CRITCON 2023—Discovery, Characterisation and Processing of Critical Minerals: Abstract Volume

The University of Adelaide
AND
Geological Survey of South Australia, Department for Energy and Mining, Government of South Australia

Edited by Jarred C. Lloyd

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Government
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Institute for Sustainability,
Energy and Resources.

ACKNOWLEDGMENT OF COUNTRY

Ngadlurlu Kaurna miyurna tampinthi. Parna yarta mathanya Wama Tarntanyaku. University of Adelaide Kaurna yartangka yuwanthi – Tarntanyangga (North Terrace), Waitengga, Roseworthyngga kuma.

Translation:
"We recognise Kaurna people. They are the landowners/custodians of the Adelaide Plains. The University of Adelaide stands on Kaurna land in Adelaide (south of the River Torrens) at Waite and at Roseworthy too."

This Kaurna acknowledgement was provided by Kaurna Elder, Uncle Rod O'Brien and Dr Robert Amery of the Linguistics Department at the University of Adelaide.

SUB CRUCE LUMEN

THE UNIVERSITY
of ADELAIDE

Yantupinarna Kaurna yartangka, ngaldu tampinthi tupa yaintya pirku wapinthi, wiwunthi yaitya yarta, yarlu, ngayirda, miyurnakuma parnaku tuwila tap purruna tarraitpayinthi. Muna tirntu parrka-parrka wanti.

Ngadluku taingi ngutu yungkurrinthi, tampinthi yurni ngantanthi pukingka, niipurna pinyathi mankurrititya, taingintya, tarrkarri pintyanthi.

Nata ngadlu padnitha, tirkatha Kuma kumangka warpulayi-utha.

Translation:
"As guests here on Kaurna land, we acknowledge everything this department does impacts on Aboriginal country, the sea, the sky, its people and their spiritual and cultural connection which have existed since the first sunrise.

Our responsibility is to share our collaborative knowledge, recognise a difficult history, respect the relationships made over time, and create a stronger future.

We are ready to walk, learn and work together."

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Energy and Mining

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THE UNIVERSITY
OF QUEENSLAND
AUSTRALIA

AUSTRALIAN
RARE EARTHS
Metals for our future

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CRITCON 2023—Discovery, Characterisation and Processing of Critical Minerals: Abstract Volume

Jarred C. Lloyd (editor) and Carl Spandler (conference lead)

Australian Critical Minerals Research Centre, The University of Adelaide, South Australia

INTRODUCTION

Critical minerals such as rare earths, graphite, lithium, cobalt, nickel, platinum group elements, indium, tungsten and gallium, are essential to modern technology, the sustainability of modern advanced societies, and the clean energy transition.

Australia, with its rich mineral endowment, globally-leading mining industry, and world-class research institutions, is in the box seat to be a global powerhouse in critical minerals exploration, mining and processing.

This conference will bring together industry, government and academia to showcase the latest projects, research and developments in critical minerals from across Australia and beyond. The conference will feature a three-day technical program of keynote, oral and poster presentations (23rd to 25th May), preceded by a workshop (22nd) and followed by a field trip (26th) to showcase South Australia's critical minerals potential.

CRITCON 2023's technical program will cover three themes of the critical mineral supply:

THEME 1 – DISCOVERY

Presentations in this theme will showcase recent critical minerals exploration successes, new research into understanding critical mineral ore systems, and advances in big data and AI that will shape the future of mineral exploration.

THEME 2 - CHARACTERISATION

Presentations in this theme will showcase recent advances in methodologies to characterise critical minerals and critical mineral ores, and present case examples of characterisation of ores and processing streams from the sub-micron scale to deposit scale.

THEME 3 – PROCESSING

Presentations in this theme will address the many challenges to industry in processing of critical mineral ores, and outline the latest research developments and improvements to overcome these challenges, thereby allowing progress to more efficient and environmentally-benign mineral processing technologies.

ORGANISING COMMITTEE:

Adam Abersteiner (UofA), Paula Angerstein (UofA), Nigel Cook (UofA), Laura Garcia Rubio (UofA), Jarred Lloyd (UofA), Fun Meeuws (UofA), Laura Morrissey (UofA), Carl Spandler (UofA), Jessica Walsh (UofA), Diana Zivak (UofA), Mitchell Bockmann (GSSA), Bronwyn Camac (GSSA), Adrian Fabris (GSSA), Carmen Krapf (GSSA), Laura Jackson (UQ), George Abaka-Wood (UniSA)

PROGRAM

MONDAY 22ND MAY

9:00 am to 3:00 pm: Pre-Conference Workshop, South Australia Drill Core Reference Library, Tonsley Innovation District.

https://www.energymining.sa.gov.au/industry/geological-survey/drill-core-reference-library

5:30 pm to 8:00 pm: Welcome Reception (drinks and canapés), The Vines Room, National Wine Centre, Adelaide

TUESDAY 23RD MAY: THEME 1. DISCOVERY

Time	Title	Presenter
08:30 – 08:40	Introduction	Michael Goodsite (University of Adelaide)
08:40 – 08:50	Welcome to Country	Uncle Rod
08:50 – 09:10	Conference Opening	The Hon Tom Koutsantonis MP, Minister for Infrastructure and Transport, Minister for Energy and Mining (Government of South Australia)
09:10 – 09:30	Critical Minerals in Australia – recent trends and policy setting	Michael Neimanis (Critical Minerals Office)
09:30 – 09:50	National geoscience: the foundation for Australia's critical minerals future	Anthony Schofield (Geoscience Australia)
09:50 – 10:10	Unravelling South Australia's critical mineral potential	Bronwyn Camac (Geological Survey of SA)
10:10 – 10:40	***Morning tea***	
10:40 – 11:00	Geological knowledge from data: A machine assisted and human driven approach	Eun-Jung Holden (University of WA)
11:00 – 11:20	Digital decisions that attract the herd	Genéne Kleppe (Digital Twinning Australia)
11:20 – 11:40	Natural source-field induced polarization exploration for an IOCG deposit	Ying Liu (University of Adelaide)
11:40 – 12:00	Recent insights into tellurium biogeochemical cycling from nano- to macro-scale	Owen Missen (University of Tasmania)
12:00 – 12:20	Metamict zircon as metal source for unconformity-related REE deposits	Jessica Walsh (University of Adelaide)
12:20 – 13:20	***Lunch***	
13:20 – 14:00	**KEYNOTE:** Lithium potential in the 3T (tin, tantalum, tungsten) belt of Central Africa	Anouk Borst (Royal Museum for Central Africa & KU Leuven)
14:00 – 14:20	The Finniss Lithium Project, Northern Territory	Graeme McDonald (Core Lithium Ltd)
14:20 – 14:40	Direct geochronology of Li-bearing minerals	Jarred Lloyd (University of Adelaide & Geological Survey of SA)
14:40 – 15:00	Key genetic processes for magmatic Ni-Cu-Co-PGE sulfide systems, and recently-developed exploration tools (geochemistry and mineral chemistry)	Margaux Le Vaillant (CSIRO)
15:00 – 15:30	***Afternoon tea***	
15:30 – 15:50	REE mobility in fluids and melts	John Mavrogenes (Australian National University)
15:50 – 16:10	Redox control on HFSE sequestration in peralkaline magmas	Brenainn Simpson (University of QLD & Geological Survey of NSW)
16:10 – 16:30	Magmatic REE mineralisation in carbonatites	Michael Anenburg (Australian National University)
16:30 – 16:50	The geology of the Mount Weld Carbonatite	Ross Chandler (Australian National University)
17:00 – 18:00	**POSTER SESSION**	
	See page 12 for list of posters	

WEDNESDAY 24TH MAY: THEME 2. CHARACTERISATION

Time	Title	Presenter
08:50 – 09:10	Drivers for Australia's mine waste renaissance: The 3 C's	Anita Parbhakar-Fox (University of QLD)
09:10 – 09:30	A 15 Gt resource of critical minerals? A comprehensive mapping of tailings and the potential for critical minerals across Australia	Gavin Mudd (RMIT University)
09:30 – 09:50	Nickel and cobalt in tailings from the Eloise Deposit, North QLD	Kam Bhowany (University of QLD)
09:50 – 10:10	Tracking indium in sulfidic mine waste and acid mine drainage environments	Olivia Mejías (University of QLD)
10:10 – 10:40	***Morning tea***	
10:40 – 11:00	Thermodynamics of critical mineral systems	Joël Brugger (Monash University)
11:00 – 11:30	**KEYNOTE:** The critical mineral potential of the world-class Olympic Dam Cu-U-Au-Ag deposit, South Australia 1. Ore to metal deportment: where do the critical metals go during processing of Cu-U-Au-Ag ores	Kathy Ehrig (BHP Olympic Dam)
11:30 – 12:00	The critical mineral potential of the world-class Olympic Dam Cu-U-Au-Ag deposit, South Australia 2. Natural and anthropogenic mineralogy	Nigel Cook (University of Adelaide)
12:00 – 12:20	A nanoscale vision of trace element distributions in critical minerals using atom probe tomography	Steven Reddy (Curtin University)
12:20 – 13:20	***Lunch***	
13:20 – 13:40	LIBS automated techniques for the mineralogical and elemental characterisation of critical mineral deposits	Rowena Duckworth (AXT Pty Ltd)
13:40 – 14:00	Latest advancements on automated mineralogy for critical minerals	Leonardo Salazar (Thermo Fisher Scientific Inc)
14:00 – 14:20	Critical minerals in north Queensland mineral deposits	Vladimir Lisitsin (Geological Survey of QLD)
14:20 – 14:40	Chemical and temporal evolution of the Mary Kathleen Complex	Antony Burnham (Australian National University)
14:40 – 15:00	REE characterisation and reprocessing potential of the Mary Kathleen tailings, QLD	Nathan Fox (University of QLD)
15:00 – 15:30	***Afternoon tea***	
15:30 – 15:50	The behaviour of REE-bearing minerals during in situ weathering	Laura Morrissey (University of SA)
15:50 – 16:10	Identifying exodermic conditions to host ionic REEs in the Gawler Craton	Rupert Verco (Cobra Resources)
16:10 – 16:30	Mineralogy and origin of REE enrichment in the clay hosted Koppamurra deposit, South Australia	Stefan Löhr (University of Adelaide)
16:30 – 16:50	Clay-hosted rare earth element mineralisation in the Esperance District of Western Australia	David Crook (OreSource Pty Ltd & Mount Ridley Mines Ltd)
17:00 – 18:00	**POSTER SESSION**	
	See for page 12 list of posters	
18:30 – 22:00	**CONFERENCE DINNER: AYERS HOUSE, NORTH TERRACE**	

THURSDAY 25TH MAY: THEME 3. PROCESSING

Time	Title	Presenter
09:20 – 09:40	Communition trends for sustainable critical minerals processing	Mark Drechsler (CBSM Mining Services)
09:40 – 10:00	Biomining critical minerals from low-grade ores and wastes	Anna Kaksonen (CSIRO)
10:00 – 10:20	Visible light fluorescence sensing for increased efficiency in lithium mineral processing	Tom Payten (University of Adelaide)
10:20 – 10:50	***Morning tea***	
10:50 – 11:10	Critical mineral hydrometallurgical process innovations	James Vaughan (University of QLD)
11:10 – 11:50	**KEYNOTE:** Application of the boycott effect in fine and coarse particle flotation	Kevin Galvin (University of Newcastle)
11:50 – 12:10	Recent research and development studies of nickel and cobalt extraction from Australian lateritic ores	Jonas Addai-Mensah (University of SA)
12:10 – 12:30	Kalkaroo Deposit - A critical minerals treasure trove	Chris Giles (Havilah Resources)
12:30 – 13:30	***Lunch***	
13:30 – 13:50	Copper and cobalt recovery from mineral wastes	Pavel Spiridonov (University of SA)
13:50 – 14:10	Cobalt Blue's Broken Hill demonstration plant – Update on the COB process development	Aaron Einthal (Cobalt Blue)
14:10 – 14:30	Sustainable recovery of Cu-Co critical minerals	Clement Lartey (University of SA)
14:30 – 14:50	Elizabeth Creek: Unlocking copper and cobalt production in the Gawler Craton	Matthew Weber (Coda Minerals)
14:50 – 15:30	***Afternoon tea***	
15:30 – 15:50	Repurposing of mining tailings for rare earth element mineral recovery	George Abaka-Wood (University of SA)
15:50 – 16:10	Rare earth production from an Australian clay hosted deposit	Jess Page (Australian Rare Earths Ltd)
16:10 – 16:30	A review of magnetic separation of rare earth minerals	Zahra Rezaee (University of SA)
16:30 – 16:50	Sustainable processing of battery critical minerals: focus on lithium & nickel	Jacques Eksteen (Curtin University)
16:50 – 17:00	Conference wrap-up	Carl Spandler (University of Adelaide)
	CLOSE OF TECHNICAL PROGRAM	

LIST OF POSTERS	
A brief review on extraction of critical battery metals from ores: Challenges and opportunities	Gertrude Acquah (University of SA)
Production mineralogy: Magnesite deposit at Prospect Ridge; north-western Tasmania	Alfredtina Appiah (University of Tasmania)
Understanding the entrainment behaviour of silicate minerals in pentlandite flotation	Linda Ayedzi (University of SA)
Where are South Australia’s carbonatites?	Mitchell Bockmann (Geological Survey of SA)
Unravelling South Australia’s critical mineral pegmatites	Georgina Gordon (Geological Survey of SA)
Secondary prospectivity of South Australia’s mine waste: Review	Laura Jackson (University of QLD)
Indium-bearing minerals and textures of drill core samples from Baal Gammon mine: An application of laser-induced breakdown spectroscopy	Olivia Mejías (University of QLD)
A sticky situation: Understanding and manipulating Si-gel formation from gangue mineral dissolution during *in-situ* leaching	Mareike Rosemann (Monash University)
Towards the development of macronutrients supply chain based on lunar resources	Manuel Varon Hoyos (University of Adelaide)
REE in phosphorites of the Georgina Basin, QLD	Diana Zivak (University of Adelaide)

REPURPOSING OF MINING TAILINGS FOR RARE EARTH ELEMENTS MINERALS RECOVERY

George B. Abaka-Wood [1,2]***, Jonas Addai-Mensah*** [1,3]***, William Skinner*** [1,2]

1. *Future Industries Institute, University of South Australia, Mawson Lakes Campus, Adelaide, SA 5095, Australia*
2. *ARC Centre of Excellence for Enabling Eco-Efficient Beneficiation of Minerals, University of South Australia Node, Adelaide, SA 5095, Australia*
3. *Department of Mining and Process Engineering, Namibia University of Science and Technology, Jackson Kaujeua Street, Windhoek 13388, Namibia*

The rapid depletion of high-grade rare earth elements (REE) resources implies that future supplies may be augmented with low-grade ores, tailings, and other unconventional resources to meet cut-off grades and, subsequently, supply demands. This paper presents an amalgamation of studies conducted on selected tailings, with the overall aim of developing efficacious methods and associated process mineralogy characterization for enhanced REE minerals recovery and upgrade. To this end, a summary of the overarching key results from froth flotation, magnetic separation, and gravity separation studies of the tailings and their implications will be presented. Reconciliation of all the findings reveals lucid links between feed ore properties, mainly mineralogy and particle size distribution, as the key influential factors that affect the beneficiation of complex low-grade tailings, although distinct differences in physicochemical properties of the valuable and gangue minerals may exist. It is clearly established that the unliberated association between REE and gangue minerals within the ore can lead to either synergistic or antagonistic effects on the quality of concentrates produced. Furthermore, the limitations presented by the poorly liberated minerals are exacerbated by their “fine” nature. With appreciable recoveries obtained using such readily available conventional separation methods, the tailings provide additional REE value to the primary commodities; hence, such material could be considered a potential resource for REE beneficiation. The learnings from the respective beneficiation studies are significantly important as they provide the knowledge base and greater understanding of the mineralogical characteristics and beneficiation response of REE minerals in typical complex, low-grade tailings.

A BRIEF REVIEW ON EXTRACTION OF CRITICAL BATTERY METALS FROM ORES: CHALLENGES AND OPPORTUNITIES

***Gertrude Acquah*[1]*, Pavel Spiridonov*[1,2]*, William Skinner*[1]*, George Abaka-Wood*[1]*, Jonas Addai-Mensah*[1]*, Richmond Asamoah*[1]**

1. *University of South Australia, UniSA STEM, Future Industries Institute, Mawson Lakes, South Australia 5095*
2. *InnovEco Australia*

Energy security, high prices and excessive use of fossil fuels, and concomitant global climate change have engendered a rapid increase in demand for alternative, sustainable energy solutions with reduced CO_2 footprint. This clean energy drive has reflected a growing interest in battery-powered electric vehicles, and other smart devices, with a projected steady increase in future demand. Efficacious extraction of critical energy metals: lithium, nickel, and cobalt from mineral resources for the production of rechargeable batteries is, therefore, crucial. Conventional mineral processing and extractive metallurgy techniques are employed to extract nickel and cobalt, largely from nickel /copper-cobalt sulphides and lithium from aluminosilicate mineral concentrates. With current rapid depletion of the sulphides, there is an all-time high impetus for the extraction of nickel and cobalt from lateritic ores, mostly low grade (e.g., < 1.2 wt%), mineralogically complex and chemically variable. Generically, the lateritic ores are not amenable to conventional physical separation and flotation techniques for upgrade. To date, the most common method of laterite beneficiation is the rejection of barren coarse particle fractions. Without recourse to significant preconcentration process, only low capital and operating expenditures, hydrometallurgical techniques such as Agitated Tank, Heap and Vat leaching, offer economic pathways to metal extraction from the low-grade ores. Such techniques, albeit, have major drawbacks, including long processing times, high lixiviant consumption, slow kinetics, low metal recovery, and poor selectivity. Notably, the complexity of laterite minerals' associations and the finely disseminated state of nickel in host minerals contribute to low values recoveries and poor selectivity during preconcentration. This work reviews recent research and technological developments, including a novel, resin-in-moist mix, ion exchange technology, for cost-effective recovery of nickel and copper from low-grade ores (InnovEco Australia). Furthermore, the key challenges and opportunities in the extraction of critical battery metals from complex aluminosilicate and lateritic ores are enunciated.

RECENT RESEARCH AND DEVELOPMENT STUDIES OF NICKEL AND COBALT EXTRACTION FROM AUSTRALIAN LATERITIC ORES

***Jonas Addai-Mensah*[1]**

1. *University of South Australia*

Like so much of nature and rest of materials, energy and allied manufacturing industries, critical metals play increasingly important technological roles in meeting sustainable development goals worldwide. As key critical metals' components of stainless steel and superalloys, nickel (Ni) and cobalt (Co) are used in the manufacture of high technology products for the aerospace, automotive, building and construction industries; magnetic alloys and batteries in the chemical/energy industries; medical and food processing equipment and other smart devices. Conventionally, nickel and cobalt are extracted, largely from nickel/copper-cobalt sulphides and nickel laterite ores using classical and new/or refined techno-economic mineral processing and extractive technologies. Australia mining sector plays a significant role in the global nickel-cobalt industry, accounting for about 28% and 16% of the world's demonstrated nickel and cobalt resources, respectively. Furthermore, the current rapid depletion of the high grade sulphidic ores globally has escalated growing interest in the extraction nickel and cobalt from laterites. In recent years, there has been increased expectation for growth of the Australian nickel-cobalt industry based on application of new cost-effective extractive technologies to the abundant lateritic resources located in Western Australia. The main challenge which confronts the processability of the Western Australian lateritic ores to date is that, whilst they account for ≈69% total Ni resources, they are characteristically low grade (e.g., < 1–2 wt%), mineralogically complex and chemically variable. These present intractable processing challenges. In this presentation, recent pre-concentration and hydrometallurgical studies of three Western Australian nickel laterites, aimed at "designing pre-feasible processing and extraction techniques through controlled leaching (heap and agitated tank)", reviewed and discussed, and the ramifications of the key findings highlighted.

MAGMATIC REE MINERALISATION IN CARBONATITES

***Michael Anenburg*[1]**

1. *Research School of Earth Sciences, Australian National University*

Rare earth element mineralisation in carbonatites is overwhelmingly associated with their iron-rich portions, often associated with barium, strontium, fluorine, carbonate, and phosphate. Ore minerals often appear in hydrothermal textures as filling of vugs, cavities, and veins. These assemblages commonly lack alkali elements (sodium and potassium). REE mobility is only truly substantial in alkali-rich brines, making these hydrothermal textures enigmatic. Post-magmatic alteration of magmatic REE minerals such as burbankite can only explain some hydrothermal textures but not all. Here we show high temperature magmatic experiments of carbonatite crystallisation, showing that REE are strongly partitioned into nominally REE-poor sodium, potassium, and calcium carbonates. These minerals are incredibly soluble in groundwater such that they are likely to be replaced within days to weeks after cessation of magmatic activity. On geological timescales this weathering is instantaneous, such that pristine unweathered REE-rich alkaline plutonic carbonatites are unlikely to exist at all. For iron-rich carbonatites, intense weathering should not be taken as an exploration indicator for mineralisation, as they are all expected to be weathered. Rapid removal of sodium and potassium, followed by additional removal of calcium and magnesium over longer durations, causes substantial volume decrease. This leads to formation of karst and collapse breccia which may be misinterpreted as evidence for explosive volcanic or subvolcanic phenomena.

PRODUCTION MINERALOGY: MAGNESITE DEPOSIT AT PROSPECT RIDGE; NORTH-WESTERN TASMANIA

***Alfredtina A. A. Appiah*[1]*, Julie Hunt*[1]*, Owen P. Missen*[1]*, Mohammad Bagher Fathi*[1]*, Lejun Zhang*[1]**

1. *Centre of Ore Deposit and Earth Sciences (CODES), University of Tasmania, Hobart 7005, Tasmania, Australia*

Critical metals play a crucial role in the advanced manufacturing industries and economies of nations worldwide because of their irreplaceable technological values in sustainable cleaner energy production. Both the demand for these metals to meet global energy security needs and the World Health Organization's (WHO) net zero-carbon emission target present major supply chain challenges, particularly to the mining industry. Magnesium is one of these critical metals because of its uses in structural alloys to produce lightweight materials. Australia contributed 2.6 million metric tonnes to the global magnesite annual production. This can be significantly increased if more investments in exploration, prospecting and characterization of new deposits are carried out to develop innovative and cost-effective production pathways for critical metals. In this regard, there is growing interest in Australia in mining magnesite, a magnesium carbonate ($MgCO_3$) mineral out of which magnesium (Mg) can be extracted from.

Although there are conventional routes for the processing of magnesite ores, including the Pidgeon and electrolytic processes, some technological challenges are still being researched. For instance, the application of intensive heating of magnesite ores is often costly; and cell cathode passivation resulting from a high impurity content of the feed thus affecting the cell performance during electrolytic process. Hence, there is a pressing need to develop an effective yet cost and environmentally friendly processing route for magnesite production.

This research seeks to undertake comprehensive characterisation of the geology, alteration, mineralogy, Mg mineralisation and chemistry of the Prospect Ridge magnesite deposit in Tasmania through core logging, several field and lab-based analytical techniques (SEM-based automated mineralogy and XRF). Appropriate and cost-effective production route(s) will be assessed based on characterisation data to extract magnesite from associated gangue and other deleterious minerals via judicious use of beneficiation and extractive metallurgical techniques. This presentation will describe preliminary results from Prospect Ridge.

UNDERSTANDING THE ENTRAINMENT BEHAVIOUR OF SILICATE MINERALS IN PENTLANDITE FLOTATION

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Nickel, a transition metal, has growing significance due to the rising demand for clean energy transition. Nickel is an important component in hydrogen fuel cells, batteries for electric vehicles and pivotal in the manufacturing of energy storage cells for renewable energy. The major source of nickel is pentlandite, which is typically found in complex association with sulphide gangue minerals such as pyrrhotite, chalcopyrite, pyrite, and various silicate minerals such as olivine, pyroxene, and quartz depending on the ore deposit. Pentlandite is often extracted from ores using froth flotation, but the complex nature of such ores often promotes the flotation of the gangue minerals via entrainment. This study focuses on understanding the entrainment characteristics of quartz (a major silicate gangue mineral) in the flotation recovery of pentlandite. To accomplish this, mineral particle sizes of -106+75, - 75+38, -38+20 and -20 µm were subjected to froth flotation in the presence of carboxymethyl cellulose (CMC) both in a microflotation and bench scale flotation cells. In addition to that, electroacoustic zeta potential measurements, Fourier Transform Infrared Spectroscopy (FTIR) and UV-Vis spectroscopy analysis of the collector concentration were investigated to provide mineral-reagent interactions that influence hydrophobicity. Results from this study suggest that flotation by entrainment of quartz increased to about 40% in the -20 µm particle size both in the absence and presence of CMC. Zeta potential measurements, UV-VIS spectroscopy, and FTIR results gave further evidence that the collector, potassium amyl xanthate (PAX), used in the flotation process adsorbed onto pentlandite and quartz mineral surfaces in the presence of CMC, and as a result, did not interfere with the depressive action of CMC. Overall, this study confirms entrainment of gangue species is dominant within fine or ultra-fine mineral particles and has the potential to affect downstream extraction process.

NICKEL AND COBALT IN THE ELOISE TAILINGS: AN EXAMPLE OF THE IMPORTANCE OF MINERALOGICAL CHARACTERISATION OF MINE WASTE FOR REPROCESSING AND REPURPOSING OPTIONS.

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The opportunity for mine waste to be a source of critical metals to support the energy transition has been gaining momentum. Globally, governments and companies have invested in reprocessing options, with Rio Tinto, Canada, recently announcing the successful extraction and purification of scandium from mine waste. However, for successful metal recovery, geochemical and mineral characterisation of mine waste is crucial.

The Eloise Copper-Gold deposit, located in Queensland's Northwest Minerals Province, was identified as a potential host of cobalt in tailings based on the region's geochemical signature and recent mine waste characterisation studies. Two tailings dams were sampled, with 10 holes hand-augered to a maximum depth of 5.6 m: 6 holes in TSF 3 and 4 holes in TSF 4. TSF 3 contains Ni (average: 301 ppm), Co (average: 78 ppm), LREE (average: 121 ppm), HREE (average: 77 ppm), Cu (average: 928 ppm) and Au (average: 0.3 ppm). Comparatively, TSF 4 has similar metal contents to TSF 3 with average values as follows: Ni at 336 ppm; Co at 94 ppm; LREE at 122 ppm; HREE at 85 ppm; Cu at 972 ppm and Au at 0.2 ppm. The low bulk abundances of metals in the two TSFs (compared to other mine wastes in the region) are reflections of the mineralogy with the dominance of silicates such as quartz, K-feldspar, biotite and plagioclase. However, pyrrhotite is present in both TSF 3 and 4 (average modal abundance of 3.1 wt. % and 5.6 wt. %, respectively), as well as pyrite (0.4 wt. % and 0.7 wt. %, respectively). In-situ analysis of sulfides by LA-ICP-MS, reveals endowment of Ni and Co, with average values of 14,500 ppm and 4,100 ppm in pyrrhotite and 2,100 ppm and 29,200 ppm in pyrite, highlighting the importance of mineralogical characterisation not only for reprocessing, but also for repurposing and rehabilitation options.

WHERE ARE SOUTH AUSTRALIA'S CARBONATITES?

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Carbonatites are carbonate-rich magmatic rocks that are highly prospective exploration targets for critical minerals due to their common association with rare earth elements (REE) and Nb mineralisation, amongst other valuable commodities. Regions of Proterozoic Australia have been identified as prospective locations for carbonatite-related mineral systems, with multiple carbonatite provinces in Western Australia and the Northern Territory containing high-grade REE deposits. Yet South Australia, although emerging as a prospective location for clay-hosted REE mineralisation, currently lacks clear evidence for carbonatite systems and subsequently has not been considered prospective for carbonatite-related REE mineralisation.

Despite the apparent lack of carbonatites, South Australia comprises many key geological features that are conducive to the formation of carbonatite systems. These include large mantle conductors that potentially indicate the presence of carbon in the mantle, an extensive metasomatised subcontinental lithospheric mantle, and multiple crustal-scale, mantle-tapping structures. The two former features being possible sources for carbonatitic melts and enrichment, and the latter as conduits for the mantle-derived melts to reach the upper crust with minimal silicate assimilation. Additionally, South Australia's protracted geological history of c. 3.2 Ga increases the likelihood of carbonatite formation through repeated magmatic events within changing crustal and mantle conditions over time. The combination of these factors suggests the lack of carbonatites in South Australia is unlikely due to their absence in the rock record, but rather due to our current inability to detect and/or identify them.

This poster presents a regional evaluation of the carbonatite potential in South Australia and discusses some of the limitations that may have permitted carbonatites to remain undetected in the state to date. This project is part of the Geological Survey of South Australia's Critical Minerals Project, and aims to determine prospective regions for carbonatites and associated mineral systems in South Australia.

LITHIUM POTENTIAL IN THE 3T (TIN, TANTALUM, TUNGSTEN) BELT OF CENTRAL AFRICA

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The Great Lakes region (Eastern DRC, Southwestern Uganda, Rwanda and Burundi) is rich in deposits mined for tin (Sn), tantalum (Ta) and tungsten (W), collectively known as the 3Ts. The mineralisation is hosted in early Neoproterozoic pegmatites (cassiterite, columbite-tantalite) and quartz veins (cassiterite, wolframite), and their alluvial and eluvial weathering products. The pegmatites and quartz veins are linked to S-type granites that were emplaced in Paleo- and Mesoproterozoic metasedimentary and -volcanic rocks. Many of the pegmatites that were historically, or are currently mined for Sn and Ta, also host significant lithium in minerals such as spodumene, amblygonite-montebrasite or eucryptite, and have thus become important targets for lithium exploration.

While the 3Ts are amenable to artisanal and small-scale mining due to intense tropical weathering (decomposition of the host rocks and heavy mineral concentration in the alluvial and eluvial cover), the lithium is largely lost during weathering. As such, only the unweathered pegmatites host potential lithium, but these require significant industrial investment to be extracted.

In this talk I will discuss the geology and exploration of Li pegmatites in Central Africa. These include the world-class Manono-Kitotolo pegmatites, DRC, which represent a giant (15 km long by 200-300 m thick) spodumene pegmatite system, currently explored by Australian company AVZ Minerals Ltd, in a joint venture with Congolese company Cominière (under the name Dathcom Mining AS). In Rwanda, lithium exploration is less advanced, although lithium-rich pegmatites are known from six localities, five of which are within the Gitarama-Gatumba pegmatite district (Buranga, Gatumba, Rubini, Rongi and Rusorora) and the sixth recently discovered at depth in drill cores by Trinity Metals Group (at Musha-Ntunga). In Burundi, only one spodumene pegmatite is documented (Ndora) but exploration has ceased due to a recent embargo on the Burundi mineral sector, while the government develops a new mining code.

Using examples from Musha-Ntunga (Rwanda) and Manono-Kitotolo (DRC) spodumene pegmatites, I will provide some insights into the mineralogical and paragenetic variability of these lithium pegmatites, and show features of high temperature deformation, magmatic-hydrothermal alteration and weathering, all of which have implications for extraction and processing.

THERMODYNAMICS OF CRITICAL MINERAL SYSTEMS

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Decades of research on mineral systems and extractive metallurgy have largely ignored critical minerals, because the challenge to their supply is recent. As a result, the fundamental thermodynamic and kinetics data required for accurate prediction of their deportment are often lacking, or are of dubious reliability. We combine state-of-the-art experimental work; computational chemistry; and numerical modelling to improve our ability to predict the behaviour of critical minerals and associated commodities in complex systems. In this talk I will present a few recent advances towards a quantitative understanding of element deportment in complex melt-fluid-mineral systems.

i. **REE** fluoro-carbonate minerals are abundant in magmatic and magmatic-hydrothermal deposits. In the case of hydrothermal deposits, however, this pauses a fundamental issue, because REE are poorly mobile in F-rich fluids, due to the low solubility of REE-fluoride minerals. Recent in-situ observations disprove this paradigm, showing high mobility of REE in carbonate-fluoride-fluids.

ii. Many critical minerals live hidden – occuring in minor amounts in **substitution for major elements** (e.g., Ge substituting Zn in sphalerite; REE in apatite; Ni,Co.As in pyrite). Few models take these substitutions into account, and thermochemical mixing properties are scarce. Using As-in-pyrite as an example, we show that computational chemistry provides a work-around experimental difficulties, and that the updated model solves important issues for the deportment of As in gold systems.

iii. Despite chemical equilibrium being the primary driver of fluid-mineral reactions, **kinetics** play a crucial role on determining mineral associations, element distribution and mineral textures. Our recent experiments revealed several unique processes during fluid-mineral interactions that cannot be predicted without systematic experiments and robust thermodynamic models. For example, the presence of trace amounts of cerium(III) during the replacement of magnetite by hematite (a common reaction in Australia's IOCG deposits) has a dramatic effects on the texture of the newly formed hematite, driving a positive feedback between mineral reaction, porosity creation, and fluid flow.

CHEMICAL AND TEMPORAL EVOLUTION OF THE MARY KATHLEEN COMPLEX

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The Mary Kathleen-Koppany-Elaine Dorothy complex in the Mt Isa Inlier, Queensland, hosts significant quantities of REE and U in addition to Cu and Au. Understanding how the REE are mobilised in such systems is crucial to developing theoretical models of REE ore formation more generally. In the Mary Kathleen Complex, crystallisation of coarse-grained allanite at 1732 ± 8 Ma, observed in drill core from Koppany, was likely due to the intrusion of the Burstall Granite into the limestones of the Corella Formation and skarn formation, as the allanite has εNd1732 = -3.8, closely comparable to ~-3 for the Burstall Granite. At ~1520 Ma at Koppany and Mary Kathleen, allanite was partially recrystallised to fine-grained mosaic-textured aggregates with higher U, $Fe^{3+}/\Sigma Fe$, Eu/Eu* and lower ΣREE; however, this allanite had identical εNd1520 to the older allanite, implying no addition of REE to the system at this time. A further stage of allanite growth occurred in calcite veins at 1473 ± 7 Ma.

A rhyolitic dyke close to the drill pad for Koppany had been heavily albitised and partially leached of REE. Zircons from the dyke were mostly discordant, due to U concentrations up to 5000 ppm; the best grains yielded concordia intercept ages of 1739 ± 9 Ma, the same as the Burstall Granite and associated aplite dykes. These aplite dykes are enriched in U, up to 31 ppm, and thus represent a viable source for the U-REE mineralisation.

THE PRIMARY GEOLOGY OF THE PALEOPROTEROZOIC MT WELD CARBONATITE COMPLEX, WESTERN AUSTRALIA

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The Paleoproterozoic Mt Weld carbonatite complex (Yilgarn Craton, Western Australia) hosts one of the largest rare earth element (REE) deposits globally. Recent deep exploration drilling of the complex has allowed this first in-depth study into the primary geology of the complex.

Mt Weld shares a similar lithological architecture to many east African carbonatite complexes (e.g. Ngualla, Chilwa Island, Panda Hill) where a central (~600 m diameter) unit of magnesio- to ferrocarbonatite is surrounded by a broad (~1.2 km thick) annulus of calciocarbonatite, itself surrounded by a fenitic halo. Primary REE enrichment occurs within the central magnesio- to ferrocarbonatites and is dominated fine-grained 'hydrothermal' monazite within fractures and vugs within the magnesiocarbonatite. Both high and low P ferrocarbonatites occur within the central unit that display (respectively) monazite or magmatic bastnasite and synchysite mineralisation.

Mineral speciation and trace element geochemistry records the magmatic to hydrothermal evolution of the complex from the voluminous REE-poor (<0.5% Total Rare Earth Oxides) calciocarbonatite units through to the REE-enriched magnesio- and ferrocarbonatites units (~2–4% TREO). Late magnesio- to ferrocarbonatite dykes occur throughout the calciocarbonatites, occasionally displaying exotic Sr-Ba-REE carbonates as evident of their highly evolved nature. Late hydrothermal events strongly influenced the modern-day mineral assemblages with much of the existing ore minerals interpreted as hydrothermal reworkings of preexisting REE-bearing minerals, particularly those of the burbankite groups.

The results of this study suggest minimal horizontal migration of ore elements during paleoregolith formation, with the overlying regolith broadly reflecting the primary trace and minor element signatures. This allows the inference of a ~5x upgrade in REE (and Nb) concentrations from the primary carbonatite to the overlying paleoregolith.

THE CRITICAL MINERAL POTENTIAL OF THE WORLD-CLASS OLYMPIC DAM CU-U-AU-AG DEPOSIT, SOUTH AUSTRALIA. 2. NATURAL AND ANTHROPOGENIC MINERALOGY

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Olympic Dam is a giant (>10 bill. tonne) IOCG deposit producing copper cathodes, U3O8 concentrate, and gold and silver bullion. The deposit is also a global-scale REE anomaly and contains many other critical minerals. Harnessing the untapped opportunity offered by these minor elements is dependent on comprehensive understanding of the deportment and behavior of each element in ore, through flotation circuits, smelting, electrorefining, and in tailings. Cutting-edge characterization methods allow visualization of distributions down to the atomic scale. Such knowledge enables identification of where critical minerals are concentrated and can support potential future revenue generation should they be amenable to low-cost recovery.

Ores are complex (>120 minerals), hematite-dominant, and preserve cycles of replacement, remobilization, and recrystallization. REE minerals (bastnäsite, synchysite, florencite, monazite, xenotime, Ca-Sr-REE-Al-phosphate-sulfates, and ppm concentrations of REE in Fe-oxides, fluorapatite and zircon) mostly report to flotation tailings. REE-fluorocarbonates and monazite are La- or Ce-dominant. Xenotime and zircon are important HREE-hosts.

Cobalt occurs in pyrite, carrollite and subordinate cobaltite. After smelting, Co largely reports to slag spinels and fayalite.

Lead-, Bi- and Ag-selenides/tellurides occur as nm- and µm-sized inclusions within Cu-(Fe)-sulphides in ore. Anode copper contains Te and Se, dissolved within copper metal and inclusions of crystalline $Cu_2(Se,Te)$. Impurity inclusions are often multiphase, commonly amorphous, host As, Bi, Sb, Sn, and Pb, and are associated with cuprite or copper grain boundaries. Arsenic and Sb occur within Cu-Bi-arsenates and subordinate Cu-Sb-compounds.

After flash smelting and electrorefining, Se and Te reach wt% levels in anode slimes. The speciation and compositions of crystalline and amorphous phases are determined in raw, decopperized, and pH-neutralized slimes. Micron-scale atoll-like structures, dominated by Cu-Ag-selenides (raw slimes) or Ag-selenides (decopperized and pH-neutralized slimes), are hosted by an amorphous (Cu)-Bi-As-Sb-Te matrix. Various As- and Sb-bearing compounds are also identified.

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CLAY-HOSTED RARE EARTH ELEMENT MINERALISATION IN THE ESPERANCE DISTRICT OF WESTERN AUSTRALIA

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Clay-hosted REE[1] deposits, recognised in southern Western Australia (Rogers 2014), have gained significant attention from exploration companies in the last two years and now span an area of at least 26,000km^2. (Mount Ridley Mines 2022).

Referred to as the Esperance REE District, mineralisation occurs in saprolite and is seeming to be agnostic to the age and composition of the underlying basement rocks. This indicates a mechanism of dissolution of primary REE minerals followed by hydromorphic dispersion and secondary deposition of REE ions or secondary minerals, however the source of the REE remains unknown.

The basement rocks to the Esperance REE District lie within the Albany Fraser Origin and comprise two main tectonic units: the Northern Foreland, defined as a portion of the reworked Yilgarn Craton dominated by Munglinup granitic gneiss, and the Kepa Kurl Booya Province comprising the fault-bounded Biranup Zone and the Nornalup Zone which includes numerous Booanya Suite intrusive granitoids (Spaggiari et al., 2011). The Biranup Zone also includes the mafic Grass Patch Complex. Much of the region is covered by Eocene-aged sediments to depth between 20 and 40, with outcrop restricted to inselbergs usually of granite.

Mineralisation within Mt Ridley's project is often between 9 m and 40 m thick, forming in subhorizontal layers, with an average assayed grade of 1,062 ppm TREO (using a 500 ppm TREO lower cut-off) and comprising 26% Magnet REO[2].

To uncover and understand the basement geology, identify the source of the REEs and the control on their distribution within the saprolite, Mt Ridley's is actively undertaking R&D studies utilising, amongst other techniques, micro-XRF technology on "end of hole" samples and SWIR analysis on drill holes samples. This paper will present some of the early findings and how these impact ongoing exploration and metallurgical studies.

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[1] REE means the 14 rare earth elements: cerium (Ce), dysprosium (Dy), erbium (Er), europium (Eu), gadolinium (Gd), holmium (Ho), lanthanum (La), lutetium (Lu), neodymium (Nd), praseodymium (Pr), samarium (Sm), terbium (Tb), thulium (Tm), ytterbium (Yb). Yttrium (Y) is usually included with REE.

[2] Magnet REO or MagREO means magnet rare earth oxides; the sum of Dy_2O_3, Nd_2O_3, $Pr6O_{11}$ and Tb_4O_7

COMMINUTION TRENDS FOR SUSTAINABLE CRITICAL MINERAL PROCESSING

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Comminution for mineral processing accounts for over 2% of global energy consumption and generates similar levels of green house gas emissions. In a typical mining operation comminution circuits may account for around 50% of its power consumption, with power accounting for around 10% and grinding consumables (media) accounting for up to 30% of mine operating costs. Mine operators are seeking continual capital and operating cost reductions to stay competitive, increasing power efficiencies from their comminution circuits and lower water demands to meet stricter regulatory requirements, higher environmental sustainability and community expectation levels.

The International Energy Agency in their 2022 report “Role of Critical Minerals in Clean Energy Transitions” identified key risk factors to meeting Net Zero by 2050 targets including long project lead times, declining resource qualities, growing ESG focus and climate changes. The IEA report (2022) identified that future mining production levels needs to increase many times, be agile, energy and water efficient with small project footprints to meet those critical mineral supply demands.

Recent trends in comminution technology include progression from energy intensive wet attrition circuits (SAG, AG, stirred and ball mills) to dry processing using High Pressure Grinding Rolls (HPGR) and Vertical Rolls Mills (VRM) to provide 30-50% energy savings and eliminate media in fine product comminution circuits. An innovative Gyratory Rolls Crusher technology has been developed in South Australia to reduce energy and water consumption, providing dry and wet crushing from ~20 mm to 20 micron fractions without media. The locally commercialised technology will provide more agile and scalable units suited for laboratory testing, exploratory sampling through to moderate scale critical mineral production operations in the next few years.

Keywords: comminution, sustainable, energy efficiency, dry processing

LIBS AUTOMATED TECHNIQUES FOR THE MINERALOGICAL AND ELEMENTAL CHARACTERISATION OF CRITICAL MINERAL DEPOSITS

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Lithium, nickel, REE and copper are among the critical elements the world now needs in high volumes. They are necessary components in solar panels, electronics, batteries, medical equipment, and many other applications, hence the minerals containing these metals are on high demand. The rapid and accurate characterisation of these elements in drill core and rock chips is therefore something of great use to the mineral exploration community.

Laser Induced Breakdown Spectroscopy (LIBS) from via either a handheld instrument, or Elemission's benchtop Coriosity or the mobile E-Core system, allows for a rapid and accurate quantitative mineral analysis of large sample specimens including drill cores, rock chips and sand fractions (+/-1mm). Unlike X-ray based techniques, LIBS can directly identify the areas enriched in light elements such as lithium and sodium which are normally undetectable, as well as all other elements in the periodic table all the way up to uranium.

Importantly, the LIBS systems have very low detection limits (10's ppm to ppb in some cases) and produce results in a matter of minutes. As well as producing atomic emission spectra of the complete sample, it also produces a high-resolution photo to complement the spectral data. Element maps and a complete mineral library can be produced from the spectra allowing geologists to have chemical, mineralogical and photographic data of their samples in the field.

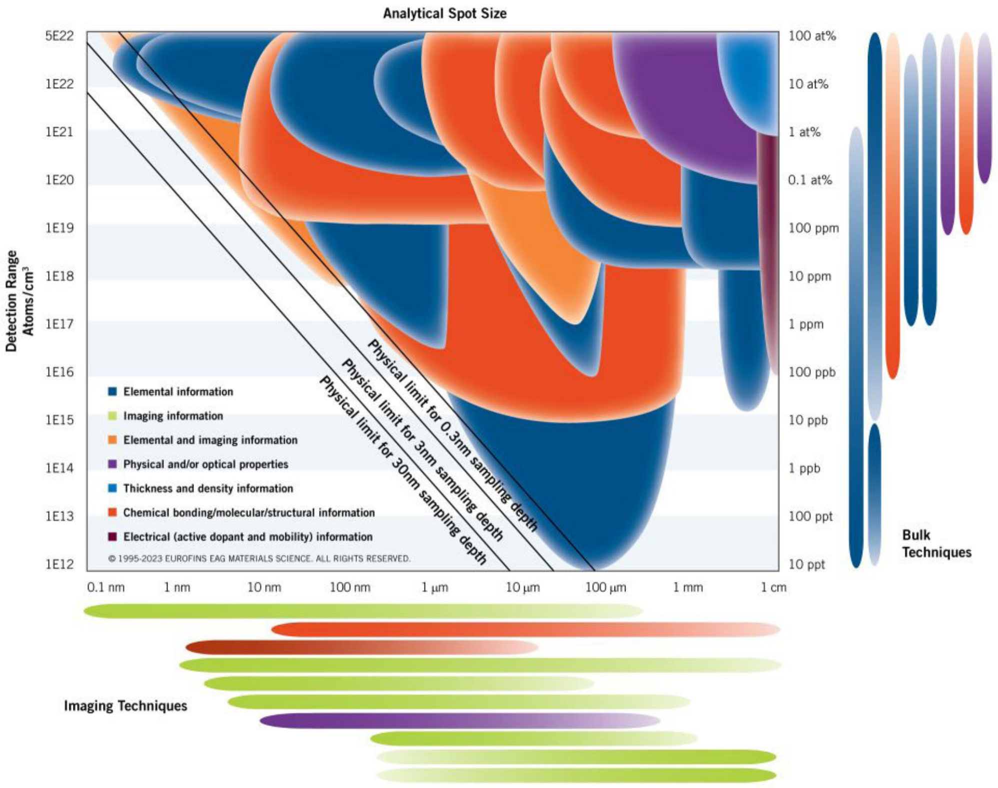

Figure 1. Sensitivity of LIBS analysis compared to other X-ray and spectral detection methods (Source: https://www.eag.com/techniques).

THE CRITICAL MINERAL POTENTIAL OF THE WORLD-CLASS OLYMPIC DAM CU-U-AU-AG DEPOSIT, SOUTH AUSTRALIA. 1. ORE TO METAL DEPORTMENT: WHERE DO THE CRITICAL METALS GO DURING ORE PROCESSING?

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Rare earth elements minerals (bastnäsite and florencite) within the Olympic Dam deposit were mentioned in the first published geological paper about Olympic Dam (Roberts and Hudson, 1983). Even though the number of recognised REE minerals within the deposit have expanded (e.g. synchysite, monazite, xenotime, Ca-Sr-REE-Al-phosphate-sulfates, and ppm concentrations of REE in Fe-oxides, fluorapatite and zircon), bastnäsite and florencite remain the predominant REE minerals. Early metallurgical testing and piloting in the 1980s, attempted to produce REE concentrates from the Cu-U-Au-Ag ores. The conclusion was recovery of REEs was not economically viable (unpublished reports). The question of REE recovery has been reinvestigated on multiple occasions since the early 1980s, resulting in the same conclusion.

The overall concentration of the REEs and REE mineralogy, grain size and intergrowth relationships with the other Olympic Dam minerals (dominated hematite, quartz, sericite, fluorite, siderite, chlorite, barite and K-feldspars, Cu ±Fe-sulphides, uraninite, coffinite and brannerite) exert the primary control on potentially recovering REEs. The average REE-mineral grain size is <10 mm and the density/magnetic properties lie within the ranges of the ore/gangue mineralogy. At the deposit scale, the REEs occur in the Cu-U-Au-Ag ores. There are no significant occurrences of REEs outside of economic sulphide mineralization. However, some minor LREE enrichment does occur in non-sulphide-bearing hematite quartz breccias.

The Olympic Dam processing plant is a fully integrated facility with milling/flotation, hydrometallurgy, pyrometallurgy and electrometallurgy sections. Tracking of the REEs and other critical minerals via routine, detailed chemical and mineralogical monitoring of plant monthly composite samples provides the insights necessary to evaluate potential REE recovery options. Over the past decade, the typical Cu-U-Au-Ag ore feed to the processing facility contains ~0.6–0.7% TREO, very low when compared to global REE producers. Approximately 95–97% of the REEs that enter the processing plant report to flotation tailings and ultimately end up in the tailings retention system.

We acknowledge funding from Australian Research Council Grant LP200100156 and BHP Olympic Dam.

COBALT BLUE’S BROKEN HILL DEMONSTRATION PLANT – UPDATE ON THE COB PROCESS DEVELOPMENT

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Cobalt Blue is developing the Broken Hill Cobalt Project. As part of feasibility studies, the company constructed and operated a testing facility in Broken Hill. Initially 90 t of ore was processed in batch campaigns in 2021–2022, with scale-up to continuously operating campaigns on up to 5,500 t of ore in 2022–2023.

The patented process flowsheet was designed to concentrate cobalt-pyrite from the ore, convert the pyrite into pyrrhotite through pyrolysis, leach the pyrrhotite, and subsequently recover the cobalt as a precipitated hydroxide.

The Demonstration Plant comprises all the key circuits. In addition to confirming overall process recoveries of >95% of the cobalt from the pyrite concentrate, the plant workstream has enabled COB to improve engineering designs, equipment selection, operating procedures, and recruit and develop staff.

Keywords: cobalt extraction, pyrite ore, process development, decomposition of pyrite, leaching of pyrrhotite

REE CHARACTERISATION AND REPROCESSING POTENTIAL OF THE MARY KATHLEEN TAILINGS, QLD

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More than 7.5 million tonnes of tailings were produced from uranium processing at the Mary Kathleen deposit, located in NW Queensland, during two phases of operation between 1958–1963 and 1976–1982. Despite known high rare earth element (REE) grades in the primary uranium ore, REE extraction was actively suppressed during mineral processing due to high rates of sulphuric acid consumption by REE-bearing minerals. Although the historical tailings were therefore known to contain elevated REE contents, the grade distribution and mineralogical hosting of REE is variable and complex. A previous drilling program sampled the historical Mary Kathleen tailings to a depth of approximately 30 metres with bulk chemical assay results indicating highly variable rare earth element contents between 0.5 and 4.7 %. This study adopted a geometallurgical approach to provide detailed geochemical and mineralogical constraints on the deportment of REEs within the tailings materials to guide opportunities for reprocessing. Selected historical tailings samples were sized and each size fraction subjected to multielement assay and mineralogical analysis (automated mineralogy and XRD) including mineral chemistry (LA-ICPMS analysis) of major mineral phases.

Overall, the Mary Kathleen tailing sampled were shown to be highly enriched in light REEs (~3 to 4 wt. %) with minor total heavy REEs (~140 ppm). Mineralogically, the tailings comprise andradite garnet, allanite, diopside and apatite as well as trace quantities (<0.5 wt. %) of ‘exotic’ REE-minerals including stillwellite, bastnasite and florencite. Mineral chemistry indicates that allanite contains up to 16 wt. % TREE content and whilst this proportionately represents the dominant REE host mineral, other phases including garnet also contain significant REE deportment, specifically with higher HREE contents. Mass balance approaches indicate more ‘exotic’ REE minerals only represent 1 % of the total REE content of the tailings and as such, reprocessing opportunities are suggested based on modified hydrometallurgical approaches (sulphuric acid leaching) to target allanite and garnet as the new ‘primary’ REE ore minerals which are known to be highly refractory in nature.

APPLICATION OF THE BOYCOTT EFFECT IN FINE AND COARSE PARTICLE FLOTATION

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The Boycott Effect (Boycott, Nature, 1920) is a powerful hydrodynamic phenomenon that arises when a dispersed suspension of bubbles, drops, or particles interacts with inclined channels. The arrangement amplifies the segregation rates, delivering stronger process intensification. This presentation outlines the application of inclined channels in flotation via the Reflux Flotation Cell and in coarse particle flotation via the CoarseAIRTM. In the Reflux Flotation Cell, the Boycott Effect leads to strong synergy in the fundamental sub-processes of flotation leading to highly effective counter current washing of the concentrate product. In the CoarseAIRTM the Boycott Effect permits fluidized bed flotation of coarse particles to be applied to the entire feed, by promoting internal classification. The presentation will also outline recent advances in particle size classification via the Boycott Effect, essential to maximizing the performance of comminution circuits.

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KALKAROO - A CRITICAL MINERALS TREASURE TROVE

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Kalkaroo is a large undeveloped copper-gold deposit containing over 1.1 Mt of copper, 3.3 Moz gold and 23,200 tonnes of cobalt in JORC resources that is currently the subject of a pre-feasibility study update by BHP. It lies in the highly mineralised but poorly explored Palaeoproterozoic Curnamona Province in northeastern South Australia. The mineralisation is stratabound, occurs at a major redox boundary and has strong analogies to the Central African Copper Belt.

Kalkaroo contains potentially recoverable levels of several critical minerals, including cobalt, molybdenum and REE. Cobalt occurs exclusively within pyrite, with clean pyrite concentrate produced by locked cycle flotation tests containing 0.29–0.34% cobalt, 2.43–3.59 g/t gold and 0.61–2.0% copper. Sulphating roasting followed by water and acid leaching recovered approximately 76% cobalt, 81% gold and 85% copper from the pyrite concentrate.

Relatively coarse-grained molybdenite occurs in the central part of the deposit mainly in later-stage fractures. Preliminary testwork indicates that more than 50% of the molybdenite can be recovered by conventional flotation.

Collaborative research with the University of South Australia's Future Industries Institute has shown that the REE are hosted by the flouro-carbonate mineral, bastnasite, in the oxidised ore at West Kalkaroo. The proportion of valuable magnet metals (NdPrDyTb) is over 40% of the total REE. Magnetic separation of the bastnasite in the process plant tailings stream shows initial promise as a concentration process.

A major advantage of critical minerals from Kalkaroo is that they are a by-product of a copper-gold mining operation and are therefore not dependent on the highly volatile critical minerals prices unlike single commodity mines.

The observed zonation of mineralisation (and alteration) in the Kalkaroo deposit from deeper tungsten-copper to copper-gold-cobalt-REE-molybdenum to shallower lead-zinc suggests metal distribution in the hydrothermal system was primarily controlled by the prevailing temperature gradient, similar to that observed in porphyry copper systems.

UNRAVELLING SOUTH AUSTRALIA'S CRITICAL MINERAL PEGMATITES

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South Australia has a rich endowment of pegmatites associated with critical minerals. While there is an increasing demand for a variety of critical minerals, the knowledge about this style of deposit in South Australia has been overlooked for many years, and the existing collection of rock samples at the Geological Survey of South Australia has been under-utilised. This review of historic pegmatite samples at the Drill Core Reference library will focus on non-destructive analytical methods to identify the most prospective samples for critical mineral discovery. The digitising and publication of this data (spectral mineralogy, pXRF analysis and high-resolution imagery) will allow these samples to be accessible online and target the most prospective samples for destructive analysis and field investigations. The compilation and publishing of new geoscience will expand the understanding of South Australia's critical mineral pegmatite potential, subsequently supporting the exploration for and the discovery of critical minerals in the State.

NATURAL SOURCE-FIELD INDUCED POLARIZATION EXPLORATION OF AN IOCG DEPOSIT

***Graham Heinson*[1]*, Ying Liu*[1,2]*, Ben Kay*[1]*, Goran Boren*[1]**

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Induced polarization (IP) is a common geophysical method of exploration for disseminated sulphides. However, in areas with deep (> 200 m) and conductive (<10 Ohm.m) cover, the technique is less successful as it requires a significant transmitter source and large-offset dipoles. An alternative approach is to use natural-variations in Earth's external magnetic field as the polarizing source of the signal, which is referred to as natural source-field IP. This paper presents a study of extracting IP information from electrical dipole observations during a broadband MT program above the Vulcan IOCG deposit as part of the Fortescue Metals Group and SA Government Accelerated Discovery Initiative project "Integrated exploration under deep cover: geophysics, geochronology, geochemistry". Inter-site transfer functions between 100 sites and reference sites were computed to determine a phase shift between electric fields in the bandwidth of 1-100 s period. Phase shifts of up to -5 degrees were centred on a region of brecciated hematite where drill holes intersected pyrite, and an inferred fault-zone from passive seismics that marks the boundary between upper crust that is resistive (>100 Ohm.m) with high magnetic susceptibility to the south of the fault, and a region of conductive crust (<10 Ohm.m) which is low magnetic susceptibility. Our study suggests that the natural source-field IP method can identify regions of polarizable minerals beneath deep cover where artificial power sources cannot be feasibly deployed. Such surveys are cheaper and quicker as only receivers are required, and 3D coverage can be obtained as the source-field is of much larger dimension than the survey array. In addition, the natural-field IP signals are observed as part of the MT program so that both electrical resistivity and polarization parameters can be determined.

GEOLOGICAL KNOWLEDGE FROM DATA: A MACHINE ASSISTED AND HUMAN DRIVEN APPROACH

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Geological interpretation is a complex task where an interpreter's bias plays an important role. As a result, interpretation outcomes are variable and uncertain, but nevertheless, these outcomes form the basis of decisions with significant environmental, social and financial implications. With the increasing use of artificial intelligence and machine learning in our daily lives such as for information search, online shopping, and virtual assistant AI, the geoscience domain has also been active in the uptake of machine learning and AI to assist in interpreting geology from data.

This talk presents innovative machine-assisted technologies that improve the efficiency and the robustness of geological interpretation of different types of geodata used in the resource industry. A number of applications of machine learning were developed in collaboration with the mining industry for the analysis and integration of multi-modal drill hole data. These applications integrate the algorithms and workflows to assist human decisions. The approach is to provide end users the control of the algorithmic process as much as possible; and to enable a seamless integration of algorithms in the interpreter's workflow using interactive visualisation. This talk also presents an on-going AI research that extracts geological insights from documents using machine reading of text. It applies advanced text mining methods and constructs a graph-based knowledge base called a knowledge graph to store and access geological information. Case studies on different mineral deposits demonstrate the effectiveness of the methods for rapidly and robustly transforming text data into structured information that faithfully represents the contents of the source reports.

SECONDARY PROSPECTIVITY OF SOUTH AUSTRALIA'S MINE WASTE: REVIEW

Laura Jackson[1], Alex Corrick[2], Zhengdong Han[1], Annah Moyo[1], Anita Parbhakar-Fox[1], Adrian Fabris[2] and Carmen Krapf[2]

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According to its Critical Minerals Strategy of 2022, Australia aims to turn into the "global critical minerals powerhouse" by 2030 by becoming an integral part of the international critical minerals supply chain (DISER, 2022). The Geological Survey of South Australia (GSSA) has recognised there is great potential to explore for critical metals in mine waste materials across the state forming part of this new supply chain. This research focused on the identification of historical mine waste with potential to host economic accumulations of critical metals in South Australia, using publicly accessible data.

For this desktop study a ranking criteria was created using four key inputs based on data available from the Mines and mineral deposits (MinDep) database, accessed via the South Australian Resources Industry Gateway (SARIG). The criteria included, i) mine status; ii) known commodity; iii) associated commodity; iv) discovery year and mine waste feature/s. The ranking was used to identify abandoned/historic mine sites with a high probability of containing critical metals in the mine waste.

The results indicate that South Australian mine waste is fertile in metals including Co, Cu, Ni, REEs and Au (Adelaide Rift Complex, Gawler Craton, Nackara Arc, Kanmantoo Group and Willyama Supergroup). The Middleback Ranges was recognised as a potential host for Mn, with notable enrichment likely in waste materials. The ranking also indicated the potential for bismuth in several sites (Gawler Craton and Nackara Arc).

Notably, studies into the economic potential of mine waste require thorough characterisation of the chemistry and mineralogy of mine waste. Follow-up studies are planned across the state to better define the critical metal tenor and deportment in these as-yet untapped potential resources.

BIOMINING CRITICAL MINERALS FROM LOW-GRADE ORES AND WASTES

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Biomining utilises the metabolic activity of microorganisms to extract (i.e., to bioleach) and recover (e.g., bioprecipitate, biosorb) metals from solid materials. Bioleaching has been applied for decades at an industrial scale for the extraction of copper from sulfidic ores; and biooxidation for the pre-treatment of refractory sulfidic gold ores to solubilise the sulfide matrix before cyanidation. There is also increasing interest in applying biomining to extract and recover resources from various mining and metallurgical wastes (e.g., slags, tailing, sludges, and ashes) and electronic wastes (e.g., batteries and printed circuit boards). Moreover, other potential applications of biomining are currently being explored, for example, targeting specific critical commodities, including rare earth elements and lithium, to meet growing demand. Biomining is especially attractive for low-grade and complex ores and wastes, which may not be economical to process through traditional metallurgical technologies and feedstocks containing penalty elements, such as arsenic. Biomining is typically carried out at ambient pressures and relatively low temperatures, providing opportunities to reduce energy consumption and the carbon footprint of processing as compared to hydrometallurgical pressure leaching and pyrometallurgical operations. Biomining can also reduce the consumption of chemical reagents, further reducing operating costs. In addition, biomining also has the potential to reduce the passivation of some minerals, such as chalcopyrite, thus improving resource extraction and recovery. This presentation provides an overview of biomining mechanisms and microbes suitable for various mineral types and commodities, and engineering applications for the implementation of microbial catalysts, including bioreactors, vats, heaps, and in situ leaching. Examples are given for some industrial-scale biomining operations across the globe. Finally, recent developments in the field and future research targets are highlighted.

DIGITAL DECISIONS THAT ATTRACT THE HERD - ACCELERATING PREFEASIBILITY DECISIONS FOR SOUTH AUSTRALIA

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1. *Digital Twinning Australia*

"You can make critical decisions about where to explore at your desktop with an increased likelihood of success".

There is a solution that can create a zero-sum monetisation model for the government whilst de risking explorer investment. This type of solution would leverage existing government tools and digital assets to decrease the time to market i.e. the time from drill core analysis to production is significantly reduced. There is a demand for technology that allows investors to have greater understanding of the economic value and prefeasibility of mining opportunities in South Australia.

A Digital Twin would enable the integration of all information necessary to make an economic decision about whether to invest in South Australia. This technology aggregates geographical information which then launches the ability to visually assess environmental, infrastructure, labour force, business and financial data. This is taking red pen markups on a photo into the world of data as an asset to be exploited. The Digital Twin technology connects these otherwise disparate datasets and makes the information available on demand for the explorer. This information can be accessed, interrogated and simulated from any location in the world, meaning powerful decisions can be made without having to be on the ground in South Australia.

This solution will deliver the world's first virtual digital core library with defensible value proposition metrics as an outcome. The doubling of South Australian government royalties is dependant on accelerating access to existing tools and making more efficient economic investment decisions. All the elements to achieve this exist, the missing link is digitally connecting them.

UNRAVELLING SOUTH AUSTRALIA'S CRITICAL MINERAL POTENTIAL

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South Australia has a rich endowment of critical minerals including zircon, graphite, REE, manganese and kaolinite amongst others. However, with emerging demand for a variety of other Critical Minerals that have historically not been explored for or mined in South Australia the Geological Survey of South Australia's 'Critical Minerals' project focuses on expanding the understanding of South Australia's critical mineral potential and by so advancing knowledge to support critical minerals discovery and exploration in the State.

Whilst global critical mineral demand is growing, the occurrence of critical minerals in South Australia, ranging from graphite to nickel, rare earths, magnesite and platinum group elements, are not uniformly understood. Many projects have not uniformly assessed the potential for these elements within mineral deposits, as part of traditional metallic exploration programs. This poses a key gap in the State's robust understanding of the potential for economic critical mineral deposits, and a significant gap in existing public geoscience data.

To address these knowledge and data gaps we are undertaking a stocktaking of mineralisation styles that produce economic grades of key critical minerals via:

i. Review and compilation of mineralisation styles for defined critical minerals using South Australian Drill Core Reference Library samples and historic records.

ii. Re-sampling and re-analysis of existing drill core occurrences from all major projects in South Australia, noting many historically would not have tested for critical mineral content or indicators.

iii. Compiling and publishing new precompetitive critical mineral geoscience data and information to increase industry and investor understanding of potential.

iv. Examining the potential for tailings, stockpiles and waste dumps from historic mining operations to host critical mineral content in partnership with The University of Queensland, Mine Waste Transformation through Characterisation (MIWATCH).

v. Undertaking a detailed economic study to qualify state, national and international drivers, which will influence a material shift to establishing a critical minerals sector and value chain in South Australia, from mining to processing and manufacture.

SUSTAINABLE RECOVERY OF CU-CO CRITICAL MINERALS

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Critical minerals such as copper (Cu) and cobalt (Co) are essential components in many high-tech products and infrastructure, placing them in high demand for global economic development and technological advancement. Efficient recovery of Cu and Co is crucial for widespread applications including electric vehicles, renewable energy sources, and advanced technologies such as smartphones, tablets, and laptops.

The flotation process is a widely used method for the recovery of Cu-Co minerals, but it requires the development of effective reagents and techniques due to the complexity of their ores. The flotation of Cu-Co minerals is highly influenced by flotation reagents, pulp conditions, and ore mineralogy. Commonly used collectors for Cu minerals include xanthates, dithiophosphates, and thionocarbamates whilst fatty acids and hydroxamic acids have been used for Co minerals. The use of depressants, such as sodium silicate, is known to improve selectivity by inhibiting gangue minerals recovery. Also, Methyl-Iso-Butyl-Carbinol and sulphuric acid are used as frother and pH modifier, respectively.

Recent advances in Cu-Co flotation indicate that flotation reagents, particle size, flotation conditions such as pulp pH, pulp density, pulp chemistry, and flotation kinetics play critical roles in improving recovery performance. Reagents development and advanced process control systems have the potential to improve efficiency and selectivity of Cu-Co flotation. However, attaining optimal flotation conditions remain unlikely owing to the complex mineralogy of the ores. Therefore, a more strategic and sustainable Cu-Co flotation approach needs to be explored to improve recovery of Cu-Co critical minerals. This presentation aims at providing information on the current state of Cu-Co minerals flotation whilst identifying persisting challenges and advances that impact its performance.

KEY GENETIC PROCESSES FOR MAGMATIC NI-CU-CO-PGE SULFIDE SYSTEMS AND RECENTLY DEVELOPED EXPLORATION TOOLS

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Magmatic nickel sulfide systems are generally well understood compared to many other commodities' mineral systems. The key genetic processes are 1) the source; the metals being sourced from the mafic-ultramafic silicate melt and the S being sourced (in most cases) from the assimilated crustal rocks, 2) the metal enrichment process linked with important interaction between the silicate melt and the sulfide melt, i.e. a dynamic magmatic system, and 3) the trap (Barnes et al. 2016). Traps are the least understood of these processes, mainly because sulfide liquid behaviour is difficult to predict and depends on the geometry of the intrusive system, the dynamics of the melt and the rigidity of the crystal framework.

All these genetic processes can generate signals within the geochemistry of the intrusive host rock as well as the chemistry of individual minerals within this host rock. Here we will describe these signals, linked with 1) sulfide interaction with the silicate melt and sulfide extraction, 2) crustal contamination of the silicate melt adding S to the system and representing evidence of thermomechanical erosion, 3) evidence for dynamic magma flow and presence of potential conduits/channels that represent prospective environments.

By understanding these signals, we can then generate practical tools and workflows for the mineral exploration industry to better evaluate prospectivity of a mafic-ultramafic intrusive body, therefore reducing the number of potential targets for more detailed exploration focused on detection of sulfides.

CRITICAL MINERALS IN NORTH QUEENSLAND MINERAL DEPOSITS

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1. *Geological Survey of Queensland*

Critical minerals are commonly economically extracted as by-products of mining of 'traditional' commodities. There are significant gaps of knowledge on the geochemistry and mineralogy of critical minerals in both primary deposits of traditional commodities and their mine wastes. Geological Survey of Queensland, in collaboration with key Australian research organisations, has undertaken a major multi-year program of geochemical and mineralogical characterisation of major mineral deposit types and key mineral systems in north Queensland, with a particular focus on the geochemistry and mineralogy of critical minerals as potential by-products.

The main primary mineral deposit types investigated by this program include: Iron-oxide copper-gold (IOCG, including: Ernest Henry, SWAN, Eloise), siliciclastic-carbonate ('SEDEX') Zn-Pb-Ag (Mt Isa, George Fisher, Dugald River), siliciclastic-mafic ('Broken Hill-type') Pb-Ag-Zn (Cannington, Maronan), sediment-hosted Cu (Mt Isa Copper, Capricorn Copper), phosphorites (Phosphate Hill, Ardmore); Sn and W skarns, greisens and veins (Mount Carbine, Wolfram Camp), Zn skarns (Mount Garnet), Cu-Sn greisens and polymetallic veins (Baal Gammon) and bauxites (Weipa, Aurukun, Bauxite Hill).

Samples from each investigated deposit were generally collected from multiple drillholes, at a downhole spacing ranging from continuous (phosphorites, bauxites, mine tailings) to 10-50 m (large primary Cu and Zn-Pb-Ag deposits), aiming to characterise deposit geochemistry and its variability. Major and trace element geochemistry (for up to 68 elements – including all critical metals) is consistently characterised using a combination of standard digestion and analytical techniques, selected to ensure near-total geochemical characterisation. Mineralogy and deportment of key critical minerals is characterised by micro-XRF mapping and automated mineralogy (MLA, TIMA).

The extensive geochemical and mineralogical database acquired during this program indicates that many primary deposits of 'traditional' commodities in Queensland and their mine wastes are significantly enriched in critical minerals, which could underpin profitable critical mineral mining industry in the state.

DIRECT GEOCHRONOLOGY OF LI-BEARING MINERALS

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Highly fractionated pegmatite systems, particularly of the Lithium-Caesium-Tantalum (LCT) classification, are not readily amenable to geochronology by traditional methods (e.g. U–Pb zircon). However, with the rapid advancement of in-situ Rb–Sr dating via laser ablation techniques in the past few years, high Rb, low Sr mineral phases (e.g. mica) have the potential to be reliable geochronometers. While the technique has significantly advanced, several challenges currently inhibit reliable interpretation of determined dates. Here we present results of a systematic investigation into the role of downhole fractionation, crystal orientation, and laser fluence to Rb–Sr dates of a variety of di- and trioctahedral (true) mica compositions. We demonstrate that the NIST and BCR glasses are a more appropriate match for downhole fractionation patterns observed for crystalline micas than the commonly used MicaMg nanopowder. Moreover, the apparent Rb/Sr ratios are more precise when normalised against glass reference materials. However, accurate age calculation using either MicaMg or glasses as the primary reference material also requires secondary matrix-matched standardisation to correct for matrix-induced offsets. Additionally, the mica crystal orientation has a significant impact on the determined Rb–Sr date. Laser ablation perpendicular to the mica cleavage planes versus parallel to cleavage planes can result in up to ~20% variation in calculated Rb–Sr dates, depending on the applied laser fluence and rubidium concentration. Finally, we provide preliminary age determinations of Rb-enriched (1–4 wt%) Li-micas (lepidolite and zinnwaldite series) from Lithium-Caesium-Tantalum (LCT) Pegmatites and discuss challenges for accurate age determinations of such materials.

MINERALOGY AND ORIGIN OF REE ENRICHMENT IN THE CLAY HOSTED KOPPAMURRA DEPOSIT, SOUTH AUSTRALIA

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Clay-hosted deposits are a major source of rare earth elements (REEs) globally, typically forming through prolonged subtropical weathering of REE-rich granitic protoliths. The Koppamurra deposit of southeast South Australia, in contrast, is developed in Pleistocene lacustrine clays overlying a marine limestone with low REE contents. Here we examine the REE+Y (REY) sources and enrichment mechanisms of this usual setting.

We find that the greatest REY enrichment (up to 5000 ppm) occurs in lacustrine clays at the base of a ~ 1–2 m thick contact zone with the underlying limestone. This zone features an increased proportion of leachable REYs (>50%), increased smectite clay abundance and a sharp increase in pH to ~8.3. Co-variation of HREEs with a suite of clay-specific elements demonstrates that HREEs are hosted mainly by Fe-rich smectite, with separate sorbed vs structurally bound HREE pools that are of similar magnitude. LREEs are mainly hosted in secondary LREE carbonates, these are preferentially intergrown with smectite but are only rarely present in kaolinite domains. Cerium occurs mainly as cerianite.

The narrow range and overlapping εNd of samples within and above the REY enriched zone suggests that enrichment is related to internal redistribution within the clay unit. The clays are isotopically incompatible with local igneous or metasedimentary rocks, $^{87}Sr/^{86}Sr$ and εNd isotopic fingerprinting identifies a Murray River sediment source that is enriched in REY due to the presence of material eroded from the Lachlan Orogen granites of southeast Australia. Deposition of these Murray-transported sediments occurred in a coastal lacustrine setting analogous to the modern-day Coorong, with tectonic uplift and shoreline progradation allowing the onset of subaerial weathering ~ 1–2 Mya. We propose that vertical and lateral solute transport allowed for the concentration of REEs in local lows in the karst-weathering impacted interface between the limestone and overlying clay, facilitated by water table oscillation and pore water redox cycling driven by seasonally contrasted rainfall. Poor soil drainage, evaporative concentration of soil waters and alkaline pH adjacent to the limestone immobilized REEs in secondary carbonates and Fe-rich smectite.

Our findings illustrate that REE mobilization and enrichment in clay deposits can occur more rapidly and in a broader range of host phases and geologic/climatic settings than is currently appreciated, with major implications not only for REE exploration but also for the use of REE as tracers in the Earth Sciences.

THE RARE EARTH SOLUBILITY QUANDARY

John Mavrogenes[1]

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Norman Bowen famously said; "…to many petrologists a volatile component is exactly like a Maxwell demon; it does just what one may with it to do." (Bowen, 1928). This could not be truer than in the case of rare earth element deposits, which often look as if they must be hydrothermal in origin, but rarely are. The high-grade ores of Bayan Obo (Smith and Henderson, 2000) look hydrothermal, but are they? The same is true for Mt Weld WA, Nolans Bore NT (Schoneveld, et al, 2015), and Mtn Pass California, which, at times, appear to be hydrothermal but are mostly magmatic. On the other hand, the Unconformity-type REE deposits of WA are difficult to ascribe to any process other than hydrothermal (Nazari-Dehkordi, et al, 2019). Even more troubling are the clay-hosted REE deposits which by all accounts appear to involve REE transport in solution. So, how soluble are REE in solution?

Most experimental estimates of REE solubilities in water-rich fluids, particularly in the presence of phosphorous are extremely low (Migdisov et al, 2009; Tropper et al, 2011; Louvel et al, 2015; Zhou et al, 2016). Recently, Louvel et al (2022) obtained elevated, qualitative solubilities in P-free fluids. This suggests that REE may be carried in solution and precipitate when mixed with P-bearing fluids. Thus, the Brown's Range HREE may have been locally sourced from zircon (Walsh and Spandler 2023) and the apparent hydrothermal REE of Mt Weld, Nolans Bore and Bayan Obo may have been transported by carbonate melt-fluid hybrids (eg, Anenburg et al, 2020)?

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THE FINNISS LITHIUM PROJECT, NORTHERN TERRITORY

***Graeme McDonald*[1]**

1. *Core Lithium Ltd*

Core Lithium has been exploring the Bynoe Pegmatite Field, 15–60 km south of Darwin, since April 2016 and has progressed the project through various stages of feasibility and approvals. Late in 2021, Core commenced development of the Grants Mineral Resource with first ore mined and crushed late in 2022.

The Bynoe Pegmatite Field has been a source of Sn-Ta production for over 100 years. However, it was not until mid-2016 that its credentials as a potentially world-class lithium district was recognised. Over 100 pegmatites are known within clustered groups or as single bodies. Individual pegmatites vary in size from a few metres wide and tens of metres long to larger bodies tens of metres wide and hundreds of metres long.

The pegmatites are predominantly hosted within the early Proterozoic metasedimentary lithologies of the Burrell Creek Formation, part of the Pine Creek Orogen. Emplacement is variable with a number of different geometries identified. The Bynoe pegmatites are classified as LCT (Lithium-Caesium-Tantalum) type and are believed to have been derived from the ~ 1845 Ma S-Type Two Sisters Granite which outcrops to the west.

Outcropping pegmatites are expressed as highly weathered clay-quartz (smectite-kaolinite) saprolite. There is no evidence of fresh spodumene as it is easily weathered, but localised occurrences of amblygonite (Li phosphate) exist.

Fresh pegmatite is composed of coarse quartz, albite, spodumene, microcline and muscovite. Spodumene, the predominant lithium bearing phase displays diagnostic red-pink UV fluorescence. Larger pegmatites are not typically zoned, but can display a thin (1–2m) quartz-mica-albite wall facies.

The region is deeply weathered and covered by areas of laterite and black soil, making surface exploration difficult. Various geophysical tools have been employed, however RC drilling remains the ultimate test of pegmatite fertility.

TRACKING INDIUM IN SULFIDIC MINE WASTE AND ACID MINE DRAINAGE ENVIRONMENTS

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Indium (In) is a critical metal essential for the transition to a low-carbon economy including its use in solar panels. However, there is a significant knowledge gap regarding the cycling of indium in mine waste environments. This study aims to understand the mobility of indium in two different geological mine waste environments as an essential first step toward designing a remining process. Core, waste rock, acid mine drainage (AMD)-impacted waters and sediment samples were collected from Baal Gammon (Sn granite-related deposit) and Mt Morgan (Au-Cu VMS deposit) abandoned/historic mines located in Queensland, Australia, and subjected to geochemical and mineralogical investigations. Preliminary results report that the waste rock from Baal Gammon contains up to 356 ppm In. Maps Mineralogy Software identified the highest indium mineral as $(Cu,Fe,Zn)_2(Sn,In)S_4$, which contains up to 8% In. Streambed sediments and stalactite formed from AMD reported up to 15 and 175 ppm In, respectively. High concentrations, up to 73 µm/L In, were measured in AMD open pit/sumps waters along with fluoride (38 to 120 mg/L). In contrast, waste rock, sediments and AMD water samples from Mt Morgan reported a maximum of 3.53 ppm In, up to 1.6 ppm In, and up to 5 µm/L In (with elevated chloride), respectively. This preliminary study concluded Mt Morgan as an indium-poor mine waste system, suggesting a decrease in indium towards Au-rich VMS. However, indium is significantly enriched in the sampled Sn-granite mine -solid and water- waste and acidic pH waters correlate with a high content of fluoride. Furthermore, preliminary synchrotron-based X-ray fluorescence microscopy (XFM) experiments reveal that secondary minerals may trap indium on their surfaces involving a biogeochemical process. Understanding the cycling of indium in mine waste systems may help identify optimal conditions for its extraction using hydrometallurgical methods, and work towards rehabilitation of these AMD-forming mine sites.

INDIUM-BEARING MINERALS AND TEXTURES OF DRILL CORE SAMPLES FROM BAAL GAMMON MINE: AN APPLICATION OF LASER-INDUCED BREAKDOWN SPECTROSCOPY

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The handheld Laser-Induced Breakdown Spectroscopy (LIBS) has been used in recent years in Earth Sciences, specifically for geochemical applications. The use of LIBS for identifying critical metals is still a new concept. Specifically, indium (In) has been identified as a critical metal in several countries as it is considered an essential commodity required to facilitate the transition to a low-carbon economy. However, the trace content of some critical metals, such as indium, becomes a challenge when using off-the-shelf field analytical tools and their default analysis methods. Based on that, the development workflows to process raw handheld LIBS information is becoming a valuable opportunity to assist in evaluating critical tenor in a range of geological materials. This study aimed to develop workflows (1, 2 and 3) to:

i. determine the emission intensity (arbitrary units: a.u.) of indium in various host minerals (e.g., sulphides, oxides);

ii. using programming methods applied to raw LIBS data; and

iii. undertake calibration/validation of LIBS results using a combination of microanalytical techniques.

Based on indium relative intensity, the preliminary results indicate that chalcopyrite is the most endowed mineral, followed by arsenopyrite, pyrrhotite, pyrite and cassiterite. Specifically, chalcopyrite that occurs as an infill massive sulphide texture displays the highest indium intensity. EPMA and LA-ICP-MS confirm the same indium-bearing minerals list, however, small grains of sphalerite and stannite with high indium contents were identified (>3,500 ppm In). These findings will help to improve the indium emission detection by host mineral including ratios of key elements such us Cu, Zn, Fe, and Sn. In the case of critical metals exploration, handheld LIBS could improve field screening in geological environments (e.g., core samples and mine wastes materials) as a rapid geochemical evaluation tool and can be used as a first analytical step towards understanding potential reprocessing options at abandoned mine sites.

RECENT INSIGHTS INTO TELLURIUM BIOGEOCHEMICAL CYCLING FROM NANO- TO MACRO-SCALE

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Tellurium (Te) is a very rare (crustal abundance ~1 ppb) chalcogen element with a limited understanding of the extent of its biogeochemical cycling. Tellurium finds its main uses in solar panels, alloys and thermoelectric devices, and is classed as a Critical Element due to uncertainty around its production and supply logistics, despite global copper and gold mining activities annually producing over 10 times as much Te as is used for industrial applications. This excess Te currently finds its ways into tailings and waste rock storage facilities, in which Te is generally rather mobile due to the high solubility of its 4+ and 6+ oxyanions in the oxidised zone. These soluble forms of Te are toxic to over 90% of microbes and form a key basis of microbe-tellurium interactions in the environment.

We proposed a holistic perspective for Te biogeochemical cycling in natural environments by analysing mineralogical and biogeochemical transformations in the regolith around tellurium-rich gold deposits. We used a combination of analytical techniques including single particle inductively coupled plasma mass spectrometry (SPICPMS) to detect elemental tellurium nanoparticles, 16S rRNA genomic sequencing to characterise the identity of microbes in the soils, and X-ray fluorescence (XRF) mapping and X-ray Absorption Spectroscopy (XAS) to analyse the elemental distribution and oxidation state of Te. XRF and XAS analyses were conducted at two synchrotrons to compare results at the K- (BL37XU beamline, Spring-8, Japan) and L3-absorption edges (ID21 beamline of the European Synchrotron Radiation Facility). The detection of elemental tellurium nanoparticles in both proximal and distal soils around Te-rich deposits, as well as on the surface of weathering grains of native tellurium, provide strong evidence for dynamic Te cycling in surface environments including a key biotransformation role played by tellurium-resistant microbes.

THE BEHAVIOUR OF REE-BEARING MINERALS DURING IN SITU WEATHERING

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Assessing the stability of common REE-bearing accessory minerals within weathered profiles can provide insights into the potential for clay-hosted REE mineralisation. The Gawler Craton, South Australia, contains 20–60m in situ weathering profiles developed on Archean granite. These profiles provide a cross section from fresh granite through to increasingly developed saprolite, culminating in a ferricrete layer. In this study we present investigate changes in REE-bearing mineral abundance throughout the weathering profile. This is coupled with analysis of the trace element chemistry and crystal structure of REE-bearing minerals.

In the fresh rock, the REE are dominantly hosted in zircon, titanite and apatite. The abundance of titanite and apatite abundance decreases significantly in the early stages of weathering and these minerals are absent from the clay-dominated rocks in the profile. Instead, REEs that could have been hosted in apatite and titanite are commonly taken up into newly formed phases such as allanite, bastnasite and rhabdophane. Zircon persists throughout the weathering profiles, but its chemistry systematically changes between the fresh rock and the weathered rock, becoming more REE depleted. This is interpreted to reflect preferential dissolution of REE-rich metamict domains within the zircon. Thorium contents of the zircon persisting in the weathering rocks also increase, particularly in discordant grains. The selective breakdown of REE-rich minerals such as metamict zircon during weathering demonstrate that weathering profiles in ancient, high SiO2 igneous rocks may be prospective without requiring significant REE enrichment in the host rock.

A 15 GT RESOURCE OF CRITICAL MINERALS? A COMPREHENSIVE MAPPING OF TAILINGS AND THE POTENTIAL FOR CRITICAL MINERALS ACROSS AUSTRALIA

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Australia's mythology is built on the contribution of mining to our economy and society (not to forget the proverbial sheep's back though), but this contribution leaves behind enormous quantities of solid wastes in the form of tailings and waste rock. The Australian mining sector has maintained strong world positions in iron ore, gold, copper, lead-zinc-silver, nickel, heavy mineral sands, coal and uranium, always built on a strong base of mineral deposits. The world, however, is changing to meet the challenge of climate change – meaning transport is being electrified, energy is moving to renewable energy (solar, wind), energy storage batteries and pumped hydro storage. This means the addition of new metals, such as lithium, cobalt, rare earths and potentially others (Te, Cd, Ga, In, Re, etc). Given that many of these 'new economy metals' are often by-products at smelters and refineries only, with mines receiving no value, this has led to supply being dominated by a select few countries – concerns about the reliability of that supply has seen such metals labelled as 'critical' in government and industry policy rhetoric. For example, in 2010 China severely restricted exports of rare earths, leading to severe price shocks and disruptions to many technologies using rare earths – which is much of the modern world in reality. But what if we could find new supplies without even building a new mine? What if we could reprocess existing mine tailings (or even previously discarded waste rock) to extract such metals? Recent research has updated and synthesized a comprehensive survey of Australian mine production, providing the basis to estimate the quantity of mine tailings (and sometimes waste rock amounts) for almost every sector of the Australian mining industry from the 1790s to 2021. This research forms the basis for the Australian Atlas of Mine Waste being developed through a collaboration between Geoscience Australia and RMIT University. On this basis, the total quantity of tailings produced to date is of the order of some 15 billion tonnes – yes, 15 Gt. To explore the potential for critical minerals in tailings where there is no geochemical data, it is possible to combine various geochemical databases to investigate whether some tailings contain concentrations of various critical minerals worthy of reprocessing (without forgetting primary metals such as Au, Cu, etc). This presentation will deliver this research – exploring the potential for Australia's ~15 Gt of tailings to contain critical minerals, outlining a compelling database, detailed mapping and more than a few surprises! The unique research is, without doubt, the most comprehensive effort ever undertaken at a national level around the world and should facilitate considerably more research and investigations of numerous types.

CRITICAL MINERALS IN AUSTRALIA – RECENT TRENDS AND POLICY SETTINGS

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Critical minerals are fundamental building blocks of the modern economy, and of increasing global geostrategic importance. As well as applications in the communication and defence sectors, a major demand driver is the investment signal that has been sent by the Paris Agreement. Meeting the Agreement's goals will need new technologies and a dramatic increase in critical minerals production – more than 40 times for lithium, and more than 20 times for cobalt and graphite (International Energy Agency, 2021). Even under the IEA's 'current stated policies' scenario, output from operating and in-development projects will not meet this demand.

Subsequently, there has been a significant increase in critical minerals exploration activity in Australia, and our share of global exploration expenditure has doubled between 2015 and 2022 – from 8% to 17%. A key driver for this activity has been government investments in publicly available pre-competitive geoscience data. While investment is ramping up – both in Australia and globally – more needs to be done to bring production online.

Several competing factors are compounding this challenge. High levels of processing and manufacturing concentration, COVID-driven disruptions, energy price spikes and geopolitical tensions have shown that market concentration leads to fragility, volatility, and unreliability of key value chains.

Australia is well positioned to use its critical mineral endowments to counter national and energy security risks. We can build on this advantage, including by building our processing capabilities and moving further along the value chain.

The Australian Government is updating the Critical Minerals Strategy, which will support the development of Australia's critical minerals mining and processing sector. It will also reflect the government's broader priorities, such as addressing climate change, growing industries in Northern Australia, genuine partnerships with First Nations communities, boosting women's economic equality, and strengthening international trade partnerships.

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RARE EARTH PRODUCTION FROM AN AUSTRALIAN CLAY HOSTED DEPOSIT

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Australian Rare Earths (AR3) is progressing inputs to feasibility studies and approvals for their South Australia Koppamurra Project, rich in clay hosted rare earth elements (REE) that are critical to producing renewable energy technologies.

AR3, in collaboration with Wallbridge Gilbert Aztec (WGA) and world class consultants, have advanced a comprehensive metallurgical test work program to develop an economic process for REE recovery from the deposit. The flowsheet evaluation is supported by robust geometallurgical models developed by the WGA Data Analytics team who applied machine learning applications to drilling and test work data.

A preliminary process flowsheet has been developed through mineralogical studies, extraction and processing tests, and a recent pilot-scale test work program, in which the following insights have been derived:

- i. Leach optimisation test work demonstrated 50% reduction in acid consumption and gangue dissolution, in the pH range 1.5 to 2.0 at ambient conditions, whilst maintaining an average recovery of 65%, up to 77% of the key magnet REEs, being Nd, Pr, Dy and Tb.
- ii. Size separation test work demonstrated early potential for >35% mass rejection in a coarse waste stream, whilst maintaining 90% of the key magnet REEs in the product stream.
- iii. Solid-liquid separation experts have progressed process technology selection test work and determination of optimal separation conditions.
- iv. Processing of an 850 kg composite sample at ANSTO, covering the entirety of the flowsheet, led to generation of a mixed rare earth carbonate product. Insights will inform design and operational criteria for piloting of a 500-tonne sample.

These insights provide an environmentally sound and commercially attractive pathway to produce a high-quality specification REE product. Pipeline optimisation test work in size separation, solid-liquid separation and impurity removal will contribute to finalising the process flowsheet and providing key inputs to a mining lease application and scoping study.

DRIVERS FOR AUSTRALIA'S MINE WASTE RENAISSANCE: THE 3 C'S

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Endless media reports and politician handshakes highlight the growing necessity for critical metals to meet our energy transition demands. To the geoscience community, this is not news. Instead, how to manage the increased volumes of mine waste that will be produced is being increasingly discussed. Mine waste is suspected to be a host of **critical metals and minerals** (i.e., cobalt, indium, REEs, Ga and Ge have typically been by-products since concentrating in waste streams). If identified as significant resources of critical metals, remining waste can support Australia's effort to adopt **circular economy** principles, a notable socio-economic driver.

Whilst this sounds relatively straightforward, practical investigations show this is anything but. From sampling to metal recovery, mine waste materials are complex and heterogenous originating, in some cases, from multiple ore sources, processed by different methods, and eventually subjected to weathering under changing climatic conditions. Therefore, multi-scale multidisciplinary **characterisatio**n is required to truly develop a valorisation process which not only recovers critical metals and minerals, but also substantially reduces any associated environmental legacy issues and mining footprints.

In collaboration with the QLD, NT, NSW and SA State Governments and Geoscience Australia mine waste (i.e., tailings, slag, waste rock and metallurgical residues) at historical and operational mines across the country have been sampled (n= 44 of 77: 2019-2024). Waste characterisation has included the use of assay, XRD, MLA-SEM and LA-ICPMS, and where relevant, LIBS, micro-XRF and synchrotron-based techniques. Highlights so far include potential for Co resources in QLDs NW Minerals Province with metallurgical studies now being conducted to recover Co from pyrite. Indium, hosted in a range of sulfides, sulfosalts and cassiterite has been recognised in greisen and VHMS mine waste, whilst Sb (and REE) enrichment has been identified in the sampled NT and several NSW metalliferous sites. New investigations are underway to better understand SAs waste with desktop studies suggesting Ni, REEs and Mn fertility. Ultimately, these data will feed into the national Mine Waste Atlas being developed by Geoscience Australia.

VISIBLE LIGHT FLUORESCENCE SENSING FOR INCREASED EFFICIENCY IN LITHIUM MINERAL PROCESSING

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Australia's world-leading lithium industry relies on the mining and processing of spodumene. However, successful and efficient extraction of lithium from the spodumene lattice is an energy-intensive process. Spodumene must be heated to a narrow temperature range around 1000 -1050°C, at which point a phase change occurs. This phase change allows increased mobility of lithium ions during later chemical extraction and therefore dramatically enhances the overall lithium recovery. Heating rock to these high temperatures is expensive, and control of the temperature is critical to ensure good lithium recovery – both inadequate and excess heating reduce lithium recovery. Enhanced sensing to accurately control this process therefore has both strong financial and environmental advantages.

Lithium, as the third lightest element, is impractical to analyse by means of existing real time techniques, such as X-Ray Fluorescence (XRF) or PGNAA. However, spodumene is an optically fluorescent material highly suitable as a target for fluorescence sensing which allows real-time, non-contact detection and quantification.

The PELL group's "Novel Fluorescence" program focuses on discovery of new fluorescence emissions for mining and mineral processing application as both cross-belt and handheld sensors. These devices can monitor and measure target minerals for faster, more informed decision making on a mine site or processing plant. The use of non-collimated visible light sources for excitation also enhances safety and therefore practical implementation: there are minimal hazards to personnel compared to other sensing techniques, which require infrared lasers, intense ultraviolet light or ionising radiation.

We will discuss possibilities for Fluorescence sensing of spodumene in mining and mineral processing, allowing real-time decision making based on optical measurements of crushed rock on-belt.

We show initial results from spodumene calcined at various temperatures, and discuss potential fluorescence application for process control to rapidly ensure furnace temperatures are correct, through feedback from optical analysis of feed and calcined product.

A NANOSCALE VISION OF TRACE ELEMENT DISTRIBUTIONS IN CRITICAL MINERALS USING ATOM PROBE TOMOGRAPHY

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Advanced mineral characterization techniques are essential for understanding the distribution of metals in critical minerals and optimizing their extraction and downstream processing. Atom probe tomography (APT) is an advanced characterization technique that enables the three-dimensional imaging and chemical analysis of minerals at the atomic scale. When applied to trace element analysis in critical minerals, APT often reveals heterogeneously distributed trace elements at the nanoscale. This distribution reflects trace element segregation to different types of mineral defects and interfaces and is, therefore, fundamentally linked to the range of defect-enhancing processes that may affect host minerals over geologic timescales, such as primary mineral growth, deformation, and fluid-enhanced recrystallization. As a result, it is difficult to predict nanoscale distributions of trace elements from standard characterization technologies. Furthermore, defects and interfaces offer energetically favourable sites for trace elements to reside, affecting their mobility and ultimately impacting extraction efficiency. In addition to characterizing trace element distribution, APT can be used to study trace element behaviour during mineral processing steps. By providing insights into the mobility and behaviour of trace elements during processing, APT can inform the optimization of processing parameters to maximize metal recovery and minimize waste.

This presentation will showcase the ability of APT to provide valuable insights into the distribution and segregation of trace elements within minerals. We will highlight how APT can establish the controlling factors on trace element segregation, consider the influence of processing on extraction efficiency, and discuss the potential for APT to be used as a tool for optimizing resource management. Additionally, we will announce an AuScope-funded program that offers Australian researchers access to APT capabilities and expertise.

A REVIEW OF MAGNETIC SEPARATION OF RARE EARTH MINERALS

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This presentation aimed to provide a review on magnetic separation of rare earth elements (REE) minerals and understand the effect of mineral characteristics and mode of operating conditions on grade and recovery of key REE minerals. REE minerals are critical to the current development of high technology materials and have various applications in alloying elements, high-strength magnets, and polishing compounds in glass and metal. This group of elements are not particularly rare in the earth's crust compared to some commonly exploited minerals (e.g. gold, silver) but found in low concentrations that is uneconomic for mineral exploitation. Initial extraction to a saleable concentration can be challenging and may require a combination of different unit operations such as gravity, froth flotation, and magnetic separation.

Magnetic separation takes the advantages of a mineral's natural magnetic property and can be performed under wet and/or dry condition. The current practice adopted in magnetic separation of REE minerals is heavily dependent on the mineralogical composition and particle size distribution of the ore being processed. Owing to this different magnetic separation strategies have been employed to produce rich REE minerals preconcentrates for subsequent hydrometallurgical extraction. Studies have shown that the extent of recovery of REE bearing minerals depends on factors such as particle size, grade and liberation of minerals, magnetic susceptibility of corresponding minerals, magnetic field strength of magnetic separators and whether the operation is performed under wet or dry condition can all affect the overall performance of separation.

To this end, this presentation, provides advances made in the use of magnetic separation as a preconcentration method for recovering and upgrading REE minerals, whiles highlighting the opportunities and challenges associated with the process.

A STICKY SITUATION: UNDERSTANDING AND MANIPULATING SI-GEL FORMATION FROM GANGUE MINERAL DISSOLUTION DURING IN-SITU LEACHING

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Copper demand is expected to rise significantly over the next two decades, driven mainly by the push for electrification as the world is moving away from fossil fuels. A significant trend in copper recovery technology is the move away from traditional Cu-concentrate mining-grinding-flotation towards more sustainable in-situ recovery via direct leaching of low-grade ores. A new leaching sequence is to be developed in cooperation with Newcrest Mining Ltd. enabling carbon-neutral copper extraction from low-grade copper ores, that will release Cu while sequestrating Fe and CO_2. This may be achieved via a two-step process, where (1) porosity is induced in the ore by acid leaching, (2) followed by leaching of chalcopyrite, $CuFeS_2$, using a carbonate-based lixiviant. The influence of gangue mineralogy on Cu-leaching processes is well acknowledged, but can be difficult to predict due to the complex mineral dissolution and precipitation reactions of mineralogically heterogeneous ore bodies. One of the major challenges of the project is the creation and maintaining of porosity for the lixiviant to access the chalcopyrite grains within the rock via dissolution of gangue minerals, and ensuring that the chalcopyrite remains amenable to leaching. It is therefore necessary to study the gangue mineral dissolution processes and the composition and structure of precipitates under varying leaching conditions. The study aims to identify novel leaching techniques to economically enhance copper extraction and suppress or alter precipitation of unwanted mineral species that prevent acidic dissolution of chalcopyrite, in particular Si-gel, i.e. by suppressing silica-gel nucleation or creating porous silica-gel. The study aims to improve the understanding and characterisation of Si-gel formation from silicate minerals on a structural level and identify element flow from complex mineral assemblages to dissolved species and precipitates to qualify and quantify the effect of silicates in the gangue on Si-gelling.

LATEST ADVANCEMENTS ON AUTOMATED MINERALOGY FOR CRITICAL MINERALS

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Automated mineralogy, analytical solution characterised by integrating automated measurement techniques based on Scanning Electron Microscopy (SEM) and Energy-dispersive X-ray spectroscopy (EDS), as a technique was first developed in the late 1970s with initial developments in automating microprobes. CSIRO first developed the QEM*SEM and QEMSCAN systems in the 1980s and 1990s, which were later spun off into a start-up company - Intellection - in 2003. The commercial market has matured and diversified with offerings from Bruker, Oxford, Tescan, Thermofisher and Zeiss. The fundamentals for mineral identification are all similar among the existing approaches: a mineral is defined and stored in a database, and BSE and/or EDS signals are used to match measured data against mineral reference data to identify the material under the beam. A high-energy particle beam is rastered across a sample to measure an entire sample.

Maps Mineralogy at its core is a computerized point-counting technique that removes operator bias when determining bulk mineralogy and derived information. However, vendor implementation details can introduce unintended bias unless operators spend significant time to detect and resolve identification artefacts.

We propose a new approach that directly models mineral complexity and SEM-EDS interactions. It automates EDS deconvolution/quantification for mineral spectra and applies this to solve a variety of problems when using SEM-EDS on geological samples. This includes boundary phases, tiny mineral grain inclusions, complex elemental interactions for solid solution series, and possible variable elemental impurities in mineral definitions. By automating these aspects, the manual operator tuning for mineral ID is significantly reduced when compared with existing commercial products such as QEMSCAN or MLA.

To illustrate this new Automated Mineralogy approach, we characterize the occurrence of Critical Minerals from various mineral deposits in Australia. This characterization includes the elemental and mineral distribution, quantitative mineralogy, deportment, and grain size distribution of the carrying minerals containing the elements and minerals of interest.

NATIONAL GEOSCIENCE: THE FOUNDATION FOR AUSTRALIA'S CRITICAL MINERALS FUTURE

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Australia is a major global supplier of critical mineral resources, ranking in the top five producers for nine of the 26 commodities on the 2022 Australian critical minerals list, and is a leading producer of many other minerals essential for the transition to net zero. To meet rapidly growing global demand, and position Australia as a reliable source of critical minerals to the world, it is essential to maintain a critical minerals resource pipeline. Geoscience Australia aims to accelerate discovery by increasing understanding of critical mineral systems, sourcing new commodities from existing assets, and delivering data and integrated interpretive products to stimulate exploration, aid future discovery success, and position communities and government to make informed decisions about future resource development.

The vast amount of precompetitive geological, geochemical and geophysical data acquired by Geoscience Australia and its predecessor agencies for over 70 years is finding new applications in exploration for critical minerals. These foundations are being built upon by new precompetitive data delivered as part of Geoscience Australia's Exploring for the Future program aimed at mapping the Earth's structure and composition from the surface and into the mantle, providing insights into the fundamental processes that lead to the formation of mineral systems, both spatially and temporally.

Drawing on research by the academia and conceptual mineral system models, these data are being integrated to produce national-scale predictive mineral potential and economic fairways maps to reduce the exploration search space and inform exploration targeting. Recognising that extracting secondary commodities from existing deposits will be an essential source for the critical mineral requirements of the future, Geoscience Australia is collaborating with international counterparts and Australian universities to undertake a national assessment of critical mineral potential in known deposits, including characterising critical minerals occurring in ores and those contained in waste from previous mining operations.

REDOX CONTROL ON HFSE SEQUESTRATION IN PERALKALINE MAGMAS

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After carbonatites, igneous rocks derived from intraplate peralkaline magmatism have the best potential for concentrating high field strength elements to economically useful abundances. However, the mechanisms which drive HFSE enrichment in peralkaline magmas remain poorly understood. Located south of Dubbo in central New South Wales, the Toongi Alkaline Magma Field encompasses a field of peralkaline magmatic bodies typically 500 to 1000 m in size, including the HFSE-enriched Toongi Trachyte, providing an ideal natural laboratory to better understand enrichment mechanisms.

Here, we use pyroxene chemistry to explore HFSE-enrichment in Toongi alkaline magmas, including electron microprobe (EPMA) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) data. Across the Toongi magmatic suites, pyroxene makes up distinct crystal populations including zoned phenocrysts, microcrysts, flow aligned groundmass crystals, and interstitial late-stage phases. Major element compositions range from diopside to hedenbergite in the most primitive bodies, and from hedenbergite to aegirine ($NaFe^{3+}Si_2O_6$) in the more evolved bodies. High resolution LA-ICP-MS maps show that enrichment in HFSE (Zr, Hf, Nb, Ta, and REEs) is coincident with aegirine crystallisation in pyroxene rims and interstitial spaces. The variation is not associated with gradual zoning expected from fractional crystallisation. Rather, abrupt enrichment in late pyroxene populations implies that a magma oxidation may be an important trigger for sequestering HFSE into solid phases. We propose that reducing conditions suppresses aegirine crystallisation and progressively saturates the residual melt with Na, depolymerising the melt and preventing the formation of minerals which sequester HFSE. This allows for HFSE to stay in the liquid phase and enrich during fractional crystallisation. In contrast, melt oxidation favours crystallisation of aegirine, removing Na from the melt and triggers the sequestration of HFSE. This has important implications for the evolution of peralkaline magmas and provides a mechanism for why some peralkaline magmas become enriched in HFSE while others do not.

COPPER AND COBALT RECOVERY FROM MINERAL WASTES

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Cobalt is one of critical minerals, that also belongs to a group of battery metals. In the modern world cobalt expands its applications from traditional cobalt-based blue pigments and wear-resistant and high-strength alloys to high-tech lithium-ion batteries and biomed applications. Cobalt compounds can usually be found in copper and nickel minerals. According to The United States Geological Survey (USGS), Australia has the second largest cobalt resources globally and takes the third place in the cobalt production. However, in our presentation we would like to draw attention to potential copper and cobalt production form secondary mineral resources such as flotation tailings and wastewater.

The tailings storage facilities represent a significant source of base, precious, and critical metals, cobalt and copper in particular. An estimated value of valuable metals contained globally in the tailings is US$3.4 trillion. The major barriers that prevent cost-effective reprocessing of tailings, include the low content of valuable metals and high content of fine fractions. In addition, tailings pose significant environmental issues, including seepage and overtopping of harmful compounds into surrounding ecosystems.

InnovEco Australia has developed a novel metal recovery technology, the resin in moist mix (RIMM) method, which uses ion exchange to enable the cost-effective recovery of valuable metals from low-grade ores, tailings and wastewater. In collaboration with the University of South Australia and COOE, a test work program of the RIMM bench top tests and drum model tests has been conducted. It has been demonstrated that this technology can recover near 100% of the acid-soluble copper and cobalt from South Australian tailings and drainage water.

Supported by the Australia-India Strategic Research Fund, this project represents a significant step towards overcoming the barriers to tailings reprocessing, unlocking the immense potential of mineral waste for the mining industry and beyond.

Keywords: Copper and Cobalt Recovery, Ion Exchange, Resin in Moist Mix, Tailings Reprocessing, Wastewater

TOWARDS THE DEVELOPMENT OF MACRONUTRIENTS SUPPLY CHAIN BASED ON LUNAR RESOURCES

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The expansion of the scope of action of the human species is taking place from the growth of the space industry. One of the most important challenges this poses has to do with reducing the dependence of future missions and colonies on Earth's resources due to the high economic cost of transporting supplies from our planet. In-Situ Resource Utilization (ISRU) is emerging as the appropriate approach to facilitate, among other things, the integration between special mining and space farming and the incorporation of local resources from celestial bodies such as the Moon in supply chains. Consequently, chemical elements such as phosphorus and potassium, which together with nitrogen are the most important nutrients for crop fertilization, will be of great importance since their use will not only be required to create the conditions for the implementation of space farming, but their availability on Earth will be less and less in the coming decades due to the growth in demand for them for use in agricultural activities, which will make their exploitation in-situ necessary. Through this project, both the main characteristics and scope, as well as the probable implications in terms of sustainability of the supply chain of phosphorus and potassium obtained from lunar materials through ISRU, will be determined prospectively. The potential for obtaining both elements by acid leaching and solvent extraction in microfluidic reactors will also be evaluated.

CRITICAL MINERAL HYDROMETALLURGICAL PROCESS INNOVATIONS

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Australia is a major exporter of critical minerals and metal products. Increased demand and challenging resources are motivating the search for process improvements that can help provide a competitive advantage. Process research and development efforts will be discussed in the context of briefly reviewing conventional approaches for lithium, cobalt and rare earth elements. Extraction of lithium from Australian spodumene has increased dramatically in the past five years to produce Li_2CO_3 and $LiOH.H_2O$ needed for rechargeable batteries. Is there an advantage to chloride process chemistry? Can something be done with the leached spodumene residue? Cobalt is also a critical component of many rechargeable batteries. Can ion exchange resin help to recover cobalt from low grade slurries or solutions? Rare earth metals are needed for magnets in wind turbine generators and electric vehicle motors. Can we efficiently produce rare earths from existing metallurgical process tailings?

IDENTIFYING EXODERMIC CONDITIONS TO HOST IONIC REE’S IN THE GAWLER CRATON

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Since Identifying clay hosed REE’s above gold mineralisation at the Wudinna Project in the southern Gawler Craton, the company has embarked on identifying a value-add opportunity in defining REE resources that overlie gold mineralisation. Through mineralogical and metallurgical characterisation, the company has actively tested proposed mechanisms for the identified changes in REE mineral phases and has subsequently adjusted exploration models to target exodermic conditions that are supportive of REE ionic adsorption. This has led the company to recently drill test the Corrobinnie paleochannel where interpreted vertical redox fronts occur through paleo-sediments. Oxidised sands and clays infill channels overlying granitic saprolites. Sulphidic and highly reduced clays overlie channel fill providing potential REDOX chemistry to maintain ionic mineralisation. The company is in the process of validating results to demonstrate the presence of ionic REE’s in a geological setting that is proven for Insitu-leach mining.

METAMICT ZIRCON AS METAL SOURCE FOR UNCONFORMITY-RELATED REE DEPOSITS

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Zircon is hailed for its chemical and physical durability, but can undergo extensive chemical and structural modification due to radiation damage via the emission of alpha (α) particles, and subsequent low-temperature hydrothermal alteration. Here, we investigate Archean zircons from arkosic metasediments of the Browns Range Metamorphics (BRM) to evaluate their role in the formation of local unconformity-related heavy rare earth element (REE) ore deposits, within the Browns Range Dome, Western Australia.

We determine that the heavy REE inventory of the BRM are primarily hosted in zircon, and that these zircons have a wide range of major element totals (77 to ~100 wt. %, including low SiO_2 and ZrO_2 contents), and high and variable 'non-formula' components (U, Th, Y, REE, Nb, P, Al, Ca, Fe, Ti, F and OH- or H_2O). Concentrations of Y+REE in some cases exceed 8 wt. %. Extensive radiation damage (metamictisation) is confirmed by structural features including porous and amorphous domains, cavities, and voids. The lack of regional thermal events over an extended period likely prevented thermal annealing of these radiation-damaged zircons. Uptake of non-formula elements in metamict zircon, most likely during sedimentation in the late Archean, promoted further radiation damage, such that these grains remained highly susceptible to alteration by subsequent hydrothermal fluid circulation.

We propose that the unconformity-related REE mineralisation was formed by saline fluids leaching Y+REE (and possibly P) from metamict zircon in the BRM, followed by ore mineral precipitation in fault zones near, and along the regional unconformity. More broadly, this model of ore formation may be relevant to other basin-hosted mineral systems, and could be used to guide exploration for unconformity-related REE deposits in Australia, and globally.

NEODYMIUM ISOTOPES UNRAVEL THE ORIGIN OF REE ENRICHMENT IN THE GEORGINA BASIN PHOSPHORITES

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In this study we examine the origin of REE enrichment in phosphate-rich sedimentary rocks (phosphorites, >18–20 wt.% P_2O_5) of the Cambrian (ca. 505 Ma) Beetle Creek Formation of the Georgina Basin, Queensland. These rocks are currently mined for phosphate fertiliser and host significant concentrations of REE (up to 0.5 wt.% total REE). The possibility of extracting REEs as a by-product of phosphate mining, in addition to relatively shallow depths and low cost of mining, make these an attractive target for the resources industry.

Bulk-rock geochemistry reveals basinal-scale differences in the total concentrations of the REEs, with phosphorite from the northern (DTREE, Barr Creek, Paradise North and South prospects) and central parts (Lily and Sherrin Creek prospects) of the Georgina Basin in Queensland having on average lower concentrations of total REE compared to those further to the south (Ardmore, Phosphate Hill and Duchess prospects). Integrating bulk-rock and mineral geochemistry, mineralogy and isotopic (Sm-Nd and Sr) datasets, we propose that the REEs in phosphorites are seawater derived, with minimal input from external sources such as diagenetic or hydrothermal fluids, or the underlying basement rocks. Instead, variations in total REE concentrations are controlled in part by the texture of the phosphorite, with pelletal (packstone to grainstone) phosphorites (dominant in the southern prospects) yielding on average higher concentrations of REEs compared to the more compact non-pelletal phosphorite (dominant in the northern and central prospects). This is likely due to the higher surface-to-mass ratio of the pelletal phosphorite resulting in uptake of higher concentrations of REE during formation in the bottom sediment pore water, as well as later dynamic coastal reworking by the seawater.

This diachroneity in the origin of REE can be explained by differences in depositional environments, with formation of the northern and central deposits taking place during early transgression (sequence set 1) where phosphorite formation occurred in oxidised, shallow supratidal to subtidal platformal environments. During the main transgressive event (sequence 2) that inundated the whole Georgina Basin, fault controlled topography in the southern domain allowed formation of phosphorites along basement highs with dispersal of phosphorite pellets resulting in significant accumulations of grainstone phosphorites in the deeper parts of the basin. These deep anoxic bottom waters were more saline (higher Na) and contained higher concentrations of REE.

This work highlights that REE prospectivity of the Georgina Basin phosphorites is among the highest globally. The enrichment of REE in phosphorite appears to be controlled largely by the composition of the seawater, with deep anoxic bottom waters associated with higher concentrations of REE. The most prospective regions for REE mineralisation include the southern prospects of Queensland (Ardmore, Duchess and Phosphate Hill), as well as phosphorite deposits along the Alexandria-Wonarah High in the Northern Territory.