

ORE SOLUTIONS

NEWSLETTER OF **CODES** CENTRE FOR ORE DEPOSIT AND EARTH SCIENCES

> SPRING 2021 **No.40**

INNOVATION AND ADAPTATION KEY TO CODES' MASTERS COURSES SUCCESS



Economic geology powerhouse: L-R: Senior Research Fellow Dr Lejun Zhang, Senior Lecturer Dr Michael Roach and CODES Director Professor David Cooke discuss content for the new 'Fundamentals of Economic Geology' Masters short course that was delivered online at CODES over two separate weeks in September/early October.

During 2021 the team at CODES has been busy preparing and delivering an increased offering of Master of Economic Geology short courses...the latest new short course – 'Fundamentals of Economic Geology' – is being delivered as we go to press, and during the remainder of the year the popular 'Geometallurgy' and 'Ores in Magmatic Arcs' courses are set to be delivered, with the latter finally able to offer a Tasmanian fieldwork component after the lifting of COVID-19 restrictions.

Since June 2020, CODES has flipped much of its delivery of postgraduate short courses from in-person to online delivery due to the travel restrictions caused by COVID. We were well-placed to do this thanks to Dr Mike Roach's development of a 3D visualisation laboratory in the time leading up to the pandemic. We have been able to integrate 3D visualisations as part of the teaching program as a substitute for hands-on rock identification and fieldwork through online tutorials and virtual field trips. We have

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FROM THE DIRECTOR

Professor David Cooke looks forward to an eventual return to normalcy for CODES in the coming months.

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successfully delivered four Masters short courses online through the past year ('Ore Deposit Models and Exploration Strategies', 'Brownfields Exploration', 'Geodata Analytics' and 'Ore Deposit Geochemistry, Hydrology and Geochronology'). Many of these units have achieved their highest-ever participation rates via online delivery. We also decided to split the units into two one-week teaching blocks, which proved to be a more compatible delivery mode for professional geologists seeking to balance the demands of work and family life with their desire for professional development.

Our enrolments in the Master of Economic Geology program remain very strong and we are pleased to see continued strong engagement with this postgraduate training program. If you are interested in applying, please visit: utas.edu.au/courses/cse/courses/s7w-master-of-economic-geology

We are also starting to see enrolments in the Graduate Certificate in Economic Geology, a new offering at UTAS in 2021 whereby students can get a Graduate Certificate for the completion of two units from the broader Masters program. For those interested in applying for the Graduate Certificate program please visit: utas.edu.au/courses/cse/courses/k5f-graduate-certificate-in-economic-geology

NEW DIRECTIONS

At the time of writing, CODES is half-way through delivering its new short course 'Fundamentals of Economic Geology' to our Master of Economic Geology and Graduate Certificate in Economic Geology students. Week 1 was delivered live online to over 50 participants from around the world on 30 August–4 September. Week 2 is scheduled for delivery on 27 September to 1 October. Participants are learning many of the fundamental skills and theory needed by all economic geologists. Topics being covered over the two weeks include ore deposit classes, environments of ore formation, mineralogy and textures, paragenesis, zoning, geochemical and geophysical characteristics of ore deposits, supergene features and the economics of Economic Geology. The course is

being presented by CODES/ UTAS staff and adjuncts (David Cooke, Noel White, Lejun Zhang, Francisco Testa, Angela Escolme, Karsten Goemann, Michael Roach, Robert Scott) and external world-leading experts from industry, government and academia (Rodney Allen, Tim Callaghan, David Green, Scott Halley, Cassady L Harraden, David Huston, Glen Masterman, Larry Meinert and Rick Valenta). The course includes a major assignment based around a virtual field mapping exercise at the Dolphin scheelite deposit, King Island, Tasmania, and we thank King Island Scheelite for provide full access to the mine and sample materials for this short course. We aim for this course to be offered annually for new students entering the Master of Economic Geology or Graduate Certificate in Economic Geology programs.

Coming up in October and November, we will be delivering our 'Geometallurgy' short course online for the first time. The unit can be taken as part of our Master of Economic Geology or Graduate Certificate in Economic Geology programs, but is also open to all interested participants from industry, government and other academic institutions. It will run on 18–23 October (week 1) and 15–19 November (week 2). Attendees will gain a comprehensive overview of practical geometallurgy, from mineral processing fundamentals to deposit characterisation. We will introduce you to a range of techniques for early-stage (e.g., exploration, prefeasibility) collection of geological information that is relevant to mining engineers and metallurgists. The program includes lectures, practical exercises (including a computer-based modelling exercise) and a virtual field trip to a mine in western Tasmania. It will be led by Dr Julie Hunt and Dr Angela Escolme and will be presented by several additional CODES/UTAS staff and students, together with sessions from world-leading experts Toni Kojovic, Teresa McGrath, Scott Halley, Naomi Boxall, Sefton Darby, Joe Pease, Laurence Dyer, Luke Keeney and David Green.

IN THE FIELD AT LAST

Our next scheduled field-based course is 'Ores in Magmatic Arcs' (22 November–3 December). Our

intention is to proceed with offering this course to domestic students who are either resident in, or can travel to, Tasmania in late November. The timing of the course roughly coincides with the period predicted for several Australian states to reach the critical threshold of 80% double vaccination, which is when travel borders may start to open. However, as Tasmania and several other states currently have zero COVID cases, participants may not be able to travel from states with active covid cases to Tasmania at this time. Nor is it possible for CODES staff to travel to states with active cases, or to travel overseas. Consequently, the two-week course will be based entirely in Tasmania. It will include a one-week field excursion to western Tasmania to learn about Cambrian polymetallic VHMS and high sulfidation

state mineralisation that formed in a back-arc setting, and Devonian-Carboniferous skarn, vein and granite-related carbonate replacement-style Sn-W-Fe-Cu-Zn-Pb-Ag deposits that formed in a post-collisional orogenic belt. The second week of the course will involve lectures and pracs at CODES, reviewing case studies of ores from magmatic arcs from South America (El Teniente, Rio Blanco, Cerro Casale, Las Bambas, Yanacocha, La Zanja, etc.), Indonesia (Tujuh Bukit, Batu Hijau, Elang), the Philippines (Lepanto-Far South East, Baguio district, Boyongan, Didipio), Papua New Guinea (Lihir, Porgera, Wafi-Golpu) and eastern Australia (Cadia, Northparkes, Cowal), utilising the extensive sample and teaching collections that reside in the CODES archives. More details regarding the course program will be advertised on the CODES website soon.

FUTURE PLANS

In 2022, we once again plan to offer several units online with intensive one-week teaching blocks over 3–4 weeks ('Fundamentals of Economic Geology' – January/February; 'Ore Deposit Models and Exploration Strategies' – June-July; 'Geodata Analytics' – August-October; 'Exploration in Brownfield Terrains' – October) and, depending on COVID travel restrictions, two field-based courses ('Advanced Field Skills in Economic Geology' – Tasmania, February; 'Volcanology and Mineralisation in Volcanic Terrains' – New Zealand, Tasmania, November). We look forward to seeing some of you and/or your team at one or more of these training and professional development events.

See further details of upcoming short courses for the remainder of the year on page 28.



Dr Michael Roach on King Island gathering data with a 360-degree camera for his 3D virtual library of geology for use in CODES' Master of Economic Geology short courses and Earth Sciences teaching materials.

WINNING STREAK

The past few months have seen CODES/Earth Sciences students and staff shine in many areas with the presentation of several awards and grants. Here are some of just the latest accolades...



Earth Sciences Honorary Research Associate and Emeritus Professor David H. Green, who recently received a SIMP-Honorary Fellow Award from Italy, is pictured here in the garden of his Sandy Bay home.

Earth Sciences Honorary Research Associate and Emeritus Professor

David H. Green AM has been awarded the Società Italiana di Mineralogia e Petrologia-Honorary Fellowship for 2021. The SIMP-Honorary Fellow Award is bestowed "in recognition of an internationally relevant scientific and organizing contribution to the advancement of the mineralogical and petrological sciences".

Professor Green has had a long and distinguished academic career at UTAS, Geoscience Australia, Cambridge University and ANU. With support from the ARC and UTAS, he established a high-pressure laboratory in the Geology Dept and used the excellent facilities and professional staff of the Central Science Laboratory to attract graduate students, post-docs and visitors. He returned to ANU as Director of the Research School of Earth Sciences (1994–2001) and "retired"

to UTAS in 2008. He has received numerous awards, recognising his work and leadership, in the form of honorary fellowships, including the election to the Academies of Sciences of Australia and Russia, and of the Royal Society of London.

Professor Green said of the SIMP award: "Honorary fellowships such as this are recognition that scientific research contributions are being used by colleagues. Italy has strong research groups in experimental petrology which are important for understanding Italy's active volcanism. It is pleasing that 40 years later, Italian colleagues are using UTAS research and have elected me to an honorific role in their national mineralogical and petrological society".

See: www.eoas.info/biogs/P004123b.htm for his entry in the Encyclopedia of Australian Science.

ASEG SCHOLARSHIP

CODES Honours student Zak Weidinger is the winner of the inaugural Richard Lane Scholarship valued at \$5,000 from the Australian Society of Exploration Geophysicists (ASEG). Zak was pitted against BSc and MSc geophysics students from across Australia to win this scholarship, so his success is a huge credit to him.

Zak's project, titled 'Geophysical investigation of the Royal George tailings repository, northeast Tasmania' uses time-lapse or four-dimensional geophysics to image and characterise changes in internal flow-paths within an acid-producing tailings dump at the Royal George legacy tin mine, Tasmania, in the hope that a remediation solution can be found to the problem of acid and metalliferous drainage at this site. Of the scholarship, Zak said:



"Being the inaugural recipient of the Richard Lane Scholarship is an honour. I have spoken with people who knew and worked with Richard and the positive impact he had in the field of geophysics and on the people he worked with was clear. I am incredibly grateful to be awarded this scholarship in his honour".

CODES Honours student Zak Weidinger amidst an electromagnetics survey of the Royal George Tailings Repository, Tasmania, May 2021. Zak is the recipient of the inaugural Richard Lane Scholarship from the ASEG.

SOCIETY OF ECONOMIC GEOLOGISTS RESEARCH GRANTS

**CODES-TMVC PhD student
Takeshy Coaquira, April 2021:**
award of \$5,000 from the Hugh
McKinstry Fund – SEG

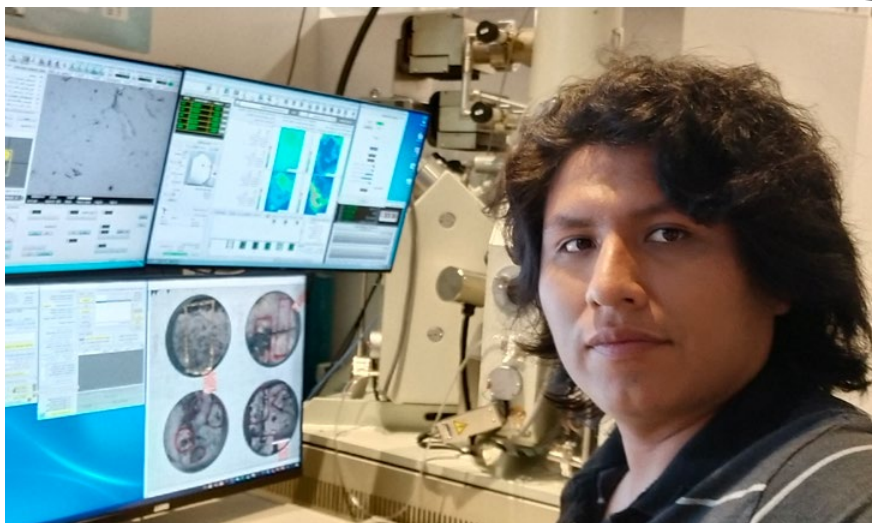
"I feel grateful to the Society of Economic Geologists for considering me for this McKinstry award; this is an exciting time during the last stage of my PhD project and a landmark in my professional career. My project focuses on understanding the evolution of the Resolution Cu-Mo porphyry system. It will evaluate the relationships between intrusions, hydrothermal fluids and mineralisation; it will determine whether one or several paragenetic stages formed the high copper grades that characterise this giant deposit."

**CODES-TMVC PhD student
Jaime Osorio, April 2021:** award of
\$4,000 from the Eric P Nelson Fund –
SEG

"I am delighted to have received the 2021 student research grant from the Eric P Nelson Fund. This grant will provide funding for both Re-Os and Ar-Ar geochronology at Valeriano porphyry-epithermal system, focusing on the construction of a time-frame of the main events of alteration-mineralisation at the deposit. Valeriano is the main study site of my PhD; since non-scientific work has been done in the past in this project, having a strong geologic background of the hydrothermal evolution of the deposit is critical for my research."

**CODES-TMVC PhD student
Xin Ni Seow, April 2021:** award of
\$4,300 sponsored by the Newmont
Corporation.

"It was an honour to receive the Student Research Grant sponsored by the Newmont Corporation as the competition for research grants is always tough. This was actually not my first time applying for these and I am glad that the efforts paid off. Receiving this grant really boosted my self-confidence as it means that my proposal won approval from the mining industry which thinks that the proposed work could be something useful for them. I will prove that they made the right decision and hope that my research outcomes will have a high impact in both academia and real-world mining exploration."



CODES-TMVC PhD student Takeshy Coaquira, recipient of a grant from the SEG's Hugh McKinstry Fund, seen here analysing white mica in the Central Science Laboratory at UTAS.



CODES-TMVC PhD student Jaime Osorio, who is currently doing his PhD remotely, carrying out fieldwork at the Valeriano porphyry-epithermal system, Chile.



CODES-TMVC PhD student Xin Ni Seow, who received an SEG Research Grant from Newmont Corporation, pictured on King Island during the recent CODES SEG Student Chapter field trip.

CoSE AWARDS

Each year the College of Sciences and Engineering (CoSE) at UTAS presents a number of key awards to research scientists, lecturers and professional staff to acknowledge their contribution to the College. This year CODES/Earth Sciences has made a very strong showing with three awards and an honourable mention for one of our PhD students.

CoSE Early Career Researcher Award 2021: Dr Indrani Mukherjee

Dr Indrani Mukherjee has received the CoSE Early Career Researcher Award for 2021, and says that it is very rewarding to see her research – about which she is so passionate – being acknowledged. Indrani's research focuses on developing a nuanced understanding of Earth's ancient marine environments. She uses novel and cutting-edge geochemical techniques to question key concepts, and explores links between early Earth evolution, the origin of complex life and formation of precious mineral deposits.

CoSE Innovation Award 2021: Dr Michael Roach

Dr Michael Roach has won the CoSE Innovation Award for 2021 for his work on the Virtual Geology library (AusGeol.org), which he has been developing over the past few years, and for his further work on developing virtual teaching resources for Earth Sciences and CODES students at UTAS. The technology he has developed was also used via a grant from the UTAS Digital Futures Program to digitise the UTAS cultural collections. Dr Roach said that he was pleased his work on 3D representations of geology has been acknowledged, and that he hoped to be able to make further substantial contributions to this field.

CoSE Leadership Award 2021: CoSE cLEAN Up Team: Shelley Urquhart with others

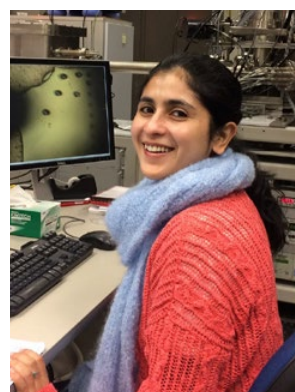
Shelley, who is Operations Manager, in the College of Sciences and Engineering, was part of a team of 17 people involved in the CoSE cLEAN transition over the past 18 months, which worked to clean up and streamline all work areas/offices within the College.

"The award represents all the hard work of many people across the School [of Natural Sciences] during 2020–21, and has resulted in a vast improvement to many spaces in our disciplines".

CoSE Executive Dean's Award 2021: Current HDR candidate: Hannah Moore (honourable mention)

Hannah is undertaking a PhD at CODES in volcanology that focuses on the 1886 eruption at Tarawera volcano, New Zealand; she is looking at microtextures of volcanic clasts from three key sites to determine magma storage, ascent and eruption conditions.

"I am very grateful to the Executive Dean for their recognition and encouragement. The honourable mention has given me confidence to continue with my efforts!"



Dr Indrani Mukherjee, winner of the CoSE Early Career Researcher Award 2021.



Dr Michael Roach, winner of the CoSE Innovation Award 2021.



Associate Professor Rebecca Carey (right) receiving a certificate to mark her award of the 2020 Dorothy Hill Medal, from the Governor of Tasmania, the Honourable Barbara Baker AC, at Government House in Hobart during September. This prestigious medal is awarded by the Australian Academy of Science each year to support research in the Earth sciences by women researchers up to ten years post their PhD. Rebecca received the medal for her internationally recognised research into volcanology – particularly the transformative outcomes derived from a 2015 research voyage. Her award was originally announced in May 2020; see item in our previous newsletter No.36. The actual medal is still 'locked down' in Canberra and will be forwarded at a separate date.

THE CLASS OF 2021

HOW CODES PHD STUDENTS HAVE WITHSTOOD THE PANDEMIC



CODES PhD student Malai Ila'ava logging drill core samples at Evolution Mining's Lake Cowal Mine in New South Wales, April 2021.

CODES HDR Coordinator Associate Professor Rebecca Carey assesses the effects the pandemic is having on our current cohort of PhD students, and concludes that more needs to be done to help them build virtual collaborative networks. Watch this space...

2021 has been a challenging time for our PhD and Masters student cohort who are living with uncertainties and disruptions to their personal and working lives. Two-thirds of our student cohort are international students, who are either here in Tasmania away from friends and family, or are conducting their research remotely, or from overseas which comes with challenges of COVID-19 restrictions. It has been heartening to see supervisors, professional staff and the student body putting in extra effort to support these students with research and non-research activities.

Research in the Earth Sciences is particularly vulnerable to the restrictions associated with COVID-19 due to restricted access to the field, rocks, microscopes and other laboratories. While here in Tasmania we have not suffered with restricted access to the CODES laboratories, fieldwork has been almost impossible outside of Tasmania. Our students are coping and adapting despite the pivoting of project topic, field areas and workplans associated with restricted access to fieldwork, infrastructure, or international collaborators and partners. We would like to show our great appreciation to professional staff from CODES and the Discipline of Earth Sciences, industry and government partners and external collaborators for not just facilitating the changes required for successful student projects, but also contributing in such a way that has enabled our students to flourish in challenging circumstances.

The PhD and Masters university experience is not just about the research output, it also includes communicating and implementing outputs to end-users and partners through conferences and workshops and networking. While presenting work in a virtual manner is almost problem-free, building collaborative networks through these virtual experiences is not. Some networks have partially filled this gap, e.g., WOMEEESA (Twitter, #Woomesa), there is more to be done, and we welcome ideas for virtual collaborative network-building with CODES students and external partners to facilitate their successes beyond their tenure at UTAS.



PETER BERGER

Supervisors: David Cooke, Shaun Barker (MDRU), Ron Berry

Project title: Modelling ore deposition in carbonates

This work is based on reactive transport modelling of ore systems particularly in carbonate formations. The first part has focused on what parameters control the oxygen isotopic patterns created as hydrothermal fluids migrate through carbonate systems. I was able to work with my former colleagues at the Illinois State Geological Survey to reinforce the simulations with data from Mississippi Valley-type systems. Another system modelled was the Mount Isa deposit (with data and samples provided by Glencore), where we investigated the transformation from dolomite to chlorite and how hydrothermal fluids might react in other adjacent formations. We also ran a sensitivity analysis on the various model parameters to isolate the controls on the system and looked at the role of pre-existing pyrite in controlling copper distribution. The third paper will either be on the modern groundwater plume of a Carlin system or an examination of carbonate solubility and factors that can counteract retrograde solubility thereby affecting permeability and fluid flow.

"My projects are going well, and I recently won second prize in the 'Poetry of Science' competition. Unfortunately, my efforts to convince my supervisors that this counts as a peer-reviewed publication seem to be falling on deaf ears."*

*See item on page 21 re this competition, which had three entries from CODES/ES geologists – all worth reading! The competition proves that geologists are not just interested in rocks.



ACACIA CLARK

Supervisors: Rebecca Carey, Martin Jutzeler

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

Acacia is researching the AD 1315 Kaharoa event which was New Zealand's most recent and largest emission of rhyolitic magma. This eruption was complex and consisted of 15 different episodes, from seven active vents across an 8-km fissure. The Kaharoa event is unusual as the deposits display characteristics of both moderate to high-intensity 'Vulcanian to sub-Plinian and Plinian' activity through density and textures of erupted clasts, wide-ranging deposit extent and event duration. It is also culturally important to the Māori of New Zealand as the widespread tephra on the North Island provides a stratigraphic marker for the arrival of Māori to New Zealand.

Acacia will investigate the drivers that allow for unsteady but sustained powerful eruptive activity, as demonstrated during the Kaharoa event. This field has not been

researched in depth and is important for understanding how large silicic eruptions function and for modelling future eruptive events. Future work for Acacia's project includes fieldwork at Mt Tarawera (the location of the Kaharoa event) where she will undertake detailed stratigraphic logging and sampling of the deposits; this is currently planned for early 2022.

"I am thoroughly enjoying being back at CODES (Acacia completed her Honours here in 2019) and working with excellent researchers again."



ABOVE: PhD student Acacia Clark has recently joined CODES to undertake research into the Kaharoa event, which took place in AD 1315 at the Tarawera Volcano in New Zealand. Here Acacia is pictured on the summit of Tarawera during a joint UTAS/University of Hawaii field trip in 2019.



CODES PhD student Peter Berger at his desk running simulations of carbonate dissolution in Carlin-type gold deposit settings.



ALEX FARRAR

Supervisors: Matthew Cracknell, David Cooke

Project title: Lithospheric architecture and geodynamic controls on the formation of giant porphyry copper deposits in the Central Andes

Project sponsor: First Quantum Minerals

Giant porphyry copper deposits in the central Andes cluster in discrete geographic camps of a similar age. This indicates that exceptional transient geologic processes affected localised regions of the lithosphere around the age of mineralisation and that the position of giant porphyry deposits is non-random. Development of favourable regions of lithosphere for significant metal concentration are thought to be linked to the overlap of structural pathways that focus fluid and magma flow from the mantle to upper crust. These structural pathways, or translithospheric faults, are notoriously difficult to identify in the field due to their subtle surficial characteristics and continental-scale.

Alex's PhD project aims to integrate field-based observations conducted at multiple scales with geophysical datasets to map the regional-scale lithospheric architecture of the Central Andes. Published geodynamic models of the central Andes will be integrated with lithospheric architecture and known deposits using Machine Learning analytical techniques, to test the relationship between structure, geodynamics and mineralisation as has been hypothesised by many.

"Having spent the past 11 years living and working outside of Australia in exploration, it's fantastic to now be living in beautiful Tasmania whilst researching fundamental questions relating to ore deposit formation and localisation, with the support of world-class researchers at CODES."



CODES student Alex Farrar is doing a PhD looking at giant porphyry copper deposits in the Central Andes; here he is pictured carrying out fieldwork at 4,500 m on the Chile-Argentina border in early 2020.



RICHARD HILL

Supervisors: Robert Scott, Matthew Cracknell, Michael Roach, David Giles (Uni SA)

Project title: Exploring the East Tennant region: Unravelling the crustal architecture, tectonic evolution and mineral systems potential of an undercover Proterozoic terrane through the integrated use of geophysics, drill hole data and machine learning/geodata analysis techniques.

Project sponsors: MinEx CRC, Strategic Energy Resources, Inca Minerals, Encounter Resources, Middle Island Resources, Datacode

The East Tennant region is an area of cover-obscured Proterozoic basement lying between the Tennant Creek mineral province in the NT and the Mount Isa mineral province in far NW Queensland. Geoscience Australia's 'Exploring for the Future' program identified crustal scale features in the area favourable for mineral systems, resulting in the follow-up collection of geophysical data and, in 2020, a ten-hole stratigraphic drilling program, run as a part of MinEx CRC's 'National Drilling Initiative'.

Richard's work will focus on utilising the recently collected drilling and geophysical datasets, and a range of other datasets (including those of sponsor companies) to unravel the crustal architecture and tectonic evolution of this poorly understood region. To understand the 4D evolution of the area, 3D geological models will be made, consistent with the geophysical data and constrained by observations from drill holes. Structural/kinematic analysis will be performed, along with geochronology and thermochronology to provide a temporal framework. A geodata analysis approach will then be used to identify areas of high potential for mineral systems identified as being likely present in the area.



PhD student Richard Hill joined CODES in August and is working to unravel the crustal architecture and tectonic evolution of the East Tennant region in northern Australia. Here he is seen drilling near Karlawinda Bore in the Pilbara, February 2018, while working for OMNI GeoX/Capricorn Metals.

"To be working in a region that is so poorly understood, with high mineral potential and very little previous exploration is a really exciting prospect. I feel that with the expertise here at CODES, I will be able to contribute to the understanding of a nationally significant area while gaining new skills in undercover exploration techniques. The school is in a beautiful setting and full of amazingly friendly and supportive people – it really feels like the right place for me."



MALAI ILA'AVA

Supervisors: Martin Jutzeler, Rebecca Carey, Ray Cas (Monash University)

Project title: Volcanic architecture of the Lake Cowal Volcanic Complex

Project sponsor: Evolution Mining (in-kind support)

The Lake Cowal Volcanic Complex (LCVC) lies within the Junee-Narromine Belt, the westernmost of four volcanic belts of the Macquarie Arc in New South Wales. Malai's research (funded by ARC Linkage Project LP190100035) is strongly field-based, using graphic logging of drill core to identify facies and interpret facies correlations to produce a district-scale 3D model of the volcanic architecture of the LCVC. Petrography and geochemistry will provide petrogenetic constraints to test and refine the model.

Malai has logged 23 km of core so far and hopes that reconciling the evolution of the LCVC to the larger scale, might contribute to the understanding of how the Macquarie Arc formed and evolved through time. Hopefully this also provides some basis for more predictive exploration targeting in the LCVC and the Macquarie Arc.

"It is a privilege to have an opportunity to work on a gold deposit like Cowal in the Macquarie Arc. I am so lucky to have my wonderful supervisors Martin Jutzeler, Rebecca Carey and Ray Cas to

teach and guide me through my project. I started remotely in December 2020 and then commenced fieldwork so I haven't been down to Hobart yet. However, even through emails it is easy to feel the sense of community within CODES and between the PhD students. I'm looking forward to coming down and meeting everyone (and to start working on my samples too!)."



DR COLIN JONES

Supervisors: Sebastien Meffre, Evan Orovan, David Cooke

Project title: The petrogenesis of the east Tasmanian Devonian granites.

Funding: ARC TMVC, Mineral Resources Tasmania (MRT), University of Tasmania Scholarship

I am in the final year of my project and currently writing up. The field location was primarily the scenic granite outcrops along the northeast Tasmanian coastline and the adjacent hinterland taking in the parts of the Eddystone, Blue Tier and Scottsdale



Dr Colin Jones is in the writing-up stage of his PhD at CODES, which is looking at the petrogenesis of the east Tasmanian Devonian granites.

batholiths. I was lucky to have the company of my supervisors and Ralph Bottrill from MRT on several field trips and their knowledge and experience of the region was invaluable.

Three principal areas of work were covered. The provenance of the Devonian granites was investigated through the analysis of zircon O and Lu/Hf isotopes which involved trips to Canberra Research School of Earth Sciences and Macquarie University in Sydney between mainland COVID-19 lockdowns. The pattern of results suggested the studied granites had material input from two distinct lower crustal or mantle sources. A second area is the geology of the igneous and metamorphic complex in the Haleys New Country pluton at the south of the Blue Tier Batholith. Thirdly, the temperature and depth of emplacement of a range of granites has been studied using zircon and quartz mineral chemistry, and the P/T paths of these granites evaluated.

These studies will hopefully add to the rich knowledge of the geology of Tasmania and perhaps play a part in unravelling the puzzle of the construction of the southeast corner of Australia.



ELENA LOUNEJEVA

Supervisors: Jeffrey Steadman, Ross Large

Project title: Geochemistry of sedimentary pyrite from the Permian-Triassic boundary

When I was involved with Ross Large's 'Trace elements in ancient oceans' project as a Laboratory Analyst at CODES, I became interested in the chemical compositions of sedimentary pyrite. I decided to explore in detail whether the chemical signatures of the early forms of pyrite found in marine sedimentary rocks may

track global changes in seawater composition that are expected to accompany mass extinction events linked to the formation of Large Igneous Provinces (LIPs). I have gathered marine sedimentary rocks from around the globe that were formed across the Permian-Triassic boundary, as it is associated with the major mass extinction and the greatest volcanic activity in Earth history that formed the Siberian basalt traps. I have conducted detailed microscopic studies of textures and collected analytical data using LA-ICP-MS and Raman spectroscopy. After studying the tiny pyrite framboids (10–50 µm in size) for many years, which was not easy, I discovered that it is likely that the most important information in these rocks is recorded by large crystals of marcasite that have not been described previously in many of these rocks. We have published a paper on the chemistry of these marcasites proposing that they reflect hydrosphere acidification as a result of magmatic activity. I was fortunate to collect all my data before the COVID outbreak, and thus it has not affected my project to a large extent.

"I enjoy discussions with my supervisors and interaction with other staff and students at CODES. I find CODES staff to be very knowledgeable and supportive of HDR students."



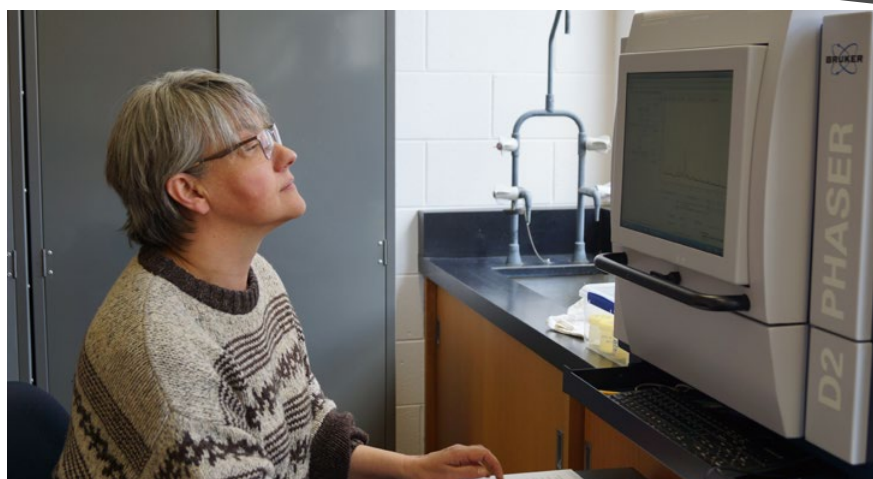
ANNAH MOYO

Supervisors: David Cooke, Clare Miller, Sebastien Meffre, Anita Parbhakar-Fox (UQ)

Project title: Application of industrial wastes in the treatment of acid and metalliferous drainage (AMD) generated by legacy mine wastes in Tasmania.

Funding: Mineral Resources Tasmania

This study seeks to investigate the effectiveness of alkaline industrial wastes for treating AMD generated by mine wastes by placing industrial



CODES PhD student Elena Lounejeva pictured in the CODES X-ray Lab using a benchtop XRD system (D2 Phaser, Bruker) designed for the speedy collection of high-quality diffractometric data.



Digging for victory: CODES-TMVC PhD Annah Moyo is seen here at the Zeehan smelter site gathering samples of waste for her PhD, which is examining the remediation of legacy mine sites in Tasmania.

wastes together with mine wastes and monitoring the drainage quality over time. This study also evaluates the placement method of the industrial waste that is more effective in AMD remediation. The alkaline industrial wastes were sourced from within Tasmania and Victoria and included green liquor dregs (GLD), wood ashes, coal ash and red mud, as well as scallop, mussel and oyster shells. The historic mine wastes were obtained from six sites previously identified as AMD hotspots. The results to date show that all the industrial wastes except wood ashes have the capacity to neutralise AMD and inhibit metal(loid) leaching by



CODES-TMVC PhD student Yi Sun (in blue) with supervisor Dr Lejun Zhang doing fieldwork as part of the AMIRA P1202 project in the Mankayan district in the Philippines in February 2018.

the mine wastes. The results also show blending and multi-layering the industrial wastes with the mine waste to be more effective than simple top covers. These findings highlight that this holistic waste management approach of reusing waste produced from other industries to remediate mine waste offers a circular economy focused on reducing the amount of industrial waste that ends up in landfill and simultaneously mitigating the anthropogenic effects of legacy mine wastes.

"My experience at CODES has modelled me into an independent researcher who can approach challenges and problems in a multi-disciplinary way."



YI SUN

Supervisors: Lejun Zhang, Angela Escolme, David Cooke

Project title: Geology of the quartz – pyrite – gold (QPG) mineralization and the new genetic model of the Mankayan district, Northern Luzon, Philippines

Industry sponsor: Lepanto Consolidated Mining Company

The Mankayan district in the Philippines is famous for contemporaneous porphyry and epithermal mineralisation. My PhD project focuses on the quartz-pyrite-gold (QPG) vein and breccia system of Mankayan. The aims of the project are understanding the geology, alteration patterns, mineral textures, chemistry and the genesis of the QPG system. There is a particular emphasis on the investigation of alteration patterns, ore texture and mineral assemblages that may impact on metallurgical processes.

I came to CODES in 2017 after working for three years in industry. My exploration experience is mainly with epithermal deposits, so the Mankayan project was an ideal site for me to explore a classic porphyry-epithermal system. This project is really excellent because I have got the best supervisor team and I was a research member of the AMIRA P1202 project. I have learned about the world's leading ideas regarding this system and have used cutting-edge analytical methods to generate systematic data. Detailed field and analytical work have revealed the controlling factors and hydrothermal evolution of the QPG mineralisation, and how this type of mineralisation fits into the porphyry-epithermal system at Mankayan.



JENNIFER THOMPSON

Supervisors: David Cooke, Leonid Danyushevsky

Project title: Textural, geochemical, and fluorescence variations of calcite in porphyry Cu-Au deposits

Jennifer Thompson's research was part of the AMIRA P1153 project within Program 1: Ore deposits and mineral exploration, and the TMVC.

The first objective of this research was to improve LA-ICP-MS analytical methodology by independently characterising a new in-house calcite reference material, and then performing LA-ICP-MS analyses at various analytical conditions and calibration methodologies and compare the accuracy and precision of the results. This research created an accurate method for trace element analysis in the mineral calcite and a procedure for LA-ICP-MS optimisation with other minerals and in other laboratories.

The second objective of this research was to collect calcite chemical variations in alteration halos around two well-known porphyry Cu-Au deposits in Indonesia (Batu Hijau, Sumbawa, and Grasberg, Papua). In the Grasberg-Ertsberg district, this research integrated multiple datasets

including calcite UV fluorescence, mineral chemistry, mineral textures, whole-rock chemistry, and district structural components to establish a proximity to ore district model several km from the district intrusion. At Batu Hijau, Indonesia, a model was developed for fluid chemistry and associated hydrothermal mineral chemical variations with increasing distance from a volcanic-hosted porphyry deposit.

Jennifer's research project has resulted in two manuscripts submitted to *Economic Geology*, and one manuscript submitted to *Geostandards and Geoanalytical Research*. This PhD project was submitted for external examination and is in the final stages of acceptance at the University of Tasmania.

"The expertise and resources at CODES have provided abundant opportunities for me to collaborate with experts in industry and academia from all around the world. I endeavoured at the beginning of this research project to make a significant impact on our understanding of hydrothermal minerals around porphyry ore deposits, and hope that I've accomplished that goal. I am proud of my time at CODES and am looking forward to more opportunities in the future in the United States."



In 2017 CODES-TMVC PhD student Jennifer Thompson undertook the Master of Economic Geology short course 'Ores in Magmatic Arcs' to Indonesia; while on the trip she collected samples from Batu Hijau (one of her PhD field sites). She is pictured on Kawah Ijen during the trip.

WHERE ARE THEY NOW?

In this issue Dr Jing Chen explains her journey from Peking University in Beijing to CODES and beyond, and reflects on the significant turning points in her career so far...

LUCKY CHANCE: HOW A 'RESERVED' YOUNG WOMAN FROM CHINA BECAME A SUCCESSFUL POSTDOCTORAL RESEARCHER



DR JING CHEN

**Postdoctoral Teaching Fellow,
Hefei University of Technology,
China**

PhD completed at CODES-TMVC in 2019 entitled 'Hydrothermal and structural evolution of the Zijinshan high sulfidation Au-Cu deposit, Fujian Province, China'.

What is your current employment and your work responsibilities?

I am currently working at Hefei University of Technology (HFUT) as a postdoctoral teaching fellow. My work focuses on research. Besides funding from the National Natural Science Foundation of China, my projects involve collaboration with local surveys and big mining companies, such as Tongling Non-ferrous Metals Group Co and Zijin Mining. I also get some consulting work, and run short courses in exploration skills – mapping and SWIR analyses. I undertake field trips

almost every month. China is very big, so you can always find the best season to go somewhere. Now, in summer, we go to Tibet and Northeast China. Occasionally there are some confirmed cases of COVID-19 in China, but our fieldwork is not affected. I feel very lucky that I can still travel and do my fieldwork during the pandemic.

What are the things you enjoy most about this role?

The most enjoyable part is teaching and training. I do not teach many classes on campus; my teaching mostly happens in the field with our PhD students, including teaching them many basic skills such as systematic sampling, mapping and core logging. These are important skills but unfortunately our current undergraduate college teaching does not include them. It's a great feeling of achievement when you find students can do a relatively independent research project and illustrate it with beautiful mapping work. It reminds me that I'm on the right track in training the younger generations of geologists.

How did you get there/your past roles and how they shaped your path?

I studied geology as an undergraduate at Peking University (PKU) from 2007 to 2011. Learning geology is not a bad choice because my dad told me geology can lead me to see a bigger world. I started my Masters in 2011, doing research on the biggest high sulfidation epithermal deposit in China – Zijinshan. In 2011 an SEG workshop was organised at China University of Geosciences (Beijing), which was very close to my uni, so I rode a bicycle to attend the workshop. I remember Zhaoshan Chang gave a talk about

epithermal deposits and I was deeply amazed. Before Zhaoshan's talk, I had never systematically learnt what porphyry and epithermal deposits are. It is not an exaggeration to say that this SEG workshop opened the door of the outside world and showed me real economic geology. Then I decided that I must study overseas. At the same time, Huayong Chen, our PKU alumni, who worked at CODES, gave a talk about IOCG deposits at the PKU campus. He introduced CODES after his talk, only one slide but very impressive. I read some articles published in *Economic Geology*, where I found half of the papers that I was interested in were all from CODES. Then I wrote an email to Huayong asking him to be my referee. I remember I directly wrote an email to Dave [Cooke] to apply to do a PhD. Honestly, I did not know he was so, so famous when I was young. Now I'm not sure I would have the courage to do this. It is a lucky story how I got to CODES – a series of coincidences that happened to a reserved and not very resourceful person. I think that SEG workshop was a great opportunity. I'm grateful that the SEG changed my life and I'd be very happy in the future if I could return this favour to the SEG.

The first few years of my PhD were tough for me because I was not well-trained in some basic field skills. But it was very worthwhile; I learnt a lot during my PhD and every skill helps me to survive my current research life. I got my job offer halfway through my PhD when I was on a field trip to Sweden and Iceland organised by the CODES SEG Student Chapter. Professor Taofa Zhou from HFUT invited me to join his team during the field trip. It was a big surprise because at that time I was a nobody in the research world.

Your career highpoint/greatest achievement to date/source of greatest satisfaction as a geologist?

Aha, currently the highpoint is still my PhD from CODES! But in my job, my source of satisfaction comes from both industry and from my students. With the former I am conducting a brownfield exploration. Nothing is more exciting than when you have predicted the target and the company has made a new tunnel and found a new orebody. Especially when the mine is about to finish its useful life. The mine can survive for another few years with our help. Although it is not as exciting as greenfield exploration when a new deposit is named after you. Still, it is very pleasing that we can give back to society and help local people.

I get great satisfaction also from my students. This year Noel [White] and I have supervised a PhD student who got an SEG student research grant. I believe my job goes beyond doing my own research work; it involves also bringing knowledge and international-level research back to China.

What did you specialise in at CODES and what did you enjoy most about CODES?

Halfway through my PhD, I had difficulties in mapping the structures and breccias which controlled the formation of giant high sulfidation epithermal deposits. Dave, José Piquer and Davey Selley helped me a lot with structural mapping and breccia interpretations. I also specialise in SWIR interpretation, which I owe to Lejun [Zhang] and Zhaoshan. They taught me not only to interpret mineral by mineral, but also the logic behind the spectra. The regular short courses and seminars at CODES were really helpful, as were the sponsors' meetings for AMIRA projects. It is always the most difficult time for every PhD student in the team, but I learnt more during sponsors' meetings than at any other time.

I enjoyed the atmosphere at CODES. Everyone loves CODES and feels as if they are a family member. Many years after we have graduated from CODES, we alumni still feel proud of the CODES name and I still feel I'm with CODES. I'm always keen to be back anytime if the travel restrictions to Australia are lifted.

How has the industry changed since you were at CODES? And how do you see it developing in the future?

The industry in China has changed to some degree. Several years ago, when a research team visited a mine site, you could feel the initial hostility from the local geologists. Now, most of the time I feel I'm welcomed. It is not as difficult to get access and data from industry as it was 10 years ago. The bridge is being built between industry and academia. But a lot of work is still needed for researchers to reduce the sense of distrust from industry. I believe good communication is always the best way; for example, sponsors' meetings! Recently we delivered updated results to our companies and they changed their first impressions after one or two meetings. The best way to have a successful project is always to prepare the best slides and talks for industry!

But there's still a lack of links between industry and academia in China. It is the work of young researchers to bring new concepts, good models, and new skills and technologies to the industry. Consulting work is always a good starting point because it does not cost too much. A company is always willing to incorporate a consultant's work into a research project if it provides good feedback.

In some remote areas, the local culture is still difficult to overcome. For many underground projects in remote areas, I have less chance of being able to go underground, which causes great inconvenience for my research. But gender discrimination is not prevalent in academia in China. Female geologists are always respected.

Words of wisdom for up-and-coming geologists graduating from CODES?

Attend conferences and be willing to share your work and knowledge. Your next sponsor may be in the audience. Particularly during the pandemic, there are more opportunities for you to present worldwide.

In the academic world, work ethics and intellectual property are very important. If you try to do things in a hurried way by hurting your reputation, it will make your future extremely difficult. So, value your reputation. Be loyal. Respect your sponsors and supervisors. Be strict with the confidentiality terms. If you are hesitant about some confidential issues, ask your supervisors. Never make a decision in rush.

If you have a project with industry, having a good relationship with local people will make your life much easier.



Dr Jing Chen (centre, back row) leading a field trip to look at lithocaps in South China. This photograph was taken in the city of Wenzhou in Zhejiang Province. Taking part in the trip were two Masters students from China University of Geoscience (Beijing) and two PhD students from Hefei University of Technology, under the guidance of two local geologists from Wenzhou 11th Geological Survey. The site is called Xiangshan, which is in Houkeng Village, where massive alunite and dickite are mined.

The lapidary people at the core shed, miners at the open pit, samplers, drivers and gate keepers, everyone can help you. So, respect their occupations and be willing to communicate with them.

Any little-known facts about yourself that you think we should know?

I must introduce my husband, Yi Sun. He is currently doing a PhD at CODES, supervised by Lejun, Ange [Escolme] and Dave. Now he is at the final writing stage and I really appreciate his lovely supervisors. They have taken good care of him during his PhD while I'm in China, especially during the COVID-19 pandemic. I feel very grateful.

We lived in Beijing before we came to Hobart. It is a new experience moving from a metropolis to a quiet and

remote place. After my life experience at Hobart, I have the confidence to build a comfortable life for myself. We learnt about chopping wood, painting, shipping second-hand furniture using our own ute. It is common in western countries but it was impossible to imagine this in our previous urban life.

One of my favourite questions about my name is what 'Jing' means in Chinese. The answer is 'quiet'. Many friends laugh because it is the opposite of me. Maybe 'crazy' would be a more suitable word. I have a strange harmony with my life at Hobart. I played badminton with my CODES friends. I regularly organised dinners at my place. I made my place a base for Chinese visiting scholars and students to Hobart. Many of them lived in my guest room before they found suitable accommodation. And some of them

lived in my guest room for a whole year! I'm very proud that I took care of them and we all became lifelong friends. After I returned to China, they also took care of me and helped me a lot!



Dr Jing Chen with her husband Yi Sun, who is currently doing a PhD at CODES, pictured at Twin Taung lake in Myanmar.

CODES CONNECT

CODES and Earth Sciences have many ways of keeping in touch with our researchers, staff, students, graduates, stakeholders, the mining and minerals research community, and industry bodies.

The CODES website (<https://www.utas.edu.au/codes>) is constantly being updated. UTAS is gradually upgrading its webpages and a new-look CODES website will be available soon.

The Discipline of Earth Sciences webpage ([https://www.utas.edu.au/natural-sciences/earth-](https://www.utas.edu.au/natural-sciences/earth-sciences)

sciences) has been updated and now has a link to the Earth Sciences Facebook page as well as short profiles with videos about some of our student researchers.

You can follow one of our Facebook pages:

f CODES: <https://www.facebook.com/CODES.UTAS/>

f Earth Sciences: <https://www.facebook.com/EarthSciUTAS/>

f TMVC: <https://www.facebook.com/tmvc.utas/>

You can also follow one of our LinkedIn pages:

in CODES: [linkedin.com/company/codes-utas](https://www.linkedin.com/company/codes-utas)

in TMVC: [linkedin.com/company/tmvc-utas](https://www.linkedin.com/company/tmvc-utas)

BECOME A SUBSCRIBER

If you want to join one of our mailing lists to receive regular updates (newsletters/annual reports/short course information/PhD opportunities or job vacancies) please email us at:

CODES.info@utas.edu.au

CODES INDUSTRY PARTNERS 2021

Several new Industry Partners have joined with CODES in the past few months; our current Industry Partners are listed here. Please contact us if you would like your company to be an important supporter of CODES' research.

PLATINUM



GOLD



SILVER



COPPER



THE ENDGAME: CODES PROJECTS YIELD RESULTS

This year has seen the finalisation of several important research projects at CODES with exciting results that in some cases are leading to further research. Here some of the leading researchers from these projects outline the outcomes of their endeavours.



Photo of core showing pyrite-chalcopryite-hematite-quartz vein with phengite to hematite selvage from the Resolution Cu-Mo porphyry deposit, Arizona, a study site for AMIRA P1202 Module 4, which came to a successful conclusion in July.

AMIRA P1202 DELIVERS NEW TOOLS FOR EXPLORERS AND MINERS – WITH MORE IN THE PIPELINE!

BY DR ANGELA ESCOLME

During June and early July, the major culminating project of the ARC TMVC Research Hub, AMIRA P1202 'Far-field and near-mine footprints: Finding and defining the next generation of Tier 1 ore deposits' led by Professor David Cooke, that has run over the past three years was brought to a conclusion. Aspirations for an in-person meeting were dashed at the last minute by developing COVID-19 outbreaks on the mainland but a series of successful final reports and meetings were held online. The project comprised of four modules: modules 1–3 (sponsored by 14 industry partners) developed exploration tools in the greenrock environment (led by Dr Mike Baker) and lithocap environment (led by Dr Lejun Zhang), and magmatic indicator minerals (led by Professor Leonid Danyushevsky), as well interpretive software for mineral chemistry data (LocatOre). Module 4 (an elective module led by Dr Angela Escolme and sponsored by six of the companies) included a broad range of additional research outcomes applicable to overprinted

porphyry systems including white mica and pyrite mineral chemistry studies, techniques in calculating mineralogy from geochemical data, and algorithms for the mineralogical and textural classification of hyperspectral images.

The project involved a large team of researchers including 12 UTAS staff, six collaborators and 17 students (PhD, Masters and Honours) from four academic institutions (UTAS, Monash University, Lakehead University and Universidad Austral de Chile). Over the course of the project, researchers worked on 28 sites across five continents to further our geological understanding and develop tools for explorers and miners. The success of the P1202 project has generated several exciting new and follow-up research initiatives that will form a new AMIRA project (proposal P1249 – see page 20) that is currently open for sponsorship and expected to commence in 2022.

JOINT PROJECT WITH CRC ORE IDENTIFIES ADVANCES IN IDENTIFYING UPGRADE POTENTIAL

BY DR JULIE HUNT

The Cooperative Research Centre for Optimising Resource Extraction (CRC ORE), based in Brisbane, came

to a successful conclusion at the end of June 2021. CRC ORE focused on improving the productivity, energy and water signatures of mining operations and delivered significant results in five program areas: Define, Separate, Extract, Control, Operate (crcode.org.au). CODES was involved in the CRC ORE 'Define' program in a collaborative project called 'Geological controls on grade-by-size fractionation' (known as P1-006) to identify links between upgrade potential via screening and geological parameters. P1-006 successfully completed deliverables that are included in the final outputs of CRC ORE (the P1-006 snapshot, summary and detailed final reports are available via the CRC ORE website to members). Summaries of work were presented at the Preconcentration 2020 Conference: 'Grade Engineering at Gramalote gold deposit, Colombia'; the Sustainable Minerals '21 Conference: 'Estimation of preferential grade-by-size deportment in gold systems'; and the SEG 100 Conference: 'Increasing efficiency through understanding geological controls on Grade Engineering'. In addition, Nathaly Guerrero has submitted her Masters thesis entitled 'Geological controls on grade-by-size fractionation in gold systems' for examination. The final



CRC ORE Annual Assembly, 2021: Dr Julie Hunt looking at the new CRC ORE WIKI with developer Patrick Walter.

CRC ORE Annual Assembly was held in May 2021 and was attended by Dr Julie Hunt and Nathaly Guerrero.

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

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

Although the project completed deliverables to CRC ORE in June 2021 it will continue until June 2022 in order to deliver additional outcomes. Masters student Karla Morales is scheduled to submit her thesis titled 'Geological predictors for pre-concentration' in February 2022. Work is ongoing on a 'Library of mineralisation styles and

upgrade potential via screening' which will be available online. Summaries of the work are planned to be presented at the 16th SGA Conference in 2022: 'Geological characterisation to identify upgrade potential and enhance mining efficiency' and 'Geological controls for pre-concentration in an intrusive-related gold deposit'.

NW QUEENSLAND PROJECT EXPANDS THE IOCG MINERAL FOOTPRINT

BY DR JEFF STEADMAN

CODES Program 3 project, 'Mineral geochemistry vectoring: Uncovering Northwest Queensland's hidden potential', came to a successful conclusion in June 2021. This project was financially supported by the Queensland Department of Natural Resources, Mines and Energy (DNRME) via the Geological Survey of Queensland. Additional in-kind support was provided by Glencore/ Mount Isa Mines, Chinova Resources, Capricorn Copper and CSIRO.

This project – led by Professor David Cooke, Dr Jonathan Cloutier, Dr Jeff Steadman and Associate Professor Shaun Barker – was the first to employ low-level trace element geochemistry across a range of hydrothermal minerals and Cu-Au systems in both

the Eastern and Western fold belts, with the aim of providing chemical 'fingerprints' of mineral systems in these areas. From this information, chemical vectors can be developed to help geologists expand the known 'footprint' of hydrothermal alteration in real-world exploration scenarios.

Key outcomes from this project include:

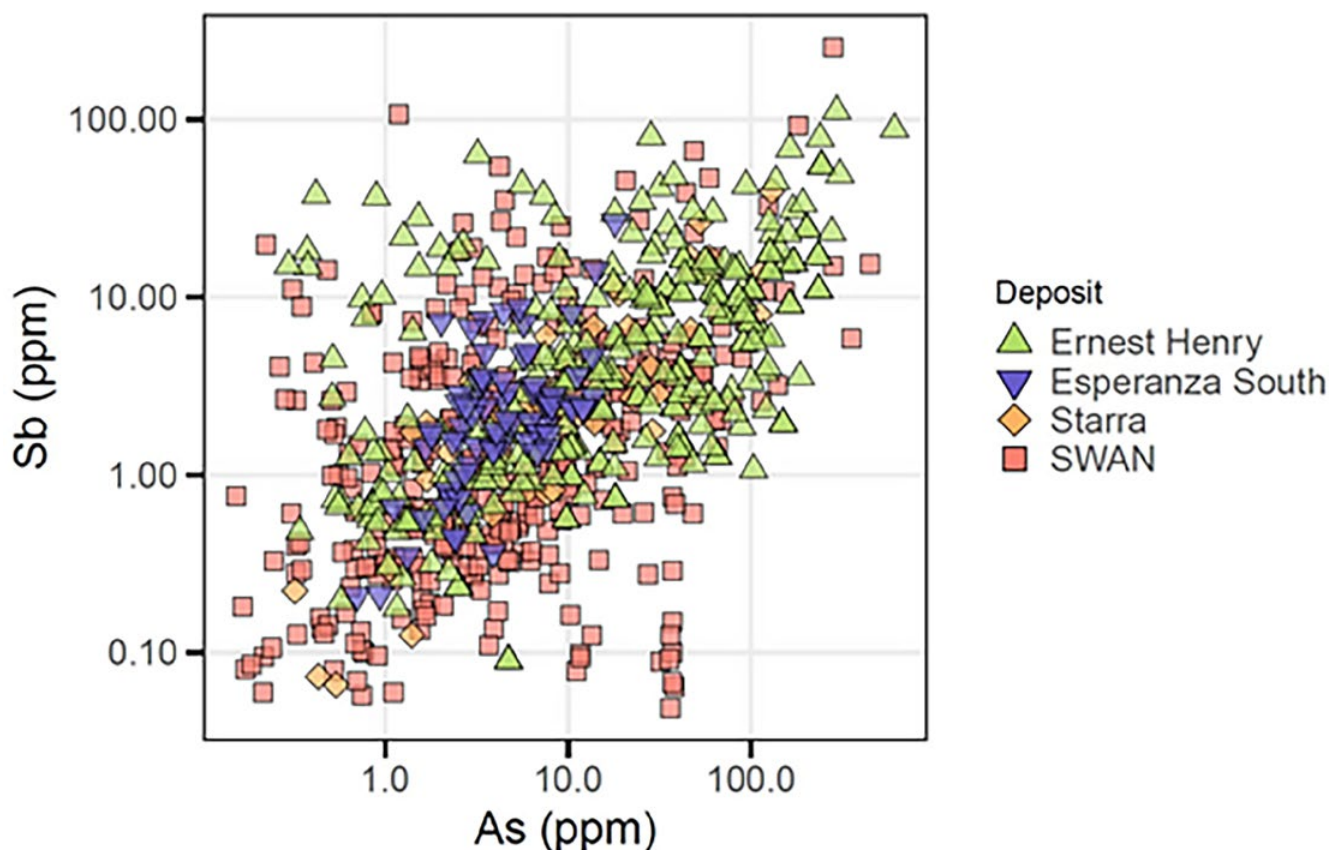
- Diagnostic chemical 'fingerprint' of pyrite related to Ernest Henry-style copper-gold mineralisation.
- Correlation of epidote trace element chemistry with distance from mineralisation at both Ernest Henry and SWAN (i.e., expanding the 'footprint').
- Re-interpretation of the local geology around SWAN, indicating the involvement of mafic intrusions in the creation of the SWAN and Mt Elliot deposits.
- Identification of pyrobitumen in hydrothermal dolomite veins at Lady Annie.
- Identification of Cu-bearing hydrothermal hematite in the chalcopyrite ore zone at Esperanza South.

Follow-on work is planned for the Ernest Henry area as part of Associate Professor Sebastien Meffre's ARC Linkage proposal on IOCG deposits (slated to begin in early 2022, if funded), with additional study sites being negotiated in both Queensland and South Australia to be negotiated with sponsor companies.

LEADING VOLCANOLOGY RESEARCH AT CODES PIVOTAL FOR UNDERSTANDING MAGMA AND ASSOCIATED FLUID FLOW DYNAMICS IN SUBMARINE SETTINGS

**BY ASSOCIATE PROFESSOR
REBECCA CAREY**

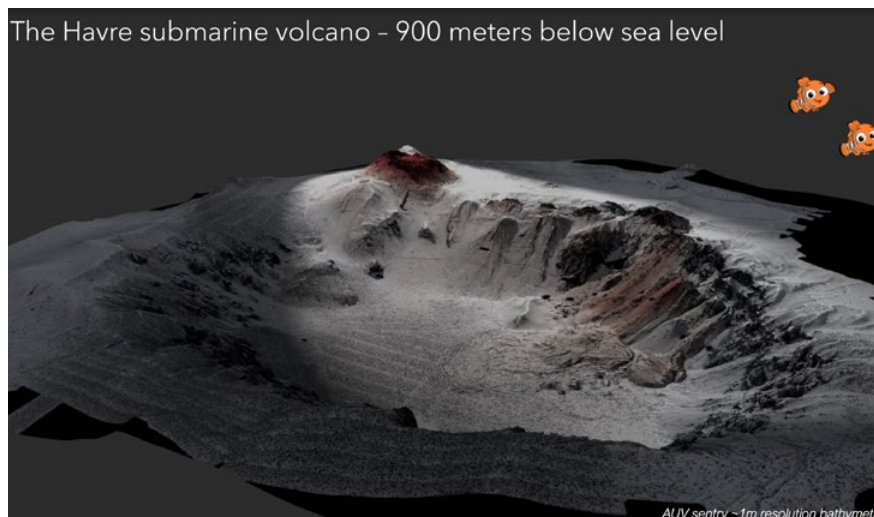
CODES has a long history of research in modern and ancient studies of submarine volcanoes, eruption process and products. Over the past decade a CODES research team led by Associate Professor Rebecca Carey has been leading an international project in submarine volcanology focused on the 2012 deep sea silicic eruption of Havre volcano, Kermadec Arc, New Zealand. A ship-based survey including remotely operated and autonomous vehicles



The NW Queensland project: Antimony (Sb) and arsenic (As) concentrations in epidote from Ernest Henry, SWAN, Starra and Esperanza South. The highest Sb and As values are present in samples furthest from known mineralisation. This is akin to the behaviour of Sb and As in epidote from porphyry Cu-Au-Mo deposits, which increases confidence in the use of epidote as an indicator mineral for IOCG-style targets in the Mount Isa Inlier.

conducted “fieldwork” (similar to what geologists would do on land), which provided a stratigraphic framework of the eruption deposits and important quantitative constraints on eruption parameters. These constraints cannot be underestimated as they have provided for the first time the missing parameters critical in the development of numerical models that help us to understand how confining pressure and water modifies magma ascent and eruption in the deep ocean.

The team includes CODES scientists Professor Jocelyn McPhie, Dr Martin Jutzeler and PhD students Fumihiko Ikegami, Acacia Clark and Erica Spain (IMAS) in addition to a further 29 students and scientists from 15 international institutions. Together this team has published 19 papers in high-profile journals that include *Nature Geoscience*, *Science Advances*, *Nature Communications* and *Earth Science Planetary Letters*. Two highlights include:



Submarine volcano research: 3D visualisation of the Havre caldera volcano at >900 m below sea level. The 2012 eruption products are highlighted in red to pink colours.

1. the role of hydrostatic pressure in modulating eruption style – at a vent depth of 900 m for the Havre eruption, the magma retained enough dissolved water and had a low enough viscosity that strain rates were too low to cause brittle fragmentation in the conduit, despite

mass discharge rates that were similar to large powerful eruptions on land. This numerical modelling may be used to infer minimum paleo eruption depths of submarine volcanic successions in the ancient Australian crust – a key parameter for ore vectoring; and

2. the first ever quantification of syn-eruptive volatile fluxes through the magma into the surrounding seafloor – at magma fluxes calculated for the 2012 eruption, numerical models calculate that a substantial fraction of the magmatic volatile budget, ~25% and 70% for two different eruptive phases, was injected into the sub-seafloor around the magmatic conduit. This research potentially explains the enigma of widespread alteration halos around magmatic-epithermal mineralisation observed in ancient volcanic terrains in Australia.

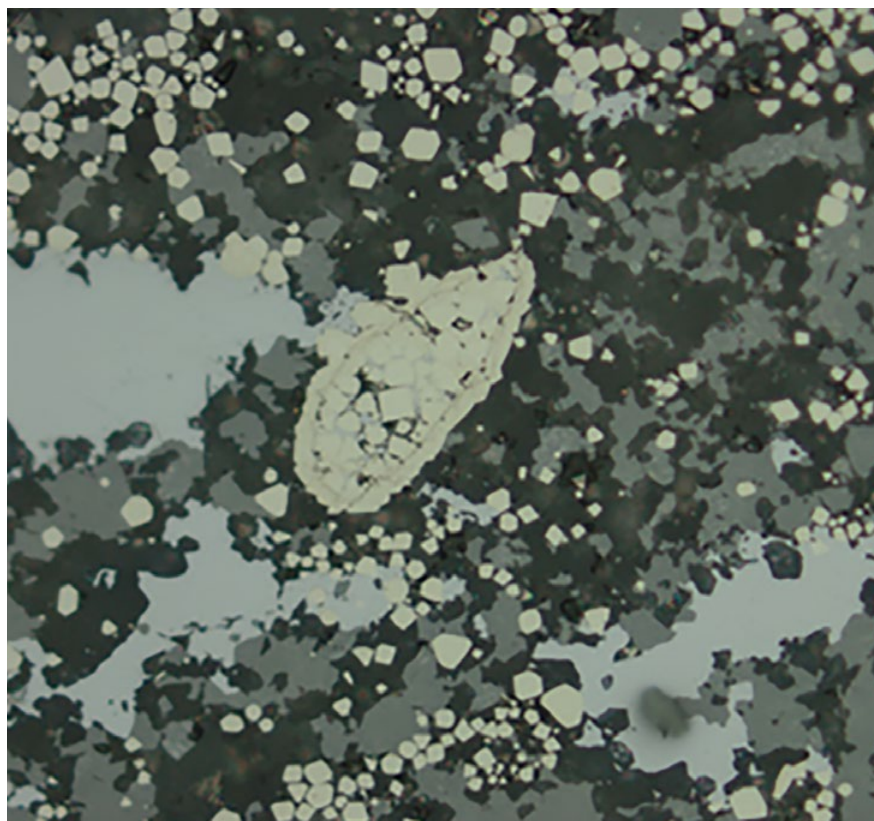
We are working with other economic geologists and industry partners to apply this new understanding to better characterise ancient eruption environments and find new critical metals resources for renewable energy.

APPLICATION OF PYRITE CHEMISTRY IN ORE DEPOSIT AND DEEP-TIME GEOLOGY

BY DR INDRANI MUKHERJEE

The PY005 project delivered its final results on 23 and 24 September 2021. This two-year project was partly funded by the Ian Potter Foundation and partly by industry (seven mining companies and two state geological surveys). The team comprised of four UTAS staff, two international collaborators, one Masters and two Honours students. This project focused on both fundamental and applied aspects of pyrite geochemistry. The former investigated the value of pyrite geochemistry in establishing deep-time trends of nutrient availability in ancient oceans and its profound impact on the evolution of early life. The latter explored the use of the pyrite technique in devising and informing exploration strategies for sediment-hosted ore deposits. The industry sub-project comprised five case studies on sediment-hosted Zn-Pb and Cu deposits in Australia, Canada and the USA.

Indrani Mukherjee, recipient of the Ian Potter Postdoctoral Fellowship, successfully completed her sub-project early this year including final reporting. The results of her sub-project provided insights into past ocean chemistry and the evolution of early complex life and generated five publications in peer-reviewed



journals (including *Geology*). Also included in this number is an invited contribution to the *Encyclopedia of the UN Sustainable Development Goals: Life on Land*, published by Springer Nature. Indrani also fulfilled the Ian Potter commitments via actively disseminating her research results through conference presentations (Goldschmidt 2020) and public outreach (National Science Week, 2019; ABC Radio interviews).

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

PY005: Pyrite (potentially replacing a bio-clast) and sphalerite in the Barney Creek Formation, northern Australia.



JOIN US: OPPORTUNITIES FOR SPONSORSHIP AS CODES CONTINUES COLLABORATION WITH AMIRA GLOBAL

CODES Director Professor David Cooke outlines three upcoming AMIRA projects scheduled to begin in coming months, and emphasises that there is plenty of time for your company to become involved in these exciting ventures...



An early start for AMIRA P1202 Module 4 research team members Dr Mike Baker and Javier Merrill with Alina Gaibor (BHP) at the Spence core facilities, Chile. This project came to a conclusion in July this year but will be followed by AMIRA P1249.

P1249

The next phase in the AMIRA Global porphyry footprints program, P1249: 'Exploring, characterising, and optimising complex orebodies – Integrated deposit knowledge to add value across the Mining Value Chain', is scheduled to commence in January 2022. This five-year project will provide its sponsors with new tools for recognising proximity to high-grade ore, and new tools, methods and workflows for translating and upscaling mineralogical, geochemical and hyperspectral data

into quantitative mineralogy for complex orebodies of copper, gold, critical and other metals. We aim to optimise orebody knowledge and provide the information required for mineralogical domaining and resource definition at the mine scale. P1249 will focus on transition zones – the alteration domains that extend from the orebody into the surrounding unmineralised rocks.

Although the primary focus of the project will be on porphyry, epithermal, carbonate replacement and skarn deposits, the project is also applicable to Mt Isa-style Cu, IOCG, orogenic

Au and other deposit styles. The research team are currently working with industry partners to finalise the sponsorship group for P1249 and determine the study sites and scope of the research program, with a planning meeting tentatively scheduled for early November 2021. The project is still open for sponsorship – for more details and inquiries contact Professor David Cooke (d.cooke@utas.edu.au) and/or Olga Verezub (olga.verezub@amira.global), who will be happy to meet with potential sponsors to provide an overview of the scope and objectives of the project.

P1206A

AMIRA Global project P1206 – ‘Identifying unique Resistate Indicator Mineral (RIM) chemistry as a guide in prospectivity for sediment-hosted copper mineralisation’ – was a one-year pilot study that was completed in April 2021. This project was funded by several mining and exploration companies, and achieved proof-of-concept regarding the potential for several resistate indicator minerals providing fertility and vectoring information for sediment-hosted copper mineralisation in the African Copperbelt. Feedback from the P1206 sponsors has been positive, and the research team are currently preparing a proposal for the next phase of the research program – P1206A – to follow on from P1206. We plan to expand the program beyond its original focus on the African Copperbelt, to investigate other Cu mineralised sedimentary basins, and to assess the fertility signatures of barren basins as comparators. The project will utilise the extensive sediment-hosted Cu sample archive from the African Copperbelt housed at CODES to ensure that any COVID-related travel restrictions do not impede project startup. The P1206A proposal will be distributed by AMIRA later in 2021. If your company is interested in learning more about P1206A, please contact Professor David Cooke (d.cooke@utas.edu.au) and/or Hayley McGillivray (Hayley.McGillivray@amira.global) to arrange a meeting to discuss the scope and objectives of the project and the sponsorship requirements.

IN ADDITION...

FURTHER OPPORTUNITIES FOR INVOLVEMENT

CODES will also be distributing an expression of interest document in 2021 to potential sponsors interested in a new collaborative industry-funded research project investigating the footprints, basinal settings and geodynamic drivers of Proterozoic Au and sediment-hosted Zn-Pb-Ag deposits. Although this project is likely to have a strong Australian focus, we also welcome expressions of interest from international industry partners. Please contact CODES.info@utas.edu.au for more information.



Sandstones and conglomerates that are facies equivalents of the Kolwezi Cu deposit footwall, Democratic Republic of the Congo.

WRITTEN IN CODES: THE POETRY OF SCIENCE



Recently ‘The Poetry of Science’ poetry competition was run in collaboration with National Science Week, and our very own CODES PhD student Peter Berger was placed second following a public voting process! His winning poem is reproduced here:

Pterosaurs

Outside of my window I hear them
screech.
They’re smaller now, all white with
sulphur crests.
Distant cousins and yet their mode of
speech
remains the same, passed down from
nest to nest.

CODES PhD student Acacia Clark, who has just started her research, also entered but was not placed. CODES Honorary Associate Dr Tony Webster received an honourable mention for his (very geological) poem.

Go to thepoetryofscience2021.wordpress.com to see all the entries. Peter Berger is No. 29, Acacia Clark is No. 17 and Tony Webster is No. 37.

RELAX AND ENJOY...

With very limited exposure to the COVID-19 virus in Tasmania and fewer restrictions than in previous months across the state, CODES and Earth Sciences staff and students have been able to hold COVID-safe social occasions, talks and meetings – much needed at a time when many of the CODES and Earth Sciences cohort is sorely missing family and friends living overseas. Here is a selection of these gatherings...



IDAHOBIT Day (May)

On 17 May PhD student Acacia Clark, Research Fellow Indrani Mukherjee and PhD student Hannah Moore (pictured here, L–R) organised a morning tea – for which they baked suitably colourful and spectacular cakes – to mark IDAHOBIT Day. IDAHOBIT stands for International Day Against Homophobia, Biphobia, Intersexphobia and Transphobia. There was a good turnout in the CODES Conference Room for the morning tea, which was run in conjunction with an online presentation from geologist Amber Jarrett from the Northern Territory Geological Survey talking about the importance of acceptance of and respect for all within the workplace.



3rd Annual Garry Davidson Memorial Footy Match (May)

In late May CODES/ES staff and students again remembered their colleague and mentor Dr Garry Davidson, who passed away in 2017. This year's memorial footy match was held under sunny skies on the main UTAS oval. Staff and students fielded enthusiastic teams but, in what is becoming something of a tradition, the staff team won out with the final score being 4 to 1, and took home the fluffy white unicorn trophy. Dr Karin Orth and Associate Professor Rebecca Carey were instrumental in organising the event.

Above: The victorious staff team: (L–R) Back row: Rob Scott, Indrani Mukherjee, Miles Smith, Matt Cracknell, Martin Jutzeler; Front row: Sebastien Meffre, Rebecca Carey and Mike Baker.

Below: Play in progress during the 3rd Annual Garry Davidson Memorial Footy Match at Sandy Bay, held in late May.





Celebratory Morning Tea (June)

CODES/ES staff and students gathered in late June to mark the arrival of new PhD students, research grants secured by students and staff, talks given by students and introducing Eleanor Marshall as the temporary CODES admin person in Karen Huizing's absence.

Left: Professor David Cooke, Associate Professor Sebastien Meffre and CODES-TMVC PhD student Emily Smyk at the CODES celebratory morning tea.

Below (L-R): PhD students Hannah Moore, Xin Ni Seow and Rhiannon Jones, Postdoctoral Research Fellow Dr Francisco Testa and Senior Research Fellow Dr Lejun Zhang celebrate the achievements of their CODES colleagues at the June morning tea.



Wear It Purple Day (August)

Wear It Purple Day exists to encourage workplaces, schools and communities to create supportive, safe, empowering and inclusive spaces for LGBTQI+ youth; it was marked at CODES by a competition for the best-dressed wearer of clothes in a purple/ LGBTQI+ theme. The joint winners were Izzy von Lichtan and Matthew Cracknell (pictured). The winners shared a pack of prizes that included purple vegetables and flowers.

KING ISLAND MINERALS AND MAGMA DO NOT FAIL TO IMPRESS

Earlier this year the CODES SEG Student Chapter organised a field trip to King Island where they were treated to some stunning geology. CODES PhD student and President of the Student Chapter Hannah Moore reports.



CODES/Earth Sciences students and staff at the Grassy Mine during the April 2021 CODES SEG Student Chapter field trip to King Island.

Between 13 and 18 April 2021, a group of 16 UTAS CODES/Earth Sciences postgrad students and staff participated in a student-run CODES SEG Student Chapter field trip to King Island. The aim of this trip was to discover the unique geology of the island, particularly focusing on the economic geology, a mutual interest amongst all students and staff on the trip. The trip was made possible by Geological Society of Australia sponsorship and fundraising activities by the CODES SEG Student Chapter.

The first day involved a trip to King Island Dairy for a cheese tasting (to well and truly clog our arteries), followed by introductory geology presentations by Dr Nicholas Direen (Adjunct CODES staff), Professor David Cooke (Director of CODES) and Dr Lejun Zhang (Senior Research Fellow). These presentations included some lively debates/heated discussions.

Day 2 was a trip to Grassy Mine to see the skarn mineralisation and Hornfels of the Grassy Group (including exquisite minerals such as scheelite

and garnet). This currently disused mine hosts Australia's largest tungsten deposit, that formed when a large mass of granite intruded into older, calcareous rocks, 351 million years ago (mya). In the afternoon we travelled northeast to Naracoopa, where we saw the equivalent unaltered rocks to those which we saw in the mine. There was a follow-up visit to the MRT core library to look at drill holes from the Grassy Mine in May 2021.

On Day 3, we visited Stokes Point, the most southerly point of the island, to

see the oldest rocks in the Southeast Australia region: the Mesoproterozoic (1300 mya) metasediments of the Surprise Bay Formation. Students and staff were thrilled by the stunning metamorphic minerals (garnet and andalusite), the tight folds of the metasediments and the more recently formed 'calcified forest'. The afternoon involved a transect through the metasediments at Cape Wickham to see the changes in the rocks with increasing proximity to the heat source, a granite intrusion, which caused the contact metamorphism.

Day 4's visit to City of Melbourne Bay was an exciting change of scene, geologically. Here lie Glacial deposits from Earth's most severe ice age ('Snowball Earth') 636 mya; this is a globally significant location for paleogeographic reconstructions for the Neoproterozoic glaciation. Some fascinating volcanic rocks can also be found at City of Melbourne Bay, including some amazing volcanic breccias and pillow lavas, which form when hot magma enters seawater. To conclude our trip on King Island, we held a BBQ celebration and the students ran a self-guided tour of the coast around Currie, where ancient sedimentary rocks of the Surprise Bay Formation can be found.

The President of the SEG Student Chapter would like to thank the Geological Society of Australia for its sponsorship; Karen Huizing for her assistance in the organisation of the trip; Zeb Zivkovic and Alex Farrar for their research and organisation of the itinerary; Nicholas Direen for taking the time to share his knowledge with us; Tim Callaghan for granting us access to the Grassy Mine; David Cooke and Lejun Zhang for their lectures on Skarn mineralisation; and all of the attendees for being so enthusiastic during the fieldtrip.

Please watch our vlog-style video from the trip here:
[youtube.com/watch?v=aCiLxbCWu18](https://www.youtube.com/watch?v=aCiLxbCWu18)

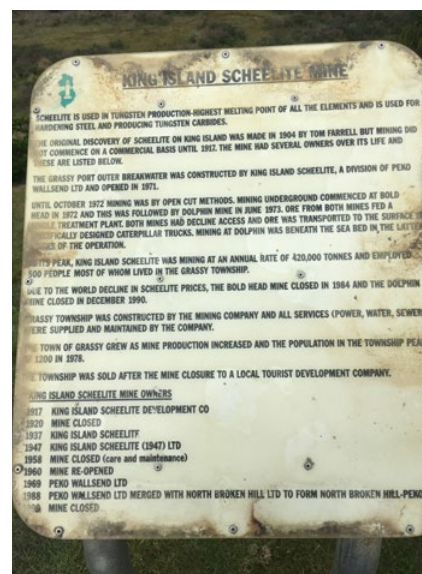
And the field trip report with details of the rocks studied is at:
www.segweb.org/pdf/students/student-chapters/university-of-tasmania-codes/Field-Trip-Report.pdf



Participants in the CODES SEG Student Chapter field trip to King Island, pictured at Stokes Point looking at metasedimentary rocks of the Mesoproterozoic Surprise Bay Formation.



Drs Michael Roach and Nicholas Direen explore the area around the Boatshed at Currie on King Island during the CODES SEG Student Chapter field trip to the island in April 2021.



Left: Bladed calcite photographed at the Grassy Mine during the field trip. Right: A weathered sign at the disused King Island Scheelite Mine succinctly details the history of the mine from its opening in 1917 until it closed in 1990.

BLAST FROM THE PAST



The young ones: this group photo of CODES staff pictured outside the CODES offices in Hobart was taken in 2003 and shows many of your current colleagues and collaborators looking keen and youthful on what appears to be a warm, sunny day.




Note: Titles given are from the date of the photo. CODES programs were not the same in 2003 as they are now.



1. **Dr Andrew Tunks:** then Masters Coordinator and lecturer/nor Managing Director, Meteoric Resources
2. **Dr Stuart Bull:** then CODES researcher/nor CODES University Associate
3. **Dr David Cooke:** then Program 5 Leader/nor a Professor and Director of CODES
4. **Mr Wally Herrmann:** then a CODES researcher/nor a consultant geologist
5. **Dr Andrew Rae:** then a CODES researcher/nor Geothermal Exploration Geologist at GNS, NZ
6. **Dr Cari Deyell:** then a postdoctoral fellow/nor Chief Geologist, Corescan
7. **Dr Cathryn Gifkins:** then CODES researcher/nor living in Canada
8. **Dr Bruce Gemmell:** then CODES Program 3 Leader/nor a Professor and CODES Adjunct Senior Researcher
9. **Associate Professor Jocelyn McPhie:** then CODES Program 2 Leader/nor Adjunct Professor in Volcanology
10. **Professor Ross Large:** then Director of CODES/nor UTAS Distinguished Professor
11. **Dr Leonid Danyushevsky:** then CODES Senior Research Fellow in the LA-ICP-MS lab/nor a Professor and Deputy Director of CODES and Leader of the CODES Analytical Laboratories
12. **Associate Professor Tony Crawford:** then Deputy Director of CODES and Program 1 Leader/nor CODES Honorary Professor
13. **Dr Mike Solomon:** then senior CODES researcher/Mike passed away in 2009
14. **Dr Robert Scott:** then CODES researcher/nor Masters Coordinator and Senior Lecturer
15. **Dr Vadim Kamenetsky:** then CODES Research Fellow/nor New Star Professor in Earth Sciences
16. **Dr Sebastien Meffre:** then CODES postdoctoral fellow/nor Associate Professor in Earth Sciences and Head of the Discipline of Earth Sciences
17. **Dr David Selley:** then CODES researcher/nor CODES Adjunct Senior Researcher
18. **Dr Fernando Della Pasqua:** then CODES researcher/nor living in New Zealand
19. **Dr Ron Berry:** then Head of the School Earth Sciences/nor Associate Professor and CODES University Associate.

CHANGING FACES

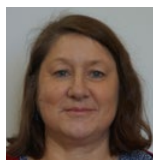
Despite the ongoing COVID-19 pandemic three new PhD students have been able to start their projects at CODES and one of our researchers has escaped to Canberra...

PHD STUDENT	START DATE	PROGRAM	PROJECT TOPIC
 Acacia Clark	May 2021	Program 4, supervised by Rebecca Carey and Martin Jutzeler	Silicic explosive volcanism: Understanding the conditions of steady and unsteady eruptive behaviour of silicic magma – the Kaharoa AD 1315 eruption
 Richard Hill	August 2021	Program 6 supervised by Robert Scott, Matthew Cracknell, Michael Roach and David Giles (Uni SA)	Prospectivity analysis of the East Tennant Region
 Shannon Frey	September 2021	Program 4, supervised by Martin Jutzeler and Rebecca Carey	Behaviour of submarine caldera-forming silicic eruptions in the Kermadec Arc

ARRIVALS



Regi Broeren joined CODES/Earth Sciences as a part-time Technical Officer in April 2021 and is working on safety issues, risk assessments and technical issues as they arise.



Eleanor Marshall has stepped into the role of CODES gatekeeper (AKA CODES Administration Officer) until the end of the year while Karen Huizing is away on long service leave.

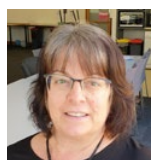


Vanessa Seabourne is now the go-to person for Earth Sciences administration matters; she took up the role of Senior Administration Officer in July and is based in the new Earth Sciences reception on level 3 (shared with Geography, Planning and Spatial Sciences) – across the stairs from the old Earth Sciences reception.

DEPARTURES



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

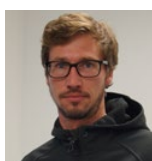


Trish McKay, Senior Administration Officer in the Earth Sciences office, moved to work in the UTAS Office of Research Services in June. Under an administration restructure her role was taken over by Vanessa Seabourne from the School of Natural Sciences College Services team.

PROMOTIONS AND NEW ROLES



Dr Paul Olin, Deputy Leader of the CODES Analytical Laboratories, has had his role converted to a continuing position.



Dr Ivan Belousov, Laboratory Analyst in the CODES Analytical Laboratories, has had his role converted to a continuing position.



Dr Angela Escolme was promoted to Senior Lecturer in August.



**A MESSAGE
FROM THE
CODES
DIRECTOR,
PROFESSOR
DAVID COOKE**

Our staff and students have continued to do great work throughout 2021 despite the frustrations and disruptions that we've all experienced with the pandemic. With the vaccine roll-out in Australia now proceeding

apace, we are preparing for the transition from isolating to avoid the hazards of COVID-19 to living with the virus endemic in the community. This is going to create more uncertainty and disruption to travel for the rest of 2021 as Australia first reopens state borders, and then tentatively reopens to the international community.

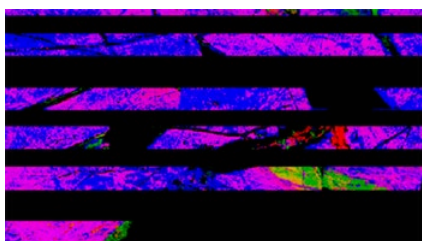
While there is uncertainty and no doubt some anxiety as to what may come during this transition, I believe that we

are all looking forward to a return to travel, so that we can reconnect with loved ones, conduct fieldwork, recruit international staff and students and hopefully participate again in face-to-face meetings and conferences in 2022.

I am sure we all have our fingers crossed for a successful transition back towards normalcy!

Best regards
Dave

UPCOMING SHORT COURSES



**GEOMETALLURGY
(KEA702/KEA711*)**

**18–23 OCTOBER AND
15–19 NOVEMBER
ONLINE**

This course will give attendees a comprehensive overview of practical geometallurgy, from mineral processing fundamentals to deposit characterisation.

Geometallurgy involves a quantified and comprehensive approach to ore characterisation in terms of critical processing attributes such as blasting, crushing, grinding, liberation, recovery and environmental management. Key outcomes of increased geometallurgical knowledge are improved forecasting, reduced technical risk, enhanced economic optimisation of mineral production, and improved sustainability. This course introduces a range of



techniques for 'early-stage' (e.g., exploration, prefeasibility) collection of geological information that is relevant to mining engineers and metallurgists. The program includes lectures, practical exercises (including a computer-based modelling exercise) and a virtual field trip to a mine in western Tasmania.

For further details and to register, see the course flyer at:

www.utas.edu.au/__data/assets/pdf_file/0007/1473838/Geomet-flyer-2021_v6-sm.pdf

**ORES IN MAGMATIC ARCS
(KEA706/KEA707*)**

**22 NOVEMBER–3 DECEMBER
IN-PERSON**

Due to COVID-19 restrictions, this two-week course will be based entirely in Tasmania. It will include a one-week field excursion to western Tasmania to learn about Cambrian polymetallic VHMS and high sulfidation state mineralisation that formed in a back-arc setting, and Devonian-Carboniferous skarn, vein and granite-

related carbonate replacement-style Sn-W-Fe-Cu-Zn-Pb-Ag deposits that formed in a post-collisional orogenic belt. The second week of the course will involve lectures and pracs at CODES, reviewing case studies of ores from magmatic arcs from South America (El Teniente, Rio Blanco, Cerro Casale, Las Bambas, Yanacocha, La Zanja, etc.), Indonesia (Tujuh Bukit, Batu Hijau, Elang), the Philippines (Lepanto-Far South East, Baguio district, Boyongan, Didipio), Papua New Guinea (Lihir, Porgera, Wafi-Golpu) and eastern Australia (Cadia, Northparkes, Cowal), utilising the extensive sample and teaching collections that reside in the CODES archives.

More details regarding the course program will be advertised on the CODES website soon.

For further information about short courses, please email:
CODES.Info@utas.edu.au OR
Master of Economic Geology Program
Co-ordinator, Dr Robert Scott:
Robert.Scott@utas.edu.au
For all other CODES contacts,
see page 2.