODES Analytical Laboratories produce.

During 2020, we have deployed workflows in opensource software packages that rapidly normalise LA-ICP-MS data signals. The use of machine learning approaches to automatically identify and classify LA-ICP-MS signals is ongoing. Automatic mineral inclusion identification and classification methods are being developed and tested based on detecting and matching time-constrained peaks between multiple elements. In 2021, we plan to further develop and test these methods, and in particular focus on validating automatic mineral inclusion identification and classification methods.

OPPOSITE PAGE: CODES Honours student Kate Jenkins is working on understanding the behaviour of garnet and rutile during laser ablation ICP-MS analysis. These results show rutile craters generated by LA-ICP-MS at various fluences, all at a pulse width of 5 ns, repetition rate of 5 Hz and spot size of 60 µm. Columns are different rutile samples of varying ages (left to right: TB-1, Victor Harbour, Wodgina) and rows are different fluences (top to bottom: 1.3, 1.7, 2.1, 3.5, 5 and 6 J/cm²).

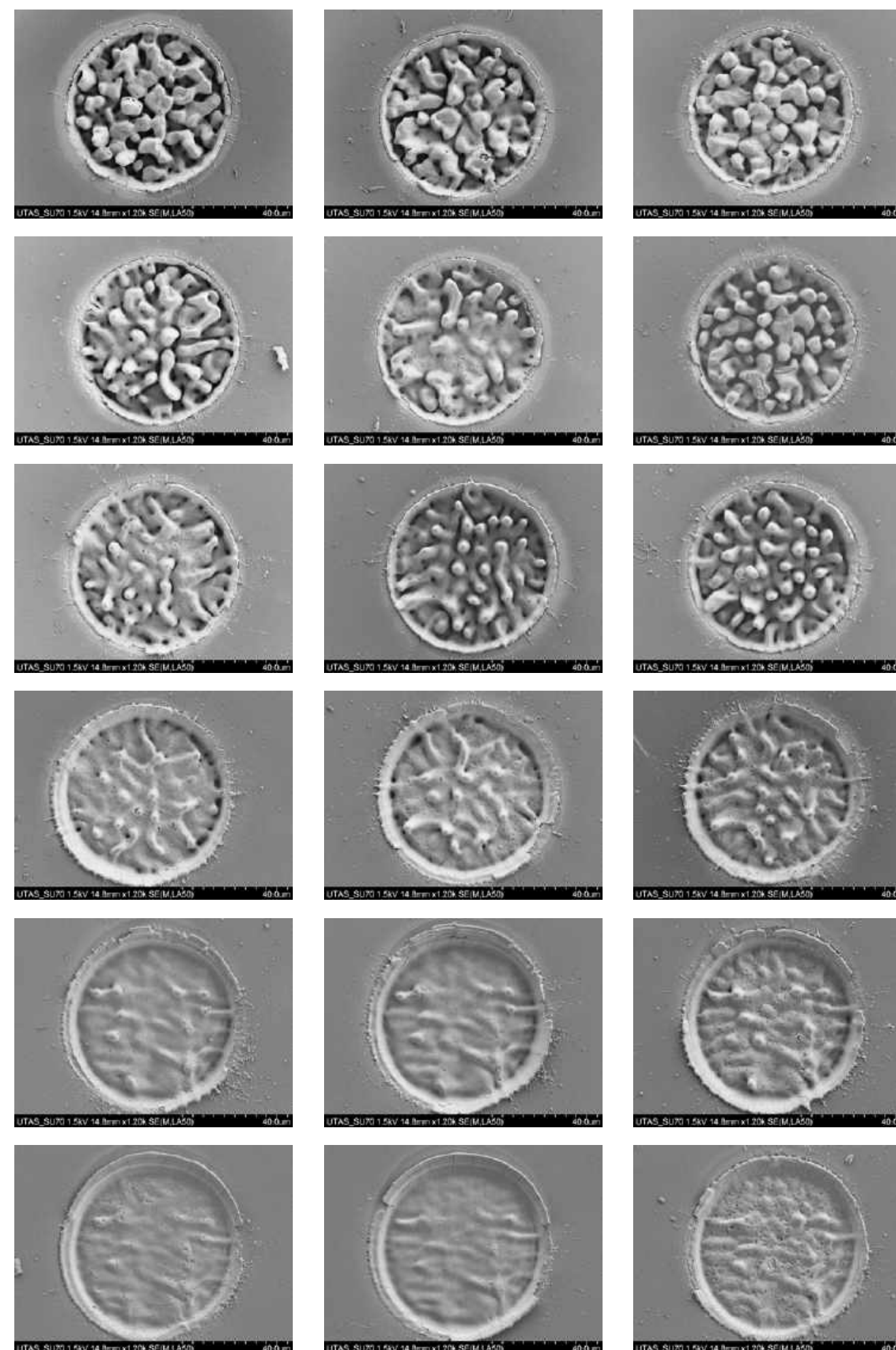


Scanning Electron Microscopy-Cathodoluminescence (SEM-CL) image of alunite (zoned mineral) and quartz (grey colour) from Tuhuh Bukit high-sulfidation – porphyry Cu-Au deposit, Indonesia, showing quartz – alunite cross-cut by later stage quartz. The analysis of these samples by CODES Analytical Laboratories is part of the AMIRA P1202 research project ‘Far-field and near-mine footprints: Finding and defining the next generation of Tier 1 ore deposits’.

Looking forward

The team will further develop its analytical research in 2021. Developments are expected to include:

- Investigating the applicability of triple-quad ICP-MS instrument for routine geological applications.
- Continued collaboration with Bristol, Grenoble, Kiel and Quebec universities and Moscow State University on the characterisation of a wide range of mineral reference materials.
- Continued development of advanced data-processing algorithms for imaging elemental distributions in minerals by LA-ICP-MS.



Program Six

Geophysics and computational geosciences

Objectives

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 that focus on three-dimensional geophysical interpretation, seismic array studies, 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 all of 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 in the mineral exploration, extraction and processing sequence.

Highlights

From a geophysical perspective, 2020 highlights for Program 6 include:

- Publication of Esmail Eshaghi's PhD research in *Geophysics* and *Ore Geology Reviews*. Esmail's research has contributed to a better understanding of the crustal features and structure of northwest Tasmania.
- Finalisation of new 2D and 3D models of the deep electrical structure of Tasmania derived from magnetotelluric measurements by Tom Ostersen in his PhD study.
- CODES PhD student Tobias Staal contributed to numerous presentations at the virtual Scientific Committee on Antarctic Research (SCAR) Open Science Conference.

This conference was originally planned to be held in Hobart but was cancelled due to the COVID-19 pandemic and held online instead.

- CODES-TMVC Honours student Wei Xuen Heng used near surface geophysical methods to model the internal structure and contents of mine waste at the legacy Endurance mine in northeast Tasmania. This project was supported by Mineral Resources Tasmania through the Mining Sector Innovation Program. The outcomes of this research were used in conjunction with concurrent hydrological and sediment geochemical studies to inform Mineral Resources Tasmania rehabilitation options for this contaminated site. The results of these projects were presented at the Geological Society of Australia Earth Sciences Student Symposium (GESSS) 2020 virtual conference in October (see <http://ecite.utas.edu.au/143903>)

In the field of computational science and data visualisation, the major achievements of 2020 were:

- The use of Dr Michael Roach's very high-quality 3D high-resolution visualisations of key Australian geological field locations proved to be extremely important to CODES researchers and Earth Sciences teaching staff as they transitioned to online research delivery and teaching during 2020 due in large part to the COVID-19 pandemic.
- In November, CODES-TMVC PhD student Steve Kuhn published the final chapter of his thesis in *Geophysics* that used a soft classification routine to identify and map concealed intrusive bodies. This important contribution provides first pass porphyry copper exploration targets in a prospective area of British Columbia.
- CODES-TMVC PhD student Peter Morse published research on Deep Earth data visualisation in *IEEE Transactions on Visualization and Computer Graphics*. This contribution forms part of his PhD thesis titled 'Interactive visualisation for data inference in the

geosciences', which was submitted in late 2020.

In the area of technology transfer major highlights for 2020 were :

- In January Dr Michael Roach led an Australasian Universities Geoscience Educators Network (AUGEN) field trip for 26 university educators to northeastern Tasmania to introduce them to new, rapidly-evolving technologies for use in the teaching of geosciences.
- Dr Matthew Cracknell and Associate Professor Shaun Barker delivered online workshops to AMIRA P1202 sponsors and CODES staff and students on the use of machine learning and data mining for geochemical data analysis and recent advances in sweep-by-sweep LA-ICP-MS data processing and pattern recognition.
- From October to December, Dr Matthew Cracknell delivered the inaugural 'Geodata Analytics' Master of Economic Geology short course. This online short course is a new addition to the Masters of Economic Geology degree and 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. Geodata Analytics is not only available to Masters students but also open to industry-based participants through the UTAS short course platform.

OPPOSITE PAGE (TOP): Dr Michael Roach at Cape Wickham on King Island pictured here in December 2020 taking photographs to be used in 3D high-resolution teaching resources. (BOTTOM): Dr Michael Roach photographing basaltic rocks on King Island – these are part of the City of Melbourne Bay Volcanics.

The program team

LEADER MICHAEL ROACH

DEPUTY LEADER MATTHEW CRACKNELL



TEAM MEMBERS:

David Cooke, Anya Reading (Physics)

PHD STUDENTS:

Alex Farrar, Umer Habib, Stewart Jackson, Stephen Kuhn, Peter Morse, Thomas Ostensen, Thomas Schaap, Tobias Staal (CODES/IMAS)

HONOURS STUDENT:

Wei Xuen Heng

COLLABORATORS:

CSIRO OCEANS AND ATMOSPHERE FLAGSHIP
Mark Hemer

FIRST QUANTUM MINERALS
Mike Christie, Tim Ireland, Chris Wijns

GEOLOGICAL SURVEY OF SOUTH AUSTRALIA

Kate Robertson, Stephan Thiel

GHD

Hugh Tassell, Will McAdam

GRANGE RESOURCES

Gilbert Charles

INSTITUTE OF MARINE AND ANTARCTIC STUDIES (IMAS)

Jacqueline Halpin, Joanne Whittaker

INSTITUTE OF MINE SEISMOLOGY

Gerrit Olivier, Brian Salmon

MINERAL RESOURCES TASMANIA

Daniel Bombardieri, Mark Duffett, Carol Steyn, Clint Siggins

MITRE GEOPHYSICS

John Bishop

RSC MINING & MINERAL EXPLORATION

Michael Gazely

UNIVERSIDAD AUSTRAL DE CHILE, CHILE

José Picquer

UNIVERSITY OF SOUTH AUSTRALIA

Tom Raimondo

WESTERN MINING SERVICES

Jon Hronsky



CODES PhD student Alex Farrar undertaking fieldwork in early 2020 near the Chile-Argentina border in the Miocene-Pliocene porphyry belt of the Central Andes, east of the township of Vicuña, Chile. Here he is seen hiking up to the top of a hydrothermal alteration zone with lithocap mineralogy at 4,800 metres, conducting field mapping and collecting structural data.

Projects

Integrating geology and geophysics for resources targeting

Geodata analytics, visualisation and decisions

Geological visualisation and virtual education

Magnetotelluric imagery of the Earth's crust and mantle

The lithosphere of East Antarctica from combined geology and geophysics

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 candidate Alex Farrar, generously supported by First Quantum Minerals, aims to solve 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.

After a brief hiatus in Alex's project due to COVID-19 lockdowns preventing fieldwork, and relocating his family from South America to Tasmania via Victoria, he has commenced full-time study on-campus in Hobart. We look forward to following his progress over the coming years.

GEODATA ANALYTICS, VISUALISATION AND DECISIONS

Leader: Anya Reading

Student: Peter Morse

This project expands the scope of research undertaken within CODES and the Discipline of Earth Sciences into geodata analytics and innovative visualisation strategies. During 2020, research into 2.5D compositing for the rapid reconnaissance of 3D volumetric data concluded with a paper describing an interactive application being accepted for publication. PhD student Peter Morse finalised his research and submitted his PhD thesis.

GEOLOGICAL VISUALISATION AND VIRTUAL EDUCATION

Leader: Michael Roach

Collaborator: Tom Raimondo

This project continues to refine and develop methods for effective geological visualisation and explores how these methods can be applied for research, education at professional, postgraduate and undergraduate levels, and for public outreach.

In January 2020 Dr Michael Roach coordinated a three-day field trip to northeast Tasmania for geoscience educators from around Australia and New Zealand. This field trip was for the Australasian University Geoscience Education Network (AUGEN) and focused on new methods for field-based education including the applications of drones, photogrammetry and field-based digital data recording. The AUGEN field trip was attended by 26 university geoscience educators.

A main focus of work in 2020 was on development of new resources for both undergraduate and postgraduate education in response to the need to migrate all our teaching programs online due to COVID. The value of these new resources was clearly demonstrated during the 'Ore Deposit Models' Master of Economic Geology short course which was run entirely online with over 200 participants from over 15 countries. Students in this short course were able to view and manipulate digital representations of rock samples and to undertake a virtual field trip to Bluestone Bay which included an assessed mapping task.



CODES collaborator José Piquer (centre, pointing) from Universidad Austral de Chile with First Quantum Minerals geologists conducting a field traverse through the Abanico basin near the township of Los Andes, Chile, in early 2020. This fieldwork was linked to Alex Farrar's PhD, which is looking at the presence of trans-lithospheric faults on the formation of giant porphyry copper deposits in the Andes.



thesis. Advanced 3D visualisation was employed to investigate relationships between the newly determined conductivity structures at depth, and crustal architecture such as granite bodies. This will inform understanding of tectonic evolution and both mineral and geothermal prospectivity for Tasmania.

THE LITHOSPHERE OF EAST ANTARCTICA FROM COMBINED GEOLOGY AND GEOPHYSICS

Leader: Anya Reading

Student: Tobias Staal

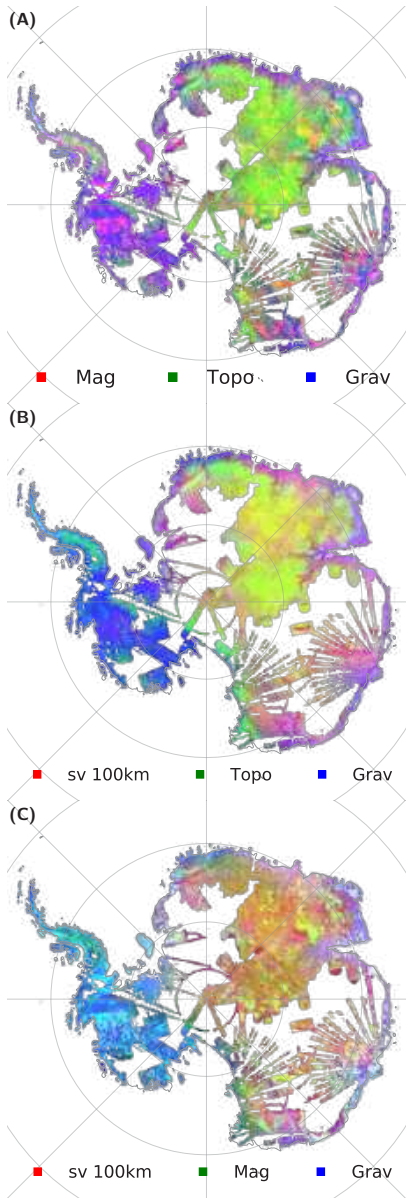
Collaborators: Jacqueline Halpin, Joanne Whittaker (IMAS)

The continental land mass of East Antarctica is one of the least understood regions on Earth. This is due to the ice cover, several kilometres thick in places, and the rock outcrops being restricted to the coastal regions. This project combined geological and geophysical data, including the use of statistical and probabilistic methods, to progress our understanding of the East Antarctic Lithosphere. Highlights of 2020 were the submission and publication of papers, by CODES/IMAS PhD student Tobias Staal and the project team, that described 1) new software to handle 3D multivariate geosciences data, and 2) a new geothermal heat flow map, Aq1, of the Antarctic lithosphere. Tobias submitted his PhD thesis in 2020 and the project has now concluded.

ABOVE: Past endeavour: Tobias Staal pictured in Antarctica at Snyders Rocks, Knox Coast, in 2016 during fieldwork for his PhD into the lithospheric structure of Antarctica. Tobias submitted his PhD for examination during 2020 and he will graduate in August 2021.

OPPOSITE PAGE (TOP): A colourful look at Antarctic lithospheric structure: Ternary maps from CODES PhD student Tobias Staal et al. (Frontiers in Earth Science, 2020) showing standardised geophysical datasets, including gravity, magnetic anomalies and surface wave tomography, represented as colour channels (red, green and blue). The resulting hues can indicate the tectonic regions. High-resolution geophysical data are still sparse in the Antarctic interior.

(BOTTOM) Dr Michael Roach prepares to launch a drone at Rossarden in northeastern Tasmania as part of research for the Virtual Geology project.



Looking forward

The computational and data science research undertaken in Program 6 will continue to provide a basis for the utilisation of new data analytical techniques within a wide range of CODES projects. The emphasis of this work, coordinated by Dr Matthew Cracknell, will be on unsupervised methods for aggregation, clustering and classification of geochemical data sets across a wide range of scales.

Geological visualisation activities in 2021 will focus on development of virtual education modules for undergraduate and professional education. This will include finalisation of the Savage River Mine virtual tour and digitisation of diverse UTAS sample collections that will form the basis for online educational resources for use in UTAS undergraduate units and in CODES Master of Economic Geology courses.

From a geophysical perspective, Tom Ostensen plans to complete his PhD project on the crustal and upper mantle electrical structure of Tasmania in 2021. Tom's new 3D electrical models will provide a fresh perspective on the intermediate and deep structure of Tasmania.

From a computation geosciences perspective, Steve Kuhn will graduate in 2021 having completed his PhD on the use of supervised and unsupervised learning algorithms for mineral exploration across a diverse range of ore deposit types.

Dr Matthew Cracknell will deliver the 'Geodata Analytics' Master of Economic Geology short course for a second time in early 2021. Given rapid advances and uptake of computation methods for processing and analysing geological data, this course will provide a timely and important addition to the Masters program. This course will bring together a number of key practitioners and researchers in the fields of signal and image processing, machine learning and

statistical analysis. Participants will gain skills in the analysis and visualisation of geoscience data with a focus on providing a platform for rapid communication of outputs to geologists to help inform decision making.

CODES PhD student Umer Habib is preparing to publish the outcomes of his research into the paleomagnetic history of southeast Australia, the history of detrital zircons from Palaeozoic rocks in Tasmania and southern Victoria, and U/Pb dates for Palaeozoic igneous rocks. These research outputs are being used to better understand the tectonic evolution of Victoria and Tasmania.

CODES PhD student Tom Schaap plans to submit his thesis in August 2021. His project has brought together a number of models of the tectonic history for southeast Australia, and he has developed a new model in a digital format which includes geological phenomena such as deformation. This work has also expanded on the close links between tectonic processes and ore deposit formation, showing the relationships between porphyry Au deposits and ancient volcanic arcs, as well as orogenic gold deposits and regional deformation strain. This work is available to be expanded upon, with more detail to be added within the model as well as in surrounding regions (see also the Lachlan Orogen project in Program 3).

Dr Matthew Cracknell is looking forward to continuing collaborations with Dr Clare Miller (Theme 2) and MRT on the used of near surface geophysics to characterise the internal structure and contents of legacy mine waste in Tasmania. A key aspect of this collaboration in 2021 will be Zak Weidinger's Honours project, which aims to use 4D geophysical methods to investigate time-varying hydrological conditions within the Royal George tailings dam, northeast Tasmania.

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:

- 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.
- 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.

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

Despite the impact of COVID-19, there was still a great deal of activity within the TMVC in 2020, including the commencement of two PhD students, four Masters students and ten Honours students. The majority of these new students are working within the AMIRA P1202 sub-project, and are spread between CODES, Lakehead University and Universidad Austral de Chile.

Notable achievements during the year included the completion of several sub-

projects, including the 'Geological and geochemical vectors to low sulfidation epithermal gold mineralization, Cerro Negro district, Deseado Massif, Argentina' project, supported by Newmont Goldcorp.

The AMIRA P1202 project team successfully delivered online sponsor review meetings in May and November, as well as conducting several online workshops, aiming to improve understanding and uptake of research findings by the project sponsors.

The major highlight for Theme 1 in 2020 was the publication of the *Economic Geology* special issue on the green rock environment in June, co-edited by Dr Evan Orovan and containing contributions from several staff and former student researchers.

The Theme 3 research team continued to make progress on various PhD student projects with Annah Moyo's bench-scale tests continuing throughout 2020, completion of Laura Jackson's study that focused on developing techniques and protocols to identify waste rock AMD potential at early-life-of-mine stages, and progress on the water chemistry chapters of Sibeles Nascimento's thesis.

The Underpinning Technologies team were busy in 2020, with papers being written on outcomes from several student projects. Progress was also made by PhD candidates Javier Merrill and Angela Rodrigues on automating the extraction of valuable information from drill core hyperspectral imagery.

It was also another productive year for student completions, with the submission of eight theses: three PhD and five Honours. Our publication outputs included 14 refereed journal articles, two book chapters, eight conference presentations and 95 reports to industry.

ABOVE RIGHT: Examples of variable rock textures automatically recognised using TMVC PhD student Javier Merrill's algorithm for textural classification derived from mineral co-occurrence probability fields applied to hyperspectral mineral maps (from AMIRA project P1202 - Module 4). OPPOSITE PAGE: Honours students Wei Xuen Heng and Olivia Wilson with Dr Clare Miller (right) at the legacy Endurance Mine site, northeast Tasmania, discussing the locations for borehole installation and geophysical surveys. By combining these multidisciplinary techniques, this project successfully characterised the internal structure of the Endurance mine wastes and determined the preferential pathways of AMD transport at the site. Knowledge generated from these Honours projects will help to inform remediation of the site.



The program team

LEADER DAVID COOKE

DEPUTY LEADER LEONID DANYUSHEVSKY



TEAM MEMBERS:

CODES: Mike Baker, Shaun Barker, Ivan Belousov, Ron Berry, Matthew Cracknell, Angela Escolme, Bruce Gemmell, Ross Large, Elena Lounjeva, Sebastien Meffre, Clare Miller, Paul Olin, Evan Orovan, Anya Reading, Terrie Sawyer, David Selley, Francisco Testa, Lejun Zhang

ENGINEERING, UTAS: Danchi Jiang

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, Amos Garay, Laura Jackson, Colin Jones, Rhiannon Jones, Stephen Kuhn, Erin Lawlis, Javier Merrill, Peter Morse, Annah Moyo, Nanda Mrabawani, Sibeles Nascimento, Jaime Osorio, Xin Ni Seow, Emily Smyk, Yi Sun, Francisco Testa, Jennifer Thompson

MONASH UNIVERSITY: Angela Rodrigues

WAIKATO UNIVERSITY, NEW ZEALAND: Rocky Barker

MASTERS STUDENTS:

CODES: Kim Boundy, Mertkan Bozoglu, Batbayar Enkhbold, Greer Lane

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

HONOURS STUDENTS:

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UNIVERSIDAD AUSTRAL DE CHILE: Reinaldo Gonzalez, Francisco Torres

COLLABORATORS:

AUSTRALIAN NATIONAL UNIVERSITY Trevor Ireland

CONSULTANT Noel White

CORESCAN Ronell Carey, 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

HEFEI UNIVERSITY OF TECHNOLOGY, CHINA Jing Chen, Yanyun Xiong, Fan Yu, Taofa Zhou

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, Michael Reid, Clint Siggins, Carol Steyn

MONASH UNIVERSITY Laurent Ailleres, Robin Armit

NEWCREST MINING Karyn Gardner, Mary Harris, Fiona Karaut, Paul Napier

NEWMONT GOLDCORP Thomas Bissig, Patricio Brividor, German Escorza, Cesar Riveros

NORRIS SCIENTIFIC Ashley Norris

UNITED STATES GEOLOGICAL SURVEY, DENVER, USA Jay Thompson

UNIVERSIDAD AUSTRAL DE CHILE José Piquer

UNIVERSITY OF ALBERTA, CANADA Robert Creaser

UNIVERSITY OF BRITISH COLUMBIA, CANADA Richard Friedman

UNIVERSITY OF QUEENSLAND Nathan Fox, 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)

- Pyrite footprints
- Magmatic-hydrothermal transition features in Sn granites of Tasmania
- Geological and geochemical vectors to low sulfidation epithermal gold mineralization, Cerro Negro district, Deseado Massif, Argentina
- Far-field and near-mine footprints: Finding and defining the next

generation of Tier 1 ore deposits (AMIRA P1202) – Modules 1–3

- Timing relationships within porphyry-epithermal deposits
- Identifying unique Resistate Indicator Mineral (RIM) chemistry as a guide in prospectivity for sediment-hosted copper mineralisation (AMIRA P1206)
- Alteration mineral chemistry at Yaojialing Zn-Au-W skarn deposit, China: Implications for ore genesis and exploration

THEME 2: OPTIMISING GEOMETALLURGICAL PREDICTION

- Characterising supergene copper mineralogy using hyperspectral techniques (on hold in 2020 so no summary provided below)
- 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

- Mineralogical domaining of low grade and no grade zones using automated drill core logging at Cadia

- Utilising industrial waste materials for AMD control
- Geometallurgy of historic mine waste: Evaluating options for reprocessing
- An enduring problem: A multidisciplinary approach to characterising acid and metalliferous drainage at Endurance Mine, northeast Tasmania

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

Project summaries

THEME 1: DETECTING PROXIMITY TO ORE (FOOTPRINTS)

PYRITE FOOTPRINTS

Leader: David Cooke

Team members: Leonid Danyushevsky, Angela Escolme, Anthony Harris, Evan Orovan, Sebastien Meffre, David Selley

Student: Erin Lawlis

Collaborators: Karyn Gardner, Fiona Karaut, Paul Napier, Stephanie Sykora

Erin Lawlis completed her PhD thesis 'Geology of the Kapit NE and Coastal Ore Zones, Lihir Gold Deposit, Papua New Guinea' in February 2020 and graduated in December 2020. Erin completed a multivariate analysis of the deportment of gold and other trace elements in pyrite, demonstrating that repeated compositional evolution of the mineralising fluids occurred throughout the epithermal life cycle at Lihir. A manuscript by David Cooke and co-authors entitled 'Lihir Alkaline Epithermal Gold Deposit, Papua New Guinea' was published in the Society of Economic Geologists Special Publication No 23

– *Geology of the World's Major Gold Deposits and Provinces* in October 2020. This project has now ended.

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. Colin Jones completed his second year of PhD candidature, fieldwork and sample collection in 2020. He has completed a significant portion of his geochronology and whole-rock geochemistry analytical campaign, as well as finishing O-isotope and Lu/Hf analyses on zircon at ANU and Macquarie University, respectively. Colin is writing up his findings which he hopes to publish in the next year.

**GEOLOGICAL AND
GEOCHEMICAL VECTORS
TO LOW SULFIDATION
EPITHERMAL GOLD
MINERALIZATION, CERRO
NEGRO DISTRICT, DESEADO
MASSIF, ARGENTINA**

Leaders: David Cooke, Noel White

Team members: Bruce Gemmell, Francisco Testa, Lejun Zhang

Collaborators: Thomas Bissig, Patricio Brivido, German Escorza, Cesar Riveros

This sub-project aimed to test and develop geological and geochemical vectors to low sulfidation epithermal gold mineralisation in the Cerro Negro district of Patagonia, Argentina. The project was completed in December 2020, and some of the major outcomes include:

- Recognition of hydrothermal alteration assemblages (i) at the district scale based on ASTER imagery and pre-existing TerraSpec data; and (ii) at the target scale based on new TerraSpec measurements. Previously unrecognised alteration zones were identified, and transitions from high-temperature to low-temperature hydrothermal alteration assemblages were reported.

- A genetic model was constructed to explain main hydrothermal events which occurred in the SE domain of the Cerro Negro district. The proposed genetic model proved to be useful to explore across the SE domain.
- Spatial overlap/overprint of LS, HS and supergene processes were documented based on mineral assemblages, textural features, and Ar–Ar geochronological constraints; mineral assemblages and textures were critical to understand the history of the Cerro Negro district as individual mineral phases formed in two or more of the LS, HS and supergene events.
- Mineralogical and textural evidence that allowed us to navigate from shallow to deep levels were identified in epithermal systems at Cerro Negro; understanding both the depth of ore formation and degree of erosion were crucial to assess whether a target is worth further drilling (e.g., diagnostic shallow features at surface) or not (e.g., eroded bonanza zone).
- Based on the integration of TerraSpec and whole rock geochemistry findings at Silica Cap, we proposed a straightforward method to detect mineral zonation across the Cerro Negro district and estimate hydrothermal alteration halo distances perpendicular to quartz veins.
- Quartz chemistry was used to navigate from shallow to deep levels in the Gato Salvaje and Silica Cap low sulfidation epithermal systems; quartz chemistry on its own, or in combination with hydrothermal mineral assemblages, textures, and whole rock geochemistry/ lithogeochemistry showed potential as a powerful tool for exploration in the Silica Cap low sulfidation epithermal system and for further applications in the Cerro Negro district.
- Evidence for lithocaps was documented in the Cerro Negro district; quartz chemistry was used for vectoring towards heat sources within the Silica Cap lithocap, providing regional insight for exploration.

**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, Evan Orovan

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

Collaborators: Laurent Ailleres, Robin Armit, Scott Halley, Peter Hollings, José Piquer, Mervin Delos Santos, Leo Subang, Noel White

AMIRA P1202 is being conducted in collaboration with researchers from Lakehead University, Monash University and the Universidad Austral de Chile. Building upon the results of the AMIRA P1153 project, this multi-year project is developing 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.

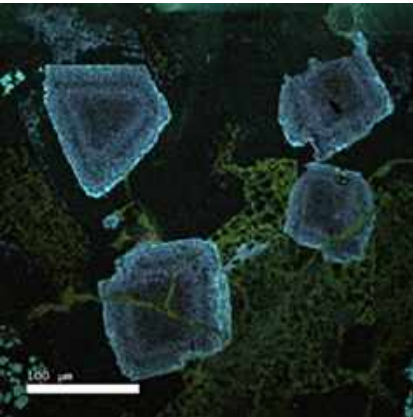
Modules 1–3 of the project focus on three key alteration domains within

the porphyry-epithermal system. These include the green rock and lithocap environments, and aspects of magmatic fertility. 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.

In 2020, the research team were able to continue research activities on study sites in Australia, Canada, Indonesia, the Philippines, Sweden, South Korea and the USA, despite the impact of COVID-19 affecting both international and domestic travel. Two blind test studies were also successfully completed on the Potrerillos and West Wall porphyry deposits in Chile. Several sub-projects within P1202 involved postgraduate students either continuing or commencing their study. Xin Ni Seow, Emily Smyk and Yi Sun have continued their PhD studies on alunite and APS mineral chemistry, the Christmas porphyry Cu-Mo deposit (USA) and Lepanto district (Philippines), respectively. Patrick Hamilton and Andrew Jedemann, both at Lakehead University, have also continued their MSc studies on the Pemberton Hills deposit (Canada). Batbayar Enkhbold has also continued his MSc study of green rock alteration at Mt Isa. Four new student projects commenced in 2020, including the MSc project of Mitch Marcelissen (Lakehead University) on magma fertility in the Sunda-Banda Arc (Indonesia), the Honours study of Ben Speakman on magma prospectivity and restite mineral chemistry in the Yerington district (USA), and the Honours projects of Reinaldo Gonzalez (Santa Marta lithocap, Chile) and Francisco Torres (Tibetano prospect, Chile) at Universidad de Austral de Chile. The AMIRA P1202 project is now in its final year and is expected to be completed on time in late June 2021.



ABOVE: Senior Research Fellow, ARC TMVC Research Hub, Lejun Zhang (left) with Senior Geologist, Northparkes mine, Jonathon Hoye (middle) and Professor Noel White (right) at Northparkes porphyry Cu-Au mine northwest of Parkes, NSW, during fieldwork as part of the AMIRA P1202 project. LEFT: Scanning Electron Microscopy-Cathodoluminescence (SEM-CL) image of APS mineral from the Tujuh high-sulfidation – porphyry Cu-Au deposit, Indonesia. This work is part of the AMIRA P1202 project lithocap research program.



**TIMING RELATIONSHIPS
WITHIN PORPHYRY-
EPITHERMAL DEPOSITS**

Leader: Evan Orovan

Team member: David Cooke

Student: Erin Lawlis

Collaborators: Robert Creaser, Richard Friedman

This project involved using high-resolution geochronology (ID-TIMS on zircon and Re-Os on molybdenite) to constrain the magmatic and mineralising events at the largest known alkalic epithermal Au deposit (Lihir, Papua New Guinea) and a calc-alkalic porphyry district (Namosi, Fiji). In 2020, two new Re-Os dating results were generated for the Lihir gold deposit that have been reported in Erin Lawlis' PhD thesis completed in February 2020. These results are currently under a confidentiality embargo with plans to publish results in 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 is 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 is supported by Anglo

American; First Quantum Minerals; Independence Group; the Japan Oil, Gas and Metals National Corporation (JOGMEC); and Rio Tinto, and is utilising 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 which are being analysed from throughout the Central African Copper Belt. Laboratory work during the project was disrupted by COVID-19 which set back the final project by several months. The project results are expected to be delivered in ~April 2021.

ALTERATION MINERAL CHEMISTRY AT YAOJIALING ZN-AU-W SKARN DEPOSIT, CHINA: IMPLICATIONS FOR ORE GENESIS AND EXPLORATION

Leader: Lejun Zhang

Team members: Mike Baker, Francisco Testa, Noel White

Collaborators: Jing Chen, Yanyun Xiong, Fan Yu, Taofa Zhou

This sub-project commenced in 2019 as a collaboration between CODES and Hefei University of Technology. It aimed to document in detail the alteration zonation patterns and alternation mineral geochemistry of the Yaojialing deposit, located in the Middle-Lower Yangtze River metallogenic belt (MLYB) in east China, in order to contribute to the overall understanding of the metallogeny and thereby facilitate effective exploration.

A couple of Honours projects have been designed within this project to:

- Investigate the alteration mineralogy, texture, paragenesis, and their zoning patterns, by field mapping, Vis-NIR (visible near infra-red) and SWIR (short wavelength infra-red) spectral analysis, thin section observations, MLA (Mineral Liberation Analysis), and colour CL (cathodoluminescence) imaging.

- Investigate the mesoscale ore textures and microscale ore textures.
- Determine the geological ages of key alteration minerals (e.g., Ar-Ar, U/Pb).
- Investigate the elements and isotopic geochemistry (in-situ C, S and O) anomalies halo around mineralisation and apply the results to the prospects.
- Investigate the geochemistry zoning pattern by whole rock multi-element analysis and alteration mineral chemistry.

Due to the COVID-19 pandemic, the student projects have been delayed. Some initial analytical work has been conducted on the samples received from the collaborators.

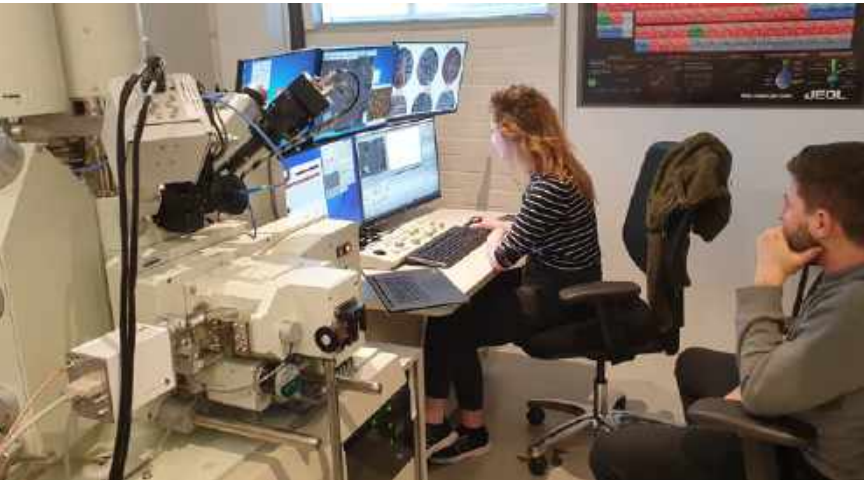
THEME 2: OPTIMISING GEOMETALLURGICAL PREDICTION

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

Leaders: David Cooke, Angela Escolme

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

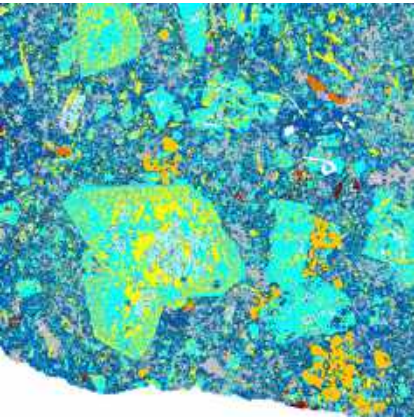
Details of the overall AMIRA P1202 project are outlined in the TMVC Theme 1 section of this annual report. The optional research module of P1202 (Module 4) is reported here in the Geometallurgy Theme, as it is the major geometallurgical research activity being conducted in the TMVC from year 4 onwards.

P1202 currently has 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 vectoring and geometallurgical assessments of the porphyry transition zone, where clay and mica alteration overprint early formed potassic alteration. The research team are working closely with Corescan at Module 4 sites to optimise mineralogical characterisation of the transition zone for exploration, evaluation and mining.

In 2020, the P1202 Module 4 research team continued research activities across several study sites despite the challenges of COVID-19. Sponsors facilitated sample shipping in the absence of fieldwork and students continued data acquisition and interpretation throughout the year. The research team are progressing well towards delivering on the project's objectives to the sponsor group (including algorithms for textural classification of hyperspectral imagery, and new white micas mineral chemistry data sets and exploration tools).



ABOVE: Work in progress: (L–R): Senior Research Fellow, ARC TMVC Research Hub, Dr Lejun Zhang, TMVC PhD student Rhiannon Jones, Professor David Cooke and TMVC Masters student Mertkan Bozoglu examining drill core samples sent from Northparkes as part of the P1202 Module 4 research within TMVC Theme 2. RIGHT: Scanning electron microscope-based mineral map of weakly altered sample from Spence Cu-Mo deposit, Chile, showing muscovite (yellow) and kaolinite (pale blue) replacing plagioclase phenocrysts (turquoise) in K-feldspar (dark blue) altered groundmass with pyrite (light orange) and chalcopyrite (dark orange) mineralisation. This analysis work is part of AMIRA project P1202 'Finding and defining the next generation of Tier 1 Ore deposits', Module 4 'Transition zone'. OPPOSITE PAGE: TMVC PhD student Rhiannon Jones using the microprobe at the UTAS Central Science Laboratory (CSL) to analyse samples of white mica from Northparkes with TMVC Masters student Mertkan Bozoglu looking on. The machine is analysing the major element chemistry of white mica from phyllic altered samples at Northparkes. This research is being done as part of the P1202 Module 4 research within TMVC Theme 2.



Two new PhD students (Rhiannon Jones and Jaime Osorio) and one Master of Economic Geology student (Mertkan Bozoglu) joined the other P1202 Module 4 PhD students, Javier Merrill, Takeshy Coaquira and Angela Rodrigues (Monash) during 2020 and all are generating exciting outcomes with impact through their case studies.

THEME 3: MINIMISING GEOENVIRONMENTAL RISKS

MINERALOGICAL DOMAINING OF LOW GRADE AND NO GRADE ZONES USING AUTOMATED DRILL CORE LOGGING AT CADIA

Leader: David Cooke

Team member: Matthew Cracknell

Student: Laura Jackson

Collaborators: Ronell Carey, Nathan Fox, Mary Harris, Anita Parbhakar-Fox, Ekaterina Savinova

Geoenvironmental characterisation at the earliest life-of-mine stages is critical for designing the most appropriate environmentally conscientious waste management strategies and storage facilities. However, geochemical tests typically used for predicting waste characteristics are texturally destructive, and therefore do not appropriately describe the geoenvironmental characteristics of the waste materials, and indeed how they might evolve regarding the role of secondary minerals in metal cycling within the surficial environment. Laura Jackson completed her PhD study in April 2020, which effectively determined the effectiveness of simple field techniques for predicting AMD properties of waste rock; developed geoenvironmental domaining tools using hyperspectral

data; demonstrated the application of LA-ICP-MS for determining low-level trace element content in sulfides and carbonates contained in drill core; and delivered a geoenvironmental testing protocol that integrated the hyperspectral and LA-ICP-MS technologies to assist with waste rock management planning at early-life-of-mine stages. This project has now concluded.

UTILISING INDUSTRIAL WASTE MATERIALS FOR AMD CONTROL

Leader: David Cooke

Team members: Sebastien Meffre, Clare Miller

Student: Annah Moyo

Collaborators: Anita Parbhakar-Fox, Michael Reid, Clint Siggins, Carol Steyn

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.

Annah commenced bench-scale accelerated kinetic leach tests on mine waste materials from six mine and smelter sites across Tasmania in 2019, using a variety of cover materials (whether green liquor dregs, wood ash, coal ash, red muds, and scallop, mussel and oyster shells) to assess their effectiveness at ameliorating acid drainage generated by oxidation of the mine wastes. The experiments continued throughout 2020 without disruption, and are scheduled to be completed in Q3 2021. Annah presented preliminary results from her experiments at the Goldschmidt2020 conference in June 2020.

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



TOP: Honours students Olivia Wilson and Eliza Fisher with Dr Clare Miller (centre) at the legacy Endurance Mine site, northeast Tasmania, discussing fieldwork and sampling plans for the day. CODES' Environmental Geology research group pursued three independent Honours research projects within TMVC's Theme 2 to effectively characterise the legacy mine wastes. This multi-disciplinary approach required careful planning, effective collaboration, and ongoing communication between the students throughout the duration of their projects. MIDDLE: TMVC PhD student Annah Moyo has been carrying out kinetic leach tests on combinations of industrial wastes and mine wastes conducted in 2-kg AMIRA cells as part of her research into using industrial waste materials for AMD control. BOTTOM: Scaled-up kinetic leach tests on combinations of industrial wastes and mine wastes conducted in 15-kg kinetic leach columns, which are part of TMVC PhD student Annah Moyo's research into the use of waste materials for managing acid-forming mine wastes.

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.

PhD student Sibeles Nascimento suspended her candidature for half of 2020 due to family illness. She has recommenced her studies and is concentrating on writing up thesis chapters on the water chemistry of the King–Queen river system and the mineralogical and geochemical properties of the King River delta tailings. Preliminary results indicate that substantial cobalt and minor copper are present in pyrite and chalcopyrite phases and are likely target metals for metals recovery.

AN ENDURING PROBLEM: A MULTIDISCIPLINARY APPROACH TO CHARACTERISING ACID AND METALLIFEROUS DRAINAGE AT ENDURANCE MINE, NORTHEAST TASMANIA

Leaders: Clare Miller, Matthew Cracknell, David Cooke

Students: Eliza Fisher, Wei Xuen Heng, Olivia Wilson

Collaborators: Clint Siggins, Carol Steyn

The Endurance Mine, northeast Tasmania, was mined for alluvial tin from 1874 to the 1980s. As with many legacy mine sites in Tasmania, mine waste management at Endurance was not designed to achieve successful closure outcomes and has led to detrimental impacts to water quality and environmental health in the form of acid and metalliferous drainage (AMD). However, the source and pathways of contaminant transport at Endurance are unclear as previous studies have

observed low pyrite content within the mine wastes. This site is now the responsibility of MRT and as it is used for recreation it is a priority for remediation.

In 2020, three Honours research projects were devised to investigate groundwater and sediment interactions at Endurance leading to AMD. These projects tackled the separate but interrelated aspects of sediment geochemistry and mineralogy (Eliza Fisher), hydrogeology (Olivia Wilson) and geophysics (Wei Xuen Heng) to build a comprehensive understanding of the groundwater system and mine waste mineralogy leading to the formation and transport of AMD at Endurance. The outcomes of these projects are being used to inform the design, monitoring and management of current and future mine waste facilities at Endurance and more widely across Tasmania.

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.

During 2020, further application of the developed prototype has revealed that wide application of the instrumentation requires synchronisation of aerosol generation by the pulsing laser with the mass cycling by the single detector mass-spectrometer, which is the most common type of mass-spectrometer currently in use. A synchronisation device has been developed in

collaboration with Norris Scientific, and tested on several applications. A paper reporting the performance of the synchronisation device has been accepted for publication in the *Journal of Analytical Atomic Spectroscopy*.

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 2020, PhD candidates Javier Merrill (CODES) and Angela Rodrigues (Monash) surged ahead with their PhD projects, which are embedded within AMIRA P1202 Module 4. Javier finalised the testing and evaluation of his mineral texture clustering algorithm. This algorithm is able to take Corescan mineral maps and

automatically identify drill core with similar mineralogy and texture. He is currently applying this algorithm to scans of drill core collected at Spence, Chile (BHP), and Tujuh Bukit, Indonesia (Merdeka). Angela continues to develop a Deep Learning system for classifying minerals from drill core hyperspectral imagery. This approach has the potential to increase the objectivity and speed of mineral map construction.

In mid-2020, Javier was awarded the Max Banks Research Scholarship in Earth Science. This prestigious award provides a top-up scholarship to candidates who demonstrate outstanding academic merit. Many thanks to the Banks family for their continued support for our fantastic research students.

INTEGRATING CHEMICAL AND MINERALOGICAL DATA LAYERS FOR ELEMENT DEPARTMENT

Leaders: Sebastien Meffre, Matthew Cracknell, Leonid Danyushevsky, Ron Berry, Shaun Barker

Team members: Ivan Belousov, Angela Escolme, Paul Olin

Student: Rocky Barker

This project aims to integrate mineralogical and chemical data from various spectral and analytical techniques in order 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 awaiting the new imaging capability in the LADR data reduction software. This capability is forecast to become available in the second half of 2021.

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. Recently, Shawn, Matthew Cracknell and Michael Gazley were invited to submit a paper to 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. Keep an eye out for this publication in 2021.

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

This project had an active final year with both Stephen Kuhn and Peter Morse submitting their PhD theses. Stephen Kuhn’s work culminated in a final paper being submitted to the leading international applied geophysics journal *Geophysics* that reported an effective method of using data-driven techniques in a challenging lithology mapping example, and at a relatively early exploration stage. This study was carried out in collaboration with industry geologist, Stephanie Sykora.

Peter Morse’s final paper associated with his PhD thesis was also published, in the top data visualisation journal, *IEEE Transactions on Visualisation and Computer Graphics*. This work used 2.5 D interactive compositing to

undertake exploratory visualisation of a 3D deep Earth dataset. The study built on previous work, employing the well-posed use of colour, transformed to the perception of features in a 3D representation.

Professor Anya Reading will convene a session at the Australian Earth Sciences Convention (early 2021) that will focus on ‘Data-driven and computational methods to reveal hidden or changing surfaces, volumes and environments’.

METHOD DEVELOPMENT FOR LASER-ABLATION ICP-MS APPLIED TO COMPLEX MATRICES

Leader: Leonid Danyushevsky

Team members: Elena Lounejeva, Paul Olin, Terrie Sawyer

Students: Nanda Mrabawani, 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.

Test studies aimed at identifying the optimal analytical conditions for analyses of plagioclase have commenced in 2020; however, they were delayed due to COVID-19 restrictions limiting access to the analytical facilities by students. As a result, testing has been finalised for plagioclase and alunite, with analytical work on apatite planned for early 2021. Testing of plagioclase and alunite has revealed that variations in analytical parameters alone cannot produce accurate results, and that introduction of correction coefficients will be required. The approach will be finalised in 2021.

Knowledge transfer and training

Knowledge transfer and training are an integral part of the TMVC, encompassing all research themes and impacting all parts of the mining value chain. During the year TMVC staff and students produced 14 refereed journal articles (including six in the ‘Exploring the Green Rock Environment’ special issue of *Economic Geology*) and two book chapters (in the SEG Special Publication 23 on the ‘Geology of the World’s Major Gold Deposits and Provinces’), provided 95 reports to industry, and delivered eight conference presentations. The team also conducted several online workshops.

Looking forward

Work in 2021 will primarily comprise of completing AMIRA projects P1202, ‘Far-field and near-mine footprints: finding and defining the next generation of Tier 1 ore deposits’ and P1206 ‘Identifying unique Resistate Indicator Mineral (RIM) chemistry as a guide in prospectivity for sediment-hosted copper mineralisation’. The final meetings for these projects are scheduled for June and April 2021 respectively.

Student projects will remain ongoing, with several PhD candidates expected to submit their theses during the year including Jennifer Thompson and Yi Sun.

While the TMVC will officially wind-up at the end of June, student theses, journal publications and conference-related activities will remain key avenues for the dissemination of the Hub’s research outcomes.



ABOVE: Core photo showing pyrite – chalcopyrite – hematite – quartz vein with phengite to hematite selvage from Resolution Cu-Mo porphyry deposit, Arizona, a study site for AMIRA P1202 Module 4. BELOW: Dr Matthew Cracknell (left) and Honours student Wei Xuen Heng conducting a geophysical survey of the mine wastes at the legacy Endurance Mine, northeast Tasmania, in 2020 as part of the TMVC research project in Theme 3 looking at acid and metalliferous drainage.



Training and education

Objectives

Produce world-class PhD, Masters and Honours geoscience graduates.

Deliver a range of professional development short courses and workshops tailored to meet the needs of the minerals industry.



LEADERS ROBERT SCOTT AND REBECCA CAREY



The 2020 Honours cohort plus other students at Doherty Hill lookout east of Queenstown in western Tasmania (Frenchman's Cap is visible on the skyline at upper right). The students are en route to Queenstown for the annual Exploration Field Skills Mapping Camp in February, which was able to take place before the COVID-19 lockdown in Tasmania.

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 subsequently progressing to senior roles in the minerals industry, state and federal governments, and academia.

Training and education activities also play a vital role in CODES' research across our six research programs. Training and education at CODES includes the Higher Degree by Research (both PhD and Masters by Research), Master of Economic Geology 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).

Highlights

2020 has been a successful year for CODES with 12 PhD, one Masters by Research and seven Honours completions. Most of these graduates and graduands have gone on to postdoctoral positions with industry and the Tasmanian State Government, or on to further study with us at the University of Tasmania. We wish them the best for their future careers. We will enter 2021 with a healthy Higher Degree Research program that consists of 35 students (not including our Master of Economic Geology students) with projects that range across the spectrum of our research programs.

It was another busy year for the Master of Economic Geology program, with 14 new students and a further two rejoining the program. Four short courses were offered during the year. Seven students either graduated or

completed the Master of Economic Geology degree in 2020. The major highlight of the MEconGeol teaching program in 2020 was the inaugural running of 'Geodata Analytics' in October–December, which easily achieved capacity. COVID-19 also necessitated the translation of 'Ore Deposit Models and Exploration Strategies' and the 'Exploration in Brownfield Terrains' short courses from face-to-face to online delivery. The time and effort that these changes required from short course presenters was greatly appreciated and ensured that the students and external industry participants received continued opportunities to take short courses while the world began to feel the full impact of COVID-19.

Fourteen students were enrolled in the Honours program in 2020. This included three mid-year starters from 2019, four who commenced mid-2020, and will complete their degrees in 2021, and one who commenced part-time in mid-2020, and will complete in 2022.



Small-scale folds in thinly interbedded shale and fine-grained volcaniclastic sandstone of the Cambrian White Spur Formation, Mount Read Volcanics, western Tasmania, as seen on the 2020 Exploration Field Skills Mapping Camp.

Postgraduate programs

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

PhD and Masters by Research Program

Much of the exciting research that we do here at CODES is produced by our PhD and Masters students – they make a major contribution to CODES' research activities and outputs. Projects at CODES range across the spectrum of our programs and include sponsorship/collaborations with industry in Tasmania, Australia and globally, and with the Tasmanian State Government, geological surveys and academic institutes across 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 2020, 48 students were enrolled in research at PhD or Masters level. We welcomed Malai Illa'ava (Australia), Rhiannon Jones (UK), Gilles Ngoran (Cameroon), Jaime Osorio (Chile), Chuang Wang (Australia) and Karla Morales (Ecuador). Nine students graduated in 2020: PhD graduates Adam Abersteiner, Nathan Chapman, David Douth, Matthew Ferguson, Amos Garay, Laura Jackson, Erin Lawlis, Francisco Testa; and Masters graduate Peerapong Sritangsirikul. Congratulations and all the best in your future careers.

2020 has not been an easy year for our higher degree research students due to impacts and travel restrictions associated with COVID-19, especially for our international students with family and friends overseas. We continue to support our students and help them navigate fulfilling their PhD

research aims and goals with the developing COVID-19 situation.

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.

It was another successful year for the Master of Economic Geology (MEconGeol) program, with 14 new admissions, and a further two rejoining, taking the program to a new record of 65 active students in 2020. CODES delivered four short courses in 2020, with 'Volcanology and Mineralisation in Volcanic Terrains' (19 participants) requiring a last-minute change to the itinerary due to COVID-19 travel restrictions, and subsequently delivery of 'Ore Deposit Models and Exploration Strategies' (229 participants) and 'Exploration in Brownfield Terrains' (47 participants) being reworked for online delivery. The other offering for 2020 was 'Geodata Analytics' (40 participants) designed specifically for online delivery, with the three parts spread between October and December with breaks in between. This totally new course will be offered annually into the Master of Economic Geology program as well as being open to external participants. Master of Economic Geology students Chloe Cavill and Franco Ferreyra graduated during 2020, with Chris Booth, Carlos Diaz, Daniel Foulds, George Maroa and Marcus Staubmann all completing their degrees during the year, set to graduate in 2021.

The four UTAS-based Masters short courses held during 2020 were:

VOLCANOLOGY AND MINERALISATION IN VOLCANIC TERRAINS 7–24 MARCH 2020

This ever-popular short course was held just prior to the first COVID-19 lockdown across Australia making planned travel to the Taupo Volcanic

Zone in New Zealand impossible for the 19 participants. Instead, the trip leaders Martin Jutzeler and David Cooke revised the field program, and participants travelled to the New Volcanics (basaltic) Province of SW Victoria for the first week of the course. While in Victoria they also examined the relatively undeformed, unaltered Devonian felsic volcanic rocks exposed to the north of Melbourne and part of the Older Volcanics province exposed on the Victorian coastline. The aim of the field trip to Victoria was to introduce participants to volcanic processes, products and nomenclature at outcrops where primary features are well-preserved, before heading to Tasmania to examine their altered and deformed equivalents, where textural interpretation is much more challenging. Once back in Tasmania, participants spent a day at CODES (lectures and practicals), a day at Mineral Resources Tasmania logging drill cores from the Mount Read Volcanic Belt and, finally, took a three-day trip to Cape Grim to examine well-exposed products of Tertiary basaltic volcanism. Despite not being able to visit the Mount Read Volcanic Belt in the second week of the course because of closure of sites due to COVID-19, the course was judged to be highly successful.

ORE DEPOSIT MODELS AND EXPLORATION STRATEGIES 1–12 JUNE 2020

Held over the first two weeks of June, this course had to be run fully online due to travel restrictions brought about by COVID-19. Despite the difficulties of having to rapidly adapt the course and manage the technicalities of Zoom, the course attracted the highest ever number of participants for any CODES Masters short course offering: a total of 229 people from 20 countries, 17 universities and institutes, 23 mining and exploration companies and three geological surveys took part. The course provided an up-to-date synopsis of key ore deposit types including porphyry, skarn and epithermal, sediment-hosted U, Cu and Pb-Zn, IOCG, and orogenic and carlin-type gold deposits. Course participants were able to work with high-resolution photographs and 3D imagery of samples, rather than the actual rocks in this online environment.

Dr Michael Roach, who has been working on creating a virtual geology portal, provided a virtual tour of the geology of Bluestone Bay on the east coast of Tasmania that was used during the course; this was presented via the 3D sharing platform Sketchfab. And participants also worked with online samples and data sets from many world-class deposits and mining districts. Many compliments were received from participants after the course wrapped up.

GEODATA ANALYTICS 5 OCTOBER–18 DECEMBER 2020 (WITH BREAKS)

In 2020 CODES introduced this new short course, which is set to become a staple of the Master of Economic Geology program. This first offering of Geodata Analytics, run by Dr Matthew Cracknell as a part-time course over several weeks from October, was over-subscribed, so a re-run of the course was planned for early 2021 to take the overflow. More than 40 students took part in the 2020 course. It covered a diverse range of fundamental data analytics topics, including data wrangling, machine learning and image processing as they apply to geological problems. Again, this course was run entirely online and was divided into three sections. In the first section participants undertook a literature review that involved uploading videos to YouTube – this turned out to be one of the highlights of the course. The second section involved 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 be. In the third section course participants were split into teams and had to tackle a geodata analytics problem; the results of these sessions were shared in a series of group presentations.

EXPLORATION IN BROWNFIELD TERRAINS 19–30 OCTOBER 2020

More than 45 students participated in this course, which was redesigned as it had to be offered fully online due to COVID-19 restrictions. A record number of 33 presenters from industry and academia delivered the sessions

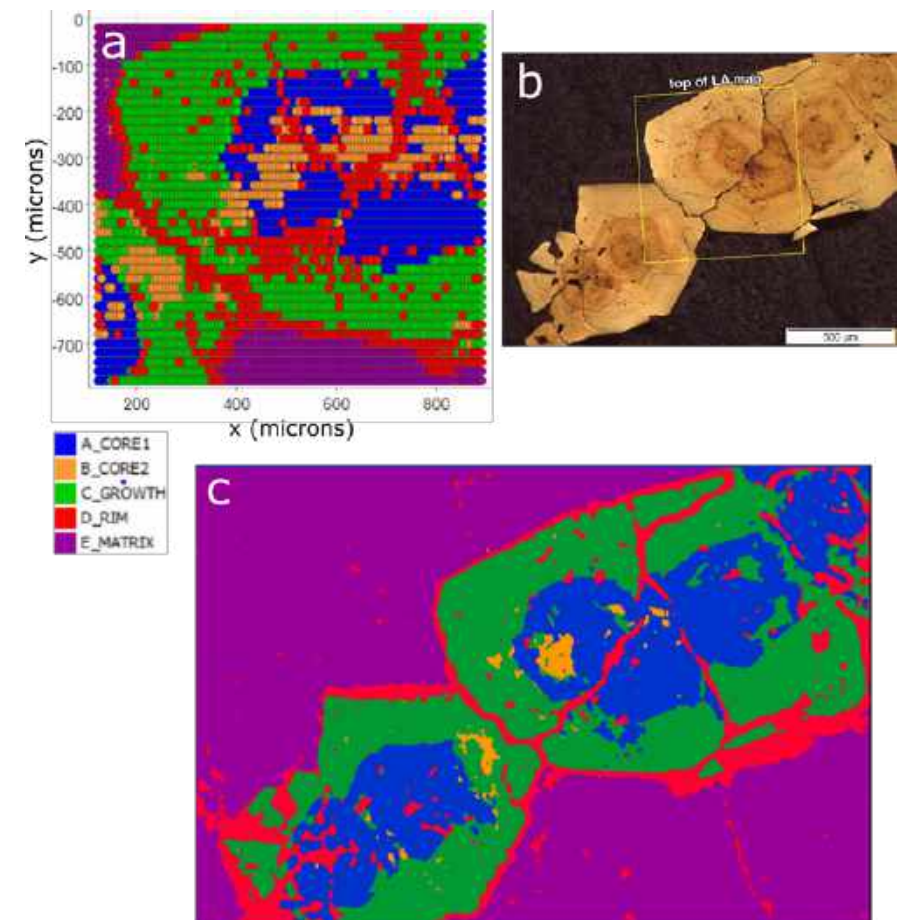


Figure 1. Fosterville pyrite: (a) clustering derived LA-ICP-MS geochemical domains; (b) optical microscopy image of NaOCl etched pyrite (yellow outline indicates LA-ICP-MS coincident region); and (c) optical microscopy image in b classified as geochemical domains.

The pyrite LA-ICP-MS map domaining assessment task for the Masters short course 'Geodata Analytics' requires students to define geochemical clusters based on mineral chemistry multielement data (a). These domains are aligned with an optical microscopy image of NaOCl etched pyrite (b). Coincident regions are used to train a classifier that predicts the spatial distribution of geochemical domains across the entire image (c).

which included two case studies: the Zn-Pb-Cu Lemarchant volcanic massive sulfide deposit in Canada in which participants learnt about 3D modelling and resource estimation and defining exploration targets. The second case study covered the Au-Ag Waihi low sulfidation epithermal deposit in New Zealand. The course also included seven panels with experts from the field.

The program for 2021:

- 7–20 February: Advanced Field Skills in Economic Geology
- Early 2021: Geodata Analytics
- 31 May–5 June AND 5–9 July 2021: Ore Deposit Geochemistry, Hydrology and Geochronology (KEA704/KEA709)
- 30 August–4 September AND 27 September–1 October: Fundamentals of Economic Geology (KEA716)
- 18–23 October AND 15–19 November: Geometallurgy
- 26 November–8 December: Ores in Magmatic Arcs

Honours Program

A total of 14 students were enrolled in the Honours Program in 2020. Of these students, three were mid-year starters from 2019, six were February starters in 2020, and five commenced mid-2020 and will complete their degrees in mid-2021 and mid-2022. The program was coordinated by Dr Angela Escolme, and the students were supervised by staff from CODES. Study areas for the Honours projects included Tasmania (7 projects), mainland Australia (4 projects) and samples from USA and Chile (2 projects). Sponsoring companies and organisations in the Honours Program included the TMVC, ARC, Mining Sector Innovation Initiative Program (MSIIP), AMIRA P1202 sponsor group, Evolution Mining, and Mineral Resources Tasmania. Mandalay Resources also provided in-kind support for one of the projects initiated in 2019. In addition, some projects were supported by internal, university-based funding from the Discipline of Earth Sciences. CODES thanks all sponsors for their valued support. These sponsorships continue to be vital to both project success and student development at a crucial phase of their studies. Potential future sponsors are encouraged to contact Honours coordinator Dr Angela Escolme for further information or to discuss their proposals.

Honours Coursework Program – VIEPS

In 2020, CODES offered only two of the usual four short courses as part of the Victorian Institute of Earth and Planetary Sciences (VIEPS) Honours coursework program due to the impact of the COVID-19 pandemic. They were:

EXPLORATION FIELD SKILLS MAPPING CAMP

Leaders: Robert Scott and Erin Lawlis

For most students, the Honours year begins with the Exploration Field Skills (EFS) Mapping Camp, which gives students the opportunity to develop or enhance skills in geological mapping, core logging and structural analysis, all within a mineral exploration context.

Sixteen students attended the camp in 2020. The eight-day camp, held in February, began with a day at the Mineral Resources Tasmania core library in Hobart, where the students logged or examined core from three diamond drill holes from the mapping area, 20 km northwest of Queenstown. The following day, the students were driven to Queenstown to begin four days of mapping in the Cambrian Mount Read Volcanics. The 4–5 km² mapping area, centred on the Hall Rivulet Canal, is located 10 km along strike to the south of the world-class Rosebery VHMS, and only ~6 km south of the Hercules deposit. The students used data collected during the mapping and core logging exercises to unravel the stratigraphy and structure of the area, and interpret the nature and likely extent of any hydrothermal alteration or mineralisation. Before returning to Hobart, each student produced their own fact and interpretation geological maps, a set of cross-sections showing the predicted subsurface extent of the prospective stratigraphy, and a report on the structure, stratigraphy and future exploration potential of the area.

ORE DEPOSIT MODELS

Course leader: Angela Escolme

Course presenters: Shaun Barker, Jonathan Cloutier, David Cooke, Angela Escolme, Robert Scott, Lejun Zhang

From 11–15 May, ten students attended the five-day Ore Deposit Models short course, which was held online for the first time! The course provides an introduction to the key features of several major classes of economically important mineral deposits. Each deposit style was discussed in terms of geological and tectonic framework, mineralisation, alteration, genetic models and exploration criteria.

The deposit types covered were:

- volcanic-hosted massive sulfide
- porphyry and epithermal
- skarn
- IOCG
- sediment-hosted copper
- Carlin-type gold
- orogenic gold

Each day of the short course involved a mixture of lectures and practical exercises. Lectures covered the general characteristics and setting of the above-mentioned deposit types, as well as the various genetic models that have been proposed to explain their formation. In the practical exercises, students examined and interpreted virtual samples or data sets from a number of mineral deposits and mineralised districts throughout the world.

Other Honours Coursework

HONOURS SKILLS WORKSHOPS

Workshops leader: Angela Escolme

Course presenters: Mike Baker, Jonathan Cloutier, Matt Cracknell, Tony Crawford, Leonid Danyushevsky, Chris Dietz, Sandrin Feig, Elena Lounejeva, Clare Miller, Paul Olin, Thomas Rodemann, Dale Sims, Lejun Zhang

From July to September, Honours and postgraduate students were invited to attend several half- to day-long skills workshops, consisting of both lectures and practical sessions. In many of the sessions students were encouraged to bring their own project data 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 2020 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 and Advanced Users** (Dale Sims, Dale Sims Consulting) 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 datasets 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 and Orange** (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.

- **Applications of Adobe Illustrator and InDesign software packages** (Jonathan Cloutier) assisted students to draw figures and collate their final thesis. Students were taught the various features of these software packages through a series of hands-on practical exercises (using their own project data) and were given a template file to use in InDesign to bring together their thesis in a more professional format.
- **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** (Angela Escolme and Elena Lounejeva) 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.
- **pXRF** (Paul Olin) introduced students to the use of portable XRF instruments for the analysis of major and trace elements in geological samples.
- **The Spectral Geologist 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** (Jonathan Cloutier) 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.
- **Introduction to Research Methods** (Sandrin Feig, Thomas Rodemann, Chris Dietz: CSL) provides students with a comprehensive overview of the facilities available at the University of Tasmania’s Central Science Laboratory including SEM, EMPA, sulfur isotopes and infrared techniques.



CODES Master of Economic Geology ‘Volcanology and Mineralisation in Volcanic Terrains’ short course participants at Aireys Inlet, southwestern Victoria, March 2020 – this was one of the few times that students and industry participants were able to get out into the field during the year.

Student programs

IN AUSTRALIA

Project locations are shown in capitals. Unless marked otherwise, student projects shown here are PhDs. Projects related to the ARC TMVC Research Hub 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. **Burns-Nichols, Justin.**
NSW (Honours)

Reconstruction of the volcanic architecture of the host rocks at E41, Lake Cowal volcanic complex, Central NSW, Australia.

4. **Cavill, Chloe.**
VIC (Masters)

Ore paragenesis and sulfur source for the Costerfield Sb-Au deposit, Central Victoria.

5. **Chapman, Nathan.**
SA

Pb-isotopic insights into the crustal evolution and metallogensis of the Gawler Craton.

6. **Dale, Rosanna.**
WA (Masters)

Au-Ag deportment variability and the effect on its flotation and recovery at the Monty VMS Cu-Au deposit, Western Australia.

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

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

8. **Dick, Lachlan.**
TAS (Honours)*

Geology and genesis of the Anchor Sn mine, NE Tasmania .

9. **Doutch, David.**
WA

The geology and geological controls on gold mineralisation at the Invincible deposit, St Ives Gold Mine, Kambalda, WA.

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

Alteration sequence of Eastern Creek Volcanics of Mount Isa.

11. **Ferguson, Matt.**
SA

Late stage magmatic-hydrothermal evolution of A-type Hiltaba event rocks in the Gawler Craton.

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

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

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

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

14. **Habib, Umer.**
VIC, NSW

Paleomagnetism and geochronology of Paleozoic rocks of Lachlan orogen in Victoria and New South Wales.

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

Ore mineral textures and their implication for gold genesis and deportment at the Tropicana Gold Mine, Western Australia.

16. **Heng, Wei Xuen.**
TAS (Honours) *

Geophysical investigation of the legacy Endurance mine site, Northeast Tasmania.

17. **Hohl, Max.**
QLD

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

18. **Ila’ava, Malai.**
NSW

The volcanic architecture of Cowal mine, Lachlan Orogen, NSW.

19. **Jackson, Laura.**
NSW*

Mineralogical domaining of low grade and no grade zones using automated drill core logging.

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

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

21. **Jenkins, Claudia.**
NSW (Honours)

Volcanic architecture of GRE46, Cowal, New South Wales.

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

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

23. **Jones, Colin.**
TAS*

Petrogenesis of northeast Tasmanian granites.

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

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

25. **Jones, Rhiannon.**
NSW*

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

26. **Kameniar-Sandery, Verity.**
VIC (Honours)

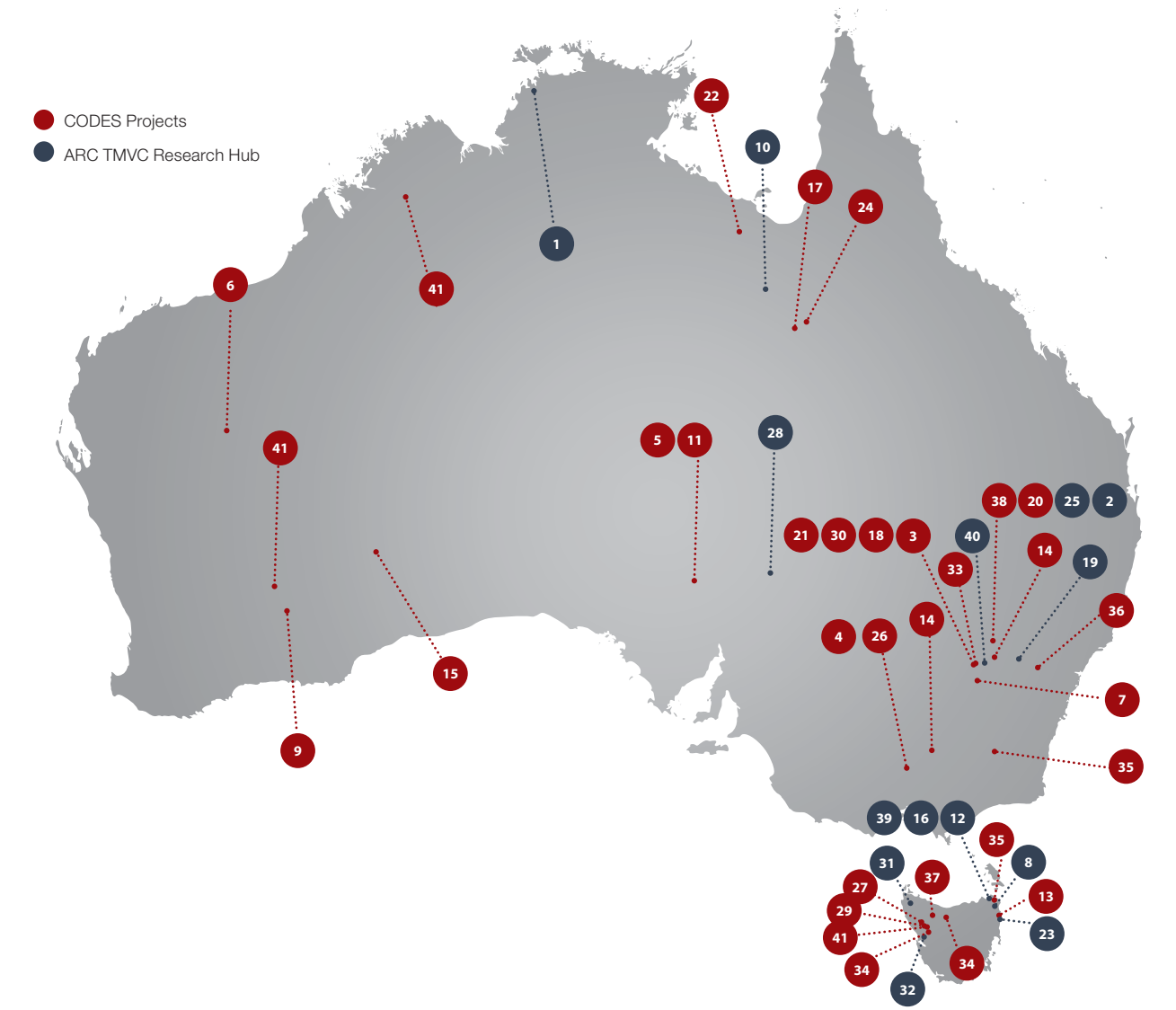
Investigation into superheavy $\delta^{34}\text{S}$ in diagnostic pyrite (Costerfield, Victoria).

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

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

28. **Lane, Greer.**
SA (Masters)*

Genesis of the Four Mile Diamictite and implications for Uranium mineralisation, South Australia.



29. **Le’Gallais, Bridie.**
TAS

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

30. **Leslie, Christopher.**
NSW

Porphyry and epithermal deposits of Cowal District, New South Wales.

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

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

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

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

33. **Ngoran, Gilles.**
NSW

Exploration targeting from next-generation volcanic facies reconstruction, Cowal District.

34. **Ostersen, Thomas.**
TAS

Geoelectric structure of the Tasmanian lithosphere.

35. **Schaap, Thomas.**
TAS, NSW/VIC

Tectonic evolution of the Palaeozoic Lachlan Orogen.

36. **Sritangsirikul, Peerapong.**
NSW (Masters)

Tectonic environment and mineral prospectivity of Rockley-Gulgong Volcanic Belt, Oberon region, New South Wales, Australia.

37. **Wang, Chuang.**
TAS

Application of seismic techniques to reconstruct volcanic architecture.

38. **Wells, Tristan.**
NSW

Magmatic fertility in the Macquarie Arc.

39. **Wilson, Olivia.**
TAS (Honours)*

Hydrogeological studies of acid mine drainage at the legacy Endurance mine site, northeast Tasmania.

40. **Winter, Riley.**
NSW (Honours)*

Geology, geochemistry and genesis of advanced argillic alteration at Currowong Hills, Wirrinnya District, NSW, Australia.

41. **Zivkovic, Zebedee.**
TAS, WA

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

Student programs

OUTSIDE AUSTRALIA

Project locations are shown in capitals. Unless marked otherwise, student projects shown here are PhDs. Projects related to the ARC TMVC Research Hub are marked with an asterisk.

1.

Abersteiner, Adam.
CANADA, FINLAND,
RUSSIA, SOUTH AFRICA

Kimberlites: Understanding their petrogenesis and uncovering the identity of their source composition.
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

Crustal architecture and geodynamic controls on the formation of giant porphyry copper deposits in the Central Andes.
7.

Firmansyah, Arga.
INDONESIA (Masters)

Geology and mineralisation of the Trenggalek district, East Java, Indonesia.
8.

Garay, Amos.
PERU*

Las Bambas Cu-skarn, Peru: Implications of whole rock, mineral, and isotope geochemistry for ore genesis and exploration.
9.

Guerrero Ramirez, Nathaly.
COLOMBIA (Masters)

Geometallurgical controls on grade by size at Gramalote Au deposit, Colombia.

10.

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.
11.

Ikegami, Fumihiko.
NEW ZEALAND

2012 submarine silicic eruption of Havre volcano and implications for ancient submarine successions in Australia.
12.

Job, Ashleigh.
CHILE (Masters)

Geology, structural control and exploration implications of Au mineralized Fenix gold project, Maricunga Belt, Chile.
13.

Knight, Joseph.
MYANMAR

The geodynamic and metallogenic setting of base- and precious-metal mineralisation in Myanmar: Implications for Cu and Au exploration.
14.

Lawlis, Erin.
PNG

Geology of the Kapit NE and coastal ore zones, Lihir gold deposit, Papua New Guinea.

15.

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.
16.

Merrill, Javier.
CHILE*

Evaluating applications of hyperspectral data for predicting mineral processing attributes and waste characteristics of slurries.
17.

Moore, Hannah.
NEW ZEALAND

Investigation of the shallow conduit processes involved in the 1886 basaltic Plinian eruption at Tarawera Volcano, New Zealand.
18.

Osorio, Jaime.
ARGENTINA, CHILE*

Anatomy of a phyllic overprint and structural evolution of Rincones de Araya porphyry deposit, San Juan, Argentina.

19.

Seow, Xin Ni.
SOUTH KOREA, USA*

Geochemistry, mechanism of formation and exploration implications of alunite supergroup minerals.
20.

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.
21.

Speakman, Ben.
USA (Honours)*

The fertility indicator potential of titanite and apatite from the Yerington district, Nevada.
22.

Sritangsirikul, Peerapong.
MAINLAND SE ASIA

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

23.

Staal, Tobias.
ANTARCTICA

The Antarctic lithosphere revealed by multivariate analysis.
24.

Sun, Yi.
PHILIPPINES*

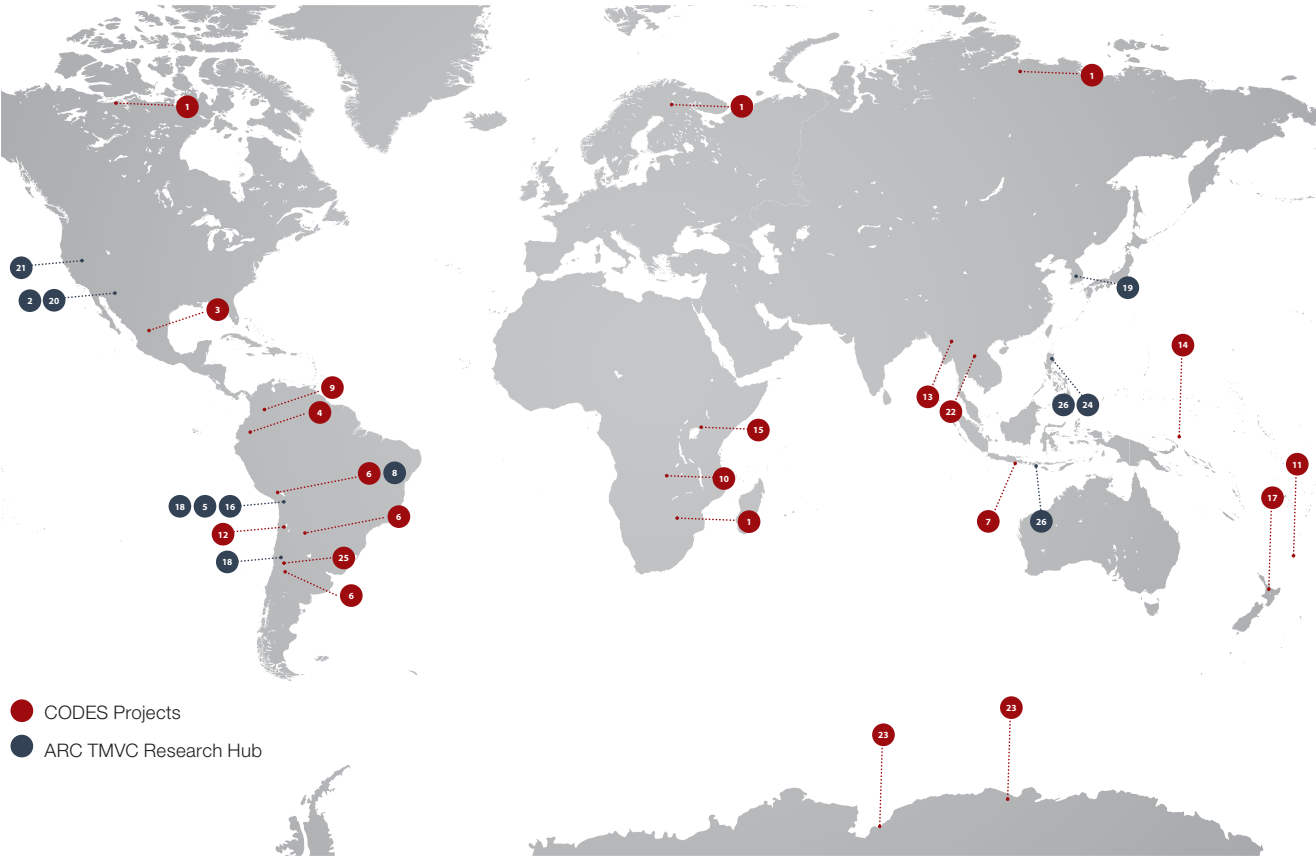
Mineralogical, textural, geochemical characterisation and geometallurgical models of Lepanto Quartz – Pyrite – Gold vein and breccia system, Philippines.
25.

Testa, Francisco.
ARGENTINA, CHILE

Tourmaline breccia pipes: San Francisco de los Andes, Argentina and Rio Blanco-Los Bronces, Chile.
26.

Thompson, Jennifer.
INDONESIA, PHILIPPINES*

Carbonate mineral chemistry in epithermal and porphyry hydrothermal systems.



Lab-based projects

- Berger, Peter.**

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

Integrating passive and active methods of seismic imaging for structural stability of tailings dams.
- 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.***

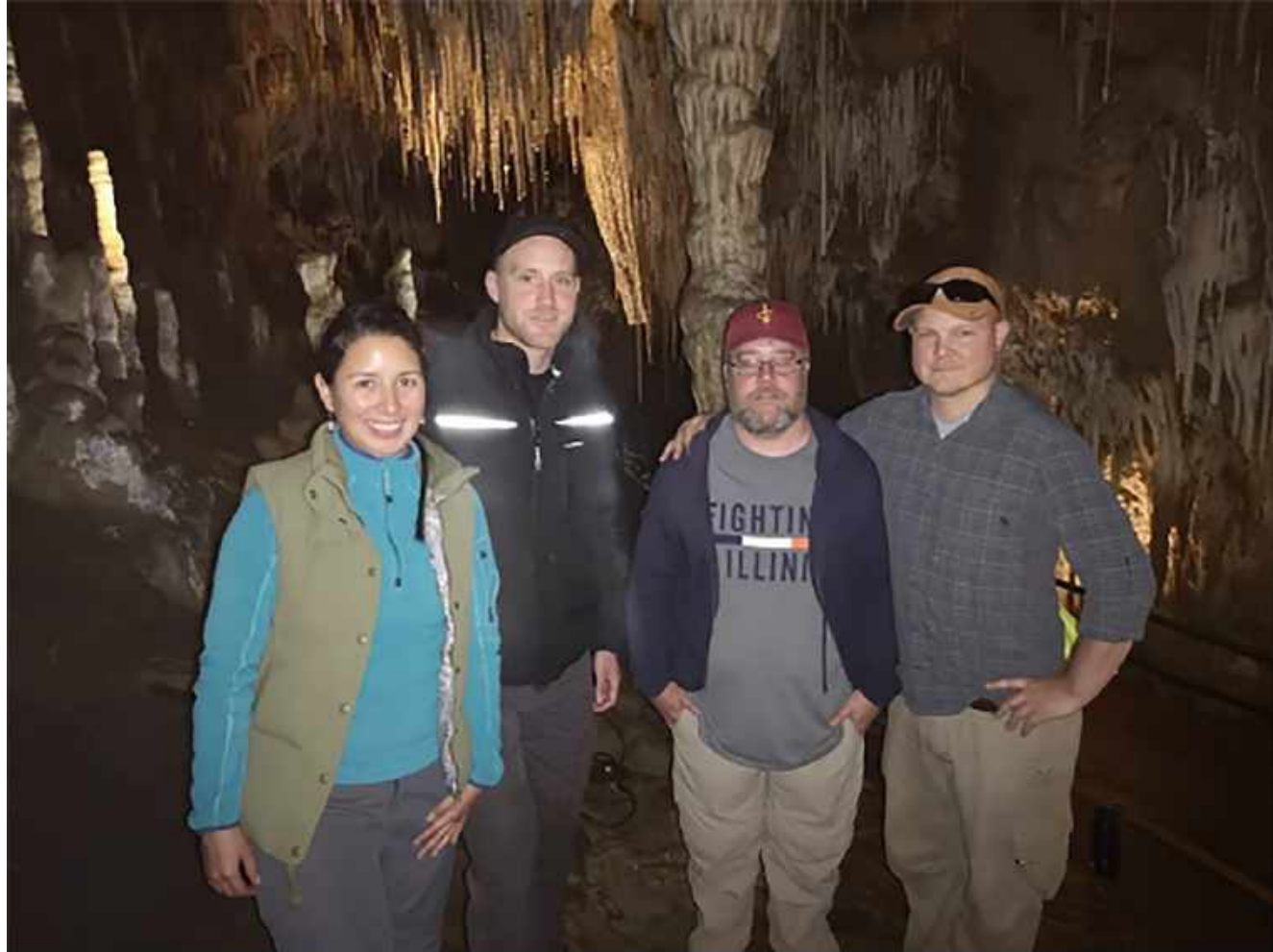
Controlling acid and metalliferous drainage at legacy sites in Tasmania using industrial wastes.
- Mrabawani, Nanda Yusentri.***

Method development for laser-ablation ICP-MS applied to complex matrices.

- 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.



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. We pride ourselves on making significant contributions to the social and professional lives of students from a diverse range of backgrounds and cultures.

Towards the end of 2020 there were changes to the executive committee for 2021 due to members of the 2020 executive committee ending their candidatures at CODES. The current committee members are: Alex Farrar (President), Karla Morales (Vice-President), Rhiannon Jones (Secretary), Hannah Moore (Treasurer) and Max Hohl (Other Executive Member). The new committee will meet regularly and, now that COVID-19 restrictions have eased slightly, will focus on fundraising

activities and planning seminars with industry professionals during 2021.

The CODES SEG Student Chapter had a lower number of students in 2020, with fewer outreach activities and field trips, as a result of the COVID-19 pandemic.

In early March 2020, prior to the COVID-19 lockdown in Tasmania, there was a one-day SEG Student Chapter field trip to the Lune River fossicking area and Hastings Caves in southwest Tasmania. Ten members went on the trip and were able to see some great geology including Jurassic-age petrified wood and agates, which were accessed with shallow digging. The trip introduced new postgraduate students to the Tasmanian geology and the process of fossicking.

From March–August 2020 access to the university was closed due to the COVID-19 pandemic, therefore SEG events were relatively limited during this time. New students arriving in Tasmania were involved in SEG drinks over Zoom to discuss what the SEG is about and what kind of activities could take place when the lockdown was lifted.

Social events

A number of social events were held after the university reopened in August with a Halloween-themed drinks event held on campus in late October. This was an opportunity to fundraise, network and advertise the SEG to new students of the university.

Lectures and meetings

In April the CODES SEG and AusIMM student chapters teamed up to facilitate a series of short talks via Zoom on industry and academic career paths, aimed at undergraduate geology students. The first talk was given by PhD student Kyle Eastman and was titled ‘Mining America’s largest superfund site: geoenvironmental and geometallurgical challenges at Butte, Montana’.

In May CODES/TMVC PhD candidates Zebedee Zivkovic and Emily Smyk presented online talks about their research and their geological backgrounds as part of this Online Technical Talk Series. Zebedee’s talk was called ‘The (varied) life of a geologist – A guide for industry geologists’ and Emily spoke about the benefits of joining the SEG Student Chapter.

Annual field trip

The proposed field trip to Arizona in 2020 was cancelled as a result of travel restrictions brought about by COVID-19. However, the SEG Student Chapter plans to run a trip to King Island, Tasmania, in 2021.

Finances and fundraising

The SEG Student Chapter received \$2,165 of Stewart R. Wallace Funding from the Society of Economic Geologists in 2017. This money has not been spent and has been rolled over for use towards a field trip in 2021. The Treasurer, Hannah Moore, keeps our geological equipment store up to date; available items include mineral ID kits, hammers, hand lenses (with LEDs!), notebooks and more. Pricing is designed so that fieldwork necessities are provided nearly at cost; this service keeps students in possession of key equipment and introduces undergraduates to the SEG Student Chapter. Sales to first-year Earth Sciences students raise considerable funds for the Student Chapter.

The next proposed field trip to King Island will be funded in part by the Geological Society of Australia (\$200 per GSA member), and the SEG Student Chapter will also be hosting drinks for a GSA meeting to raise funds for the field trip.

RIGHT: In October 2020 the CODES SEG Student Chapter ran a Halloween-themed fundraiser in the CODES Rock Garden. Here CODES students and staff enjoy the Halloween-themed food and drink. OPPOSITE PAGE: CODES SEG Student Chapter members (L–R): Master of Science student Karla Morales, and CODES PhD students Max Hohl, Peter Berger and Zebedee Zivkovic pictured inside Hastings Caves during a fossicking trip to the area before the COVID-19 lockdown took place.

Looking forward

Our HDR program is looking healthy and stable in 2021. Intake of new PhD and Masters students in 2021 will be impacted by COVID-19 travel restrictions and we will monitor the situation carefully so that an international student cohort who traditionally make up a high percentage of our HDR program can join us in 2021.

An important milestone will be reached in 2021 with the running of the inaugural ‘Advanced Field Skills in Economic Geology’ Masters short course, which is planned for February. This course will provide instruction and training in a variety of fundamental and advanced mapping and field skills suitable for use in the minerals industry. The first week of the course will be run in conjunction with the long running Exploration Field Skills Mapping Camp for fourth-year students on Tasmania’s west coast and will then move to northeast Tasmania for several more days of instruction. Techniques covered will include graphic and structural core logging volcanic facies mapping and interpretations, and structural mapping and analysis of simply deformed regions.

‘Fundamentals of Economic Geology’ will also be making its debut in 2021 aiming to give participants the fundamental skills needed by all economic geologists. This short course is suitable

for geoscientists keen to gain a stronger understanding of ore deposits. And this short course will also form the core unit for our new Graduate Certificate in Economic Geology, whereby students complete two of our Masters short course offerings within a one-year period. This qualification can be counted as credit towards our Master of Economic Geology degree should participants wish to continue with further study.

With the influx of new students into the Master of Economic Geology program in 2020 and the increasing interest from participants who are based outside Australia but can benefit from online delivery of these courses, we expect enrolments to continue to increase in 2021. Conversely, Honours enrolments are likely to decline for the next few years, following a decrease in undergraduate student numbers due to the ongoing mining boom. However, undergraduate student numbers should improve in future years if career opportunities in the minerals industry continue to improve as they have over recent years. We will continue to run the series of Honours workshops introduced in 2016, as well as the successful courses run in conjunction with the Victorian Institute of Earth and Planetary Sciences (VIEPS) – COVID-19 restrictions permitting.



Outreach and media

As we are all painfully aware, 2020 was a year like no other, and the restrictions brought about by the COVID-19 pandemic wrought havoc with all physical gatherings. So, face-to-face outreach opportunities were few and far between for CODES and Earth Sciences during the year. But a few events were possible after the Tasmanian COVID-19 lockdown while adhering to social distancing guidelines. And one or two took place prior to the restrictions coming into place. Media interviews and appearances were able to go ahead in the main.

Virtual Open Day

As with many events in 2020, the UTAS Open Days were held online. On 28–30 August prospective students and interested members of the public had a chance to find out what's on offer at UTAS. Described as 'an immersive and interactive online experience' the 2020 Open Days allowed people to enter a virtual world and discover everything they needed to know about Earth Sciences courses, life at UTAS and the island of Tasmania.

The Rock Library

In 2020 Izzy von Lichtan, the CODES Rock Library Curator, was asked to make a cast of the fossil *Banksiops townrowi*, a type fossil found by Max Banks (a founding professor in the geology department at UTAS). The fossil has recently been renamed after Max, and his family requested that the cast be made.

Banksiops townrowi, is a small, near complete, Triassic (around 240 million years old) amphibian skull found at Old Beach by Max Banks and was described by Cosgrif in 1974 as *Blinasaurus townrowi*. This has been more recently been renamed to *Banksiops townrowi* in honour of Max's contribution to the field of palaeontology, especially Tasmanian palaeontology.

Izzy said: "The Banks family requested copies of any information that we had on the fossil, including photographs of the painted reconstruction that Max assisted with in the 1970s. As part of this, I made a cast of *Banksiops townrowi* from a mould that I had already made previously for teaching

purposes, and painted it to look like the fossil to pass to the family. The photographs (opposite below) are of the finished fossil cast."

School visits and trips

There were far fewer opportunities for outreach visits to schools and colleges in 2020. However, some staff did manage to get out and about after the main COVID-19 lockdown was lifted in Tasmania.

- In October Associate Professor Rebecca Carey visited Rosny College to talk to Year 11 and 12 students about the exciting world of volcanology research.
- In late October Rebecca visited Peregrine School near Cygnet to talk about volcanoes and her research into volcanology (see the drawing done by one seven-year-old student from that visit).
- And on 1 December, Rebecca visited Lenah Valley Primary School to again talk about the wondrous world of volcanoes and how young people might be involved in research into this area when they grow up.

LEFT: Associate Professor Rebecca Carey (centre) pictured in October 2020 with students from Rosny College conducting experiments to illustrate the workings of a volcano. OPPOSITE PAGE (TOP): Dr Karin Orth pictured in a promotional shot for an ABC Radio Hobart talk she did in February 2020; she discussed the remnant volcano near Long Beach in Sandy Bay, Tasmania. BOTTOM (LEFT): The top of the cast of the fossil *Banksiops townrowi*, a type fossil found by Max Banks (a founding professor in the geology department at UTAS), made by CODES Rock Library Curator Izzy von Lichtan at the request of the Banks family. The cast is of the creature's head, and eye sockets and nostrils can clearly be seen. BOTTOM (RIGHT): The underside of the fossil cast shows (at bottom left) a tooth.



Guest lectures

- On 16 March Dr Martin Jutzeler gave an online guest lecture titled 'Recent advances and hazard mitigation for submarine volcanism' to around 40 students at the Bandung Institute of Technology (ITB), Indonesia. This talk has since had many more views on YouTube. This lecture is associated with a UTAS-ITB Memorandum of Agreement and collaboration with Indonesian colleagues.
- Dr Peter McGoldrick gave a face-to-face talk in Hobart to the Tasmania branch of the GSA on 6 August in which he gave an overview of the concepts and timing of the origins of complex life forms.
- Dr Indrani Mukherjee gave a Zoom webinar talk for the Royal Society of Tasmania on 4 October entitled 'An account of Earth's Middle Ages – life and resources'. Around 45 people logged on to hear this talk. Her presentation expanded on her PhD research which advanced knowledge of Precambrian atmosphere-ocean dynamics in shaping the course of early evolution. This talk was given in relation to Indrani's Royal Society of Tasmania Annual Doctoral Award.
- Dr Clare Miller did a talk for the GSA at Hadley's Hotel in Hobart on 15 October. The title of her talk was 'Impact of climate warming on the speciation and long-term stability of arsenic in sub-Arctic lakes: Implications for environmental monitoring of mining impacted sites'.

Media

- Dr Indrani Mukherjee did an interview in January 2020 with Rick Goddard of ABC Radio Hobart for the *Breakfast* program regarding her Royal Society of Tasmania Annual Doctoral Award, which was presented in 2019. This is usually awarded to two people each year for significant contribution to their research field during the course of their PhD. As part of her award, Indrani gave an address to the Royal Society during 2020 (see Guest lectures).
- In February Dr Karin Orth did an ABC Radio interview for the *Drive* program with Lucy Breden in which she talked about the remains of a volcano dating back 26 million years situated just a short walk from Long Beach in Sandy Bay. See: <https://www.abc.net.au/radio/hobart/programs/drive/sandy-bay-volcano/12010168> The details about this talk were sent out to GSA members across Australia via Karin's links with the GSA.
- On 31 May Dr Martin Jutzeler's research was featured in an article by Sally Glaetzer in the *Sunday Tasmanian* newspaper. It was entitled 'Mission to uncover sea volcano dangers' and discussed an upcoming sea voyage to the Kermadec Arc to investigate giant submarine volcanoes.





LEFT: A drawing of a volcano done by a seven-year-old student from Peregrine School when Rebecca Carey visited the school in October 2020. RIGHT: Dr Martin Jutzeler's research into underwater volcanoes featured in the Sunday Tasmanian during May 2020 (image courtesy of The Mercury). The proposed sea voyage to the Kermadec Arc in October 2020 was postponed due to COVID-19.

- Dr Indrani Mukherjee was interviewed by Michael Marshall for the *New Scientist* online magazine (published in June 2020) about her research with Professor Ross Large into the evolution of complex cells.
- On 12 June Dr Martin Jutzeler gave a talk on ABC Radio Northern Tasmania on the topic of 'Pumice rafts and maritime hazards'.
- Dr Karin Orth did a radio interview on 24 August with Paul MacIntyre from ABC Radio Hobart about Pompeii and the date of the eruption.
- An online article by researcher and past PhD student Dr Josh Phillips on Green Rock Minerals was published in August 2020: See: <https://www.linkedin.com/pulse/green-rock-mineral-chemistry-targeting-porphry-systems-josh-phillips/>
- Associate Professor Rebecca Carey appeared on the ABC TV's 'Faces of Tassie' on Saturday 10 October talking about her career as a researcher into volcanology: See: Volcanoes are 'the most spectacular landscapes on Earth' | Faces of Tasmania | ABC Australia

UTAS media

CODES-TMVC and Earth Sciences researchers, students and staff were showcased in a number of UTAS

intranet articles during 2020, with the trend set to continue into 2021.

Examples from 2020 were:

- 'Pumice, a powerful force on the ocean', which looked at Dr Martin Jutzeler's research into pumice rafts, and was featured in the online UTAS *Research to Reality* publication (April 2020). <https://takeflight-app1.its.utas.edu.au/news/2020/4/30/997-pumice-a-powerful-force-on-the-ocean/>
- 'Online short course draws global audience', an account of the online Masters course titled 'Ore Deposit Models and Exploration Strategies', which attracted more than 200 participants (July 2020).

- 'Blue lakes draw student researchers post lockdown', which looked at three TMVC Honours students' projects that are investigating the remediation of a mine site in northeast Tasmania (July 2020).
- 'Defunct mine a site for environmental discovery' published in the online UTAS *Research to Reality* publication; it covered the research of TMVC Honours student Olivia Wilson in detail (November 2020). <https://www.utas.edu.au/news/2020/11/12/1083-defunct-mine-a-site-for-environmental-discovery/>

Social Media at CODES

CODES/Earth Sciences has an active presence on social media:

-  CODES Facebook page: <https://www.facebook.com/CODES.UTAS/>
-  Earth Sciences Facebook page: <https://www.facebook.com/EarthSciUTAS/>
-  TMVC Facebook page: <https://www.facebook.com/tmvc.utas>
-  CODES LinkedIn: [linkedin.com/company/codes-utas](https://www.linkedin.com/company/codes-utas)



Contact metamorphic ovoids within the Mesoproterozoic Surprise Bay Formation adjacent to the Neoproterozoic Cape Wickham Granite, King Island (photo by Rob Scott).

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 2020, the group of CODES' Industry Partners comprised of ten Australian and international mining companies: Anglo American, AngloGold Ashanti, Barrick, CMOC-Northparkes, Evolution, First Quantum Minerals, Mount Isa Mines (Glencore), Newcrest Mining, Rio Tinto and Teck.

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. 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 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>



A screenshot provided by Dr Mike Baker of one of the 2020 Amira P1202 meetings held online – there was huge interest and uptake of online participation in Amira meetings during the COVID-19 lockdown in 2020.



Workforce: (L–R): Dr Clare Miller, Associate Professor Sebastien Meffre and Professor David Cooke at Savage River Mine, an open-cut iron ore mine in northwest Tasmania operated by Grange Resources, on a trip to discuss research proposals with industry in late 2020.

Role of Amira Global

Amira 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 2020 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 sit within the ARC TMVC Research Hub.

Research collaborations

In 2020, 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 117 international and 22 national organisations. Many research meetings, including those with Amira, took place online during 2020, which enabled many collaborators in remote locations to take part.

CODES Industry Partners 2020

PLATINUM



GOLD



SILVER



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 2020, 188 research reports were presented to industry clients. Meetings (mainly online) were also held to present and discuss progress and adoption of research results.

Publications targeted at end-users

CODES also delivers knowledge and applications to end-users and the wider scientific community through a selection of special publications that represent the culmination of major research efforts by the Centre's staff. The following publications were sold during 2020.

- *Altered volcanic rocks: A guide to description and interpretation* (2005). Authors: C. Gifkins, W. Herrmann and R. Large (22 copies).
- *Basins, fluids and Zn-Pb ores. CODES Special Publication 2* (1999). Editors: O. Holm, J. Pongratz and P. McGoldrick (1 copy).
- *Geophysical signatures of copper-gold porphyry and epithermal gold deposits, and implications for exploration* (2011). Author: T. Hoschke (14 copies).
- *Giant ore deposits: Characteristics, genesis and exploration. CODES Special Publication 4* (2002). Editors: D. Cooke and J. Pongratz (3 copies).
- *Earth, Universe, Cosmos* (1996). Author: S. Warren Carey (2 copies)
- *The expanding Earth: A symposium* (1981). Editor: S Warren Carey (6 copies).
- *The geology and origin of Australia's mineral deposits* (2000). Authors: M. Solomon and D.I. Groves (1 copy).

- *Volcanic environments and massive sulfide deposits* (2000). Editors: J.B. Gemmell and J. Pongratz (3 copies).
- *Volcanic textures: A guide to the interpretation of textures in volcanic rocks* (1993). Authors: J. McPhie, M. Doyle and R. Allen (26 copies).
- *24ct Au workshop. CODES Special Publication 5* (2004). Editors: D. Cooke, C. Deyell and J. Pongratz (2 copies).

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. 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 more than 1,000, with 31 different presenters from CODES involved in delivering the courses or leading the conferences or field trips. 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.



2020 SHORT COURSES, WORKSHOPS, CONFERENCES AND FIELD TRIPS LED BY CODES

TITLE	PRESENTERS	NO.	LOCATION	DATE
Field Geology in the 21st Century: Australasian Universities Geoscience Educators Network (AUGEN) Field Meeting	Michael Roach, Sebastien Meffre, Karin Orth	26	Northeast Tasmania	29–31 January
Exploration Field Skills Mapping Camp (VIEPS)	Robert Scott, Erin Lawlis	16	Hobart/western Tasmania	16–23 February
Volcanology and Mineralisation in Volcanic Terrains (MEconGeol short course)	David Cooke, Martin Jutzeler, Andrew McNeill, Robert Scott	19	Victoria/Hobart, northwest Tasmania	7–24 March
AMIRA P1202 Sponsors' Review Meeting 4	Mike Baker, Shaun Barker, David Cooke, Matthew Cracknell, Angela Escolme , Scott Halley, Javier Merrill , Angela Rodrigues, Emily Smyk, Lejun Zhang	60	CODES, Hobart (online)	6–7 May
Ore Deposit Models (VIEPS)	Angela Escolme, Jonathan Cloutier, David Cooke, Robert Scott, Lejun Zhang	6	CODES,Hobart (Online)	11–15 May
Ore Deposit Models and Exploration Strategies (MEconGeol short course)	David Cooke , Tim Baker, Shaun Barker, Jonathan Cloutier, Angela Escolme, Bruce Gemmell , Steve Garwin, Scott Halley, Margy Hawke , Ned Howard, Tim Ireland, David Wood, Cam McCuaig, Andrew McNeill, Nick Oliver, Evan Orovan, Robert Scott, David Selley , Rick Valenta, Noel White , Andrew Wurst, Lejun Zhang	229	CODES, Hobart (online)	1–12 June
AMIRA P1202 Module 2 Workshop	Patrick Hamilton, Xin Ni Seow, Yi Sun, Noel White, Lejun Zhang	102	CODES, Hobart (online)	24 July
AMIRA P1202 Module 3 Workshop	Mike Baker, Leonid Danyushevsky , Peter Hollings	80+	CODES, Hobart (online)	29 July
GSA Tasmania branch: Tasmania's oldest fossil Horodyskia williamsi: animal, mineral or vegetable?	Peter McGoldrick	30	Hadleys Hotel, Hobart	6 August
AMIRA P1202 Module 1 Workshop	Mike Baker, Shaun Barker, Matthew Cracknell , Andrew Jedemann, Mitch Marcelissen, Emily Smyk	90+	CODES, Hobart (online)	7 August
AMIRA P1202 Geochemical Data Mining and Machine Learning Workshop	Matthew Cracknell	50+	CODES, Hobart (online)	19 August
AMIRA P1202 Sweep-by-Sweep Workshop	Shaun Barker, Matthew Cracknell	60+	CODES, Hobart (online)	25 August
AMIRA P1202 Module 1 Workshop - repeat	Mike Baker	15	CODES, Hobart (online)	25 September
Geology for Gold Metallurgists	Angela Escolme, Julie Hunt , Teresa McGrath	50	CODES, Hobart (online)	1, 8 and 15 October
Geodata Analytics (MEconGeol short course)	Matthew Cracknell , Rocky Barker, Shaun Barker , Natalie Caciagli Warman, Michael Gazley, June Hill, Shawn Hood, Kyen Knight, Javier Merrill , Angela Rodrigues	53	CODES, Hobart (online)	5 October–18 December (with breaks)
AMIRA P1202 Module 2 Workshop - repeat	Patrick Hamilton, Xin Ni Seow, Yi Sun, Noel White, Lejun Zhang	~50	CODES, Hobart (online)	7 October
Geological Society of Australia Earth Sciences Student Symposium (GESSS-TAS session)	Carlos Diaz, Acacia Clark, Umer Habib, Wei Xuen Heng, Max Hohl, Rhiannon Jones, Peter McGoldrick, Sebastien Meffre, Hannah Moore, Tom Schaap, Olivia Wilson	60	CODES, Hobart (online)	12–17 October
GSA Tasmania branch: Impact of climate warming on the speciation and long-term stability of arsenic in sub-Arctic lakes: Implications for environmental monitoring of mining impacted sites	Clare Miller	~12	Hadleys Hotel, Hobart	15 October
Exploration in Brownfield Terrains (MEconGeol short course)	Jonathan Cloutier , John Ashton, Shaun Barker , Nick Cook, Kevin Creel, Kim Denwer, Bruce Gemmell , Scott Hall, Scott Halley, Jeff Hedenquist, Kate Hine, Terry Hoschke, Ned Howard, David Isles, David Kelley, Ross Large , Andrew McNeill, Gustav Nortje, Michael Roach , Dave Rhys, Shaun Schneider, Robert Scott , Ian Scrimageour, David Selley, Michael Vande Guchte, Tony Webster, Andy Wurst, Lesley Wyborn	47	CODES, Hobart (online)	19–30 October
AMIRA P1202 Sponsors' Review Meeting 5	Mike Baker, Jonathan Cloutier, Takeshy Coaquira, David Cooke, Angela Escolme , Scott Halley, Christian Ihlenfeld, Rhiannon Jones , Martin Kock, Javier Merrill, Jaime Osorio, Xin Ni Seow, Lejun Zhang	73	CODES, Hobart (online)	25–26 November



LEFT: A total of 229 participants (red) logged in from across the globe to take part in the two-week intensive 'Ore Deposit Models and Exploration Strategies' Masters online short course held in June 2020. Many were based in the same centres. Several participants from Barrick (blue) logged in from locations in the USA and several from Rio Tinto (black) logged in from locations in Australia. OPPOSITE PAGE: Participants of the Australasian Universities Geoscience Educators Network (AUGEN) NE Tasmania Field Meeting, entitled 'Field Geology in the 21st Century', 29–31 January 2020. This three-day field trip was organised and run by Dr Michael Roach, and saw 26 educators from Australia and New Zealand universities come together to discuss new technologies for use in the teaching of geosciences.

Performance indicators

PERFORMANCE MEASURES

	TARGET	2020
Research Findings (CODES and Earth Sciences)		
Publications in international journals	50pa	92
Percentage of publications in high-quality international journals	70%	77%
Reports to industry collaborators	80pa	188
Special issues and/or research monographs	1 per 2 years	3
Invitations to give keynote conference presentations	10pa	1
Papers at national/international meetings	70pa	32
Research Training and Professional Education		
Percentage of HDR students attracted from interstate	25%	16%
Percentage of HDR students attracted from overseas	65%	51%
Number of Honours students in CODES' programs	15	14
Number of HDR students in CODES' programs	50	48
Percentage of students in projects linking with industry	80%	71%
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	1,000+
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 dramatically reduced the number of conferences that CODES researchers and HDR students were able to attend in 2020. Similarly, international HDR student commencements were impacted due to Australian border restrictions. Meetings with industry representatives were online via Zoom for the most part.

The Twelve Apostles on the Great Ocean Road, Victoria, which participants of the 2020 'Volcanology and Mineralisation in Volcanic Terrains' Master of Economic Geology short course stopped to admire (photo by Clare Miller).



Finances

2020 income

Total CODES income was \$7.2 million (see Table 1). This was derived principally from UTAS (27%) and the combined income sources of the ARC TMVC Research Hub (23%). Significant income was also generated via Industry and Contracts/consultancies/revenue raising (19% each) (see Figure 1). The main income streams over time are compared in Figure 2, showing an increase in overall income to CODES in 2020 when compared to 2019. This increase occurred in most categories, in part due to sustained use of the CODES Analytical Laboratories which were able to remain operational during the COVID-19 lockdown. Additional industry Partner Organisation funding was also received to the ARC TMVC Research Hub over and above that committed in the original agreement.

Summary of the main income streams to CODES in 2020:

- **Host institution support:** Funding from UTAS in 2020 was \$1.9 million, comparable to the figure for 2019, 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.
- **ARC TMVC Research Hub:** The combined income sources for the TMVC amounted to \$1.7 million in 2020, comprising of funding from industry Partner Organisations (\$1.5 million), and other sources including Additional Funder Projects (\$158k).

- **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 above).

- **Contracts/consultancies/revenue raising:** Combined funding of \$1.3 million comprises funding related to Short Courses (\$163k), Analytical Services (\$1.2 million) and Book Sales (\$10k).

2021 income estimates

There is expected to be a decrease in external research funding to CODES in 2021 when compared to 2020, due to several larger research projects coming to an end during the year. UTAS and Other funding to CODES is expected to remain steady into 2021.



A view of the contact between the Yarra Creek Shale and the City of Melbourne Volcanics at City of Melbourne Bay, King Island (photo by Rob Scott).

TABLE 1: CASH INCOME FINANCIAL STATEMENT 2020

ARC Transforming the Mining Value Chain Research Hub

ARC Industrial Transformation Research Project	0
Partner Organisations	1,502,713
- AMIRA Global	1,280,098
- BHP Billiton Olympic Dam	222,615
- Newcrest Mining	0
Host Institution	0
Additional Funder Projects	144,611
Miscellaneous	13,429
	1,660,753

ARC Grants

Discovery Grants	19,895
Linkage Grants	258,493
	278,388

Other Commonwealth Government

Specific Projects	599,016
	599,016

State Government

Specific Projects	6,000
	6,000

Industry/private

CODES Industry Partners	365,000
Cooperative Research Centre Projects	338,024
Directly Funded Research Projects	512,846
Directly Funded Student Projects	157,415
Miscellaneous	23,025
	1,396,309

Contracts/consultancies/revenue raising

Short Courses	162,809
Book Sales	10,334
Miscellaneous (incl. Analytical Services)	1,163,145
	1,336,288

University of Tasmania - host institution support

Operating Grant	748,826
Scholarships and Tuition Fee Waivers	1,088,108
Strategic Projects	100,000
Miscellaneous	600
	1,937,534

Total annual income

	7,214,289
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FIGURE 1:
Total Cash Income 2020

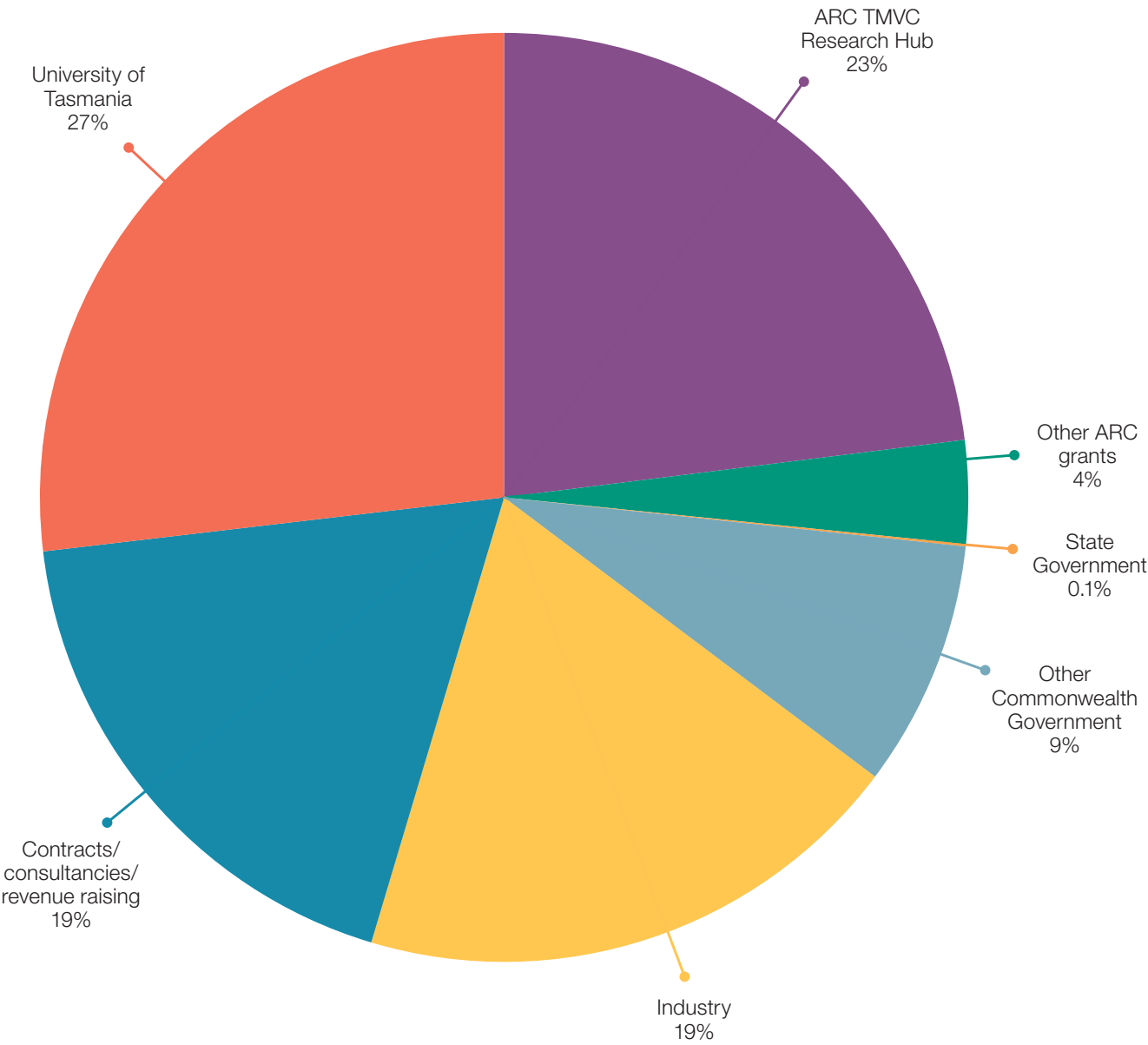
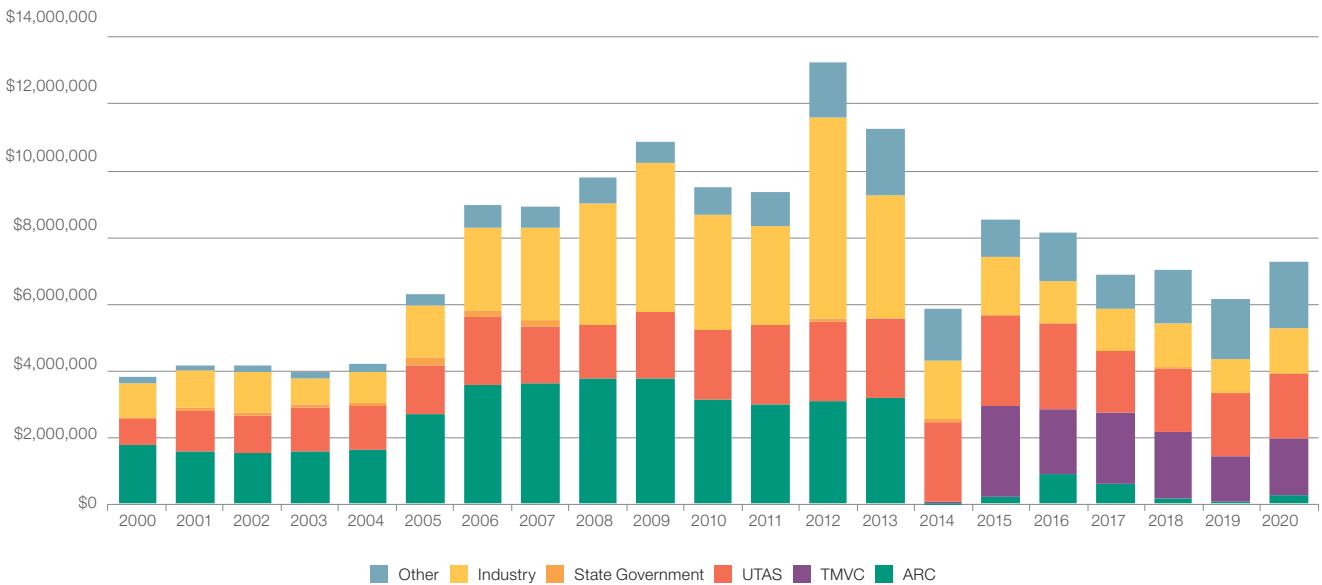


FIGURE 2:
Comparison of CODES
main income streams 2000–2020



Notes to, and forming part of, the financial statements for 2020

The financial pages of this Annual Report were prepared by Helen Scott (ARC TMVC Research Hub Manager). Data for the financial statements were 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 2020, or centrally administered for CODES RHD students (as in the case of scholarships and tuition fee waivers).

Aireys Inlet, southwestern Victoria (photo by Clare Miller).



2020 publications

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Abersteiner, A., Kamenetsky, V.S., Goemann, K., Kjarsgaard, B., Fedortchouk, Y., Ehrig, K., and **Kamenetsky, M.**, 2020, Evolution of kimberlite magmas in the crust: A case study of groundmass and mineral-hosted inclusions in the Mark kimberlite (Lac de Gras, Canada): *Lithos*, v. 372–373, Article 105690.

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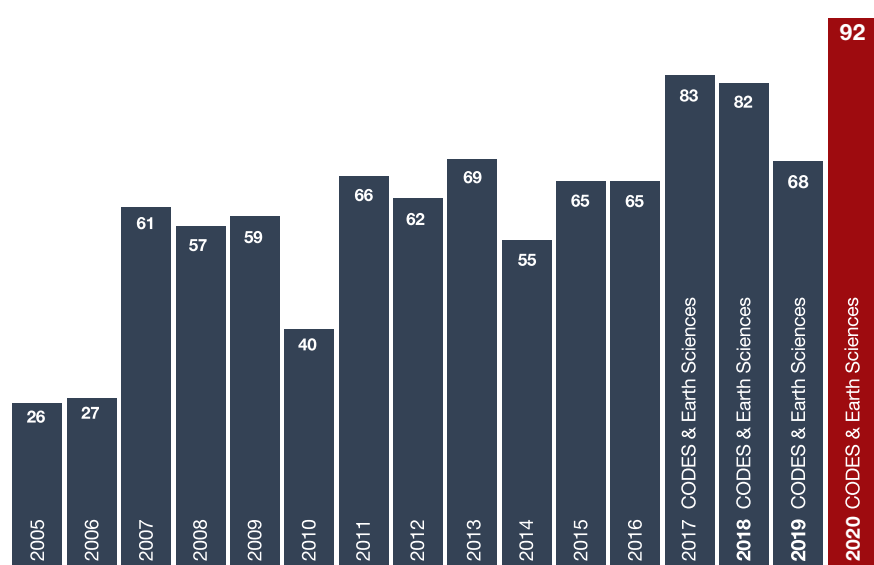
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Participants of the 2020 'Volcanology and Mineralisation in Volcanic Terrains' Masters short course at Aireys Inlet, Victoria (photo by David Cooke).

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Top of lithocap at 5,000 metres, on the Chile–Argentina border, taken by CODES PhD student Alex Farrar in early 2020 while doing fieldwork for his PhD on giant porphyry copper deposits, which falls within Program 6 and is supervised by Dr Matthew Cracknell and Professor David Cooke.

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*Barker, S., and Cracknell, M., 2020, Hands on sweep-by-sweep data: Batu Hijau epidote: AMIRA P1202 Sweep by Sweep Workshop, Hobart, 25 August 2020, 3 p.

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Students and industry participants pictured at Mount Leura, Camperdown, Victoria, examining basaltic lava flow overlying scoria fall deposit on the Volcanology Master of Economic Geology short course, March 2020.



LEFT: Neoproterozoic granite tors at Disappointment Bay, King Island (photo by Rob Scott). OPPOSITE: Granville Harbour, February 2020, West Coast third-year field trip. Rick Laffer looking at the geology of the granites and their mineralogy and taking a break to stare at the waves.

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Beach view taken at Aireys Inlet, southwestern Victoria, by Clare Miller during the ‘Volcanology and Mineralisation in Volcanic Terrains’ Master of Economic Geology short course, March 2020.

Appendices

CODES postgraduate students 2020

Bachelor of Science (Honours) (14)

Student	Supervisors	Research Program	Project	Support
Justin Burns-Nichols ^	Jutzeler, Carey	4	Reconstruction of the volcanic architecture of the host rocks at E41, Lake Cowal volcanic complex, Central NSW, Australia	Evolution Mining
Lachlan Dick *^	Orovan, Baker	1	Geology and genesis of the Anchor Sn mine, NE Tasmania	ARC TMVC
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
Wei Xuen Heng *^	Cracknell, Miller, Roach	2, 6	Geophysical investigation of the legacy Endurance mine site, Northeast Tasmania	MRT, ARC TMVC, GHD
Claudia Jenkins ^	Jutzeler, Carey	4	Volcanic architecture of GRE46, Cowal, New South Wales	Evolution Mining
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
Verity Kameniar-Sandery ^	Scott	3	Investigation into superheavy $\delta^{34}\text{S}$ in diagnostic pyrite (Costerfield, Victoria)	Mandalay Resources, CODES
Fu Rong Mah *	Miller, Meffre, Prahadal (Geography)	2	Investigating passive remediation of copper and acid mine drainage using Baloskion tetraphyllum, Western Tasmania	MRT, ARC TMVC
Hugh Sayers	Meffre	2, 3	Understanding framboidal pyrite formation mechanisms and their potential environmental implications	
Ben Speakman *^	Barker, Baker	1	The fertility indicator potential of titanite and apatite from the Yerington district, Nevada	AMIRA P1202, ARC TMVC, UTAS Foundation
Olivia Wilson *^	Miller, Cracknell	2	Hydrogeological studies of acid mine drainage at the legacy Endurance mine site, northeast Tasmania	MRT, ARC TMVC, GSA Endowment Fund, GHD
Riley Winter *	Zhang, Baker, White	1	Geology, geochemistry and genesis of advanced argillic alteration at Currowong Hills, Worrinya District, NSW, Australia	ARC TMVC

* Affiliated with the ARC TMVC Research Hub # Degree completed, not yet graduated ^ Graduated § Withdrawn

Master of Economic Geology (65)

Student	Supervisors	Research Program	Project	Support
Michael Adams			coursework only	
Greg Amalric			coursework only	
Robert Ayres			coursework only	
Stuart Badock			coursework only	
Emma Beattie			coursework only	
Mark Bolario	TBC		TBC	
Christopher Booth #			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	
Jimmy Carranza Meza			coursework only	
Nicole Casilla			coursework only	
Kaitlin Catalano			coursework only	
Glen Cathers			coursework only	
Chloe Cavill ^	Scott	1, 3	Ore paragenesis and sulfur source for the Costerfield Sb-Au deposit, Central Victoria	Mandalay Resources
Brianna Clark			coursework only	
Sarah Cochrane			coursework only	
Jamin Cristall			coursework only	
Roseanna Dale	Escolme	2	Au-Ag deportment variability and the effect on its flotation and recovery at the Monty VMS Cu-Au deposit, Western Australia	Sandfire Resources
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
Jamie Carlos Diaz Castro #	Cooke	1	The Cascabel Cu-Au-Ag porphyry cluster in northern Ecuador	SolGold
Laura Dowling			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	
Franco Ferreyra ^			coursework only	
Arga Firmansyah	Cooke	1	Geology and mineralisation of the Trenggalek district, East Java, Indonesia	PT Pamapersada Nusantara
Daniel Foulds #			coursework only	
Emma Haley			coursework only	
Brendan Hardwick	Meffre, Doyle (AngloGold Ashanti)	1, 3	Ore mineral textures and their implication for gold genesis and deportment at the Tropicana Gold Mine, Western Australia	AngloGold Ashanti
Michael Harris			coursework only	
Jonathan Higgins			coursework only	
Kyle Hodges			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	

* Affiliated with the ARC TMVC Research Hub # Degree completed, not yet graduated ^ Graduated § Withdrawn

Master of Economic Geology (65) (cont.)

Student	Supervisors	Research Program	Project	Support
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	
Sitthinson (Gun) Kultaksayos #	Meffre	3	Provenance of early to mid-Paleozoic sediments in Tasmania: When did Tasmania join with Australia?	ARC Linkage
Greer Lane *	Baker, Orovan, Zhang	3	Genesis of the Four Mile Diamictite and implications for Uranium mineralisation, South Australia	Heathgate Resources
Esther Little			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	
Alister Orton			coursework only	
Robbie Parr			coursework only	
Jose Pascual			coursework only	
Bailey Payten			coursework only	
Thomas Pearson			coursework only	
Luke Pickering			coursework only	
Chris Piggott			coursework only	
Hugo Rios Mansilla	TBC		TBC	
Torrin Rowe			coursework only	
Markus Staubmann #			coursework only	
James Taylor			coursework only	
Luke Timmermans			coursework only	
Victor Torres Pachecho			coursework only	
Megan Weatherman			coursework only	

Master of Science (3)

Student	Supervisors	Research Program	Project	Support
Nathaly Guerrero Ramirez	Cracknell, Hunt, Escolme	2	Geometallurgical controls on grade by size at Gramalote Au deposit, Colombia	CRC ORE, UTAS
Karla Morales	Hunt, Cracknell, Roach	2	Geological predictors for pre-concentration	CRC ORE, UTAS
Peerapong Sritangsirikul ^	Meffre, Steadman	3	Tectonic environment and mineral prospectivity of Rockley-Gulgong Volcanic Belt, Oberon region, New South Wales, Australia	Royal Thai Government Scholarship

* Affiliated with the ARC TMVC Research Hub # Degree completed, not yet graduated ^ Graduated § Withdrawn

Doctor of Philosophy (46)

Student	Supervisors	Research Program	Project	Support
Adam Abersteiner ^	V. Kamenetsky, M. Kamenetsky, Goemann (CSL)	4	Kimberlites: Understanding their petrogenesis and uncovering the identity of their source composition	UTAS, ARC Discovery, Institute of Seismology and Volcanology – RAS
Peter Berger	Barker, Cooke	1	Understanding and predicting hypogene and supergene footprints of Carlin-type gold deposits using a hydrochemical modelling approach	UTAS
Nathan Chapman ^	Meffre, V. Kamenetsky	4	Pb-isotopic insights into the crustal evolution and metallogenesis of the Gawler Craton	CODES, BHP
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
Rob Davidson	Gemmell, Cooke	1	Geology and genesis of the San Sebastian vein system, Durango, Mexico	Hecla Mining, UTAS
David Douth ^	Scott, Cas	1, 3, 4	Origin, geochemistry, stratigraphic and structural setting of the Archean Invincible gold deposit, St Ives gold camp, Yilgarn Craton, Western Australia	St Ives Gold
Kyle Eastman *§	Escolme, Zhang, Cooke	2	Geological and geometallurgical characterization of porphyry deposit alteration overprints	AMIRA P1202, ARC TMVC, SEG, UTAS
Alex Farrar	Cracknell, Cooke	1, 3, 6	Crustal architecture and geodynamic controls on the formation of giant porphyry copper deposits in the Central Andes	First Quantum Minerals
Matt Ferguson ^	V. Kamenetsky, Ehrig (BHP), Meffre	4	Late stage magmatic evolution of A-type rocks around and to the southeast of Olympic Dam, South Australia	UTAS, ARC Linkage, BHP, SEG, GSA
Amos Garay ^^	Cooke, Baker, Zhang	1	Las Bambas Cu-skarn, Peru: Implications of whole rock, mineral, and isotope geochemistry for ore genesis and exploration	AMIRA P1153, ARC TMVC, UTAS Foundation, SEG
Umer Habib	Meffre, Roach, Musgrave (GSNSW)	3, 6	Paleomagnetism and geochronology of Paleozoic rocks of Lachlan orogen in Victoria and New South Wales	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
Max Hohl	Barker, Cloutier, Steadman	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	The volcanic architecture of Cowal mine, Lachlan Orogen, NSW	ARC Linkage, UTAS, Evolution Mining
Laura Jackson ^^	Parbhakar-Fox (UQ), Cooke, Fox (UQ)	2	Mineralogical domaining of low grade and no grade zones using automated drill core logging	ARC TMVC, UTAS, Newcrest Mining, Corescan
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 *	Orovan, Cooke, Meffre	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 Northparkes Cu-Au porphyry deposit, 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

* Affiliated with the ARC TMVC Research Hub # Degree completed, not yet graduated ^ Graduated § Withdrawn

Doctor of Philosophy (46) (cont.)

Student	Supervisors	Research Program	Project	Support
Erin Lawlis ^	Cooke	1	Geology of the Kapit NE and coastal ore zones, Lihir gold deposit, Papua New Guinea	Newcrest Mining, UTAS, SEG
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	Porphyry and epithermal deposits of Cowal District, New South Wales	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, 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
Jaime Osorio *	Zhang, Cooke, Escolme, Piquer (UACH)	1	Anatomy of a phyllic overprint and structural evolution of Rincones de Araya porphyry deposit, San Juan, Argentina	ARC TMVC, UTAS, AMIRA P1202, 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
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 Staal #	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
Francisco Testa ^	Cooke, Baker	1	Tourmaline breccia pipes: San Francisco de los Andes, Argentina and Rio Blanco-Los Bronces, Chile	UTAS, AMIRA P1060

Doctor of Philosophy (46) (cont.)

Student	Supervisors	Research Program	Project	Support
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, Meffre	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
Tristan Wells	Meffre, Cooke, Steadman	1, 3	Magmatic fertility in the Macquarie Arc	ARC Linkage, UTAS, CODES, NorthParkes
Zebedee Zivkovic	Barker, Cloutier, Danyushevsky, Meffre	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 2020

Investigators	Project	Funding Body	Period	ARC Funding for 2020	Partner Funding for 2020	UTAS Funding for 2020	Misc Funding for 2020
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 International, BHP, Newcrest Mining, UTAS	2015–2021	**	\$1,502,713	**	\$13,429

Additional Funder Projects within the ARC TMVC Research Hub 2020

Investigators	Project	Funding Body	Period	Funding for 2020
Cooke, White, Zhang, Gemmell, Testa	Geological and geochemical vectors to low sulfidation epithermal gold mineralization, Cerro Negro district, Deseado Massif, Argentina	Oro Plata SA	2017–2020	\$69,854
Miller, Cracknell, Wilson (student)	Hydrogeological studies of acid mine drainage at the legacy Endurance mine site, northeast Tasmania	Mineral Resources Tasmania	2020	\$28,750
		GSA Endowment	2020	\$1,000
Miller, Cracknell, Cooke, Fisher (student)	Geochemical analysis of mine waste and pit lakes at Endurance Mine, northeast Tasmania	Mineral Resources Tasmania	2020	\$16,972
Orovan, Cooke, Jones (student)	Petrogenesis of northeast Tasmanian granites	Mineral Resources Tasmania	2018–2021	\$10,000
Cracknell, Miller, Roach, Heng (student)	Geophysical investigation of the legacy Endurance mine site, Northeast Tasmania	Mineral Resources Tasmania	2020	\$8,382
Baker, Orovan, Zhang, Lane (student)	Genesis of the Four Mile Diamictite and implications for Uranium mineralisation, South Australia	Heathgate Resources	2020–2021	\$6,436
Barker, Baker, Speakman (student)	The fertility indicator potential of titanite and apatite from the Yerington district, Nevada	UTAS Foundation	2020	\$5,000

Zhang	Alteration minerals chemistry at Yaojialing Zn-Au-W skarn deposit, China: implications for ore genesis and exploration	Hefei University of Technology	2019 - 2021	#
Zhang	Geochemical and mineralogical vectors to the ore at Bilihe-Hadamiao district, Inner Mongolia, China	Peking University	2017 - 2020	**
		Inner Mongolia Mining Technology Research Institute	2017 - 2020	**
Zhang, Escolme, Cooke, Sun (student)	Mineralogical, textural, geochemical characterisation and geometallurgical models of Lepanto Quartz – Pyrite – Gold vein and breccia system, Philippines	Society of Economic Geologists	2019 - 2020	**
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 2020

Investigators	Project	Funding Body	Period	ARC Funding for 2020
King (ANU), V. Kamenetsky	Impact of hot gas on volcanic rocks and ore-forming processes	ARC	2020 - 2023	\$19,895

ARC Linkage Grants 2020

Investigators	Project	Funding Body	Period	ARC Funding for 2020	Partner Funding for 2020
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	\$258,493	\$46,000
Meffre, Whittaker (IMAS), Norman (ANU), Cracknell, Belousova (Macquarie), Collins (UoN), Arundell (IMEx Consulting), Cooke	Ore deposits and tectonic evolution of the Lachlan Orogen, SE Australia	ARC, Rio Tinto, Alkane Exploration, Sandfire Resources, Evolution Mining, Geoscience Australia, Geological Survey of New South Wales, Heron Resources, Mineral Resources Tasmania, Northparkes Mines, New South Resources, AngloGold Ashanti, Geological Survey of Victoria, Emmerson Resources	2016 - 2020	**	**

CRC Projects 2020

Investigators	Project	Period	ARC Funding for 2020	Partner Funding for 2020
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	\$338,024	\$0

^ projects with greater than \$2,000 external funding per year ** all project funding received, project still active # funding milestones delayed

Industry and other externally funded research grants 2020

Investigators	Project	Funding Body	Period	Funding for 2020
Mukherjee, Steadman, Large, Olin	Application of pyrite chemistry to exploration and deep-time geology	Ian Potter Foundation	2019	\$0
		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 - 2020	\$450,000
Barker, Steadman, Cooke	Mineral geochemistry vectoring uncovering North West Queensland's hidden potential	Geological Survey of Queensland	2018 - 2020	\$370,600
Cracknell, Cooke, Farrar (student)	The geodynamic and tectonic influence on giant porphyry copper deposit architectural controls	First Quantum Minerals	2020 - 2023	\$98,175
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	\$83,831
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	\$77,050
Large, Hawke, Olin	Pyrite vectors for the Cobar Basin	Dept of Industry, Innovation and Science	2019 - 2020	\$16,431
		Peel Mining	2019 - 2020	\$32,862
Cooke, Diaz (student)	The Cascabel Cu-Au porphyry cluster in northern Ecuador	SolGold	2019 - 2020	\$32,240
Gemmell, Cooke, Davidson (student)	Geology and genesis of the San Sebastian vein system, Durango, Mexico	Hecla Mining Company	2017 - 2020	\$20,000
Jutzeler, Carey	Volcanic architecture and eruption behaviour at Site U1437 Izu-Bonin-Mariana rear-arc, IODP 350	IODP (via Australian National University)	2019 - 2020	\$20,000
Danyushevsky, Belousov, Meffre, Jenkins (student)	Characterisation of elemental fractionation in U-Pb dating by LA-ICP-MS analysis of rutile and garnet	AusIMM	2020 - 2021	\$2,000
Scott, Maroa (student)	Characterization of the geology, mineralization and genesis of the Bumbo polymetallic sulphide deposit within the Busia-Kakamega Greenstone Belt, Western Kenya	Acacia Mining Kenya	2019 - 2020	**
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	**

^ projects with greater than \$2,000 external funding per year ** all project funding received, project still active # funding milestones delayed



Estuary of the Sea Elephant River, King Island (photo by Rob Scott).

Visitors 2020

INDUSTRY VISITORS TO CODES IN 2020

NAME	COMPANY
Kristyn Adamczyk	Sandfire Resources
Mark Arundell	IMEx Consulting
Andrew Barker	Evolution Mining
Rodney Dean	Alkane Resources
Glen Diemar	New South Resources
Mark Doyle	AngloGold Ashanti
Ana Liza Garcia-Cuison	Emmerson Resources
Brendan Hardwick	AngloGold Ashanti
Maxwell Morissette	Visitor
Ashley Norris	Norris Scientific
Josh Phillips	Freeport McMoRan
Alex Richards	Rio Tinto
Damien Stephens	Sandfire Resources
Karen Wilson	Agilent

NATIONAL ACADEMIC AND GOVERNMENT VISITORS IN 2020

NAME	INSTITUTION
Mark Duffett	Mineral Resources Tasmania
Rob Duncan	Department of Economic Development, Victoria
Barbara Frankel	Australian Antarctic Division
John Greenfield	Geological Survey of New South Wales
David Huston	Geoscience Australia
Amber Jarrett	Geoscience Australia
Robert Musgrave	Geological Survey of New South Wales
Michael Vicary	Mineral Resources Tasmania
Elsbeth Wishart	Tasmanian Museum and Art Galley

INTERNATIONAL ACADEMIC AND GOVERNMENT VISITORS IN 2020

NAME	INSTITUTION
Minli Cui	China Geological Survey
Xianzheng Guo	China University of Geosciences in Wuhan
Feng Qin Ran	Chengdu University of Technology

RIGHT: Trial Harbour, western Tasmania: Rick Laffer, Sebastien Meffre and Umer Habib walking home along the beach after a long day of looking at rock outcrops. This photo was taken by Honours student Erik Fabreschi during the third-year Earth Sciences field trip in February 2020.





TOP: First-year Earth Sciences students pictured during their first practical for 2020 at Darwin Cliff, Lower Sandy Bay, during February. Izzy von Lichten (right) is talking about a volcanic eruption that occurred ~26 Ma not far from where they were standing. ABOVE LEFT: CODES PhD student Alex Farrar pictured during fieldwork at Salar de Maricunga in the Atacama Desert, Chile. Alex's work falls within programs 1, 3 and 6. This photo was taken in early 2020, before the COVID-19 lockdown came into effect. ABOVE RIGHT: CODES Honours student Till Gallagher pictured at the MRT Mornington Core Library where he is cutting rock for further examination. His Honours research is looking at the nature, structure and origin of the St Marys porphyry, northeastern Tasmania.

CODES

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