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'EARTH, SEA AND SKY'— SPECIALIST GROUP IN GEOCHEMISTRY, MINERALOGY & PETROLOGY (SGGMP) BIENNIAL CONFERENCE ABSTRACTS

SJ Barnes and K Gessner (eds)

Government of Western Australia
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PERTH 2022

Geological Survey of Western Australia

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About this publication
This Record was prepared for 'Earth, Sea and Sky'— the biennial meeting of the Specialist Group in Geochemistry, Mineralogy & Petrology (SGGMP) in Yallingup, Western Australia, from 7–11 November 2022. The Geological Survey of Western Australia (GSWA) is releasing the abstract volume and program as part of its Record Series to ensure a wider distribution. The scientific content of the Record, and the drafting of figures, has been the responsibility of the authors. No editing has been undertaken by GSWA.

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Cover image: Journey to the centre of the Kimberley (© 2010 PL Schubert)

Preface

The Specialist Group in Geochemistry, Mineralogy and Petrology (SGGMP) of the Geological Society of Australia has run a series of biennial meetings. The ethos of the meetings has been to bring a small group (usually around 50-60, 100 this time) of geoscientists in these areas of research together in a conducive environment close to some interesting rocks to talk science and share ideas. Having the rocks close by is the essential component, keeping the science grounded in actual field observations and letting geoscientists do what they most love to do: argue on and about outcrops. The 2022 Yallingup meeting was conceived in this spirit, being located within easy reach of the superb coastal outcrops of the late Proterozoic Leeuwin Inlier in the historic setting of Caves House, Yallingup, one of the jewels of south-western Australia. Prof. Nick Timms from Curtin University volunteered to lead two afternoon field trips in the Leeuwin Inlier and Dr. Tim Ivanic from the Geological Survey of Western Australia agreed to, on the way back top Perth, lead the conference attendees to exposures of the Southwest Terrane of the Archean Yilgarn Craton.

The conference was scheduled over two full days and two half days, featuring a total of 61 talks and 19 posters, divided into four main sessions: tectonics and geochronology, fluids and mineral deposits, magmatism mineralogy and petrology, and sedimentary and other miscellaneous geochemistry topics. Topics range from extra-terrestrial influences on continent formation through origin of life, the fine points of modern geochronology, classic ore deposit petrology, data interoperability and beyond. Keynotes include Prof. Martin Van Kranendonk on "The elements for an origin of life on Land: Evidence from the Pilbara Craton, Australia", Prof Jon Blundy on "Chemical differentiation by mineralogical buffering in crustal hot zones", and Dr. Margaux Le Vaillant (SEG Waldemar Lindgren medallist in 2021) on "Liquid sulfide transport in magmatic systems". Abstracts for all the talks and posters can be found in this volume in alphabetical order by author.

Grateful thanks are due to the conference committee, Pete Kinny (sponsorship), Louise Schoneveld (workshops), Lucy McGee and John Foden (programming), and Nick Timms and Tim Ivanic (field trips). Klaus Gessner compiled the abstracts, and Tim Holland and Sue Fletcher in the GSA office provided essential support. Blanca Beltran Fortuny, events manager at Caves House, made planning easy and provided us with a welcoming and comfortable venue.

We thank our sponsors for making the meeting affordable to many, and particularly to students. The event sponsors were Chalice Mining, BHP, CSIRO Mineral Resources, Curtin University, the Geological Survey of WA and Business Events Perth.

Further information on SGGMP can be found at https://gsasggmp.wixsite.com/home

Steve Barnes

SGGMP Chair 2021-22

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Program

Monday 7th November 2022 - Tectonics and Geochronology			
Session chair	**Time**	**Presenting author**	**Title**
	8:30 AM		*Welcome to country*
Oliver Nebel	8:45 AM	Michael Brown	The style and tempo of tectonics since the Archean
	9:05 AM	David Mole	Geodynamic transition at 2.7 Ga in Earth's largest craton
	9:25 AM	Tim Ivanic	New interpreted bedrock geology of the southwest Yilgarn: implications for geodynamics and mineralization
	9:45 AM	Azim Rossalim	Patterns of Tectonic Evolution:Interpolation of Isotopic Data in Yilgarn Craton
	10:05 -10:30 AM		*Morning tea*
Pete Kinny	10:30 AM	Riley Rohrer	Multiple dates with models; analysing multiple minerals in metapelites to better understand the history of the Proterozoic Fraser Zone, Western Australia
	10:50 AM	Imogen Fielding	Updated age constraints for the timing of metamorphism in the South West Yilgarn craton
	11:10 AM	Samantha March	The inhibited response of accessory minerals during HT-UHT reworking
	11:30 AM	Alan Collins	Full plate tectonic reconstructions as essential pre-requisites to quantifying the earth system in deep time: a new 1.8 Ga to present full-plate tectonic reconstruction
	11:50 AM	Anthony Clarke	The unroofing of Archean crustal domes as recorded by detrital zircon and apatite
	12:10 - 1:10 PM		*Lunch*
Imogen Fielding	1:10 PM	Martin Van Kranendonk	Keynote: The elements for an origin of life on Land:Evidence from the Pilbara Craton, Australia and implications for the search for life on Mars
	1:40 PM	Kathy Kuper	Implications of high-grade metamorphism on detrital zircon data sets from the Fraser zone, Western Australia
	2:00 PM	Steven Reddy	Carbon in mineralogic grain boundaries
	2:20 PM	Cilva Joseph	Xenotime: A new impact geochronometer?
	2:40 PM	Christopher Kirkland	A galactic tempo in crust production?
	3:00 - 3:30 PM		*Afternoon tea*
Margaux Le Vaillant	3:30 PM	Max Droellner	A Hadean-Eoarchean protocrust beneath the SW Yilgarn craton?
	3:50 PM	Hugo Olierook	Oldest magmatic Ni-Cu deposit a consequence of secular change in global tectonic regime
	4:10 PM	Alejandra Bedoya Mejia	Apatite triple dating uncovers the thermo-tectonic history of the Coompana and Madura provinces
	4:30 PM	Milo Barham	Depositional age is just a number: Detrital zircon age spectra and tectonic setting

Tuesday 8th November 2022 - Fluids and Mineralisation			
Session chair	**Time**	**Presenting author**	**Title**
Michael Hartnady	8:30 AM	Joel Brügger	Volume Matters: Aqueous fluids in the Deep Earth
	8:50 AM	Marco Fiorentini	Dynamics of metal and volatile flux across the lithosphere
	9:10 AM	Margaux Le Vaillant	Keynote: Liquid sulfide transport in magmatic systems
	9:40 AM	Jessica Walsh	Zircons Achilles heel: metamictisation, metal mobility, and REE mineralisation
	10:00 AM	Oliver Pring	Insights into the transfer of metals between mafic enclaves within a host granite using Cu isotope analysis
	10:20 AM	Srijita Ray	The behaviour of rare earth elements (REEs) in carbonate melts and phosphate ore minerals
	10:40 - 11:00 AM		*Morning tea*
Jessica Walsh	11:00 AM	Zara Woolston	In-situ S isotopes and Rb–Sr dating of the Cu mineralisation and regolith at Kapunda, SA.
	11:20 AM	Louisa Hebditch	Puzzling Pentlandite: Low-Temperature Alteration and the Effect on Sulphur Isotopes of Pentlandite from the Mawson Prospect in the Fraser Zone, Western Australia
	11:40 AM	Walter Witt	Syenitic intrusions with associated gold: the search for fertility criteria
	12:00 PM	Coralie Siegel	Mafic intrusion-hosted Ni-sulfide deposit emplaced during the Widgiemooltha dyke event, Eastern goldfields, WA
	12:20 PM	Christina Loidolt	Carbonates, Sulfides and U-REE-Cu-Au Mineralisation, NW Queensland
	12:40 PM	Jarred Lloyd	In-situ Rb–Sr dating of lithium pegmatites
	1:00 - 6:00 PM		*Field trip: Leeuwin Complex south, Augusta area*

Wednesday 9th November 2022 - Magmatism, Mineralogy and Petrology			
Session chair	**Time**	**Presenting author**	**Title**
Laura Morrissey	8:30 AM	Tim Johnson	BOOM … Continent
	8:50 AM	Michael Hartnady	Fluid processes in the early Earth and the growth of continents
	9:10 AM	Pete Kinny	$^{87}Sr/^{86}Sr$ in apatite inclusions in zircon – a window to the early Earth
	9:30 AM	Eric Vandenburg	Paleogeographic controls on granitoid chemistry reveal the Mesoarchean diversification of tectonomagmatic regimes
	9:50 AM	Yongjun Lu	Paleoproterozoic magmatism in the Pilbara Craton: insights from the c. 1.8 Ga hydrous and oxidized Bridget Suite
	10:10 -10:40 AM		*Morning tea*
Richard Arculus	10:40 AM	Dave Kelsey	Pressure–temperature–time (P–T–t) dataset for the southwest Yilgarn: showcasing the GSWA's ongoing metamorphic map development
	11:00 AM	Janne Liebmann	Pb Isotopes of the Curnamona Province, an example of extreme crustal fractionation in the Proterozoic
	11:20 AM	Greg Yaxley	Petrogenesis of Carbonatites
	11:40 AM	Louise Schoneveld	The survival of complex Cr-zoning from pyroxene through transformation into amphibole
	12:00 PM	Oliver Nebel	From 'many rocks to get an age' to 'many ages from one rock' - On the age-old problem of dating a granite
	12:20 - 1:20 PM		*Lunch*
Carl Spandler	1:20 PM	Jon Blundy	Keynote: Chemical differentiation by mineralogical buffering in crustal hot zones
	1:50 PM	John Foden	Pyroxene-rich xenoliths Sangeang Api volcano East Sunda arc: Magma supply system and fractionation controls
	2:10 PM	Adam Abersteiner	Petrology and geochemistry of the Sveinar-Randarhólar fissure (Iceland): Insights into post-glaciation magmatism
	2:30 PM	Michael Anenburg	REE-mineralised calcite carbonatites result from silica contamination and antiskarn formation
	2:50 - 3:10 PM		*Afternoon tea*
Louise Schoenveld	3:10 PM	John Mavrogenes	Mount Hagen, PNG: A deep-arc crystal mush
	3:30 PM	Xueying Wang	The elusive trace element pattern in arc lava – New clues from Sn isotopes
	3:50 PM	Han Qi	The generation of sodic and potassic granitoids by fluid-fluxed and fluid-absent melting in continental arcs and back-arcs: an example from the Yangtze Block in South China
	4:10 PM	Chris Clark	Monazite in extremis
	4:30 PM	Richard Arculus	Adakites : Slab melts and porphyry copper parents?
	4:50 PM	Kevin Frost	Gonneville PGE-Ni-Cu-Co deposit, Yilgarn Craton, Western Australia
	7:00 PM		*Conference dinner*

Thursday 10th November 2022 - Sedimentary and other geochemistry			
Session chair	**Time**	**Presenting author**	**Title**
Alan Collins	9:00 AM	Juraj Farkaš	Calcium and strontium isotope constraints on the origin and diagenetic history of ancient marine carbonates
	9:20 AM	Claudio Delle Piane	On the origin of quartz in the Velkerri Formation: implications for the Si cycle in the Mesoproterozoic.
	9:40 AM	Darwin Subarkah	The depositional window and palaeoenvironment of the economic Proterozoic Glyde Package, greater McArthur Basin, northern Australia
	10:00 AM	Morgan Blades	Dating and characterising a newly discovered sedimentary sequence in the Northern Territory
	10:20 - 10:40 AM		*Morning tea*
Morgan Blades	10:40 AM	Georgie Virgo	Facies analysis and multiproxy geochemistry of Tonian to Cryogenian succession in Adelaide Rift Complex, South Australia
	11:00 AM	Ruiqi Zheng	New constraints on the origin and post-depositional history of Neoproterozoic Breamar ironstones (SA): Insights from core logging, micro-scale mineral mapping and in-situ Rb-Sr dating
	11:20 AM	Bruno Vieira Ribeiro	Constraining the time-strain evolution of shear zones: Insights from muscovite textural and isotopic analysis
	11:40 AM	Isabel Zutterkirch	A new approach to geochronology in very fine-grained sediments
	12:00 PM	Laura Morrissey	Accessory mineral stability and REE mobility during weathering
	12:20 PM	Alexander Prent	Geochemistry data interoperability and making the world fair through Onegeochemistry
	12:40 PM	Jeremy Wykes	The MEX beamlines at the Australian Synchrotron
	1:00 - 5:00 PM		*Field trip: Leeuwin Complex north, Yallingup-Dunsborough*
	6:00 PM		*SGGMP AGM*

List of poster presentations - posters will be available to view at tea and lunch breaks, and after talks on Monday and Wednesday	
Presenting author	
Evgeniy Bastrakov	Sulphate complexes of YREE: a key to understanding unconformity-related HREE deposits
Raphael Johannes Baumgartner	Stromatolites from the Paleoarchean Dresser Formation: Crossroads between geology and biology
Matilda Boyce	A window into the early mantle: Archean anorthosites of the Narrter Terrane, Western Australia
Stefano Caruso	The origin of volatiles in the Ni-Cu-Co Ovoid deposit of the Voisey's Bay complex. New insights on the role of accessory minerals in ore-forming processes
Bradley Cave	Geology, age and alteration of the dolerite dykes at the Hilton and George Fisher Zn-Pb-Ag deposits, NW Queensland: Implicatiosn for a revised deposit model
Maria Cherdantseva	New insights into metal transport mechanisms across the lithosphere
Alan Collins	Age, clay-mineral provenance and REE geochemistry of middle Ediacaran shales and impactites from the Adelaide and Centralian Superbasins
Sarah Gilbert	In-situ Rb-Sr Geochronology - Reference Mataerial Charracterisationand Future Directions
Madeleine Ince	The interplay between magma source, geodynamic evolution and Cu-Au endowment in convergent margin settings: an example from zircon U-Pb, O and Lu-Hf systematics of the Farallon Negro Volcanic Complex, Argentina
David Mole	Isotopic atlas of Australia - an update
Melissa Kharkongor	Apatite laser ablation Lu-Hf geochronology: a new tool to date mafic rocks
David Mole	Crustal architecture of Precambrian Australia's south-eastern margin – an isotopic perspective
Justin Payne	Concordance and chemical abrasion as pathways to improved trace element geochemistry in zircon and other accessory minerals
Zsanett Pintér	Fantastic Scapolites and how to MEASURE them. electron microprobe analysis of Scapolite: protocols and pitfalls
Alexander Prent	Timing and effects of fluid-driven metamorphism on deformation and shear zone widening
Ian Smith	Magma chambers do exist: The example of the Mt Dromedary monzonite complex
Michael Anenburg	A potential "chromite sponge"? Adherence of sulfide liquids to chromite and other spinels in high temperature experiments
Anne Virnes	Sulfur isotopic variability and Pd content of pentlandite in the MKD5 komatiite-hosted Ni-Co-Cu sulfide deposit, Mount Keith, Western Australia

Abstracts

Petrology and geochemistry of the Sveinar-Randarhólar fissure (Iceland): Insights into post-glaciation magmatism

[1,2]Adam Abersteiner, [2]Christoph Beier, [3]Sæmundur Ari Halldórsson, [3]Edward W. Marshall, [2,3]Eemu Ranta
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The Icelandic extensional, intraplate environment has experienced extensive changes in lithostatic pressures during deglaciation in the past at least ~11ka. This study focuses on the early-Holocene Sveinar-Randarhólar fissure system (Central East Iceland), which formed contemporaneously and/or in response to recent deglaciation. The Sveinar-Randarhólar fissure system consists of a discontinuous row of scoria craters (typically <50 – 100m in height and <100 – 300m in diameter) and the associated Sveinahraun basaltic lava flows, which together extend for more than 75km from the southern side of the Route 1 Highway (~20km east from Mývatn) to Raufarhöfn on the northern coast. This crater row and associated lava flows presents an excellent opportunity to examine the geochemical variability across a long fissure system. Moreover, it is unknown whether the Sveinar-Randarhólar fissure is related to other larger magmatic systems (e.g., Askja volcano), or formed from an independent magma source(s).

Our petrographic, geochemical, radiogenic Pb and thermobarometric data of the Sveinar-Randarhólar fissure shows that there is almost unambiguous homogeneity across the entire fissure system. Furthermore, major and trace element data, as well as radiogenic Pb isotopes, shows that the Sveinar-Randarhólar fissure bears close composition overlap with basaltic lavas from the Askja volcano, which is located 65km to the south with no visible extrusions of the fissure in between. We present a preliminary geodynamic model for the Sveinar-Randarhólar fissure to show that lateral magma propagation from Askja was likely initiated by caldera collapse which was linked to a contemporaneous eruption at the main volcanic edifice and that lateral magma transport was largely controlled by the topography and the extent of glaciation in the region at the time.

A potential "chromite sponge"? Adherence of sulfide liquids to chromite and other spinels in high temperature experiments

[1]ANENBURG, Michael, [1]KEANE, Kathryn, [2]CHERDANTSEVA, Maria

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Sulfides are ubiquitously associated with chromite reefs in layered mafic intrusions, but the causes for these textures aren't entirely clear. We have conducted many high temperature experiments over the past few years that contained both a solid spinel-group mineral (often chromite) and liquid sulfide droplets, in a matrix of silicate melt ± minerals. We observe that sulfide droplets overwhelmingly adhere to spinels, but do not show any wetting behaviour. Smaller sulfide droplets are round and tend to touch spinel on a small contact point. Larger sulfide droplets often deform from an ideal round shape to avoid spinels, yet the spinels still stick to the droplets. Isolated sulfide droplets which are not adhering to a spinel are exceedingly rare. This behaviour appears independent of starting geometry, pressure, temperature, oxygen fugacity, spinel composition, and silicate/melt compositions, in the ranges that we accessed experimentally. Sulfide liquids adhere to both pre-existing and newly grown spinel. While dense spinel-group minerals often remain in their initial position within the experiments without sinking, sulfide liquids are often transported inside the experimental capsule and concentrated within spinel layers. Some sulfide droplets appear to be climbing upwards through a stationary spinel-rich layer inside silicate melt matrix. These observations might contribute towards our understanding of the common chromite–sulfide association in magmatic intrusions.

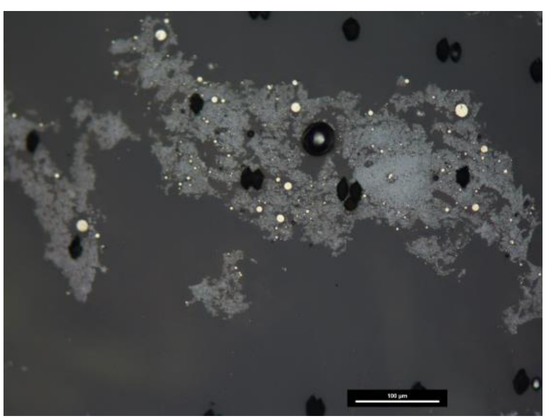

Figure 1: Sulfide droplets (bright yellow) associated with chromite (light grey) in a matrix of silicate glass (dark grey).

REE-mineralised calcite carbonatites result from silica contamination and antiskarn formation

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Many carbonatite complexes are zoned with barren calcite carbonatites at the exterior and REE-mineralised dolomite and ankerite carbonatites at the cores. REE mineral hosts are often REE-fluorcarbonates or monazite, intimately associated with baryte and strontianite. This observation is consistent with experimental work showing that a carbonatite melt will fractionate by crystallising calcite followed by dolomite and ankerite, at which stage REE are sufficiently concentrated to form igneous alkali REE carbonates (e.g., burbankite), which are then altered to the currently observed assemblages. However, some carbonatite-hosted REE deposits are lacking any dolomite or ankerite, and the baryte + REE-fluorcarbonate association appears primary rather than alteration of burbankite. These carbonatites are also rich in silicate minerals such as aegirine, alkali amphiboles, and phlogopite. One example of a similar system is the well-preserved Maoniuping carbonatite in the Mianning-Dechang belt. We observe ubiquitous reaction textures between the initially alkaline carbonatite melt and the siliceous host rock. Quartz syenite clasts are silica-depleted towards the contact with the carbonatite, and growth of aegirine, phlogopite, and arfvedsonite is observed at the contact from the carbonatite side. The only carbonate mineral is calcite, which serves as the matrix for the silicate minerals, and pegmatite-textured fluorite, baryte, and bastnäsite. We propose a process in which intrusion of evolved Fe–Mg–REE-rich alkali carbonatite melt which would otherwise form burbankite-bearing ankerite carbonatites, reacts with the silicate host rocks. The reaction consumes Na, K, Fe, and Mg from the carbonatite melt to refractory ferromagnesian silicate melts. The lack of Na prevents burbankite from forming, the lack of Mg and Fe prevents ankerite from forming, and bastnäsite & baryte form directly from the now solidified melt instead of forming as alteration from precursor minerals.

ADAKITES: SLAB MELTS AND PORPHYRY COPPER PARENTS?

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The world's largest current Cu resource is volcanic arc-hosted, porphyry copper deposits (PCD). Whether unusual parental magmas or fortuitous combinations of processes accompanying emplacement of common parental arc magmas (e.g., basalt) is required for ore deposit formation, remains unclear. Spatial and tectonic associations of adakite (andesite with high La/Yb, Sr/Y) with porphyries exist, but genetic links are debated. Delayed saturation with Cu-bearing sulfides consequent to elevated redox state seems essential for late-stage exsolution of Cu-bearing hydrothermal fluids. Partial melting of subducted, hydrothermally altered oceanic crust in the eclogite stability field are invoked to account for andesitic compositions, residual garnet signatures, and the putative oxidized character of adakites. Alternative petrogeneses include partial melting of lower crustal, garnet-bearing sources and extensive intra-crustal amphibole fractionation. Here we demonstrate mineral-hosted, adakite glass (formerly melt) inclusions in submarine lavas of the New Hebrides arc are oxidized relative to island arc (and mid-ocean ridge) basalts, are H_2O-S-Cl-rich, and moderately enriched in Cu. Polynomial fitting of chondrite-normalised, rare earth element abundance patterns shows precursors of these adakites were derived from partial melting of subducted slab and experienced garnet fractionation. Genuine adakite melts are plausible progenitors for PCD formation given high oxidation states, sulfur, water, and chlorine contents, all derived from origins as partial melts of subducted eclogitic crust. These findings show the link between adakites and PCD stems from the slab melt origin, and explains why 'adakites' found in non-arc settings are rarely associated with PCD. Exploration of global, putative adakite compositions shows that residual garnet is crucial for adakite petrogenesis whereas garnet-free amphibolite can be excluded as a protolith. Furthermore, only fractional crystallization of garnet generates distinctive increasing lambda 1 (slope) and lambda 2 (negative slope) on chondrite-normalised, rare earth element abundance patterns. The extent of garnet fractionation can be quantified as a garnetometer.

DEPOSITIONAL AGE IS JUST A NUMBER: DETRITAL ZIRCON AGE SPECTRA AND TECTONIC SETTING

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Detrital minerals are a product of catchment geology, sedimentary processes and climate at the time of deposition (as well as the deeper past through sediment recycling). The detrital record therefore offers significant potential to reconstruct aspects of Earth history that otherwise have been lost due to the vicissitudes of weathering, erosion, and tectonic overprinting. Tectonic setting is of fundamental importance to understanding the evolving face of our planet and its mineral endowment. However, reconstructing the tectonic setting of ancient crustal fragments can become complicated by the incompleteness of the geological record. Importantly, characteristics of detrital zircon populations can be related to the tectonic environment in which the host sediments accumulated. Detrital zircon populations that accumulate in convergent tectonic settings commonly display well-defined young age modes derived from a fertile arc or orogenic belt. In contrast, detrital zircon populations from passive margins/extensional settings are commonly polymodal reflecting more significant sediment recycling and mixing from geologically heterogeneous catchments. Two new metrics have been defined relating to (i) the difference between the 10^{th} and 50^{th} percentiles of a detrital zircon age population, and (ii) a distribution analysis of age population modality and dispersion. Importantly, these new metrics can help distinguish tectonic settings without knowledge of depositional age.

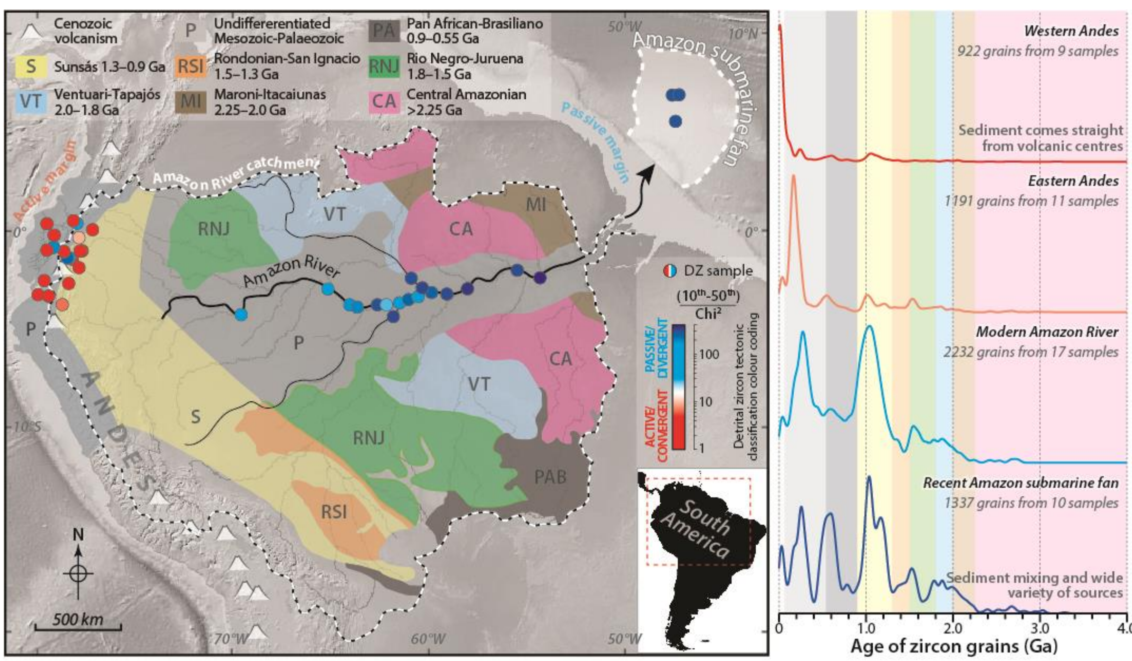

Fig. 1 Demonstration of the effectiveness of the novel tectonic setting classifier applied to modern sediment samples traversing South America's convergent to passive margins.

SULPHATE COMPLEXES OF YREE: A KEY TO UNDERSTANDING UNCONFORMITY-RELATED HREE DEPOSITS

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Heavy rare earth elements are essential in renewable energy and high-tech products. Some natural rare earth element (REE) deposits exhibit heavy rare earth element (HREE) enrichment from < 10% to ~85% of the REE budget (Williams-Jones et al., 2015).

Controls on REE fractionation in hydrothermal systems are imposed by (1) changes in the relative stability of REE aqueous complexes with temperature (Migdisov et al., 2016) and (2) incorporation or rejection of REE by crystalline structures. Also, the REEs are invariably found as solid solutions but not as pure minerals. REE and yttrium (Y) sulphate complexes are some of the most stable REE and Y aqueous species in hydrothermal fluids (Migdisov and William-Jones, 2008, 2016; Guan et al., 2022) and may be responsible for REE transport and deposition in sediment-hosted deposits. Within the unconformity-related deposits, REEs are hosted mostly by xenotime ($(Y,Dy,Er,Tb,Yb)PO_4$) and minor florencite ($(La,Ce)Al_3(PO_4)_2(OH)_6$) (Nazari-Dehkordi et al., 2019). Modelling the stability of xenotime in the H-O-Cl-(±F)-S-P aqueous system is critical for understanding HREE enrichment in this mineral system.

We use a newly derived thermodynamic dataset depos for $REESO_4^+$ and $REE(SO_4)_2^-$ aqueous complexes to generate stability diagrams illustrating mechanisms of REE transport and deposition in the above deposits. Sulphate Y and REE complexes may dominate even in chloride-rich brines and facilitate REE mobilization in acid oxidizing environments. Previously Nazari-Dehkordi et al. (2019) proposed an ore genesis model involving the mixing of discrete hydrothermal fluids that separately carried REE + yttrium and phosphorus. The speciation model that includes sulphate complexes expands this scenario; a process resulting in fluid neutralization or reduction will also promote precipitation of xenotime enriched in HREEs.

STROMATOLITES FROM THE PALEOARCHEAN DRESSER FORMATION: CROSSROADS BETWEEN GEOLOGY AND BIOLOGY

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Sulfidized stromatolites from the 3.48 Ga Dresser Formation are widely considered as a benchmark for the oldest preserved evidence of life on Earth. However, since their discovery in the 1980s, biogenic interpretations have mostly relied on morphological and textural characteristics. Recent microanalytical characterizations of unweathered stromatolite samples from drill cores collected in 2007 provided additional evidence for biogenicity through the discovery of i) putative microbial remains, ii) micromineralogy that is consistent with the sulfidization of a microbial substrate, and iii) enrichments of transition metals and metalloids (especially nickel, zinc, and arsenic) within crinkly stromatolite laminae, which are consistent with an adsorption onto microbial substrates. In 2019, the Dresser Formation was redrilled to intersect texturally and petrographically diverse stromatolites. These materials provide an excellent opportunity to further investigate these unusual and very ancient microbialites.

Elemental mapping of sulfidized stromatolites in the newly acquired drill cores aids in documenting biological morphologies and microtextures that interfere with, or contrast sharply to, immediately adjacent – and demonstrably abiotic – rock fabrics arising from geological processes. Integration of these data with micromineralogical analyses and Raman Spectroscopy mapping for organic matter indicate stromatolite formation via: i) accretion of organic matter, which is occasionally preserved as filaments and strands that resemble degraded biofilm remains; ii) (near-) coeval precipitation of microspherulitic barite, whose morphology is indicative of low-temperature precipitation onto organic matter; iii) early precipitation of nanoporous pyrite that is enriched in transition metals and metalloids; iv) termination of stromatolite growth, such as by evaporative exposure and subsequent sediment infill; v) widespread growth of coarse barite crystals in the subsurface, which cut up into, or plastically deform, the stromatolites. Collectively, our observations reaffirm that the Dresser Formation stromatolites flourished in hydrothermally recharged and fluctuating shallow marine brines of a tectonically active megacaldera complex.

APATITE TRIPLE DATING UNCONVERS THE THERMO-TECTONIC HISTORY OF THE COOMPANA AND MADURA ROVINCES

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The Madura and Coompana Provinces, located between the Gawler and Yilgarn cratons, represent the crystalline basement under the Eucla Basin. Given the remoteness and the lack of basement outcrop, this area has remained largely unstudied, despite being key to our understanding of the Proterozoic evolution of southern Australia. Recent seismic surveys and drilling campaigns have mapped the structural architecture and provided the samples required to study the tectonic history of this vast area. In this study, apatites were separated from drilled bedrock samples and were triple dated using the apatite Lu-Hf (ALu-Hf), U-Pb (AU-Pb) and fission track (AFT) methods, with the aim to advance understanding of the thermo-tectonic evolution of the Coompana and Madura Provinces. Laser ablation ALu-Hf ages from the western Coompana and Madura Provinces range between ~1142 and 1500 Ma, similar to their corresponding (previously published) zircon crystallization ages. However, samples from eastern Coompana yield ALu-Hf ages of ~1150-1190 Ma, which are significantly younger than their corresponding magmatic ages and in agreement with the timing of widespread metamorphism, late pluton emplacement, and deformation. The differences in ALu-Hf ages between the eastern and western Coompana Provinces can be interpreted as reflecting two contrasting thermal/structural crustal evolutions. The AU-Pb ages obtained range between ~1074 and 1347 Ma, interval where at least two known metamorphic/magmatic events have been recognized. The younger ALu-Hf and AU-Pb ages obtained in the eastern Coompana, could be linked to deformation and A-type magmatism at ca.1180-1150 Ma which appears to be locally focused in the eastern part of the study area. AFT analysis produced central AFT ages of ~205-362 Ma, with high single-grain age dispersion, suggesting the low temperature cooling history reflects prolonged and/or episodic cooling. Thermal history models will be presented across the structural architecture to elucidate the role of inherited structures in the cooling history.

DATING AND CHARACTERISING A NEWLY DISCOVERED SEDIMENTARY SEQUENCE IN THE NORTHERN TERRITORY

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The greater McArthur Basin encompasses a series of laterally continuous Palaeoproterozoic basin systems, within the Northern Territory, that span over half a billion years of Earth's history. Collectively, these represent the McArthur Basin, the Beetaloo Sub-basin, the Tomkinson Province, the Birrindudu Basin and the South Nicholson Basin.

As a part of the MinEx CRC initiative, stratigraphic drillhole-NDIBK10, located ~200 km east of Tennant Creek, was drilled in this Murphy to Tennant region, Northern Territory. Originally targeting basement, drilling revealed an unknown sequence of sedimentary rocks below Cambrian basalts of the Helen Springs Volcanics. The main aims of this study was to understand when the original sediments were deposited, under which depositional conditions, and whether the resulting sedimentary rocks still record the chemistry of the environment at which they formed or have been overprinted by later diagenesis or hydrothermal alteration. This sedimentary package is comprised of turbidites, carbonates and sands; and overall can be interpreted to represent two main transgressions. Combined Rb–Sr and U–Pb geochronology establish a depositional window between 1534 Ma and 1671 Ma, with trace element geochemistry in shales suggesting that these were deposited in a primarily oxic environment. The provenance of the detrital zircons within NDIBK10 shows similarity to the Favenc Package (and Bullita Group in the Birrindudu Basin), which could provide a correlative. Populations within these sediments also suggest derivation from the south Aileron Province; however, recycling of other basin material cannot be discounted. This study shows how powerful a multi-proxy approach is when trying to understand unknown sequences and from the collection and interrogation of these data, we have been able to make informed hypotheses of the possible provenance and correlations of this unknown sedimentary rock package.

CHEMICAL DIFFERENTIATION BY MINERALOGICAL BUFFERING IN CRUSTAL HOT ZONES

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Mineralogical buffering of melt chemistry in hot zones is proposed as an important mechanism of chemical differentiation. Mineralogical buffering can operate at the low melt fractions observed in geophysical surveys of igneous crust, providing an alternative to traditional concepts of assimilation-fractional crystallization and liquid lines of descent. Reaction between buoyant, percolating melts and surrounding mush leads to chemical buffering by the local mineral assemblage. Where this assemblage has low thermodynamic variance the resultant multiply-saturated melts will show limited chemical variability. I use the concept of multiple saturation to explore the chemical consequences of percolative reactive melt flow using data from published experiments on a wide variety of starting materials. I show that the common, low-variance hornblende gabbronorite assemblage clinopyroxene-hornblende-orthopyroxene-magnetite-plagioclase-ilmenite (CHOMPI) coexists with fluid-saturated melt over a wide range of pressure (1 to 10 kb) temperature (800 to 1050 °C) and fluid composition (XH_2O of 1.0 to 0.3). CHOMPI melts cover a wide compositional range (54 to 74 wt% SiO_2; 4.4 to 0.1 wt% MgO) that can be parameterized in terms of five independent variables: pressure, temperature, fO_2, molar CO_2/H_2O in the fluid and melt K_2O content. Melt composition can be inverted to recover pressure (±1.3 kb), temperature (±16 °C) and fluid molar CO_2/H_2O (±0.43) of CHOMPI-saturated melts. If a natural magma composition can be shown to lay on or close to the CHOMPI saturation surface then the conditions under which the melt was last in equilibrium with this hot zone mineral assemblage, prior to ascent and eruption, can be established. I apply this method of magma source thermobarometry and hygrometry to recent eruptions from fifteen Cascades arc volcanic centres. Calculated pressures range from 1.3 to 5.8 kb (5 to 21 km depth) with significant along-arc and temporal variation. These variations have implications for mush architecture and dynamics beneath the arc.

A WINDOW INTO THE EARLY MANTLE: ARCHEAN ANORTHOSITES OF THE NARRYER TERRANE, WESTERN AUSTRALIA

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Archean anorthosite complexes are distinctive, mantle-derived cumulate rocks that form a minor but important component of many Archean granite-greenstone terranes. As Archean anorthosites present little evidence of crustal contamination, their petrogenesis has significant implications for early mantle evolution, continental growth and geodynamic processes. Here we present whole-rock geochemistry, plagioclase chemistry and geochronology (U-Pb, zircon) of Paleoarchean to Eoarchean anorthosites and leucogabbros from the Narryer Terrane of the Yilgarn Craton, Western Australia, including from the 3.73 Ga Manfred Complex, the oldest known anorthosite complex on Earth. These anorthosites and leucogabbros typically occur associated with ultramafic units in fragmented pods within quartzofeldspathic gneisses. Despite regional amphibolite to granulite facies metamorphism and intense deformation, igneous minerals and textures within the Manfred Complex are locally remarkably well-preserved. These results indicate that primary magmatic chemistry is intact within anorthosites and leucogabbros of the Manfred Complex. The implications for the composition and evolution of the early mantle are discussed.

THE STYLE AND TEMPO OF TECTONICS SINCE THE ARCHEAN

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Based on the crustal record of magmatism and metamorphism, Earth likely evolved from a single-lid (sluggish or squishy) to a mobile-lid tectonic mode during the late-Archean–early-Proterozoic. Time-constrained data show a strong temporal clustering of metamorphism associated with periods of supercontinentality and a close spatial relationship with inferred plate margins since the Archean. Statistical analysis shows that bimodality in *T/P*—a characteristic feature of convergent plate boundaries since 200 Ma—developed during the Paleoproterozoic and became increasingly distinct thereafter; late Archean metamorphism was unimodal. Thus, a strong case can be made for plate tectonics since the early Paleoproterozoic; a single-lid episode in the Mesoproterozoic seems unlikely. However, a peak in metamorphic *T/P*, dominant anorthosite and rapakivi suite magmatism, and longevity of passive margins in the Mesoproterozoic suggest a plate slowdown, as verified by geophysical modeling. Statistical analysis of time series of *T/P* and cooling rate identifies change points in the Paleoproterozoic and early Paleozoic, recording two state shifts: one following stabilization of subduction after the emergence of continents and the Siderian glaciations, which led to an enhanced sediment supply along continental margins and a period of increased orogenic activity throughout the amalgamation of Nuna, and another following the Cryogenian glaciations, which led to an increased sediment load in trenches that kick-started modern-style plate tectonics characterized by low *T/P* and UHPM. In the Archean, unstable subduction at various locations created conflicting signals in the geological record, and there is evidence of late-Archean regional plate-like behavior, but the shift to global plate tectonics cannot be confirmed before the early Paleoproterozoic. Lastly, the changing abundances of komatiites, anorthosites and kimberlites through time are consistent with an evolution from early bottom-up asymmetric, to symmetric, to modern top-down asymmetric mantle geodynamics.

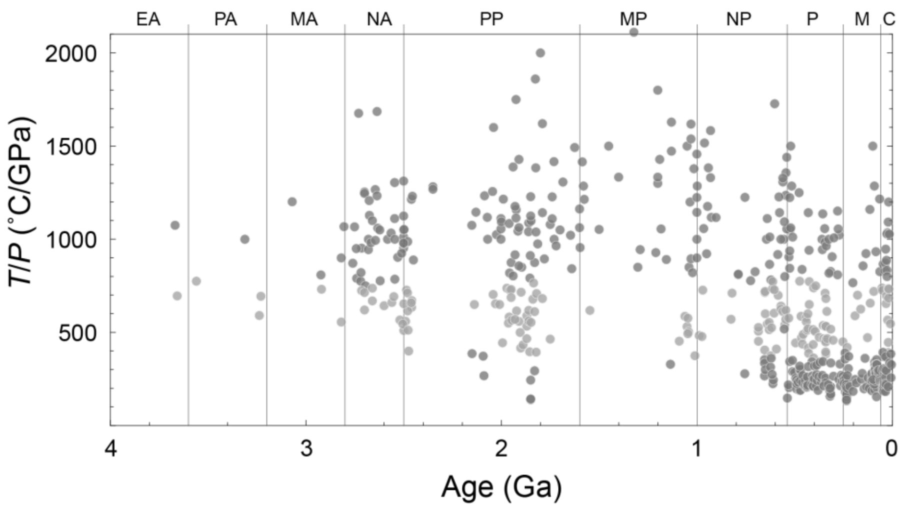

Figure. The spread of metamorphic *T/P* increased from c. 2.8 Ga to a maximum at c. 1.8 Ga, due to the emergence of plate tectonics, before trending to lower T/P with secular cooling.

Volume Matters: Aqueous fluids in the Deep Earth

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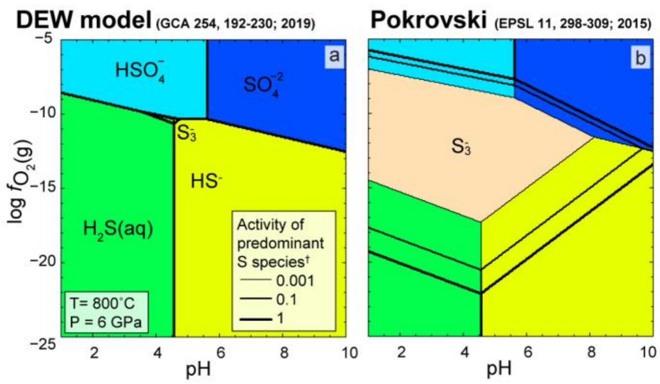
The cycling of water, carbon, and sulfur between atmospheric, crustal, and mantle reservoirs in subduction zones is fundamental for the evolution of a habitable Earth and formation of some of its most valuable metal resources. Over the past decade, innovative theoretical thermodynamic extrapolations have extended our capacity to understand the role of aqueous fluids in the deep Earth.



Yet, the pressure dependence reactions involving fluid-borne species remains poorly constrained, and sulfur provides a prime example of the universal difficulties in retrieving volumetric properties of aqueous complexes. Recent experiments suggest that S_3^- may dominate S speciation at high pressure, instead of hydrosulfide (HS^-, $H_2S(aq)$) or sulfate (HSO_4^-, SO_4^{-2}). However, predictions of S_3^- stability beyond the range of PT conditions covered by experiments (quantitative to 0.5 GPa) depend on fitting procedure: as shown in the figure, while Prokrovski and his team predicted the high stability of the polysulfide ion at supra-subduction pressures, the thermodynamic properties included in the updated DEW thermodynamic database suggest a negligible contribution of this species to S cycling. Yet, both sets of thermodynamic properties reproduce the experimental data within experimental error.

The fundamental issue is that experiments at relatively low pressures (≤0.5 GPa) provide little information about the pressure-dependence of the partial molar volumes of aqueous species.

We are exploring the hypothesis that classical molecular dynamic (MD) simulations offer a solution to this dilemma. This method has long been known to reproduce volumetric properties to great accuracy at room temperature, and may circumvent the fundamental difficulties associated with the derivation of partial molar volumes of dilute aqueous species from experiments. MD supported molar volumes suggest that S_3^- can contribute to linking the oxidation of the wedge and its enrichment in chalcophile metals and Ba in fluid-rich environments.

The origin of volatiles in the Ni-Cu-Co Ovoid deposit of the Voisey's Bay complex. New insights on the role of accessory minerals in tracing ore-forming processes

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The 1.34Ga complex Voisey's Bay Complex is a troctolite-anorthosite-diorite suite hosting multiple Ni-Cu-Co deposits. Mineralised zones occur in the two tabular magma chambers (Eastern Deeps and Western Deeps) as well as in the magma conduits (Ovoid, Mini-Ovoid conduits and Eastern Deeps feeder). Nickel-copper sulfides have disseminated to semi-massive textures at the base of the Eastern Deeps chamber, whereas sulfides are only disseminated in the Western Deeps chamber. In the conduits, sulfide textures range from disseminated to massive and develop sulfide-matrix breccia textures along the footwall contacts. Sulfide-matrix breccias comprise endogenously-derived troctolite, olivine gabbro and peridotite fragments as well as paragneiss and orthogneiss xenoliths of the Tasiuyak and Nain country rocks, respectively. This texture is interpreted to develop through the downward percolation of sulfide melt displacing the interstitial silicate melt between silicate fragments. However, the origin of the biotite-hornblende rims developed at the interface between the silicate clasts and the sulfide matrix is yet to be fully understood. Detailed textural analysis suggests that hydrous silicates formed by reaction with a volatile component derived from the sulfide liquid. Although experimental and field evidence support the solubility of minor amounts of water and halogens in sulfide melts, it is questionable that the K required for the formation of biotite could have the same origin. Furthermore, the occurrence of accessory minerals such as apatite and ilmenite, which are commonly regarded as residual, within or in close association with sulfides in mineralised breccias is at odds with conventional genetic models of magmatic Ni-Cu-Co sulfide deposits.

In this study we characterise the trace element composition of apatite, biotite and Fe-oxides in barren troctolite, sulfide-rich and sulfide-poor breccia samples to trace the origin of the volatile component in the Ni-Cu-Co Ovoid deposit. Furthermore, we explore the ability of these accessory phases to record the effects of ore-forming processes and their potential as vectors toward mineralisation.

GEOLOGY, AGE AND ALTERATION OF THE DOLERITE DYKES AT THE HILTON AND GEORGE FISHER ZN-PB-AG DEPOSITS, NW QUEENSLAND. IMPLICATIONS FOR A REVISED DEPOSIT MODEL.

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The George Fisher and Hilton Zn-Pb-Ag deposits sit ~20 km north of Mount Isa. Dolerite dykes are situated within both deposits. However, the temporal and petrological relationship between the dykes and the adjacent Zn-Pb-Ag mineralisation has not previously been considered and could have significant implications to the currently accepted syn-diagenetic metallogenic model. In drill core, the dolerite dykes are a homogenous grey to green-grey rock that are overprinted along their margins by Zn-Pb-Ag mineralisation. In-situ apatite U-Pb geochronology performed on the dolerite dykes produce an age of 1619 ± 22 Ma and 1611 ± 21 Ma at the Hilton and George Fisher deposits, respectively. This is consistent with intrusion during the earliest phases of the 1620–1500 Ma Isan Orogeny. The dolerite dykes have experienced multiple stages of post-emplacement alteration/veining. This includes: (1) Quartz-albite-K-feldspar alteration/veining; (2) Dolomite alteration/veining; (3) Biotite-chlorite-sulphide alteration; (4) Late veining. Monazite from a quartz-albite-K-feldspar vein in the Hilton dyke produces an age of 1513 ± 16 Ma, constraining the maximum age of alteration within the dolerite dykes. To assess the timing of alteration in the adjacent George Fisher Zn-Pb-Ag deposit, in-situ Lu-Hf geochronology was performed on pre-mineralisation calcite from a section of stratabound Zn-Pb-Ag mineralisation, and a paragenetically late sphalerite-calcite vein. Calcite from the pre-mineralisation alteration assemblage produces a Lu-Hf age of 1501 ± 32 Ma, which is interpreted to constrain the maximum age of stratabound Zn-Pb-Ag mineralisation. Calcite from the late cross-cutting vein produced a Lu-Hf age of 1289 ± 26 Ma, which is interpreted to constrain the late faulting throughout the deposit. The evidence presented in this study suggests that the dolerite dykes intruded during the early Isan Orogeny at ca. 1620 Ma, and experienced subsequent hydrothermal alteration during D_3 of the Isan Orogeny coeval with Zn-Pb-Ag mineralisation.

NEW INSIGHTS INTO METAL TRANSPORT MECHANISMS ACROSS THE LITHOSPHERE

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The problem of transportation of dense metal-rich sulfide liquid by magma from the mantle across the lithosphere has been discussed in literature dedicated to magmatic sulfide deposits for decades. Firstly, it was suggested that all the metals need to be dissolved in the magma to be efficiently transported. However, the results of experimental works and numerous natural examples do not confirm this theory. Recently, the hypothesis that the transportation of sulfide liquid could have been facilitated by volatile phases present in magma has become extremely popular. Many different theories have appeared based on the documentation of close spatial associations of sulfides with various volatile-rich phases. All of them emphasize the adherence of volatiles to sulfide liquid and the importance of compound bubbles. Depending on the depth of the emplacement the volatile phase can be represented by CO2 supercritical liquid, aqueous phase, or gas bubbles, which tend to stick to sulfide liquid, increasing its buoyancy. Our detailed study of several mafic-ultramafic intrusions with sulfide mineralization shows that the paragenetic association is not enriched only in volatiles, there are a lot of other elements that play a part in its composition. Wherein the selection of these elements is not characteristic for mafic magma, but rather belongs to carbonatite liquid. In some examples, we even observe the pieces of evidence of immiscible behavior of these carbonatite-looking envelopes surrounding sulfide globules. To check the theory of the ability of immiscible carbonatite melt to be a transportation agent for sulfide liquid we run several experiments, which preliminary confirmed the hypothesis.

Monazite in extremis

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Monazite is fast becoming the go to geochronometer for establishing the timing of metamorphic, deformational and hydrothermal events in crustal rocks. This is principally due to monazite forming in rocks that are petrologically useful (e.g. metapelites), it's susceptibility to recrystallization (both fluid and deformation driven) and the suite of trace elements it incorporates during growth. In dry conditions (i.e. the melt-depleted lower crust) monazite has a high closure temperature. It therefore has the ability to record the timing of prograde to peak metamorphic conditions. The reactivity of monazite in the presence of fluid allows the timing of post-peak fluid and melt crystallisation events to be constrained. Under high-stress monazite will recrystallise, forming new crystals that can be used to constrain the age of deformational events – this feature is particularly useful as high-grade reworking of lower crustal rocks often leave no geochronological record within other accessory minerals (e.g. zircon). However, it has long been recognised that monazite can record a cryptic range and/or distribution of ages that are difficult reconcile with how we traditionally believe the lower crust responds to deformational events – e.g. the anhydrous nature of lower crustal rocks and the preservation of granulite facies mineral assemblages.

Here we present datasets collected by a suite of microanalytical techniques on monazite grains from lower-crustal rocks that have experienced deformation, fluid-rock interaction and ultrahigh temperature and/or pressure metamorphism. To better understand how monazite behaves in these environments we integrate electron probe, electron backscatter diffraction, laser ablation split stream petrochronology, transmission electron microscopy and Atom Probe Tomography datasets to image and quantify behaviour of key elements. When used sequentially, these techniques provide a detailed view of the processes that re-distribute U-Th-REE-Y-Pb at the micro to nanoscale. Understanding how monazite behaves under different stress and thermal conditions is the key to using this geochronometer to develop and refine event chronologies in the deep crust.

THE UNROOFING OF ARCHEAN CRUSTAL DOMES AS RECORDED BY DETRITAL ZIRCON AND APATITE

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This study presents *in-situ* U-Pb, Lu-Hf, and Sm-Nd isotopic data for detrital zircon and apatite collected from ephemeral streams of the East Pilbara Terrane, Western Australia. A tandem apatite-zircon approach may conceptionally offer more holistic insights into crust formation, given their disparate abundances in felsic versus mafic lithologies. Apatite U-Pb data define a single age peak at c. 2.9 Ga, consistent with labile, proximal, first-cycle detritus from the Pilbara Craton. Conversely, zircon, a more refractory and durable mineral, records a more diverse geological history with U-Pb ages spanning from 3.6 to 0.2 Ga. The apatite U-Pb age of c. 2.9 Ga records the timing through the Pb closure temperature during regional cooling, while the Lu-Hf and Sm-Nd isotopic systems in the same grains yield c. 3.2 Ga isochrons, consistent with magmatic crystallisation at that time. The apatite crystallisation age, initial $^{143}Nd/^{144}Nd$ and trace element geochemistry (Eu/Eu*) imply a broadly chondritic source locally derived from the East Pilbara Terrane. Conversely, zircon εHf data reveal a broadly chondritic Paleoarchean proto-crust undergoing continual isotopic evolution punctuated by the input of juvenile material on a quasiperiodic basis. Detrital zircon grains track this process from a c. 3.8 Ga component that may have acted as a nucleus for subsequent crust formation. The oldest detrital zircon are more variable in εHf than primary igneous crystals of the same age, encompassing more evolved components suggesting that the detrital zircon record preserves the unroofing of a crustal nucleus. The detrital zircon load arguably provides a more complete record of the evolved older crust in the region than the domes alone. Specifically, we show that the evolved cores of domes are preferentially eroded due to their structural position and lost into the detrital archive.

Full plate tectonic reconstructions as essential pre-requisites to quantifying the earth system in deep time: a new 1.8 Ga to present full-plate tectonic reconstruction

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Full plate tectonic reconstructions of Earth in deep time are pre-requisites for understanding and quantifying the links and feedbacks between the solid earth and earth surface systems in deep time. They provide a framework where an evolving plate tectonic circuit is able to be interrogated to test causative hypotheses as to how the climate, biosphere, atmosphere and hydrosphere evolved. As such, these models provide a way forward to bring testability to deep time hypotheses in ways that haven't existed in the past.

Here we modify and build on the previous 1Ga to present model (Merdith et al. 2021, Earth Science Reviews) and present a full-plate tectonic reconstruction from 1.8 Ga to present, focussed on the region of the Australian continental lithosphere. This is a work in progress and is presented to stimulate discussion and obtain feedback.

Age, clay-mineral provenance and REE geochemistry of middle Ediacaran shales and impactites from the Adelaide and Centralian Superbasins

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The Ediacaran of SA is interrupted by the impact of a major bolide centred on Lake Acraman in the Gawler Craton. Deposits from this impact form a rare absolute chronostratigraphic marker through the Adelaide Superbasin and the Officer Basin. However, the impact itself has proved hard to directly date. Here we present Rb–Sr age data collected using the novel in-situ Rb–Sr LA-ICPMS/MS technique from impact-generated clay and stratigraphically enveloping shales.

A ca. 5 mm thick impact-generated claystone collected at Arkaba Creek in the central Flinders Ranges yielded an age of 580 ± 18 Ma (2 s.d., n = 99, MSWD = 0.69) with a radiogenic initial $^{87}Sr/^{86}Sr$ value of 0.7219 ± 0.0034. Data collected from the 'Proteus' (LA-ICPMS/MS-MC) confirmed the age of the impactite clay layer (572 ± 30 Ma, n=54) and initial ratio (0.731 ±0.009). We interpret this as directly dating the age of impact. Angular feldspar clasts that directly in contact with the impactite claystone yielded Mesoproterozoic ages consistent with clasts transported as ejecta/tsunami deposits from the Gawler Craton.

Shale samples collected from drill cores through the Dey Dey Mudstone in the Officer Basin samples directly above and below the Acraman impact layer preserve consistent Rb–Sr shale ages considerably older than their depositional age. Eight shale samples from Giles-1 and Murnaroo-1 yield a weighted mean age of 808 ± 32 Ma (MSWD = 0.54). These ages are coeval with the Wooltana Volcanics that lay over much of the Gawler Craton at the time, likely representing clay mineral alteration of these volcanics soon after eruption. The data support petrographic shale studies that have demonstrated a relative decrease in authigenic clay formation and corresponding increase in detrital clay minerals in the Ediacaran.

Unravelling the Birrindudu basin - Geochronology from the Limbunya and Wattie Groups

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Spread over an expanse of 36000 km^2 in northwestern NT, the Birrindudu basin is receiving much attention, following the introduction of the concept of a greater McArthur basin. The greater McArthur basin comprises of unified Paleo-Mesoproterozoic sedimentary successions of the vast McArthur basin, Birrindudu basin and Tomkinson Province (Close, 2014). These intra-cratonic basins have been noted to share lithological and chronological similarities, and are suggested to be interconnected at the time of deposition (Munson 2016). Geochronology can serve as a vital tool for intrabasinal correlation, the ages for Birrindudu succession remains loosely constrained. We attempt to use detrital zircons to fill these geochronological gaps and build a chronostratigraphic framework for the Birrindudu Basin.

We present LA-ICP-MS U–Pb ages of detrital zircons from sandstones within the Palaeoproterozoic Limbunya and Wattie Groups to define their maximum deposition ages. We particularly focus on field samples collected from the Wattie Group that to date have not had any geochronological studies.

These data are used to address the age of deposition of these groups, as well as to address the possible relationship of the Wattie Group with the post-Isan sequences elsewhere in the greater McArthur Basin (the Favenc package). We also address possible tectonic drivers for this notable transition in the greater McArthur Basin from carbonate to siliciclastic deposition that continues through the Wilton Package to the ca. 1320 Ma termination of deposition in the superbasin.

On the origin of quartz in the Velkerri Formation: implications for the Si cycle in the Mesoproterozoic.

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The marine silicon cycle is coupled to the precipitation of quartz in basinal mudstones and to the cycles of elements like carbon and phosphorous that are critical to interpretation of the histories of life and climate on Earth. In Phanerozoic siliciclastic, fine-grained sediments, quartz in excess of the detrital component has been attributed to the dissolution and recrystallization of the siliceous skeletons of marine plankton (biogenic silica). In the absence of biosiliceous skeletal grains, the pathway for Si transfer from seawater and its distribution into Pre-Cambrian sediments is poorly understood.

We studied the organic-rich marine mudstones of the ca. 1.38 Ga Velkerri Formation, a key archive for the Mesoproterozoic ocean chemistry and an economically important source rock of the McArthur Basin, Northern Territory. Using microstructural, geochemical, and petrophysical analyses we infer that a significant amount of quartz (up to 45 % of total rock volume) in the organic-rich layers of the Velkerri Formation is not of detrital origin. Instead, it precipitated in situ as an early diagenetic phase in subunits characterized by high organic and phosphorus contents indicative of high primary productivity at the time of deposition. We infer that this early diagenetic quartz results from recrystallization of bacterially associated amorphous silica, consistent with recent work pointing to the likelihood that marine cyanobacteria have long possessed the ability to concentrate Si from sea water to levels comparable or even exceeding those observed in diatoms and to pass it into the sediment.

We estimate that the Velkerri Formation contains several thousands of km^3 of diagenetic quartz. This quartz volume represents an important mineral record of the silica cycle that suggests a critical and, so far, overlooked cyanobacterial role in Si sequestration within non-chert lithologies in Mesoproterozoic sedimentary basins.

A HADEAN–EOARCHEAN PROTOCRUST BENEATH THE SW YILGARN CRATON?

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The study of Earth's early crust is challenging due to a scarcity of Hadean–Eoarchean material. However, information on ancient crust may be inherited through the isotopic legacy in reworked younger crust and the detrital record. We analysed the U-Pb and Lu-Hf isotopic composition of detrital zircon from littoral and fluvial sediments of the Scott Coastal Plain in southwestern Australia. Source regions for this detritus include the Archean Yilgarn Craton, the Proterozoic Albany-Fraser Orogen, and the Neoproterozoic–Paleozoic Pinjarra Orogen. The Hf isotopic signature from this detritus captures over 3 Gyr of crustal evolution. Three vertical εHf(t) arrays are interpreted to reflect episodic mixing of juvenile and crustal sources, with the lower bound defining a trend towards Hadean–Eoarchean mantle extraction, which is compatible with maximum two-stage Hf model ages around 4-3.8 Ga. This data implies a consistent coherent Hadean–Eoarchean crustal vestige that survived over 2 Gyr of episodic crustal reworking. The petrological composition of this ancient source appears similar to average Archean granite-greenstone as constrained by its $^{176}Lu/^{177}Hf$ of 0.013. These observations suggest ancient crust in the southwest of WA coincides with a geophysically anomalous response, indicative of thickened crust. Comparison to global Hf compilations shows similarity in ancient source extraction timing in most cratons at c. 3.8 Ga, at the end of the late heavy bombardment, consistent with extensive protocrust formation (or increased preservation) at or from this time. In stark contrast, zircon grains from both Jack Hills and Acasta reveal a dissimilar, older, more mafic, Hf trend, implying no genetic relationship in crust production to that in the Yilgarn, and perhaps suggesting an earlier distinct (impact related?) mode of crustal nuclei generation.

CALCIUM AND STRONTIUM ISOTOPE CONSTRAINS ON THE ORIGIN AND DIAGENETIC HISTORY OF ANCIENT MARINE CARBONATES

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Marine sedimentary carbonates – composed of calcite, aragonite and dolomite – represent valuable archives of past seawater chemistry and evolution of the Earth's system over geological time. Traditionally, stable carbon and oxygen ($\delta^{13}C$ and $\delta^{18}O$) isotope studies of marine limestones and fossil carbonates have been used to reconstruct, respectively, past changes in the oceanic C cycle and variations in past seawater temperature through time. However, complications related to post-depositional alteration of the above isotope proxies in ancient carbonates complicate their applicability for robust palaeo-environmental interpretations, thus calling for new ways how to better constrain and untangle secondary diagenetic processes from the 'primary marine' signals recorded in carbonate archives.

Here we present results on the application of coupled calcium ($\delta^{44/40}Ca$) and strontium ($\delta^{88/86}Sr$ and $^{87}Sr/^{86}Sr$) isotope approach to better quantify such phenomena in marine limestones deposited during the late Silurian, at two distant palaeo-locations / continents, and recording the largest positive carbon isotope anomaly in the Phanerozoic, so-called MLCIE (Mid-Ludfordian Carbon Isotope Excursion) reaching globally $\delta^{13}C$ value of around +8 per mil (Fryda et al., 2021). Previously published Ca isotope data (Farkas et al., 2016) from these unique marine carbonates are coupled with (i) new stable and radiogenic Sr isotope data, and (ii) advanced MATLAB-based numerical models of fluid-rock interactions (Staudigel et al., 2021) to better constrain the origin of purported 'kinetic effects' recorded in these carbonates linked to changes in late Silurian seawater chemistry (i.e., marine carbonate hypersaturation event) versus possible diagenetic effects. In addition, we will also present new and ultra-high precision data for metal isotope applications acquired via a recently installed TIMS-ATONA system from IsotopX, hosted at University of Adelaide (funded via AuScope), which illustrate that Sr isotope ratios can be measured with precision of ~2 ppm (sd), corresponding to uncertainty on $^{87}Sr/^{86}Sr$ ratios of +/- 0.0000015, thus providing new and enhanced research capabilities for future Sr and Ca isotope studies.

References: ***Fryda et al. (2021)*** The Mid-Ludfordian (late Silurian) Glaciation: A link with global changes in ocean chemistry and ecosystem overturns. *Earth-Science Reviews*, Vol. 220, 103652; ***Farkas et al (2016)*** Calcium isotope constrains on the marine carbon cycle and $CaCO_3$ deposition during the late Silurian (Ludfordian) positive $\delta^{13}C$ excursion, *Earth and Planetary Science Letters*, Vol. 451, 31-40. ***Staudigel et al (2021)*** An abrupt Middle-Miocene increase in fluid flow into the Leeward Margin Great Bahama Bank, constrains from $\delta^{44}Ca$ and Δ^{47} values, *Earth and Planetary Science Letters*, Vol. 553, 116625.

UPDATED AGE CONSTRAINTS FOR THE TIMING OF METAMORPHISM IN THE SOUTH WEST YILGARN CRATON

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Ongoing geological studies conducted by the Geological Survey of Western Australia (GSWA) are helping to better constrain the timing and pressure (*P*)–temperature (*T*) conditions of metamorphism in the south west Yilgarn Craton. Previous geochronological investigations in the region have focused on U–Pb zircon, but zircon in many samples across the region have a scarcity of metamorphic overgrowths, resulting in limited direct metamorphic dates. However, new geochronological data using a range of chronometers are revealing a longer lived history than previously recognized. Recent in situ U–Pb monazite geochronology integrated with phase equilibria modelling shows that protracted high-temperature metamorphic conditions persisted for at least 30 Ma, from 2665 to 2635 Ma. The age range extends the timing of high-grade metamorphism previously estimated at 2649–2640 Ma. Episodic, high-grade Proterozoic reworking is evident along the western margin of the Yilgarn Craton with U–Pb monazite and Lu–Hf garnet ages spanning from c. 1840 to 620 Ma. Lower temperature chronometers also preserve a more detailed history that is not recorded by the higher temperature chronometers. Rb–Sr dating of biotite from three samples along an east–west transect across the south west Yilgarn Craton show a range in isochron ages, from c. 580 Ma along the western margin to c. 2477 Ma in the east within the Youanmi Terrane. The c. 580 Ma age is similar to previous Rb–Sr whole-rock and biotite data along the margin, and supports a lower temperature Neoproterozoic reworking event. Partial resetting of the Rb–Sr system is evident within the Corrigin Tectonic Zone near the boundary between the South West and Youanmi Terranes, whereas the c. 2477 Ma age in the Youanmi Terrane records either a separate thermal event or protracted, long-lived cooling from peak metamorphism.

PYROXENE-RICH XENOLITHS SANGEANG API VOLCANO EAST SUNDA ARC: MAGMA SUPPLY SYSTEM AND FRACTIONATION CONTROLS

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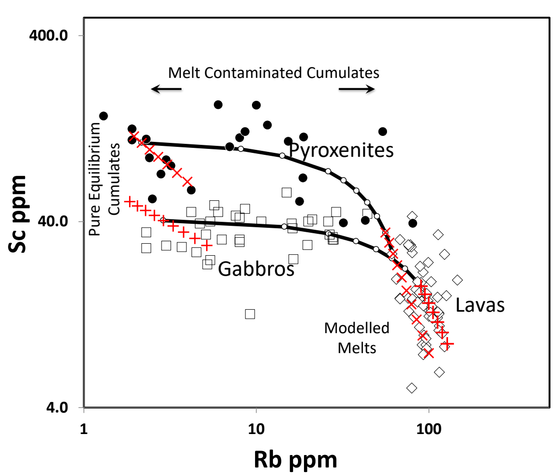
Sangeang Api is an active volcano (last major eruption in 2014) in the eastern Sunda Arc. It erupts a potassic, undersaturated , alkali suite of oxidized and volatile-rich *Ne*-basalts to *Ne*-basaltic-trachyandesites. These entrain abundant cumulate xenoliths. It is a rear arc volcano 185km above the north dipping subducting Indian Oceanic plate.

The cumulate xenoliths comprise two distinct groups, gabbros and pyroxenites. Pyroxenites are composed of either CPX + Olivine or CPX+Magnetite. Gabbros are composed of An-rich (An90) plagioclase + CPX + Magnetite. There is very good evidence that differentiation of the lavas is driven by crystallization of the cumulate assemblages that form the xenoliths. Mg-hastingsite-pargasite amphibole is a common phase in both groups of xenoliths. In pyroxenites it is generally intercumulate whereas in the gabbros it occurs as either interculumate or cumulate phases. It is also common as phenocrysts in the lavas.

Calibrations of amphibole-melt equilibria (Ridolfi et al., 2010; 2012) provide estimates of the P, T, fO2 and water content of melts from which the xenoliths crystallised. Sangeang Api amphiboles record almost continual crystallisation from Moho to mid-crust from 974 to 338MPa. P-dependent H_2O declines from 6.51 to 3.15wt.% suggesting vapor-saturated decompression. Decompression from Moho depths was accompanied by oxidation from ΔNNO+0.2 to ΔNNO+1.15, whereas further decompression from pressures less than 600MPa was accompanied by reduction to ΔNNO+0.05. Redox changes are driven by volatile loss. Amphibole phenocryst data suggest eruption from P < 330MPa.

The textural occurrence of amphibole and geochemical constraints (Figure) imply melt percolation through vertically stacked crystal tracts and incomplete melt extraction from cumulate crystal piles. Rapid percolative melt flow probably resulted in previously reported (Turner, Foden et al., 2003) ^{226}Ra excess .

Figure: Modelled composition of cumulate minerals and coexisting melts (red crosses) and cumulate contamination mixing curves (black curves).



Dynamics of metal and volatile flux across the lithosphere

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Ore deposits are loci on Earth where energy and mass flux are greatly enhanced and focussed, acting as magnifying lenses into metal transport, fractionation and concentration mechanisms through the lithosphere. Magmatic systems play a crucial role in enriching the crust with volatiles and elements that reside primarily within the Earth's mantle, including economically important metals like nickel, copper and platinum-group elements.

Magmatic arcs are terrestrial environments where lithospheric cycling and recycling of metals and volatiles is enhanced. However, the first-order mechanism permitting the episodic fluxing of these elements from the mantle through to the outer Earth's spheres has been elusive. To address this knowledge gap, this study focusses on the textural and minero-chemical characteristics of metal-rich magmatic sulfides hosted in amphibole-olivine-pyroxene cumulates in the lowermost crust. Results show that in cumulates that were subject to increasing temperature due to prolonged mafic magmatism, which only occurs episodically during the complex evolution of any magmatic arc, Cu-Au-rich sulfide can exist as liquid while Ni-Fe rich sulfide occurs as a solid phase.

This scenario occurs within a 'Goldilocks' temperature zone at ~1100–1200 °C, typical of the base of the crust in arcs, which permits episodic fractionation and mobilisation of Cu-Au-rich sulfide liquid into permeable melt networks that may ascend through the lithosphere providing metals for porphyry and epithermal ore deposits. This may be a common but cryptic mechanism that facilitates cycling of volatiles and metals from the mantle through the lower-to-mid continental crust all the way to the upper crust, which leaves little footprint behind by the time magmas reach the Earth's surface. In this framework, ore deposits are not merely associated with isolated zones where serendipitous happenstance has produced mineralisation. Rather, they are depositional points along the mantle-to-upper crust pathway of magmas and hydrothermal fluids, synthesising the concentrated metallogenic budget available.

Gonneville PGE-Ni-Cu-Co deposit, Yilgarn Craton, Western Australia

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The Gonneville PGE-Ni-Cu deposit discovered in March 2020 in the Darling Ranges only 70km from Perth represents the most significant discovery of orthomagmatic PGE-Ni-Cu mineralisation in Australia in the last two decades and is the single largest PGE deposit ever discovered in Australia.

The Gonneville deposit is hosted in a differentiated ultramafic-mafic intrusion ~1.9km long x 0.65km thick which is located at the southernmost extension of a c. 30km long interpreted ultramafic-mafic intrusive complex named the 'Julimar Complex'. The Gonneville intrusion is composed of dominantly harzburgite with lesser zones of pyroxenite, gabbronorite and leucogabbro, with the ultramafic component representing > 60% by volume of the intrusion. The Gonneville intrusion has a relatively limited dip extent (~1.6km) as evident from recent seismic surveying and therefore appears to define a high aspect ratio consistent with well-endowed chonolith-type intrusions worldwide. The location of the Julimar Complex only 10km from the western margin of the Yilgarn craton is considered important as most Tier-1 orthomagmatic deposits show a preferential siting along craton margins.

Igneous minerals are almost entirely replaced by a greenschist facies metamorphic assemblage of serpentine (ex olivine), amphibole-chlorite (ex orthopyroxene) and clinozoisite (ex feldspar), with chromite the only preserved igneous phase albeit extensively replaced by magnetite. Sulphide assemblages comprise pyrrhotite-pentlandite-chalcopyrite +/- minor pyrite. At the macro-scale there is moderate preservation of igneous textures including relict opx oikocrysts and olivine cumulates (ortho-mesocumulate) and olivine-sulphide cumulates in high-sulphide zones. Orthomagmatic mineralisation shows a wide range of sulphide volumes from massive, matrix to disseminated with associated high-moderate Ni, Cu, Co and PGE, through to low sulfur mineralisation which is PGE-dominant. The deposit as a whole shows a consistent Pd/Pt of ~4:1 and Ni/Cu in sulfur-rich zones of ~2.5:1. The majority of ultramafic rock types contain elevated levels of Pd (av. 0.2-0.4ppm).

The Gonneville intrusion and the host greenstone belt show the superimposed effects of heterogenous deformation and metamorphism including localised ductile/brittle faults, magnetite veining in serpentinite and metamorphic fabrics in metasediment and amphibolite units. The sequence is intruded by post-mineral granitoid sills/dykes and the entire succession is cut by dolerite dykes swarms.

U-Pb zircon dating of a rare pegmatoidal phase within the Gonneville intrusion has defined an igneous crystallization age of 2668 +/-4 Ma which is very close to the crystallization age of cross-cutting granitoid intrusions (2663 +/-8 Ma).

IN-SITU Rb-Sr GEOCHRONOLOGY – REFERENCE MATERIAL CHARACTERISATION AND FUTURE DIRECTIONS

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The recently developed technique for in-situ Rb-Sr geochronology by laser ablation tandem ICP-MS (LA-ICP-MS/MS) is becoming more widely used for dating igneous and detrital micas (phlogopite, muscovite and biotite) and feldspars (orthoclase), as well as authigenic clay/mica minerals (glauconite, celadonite, illite) in a range of geological and tectonic settings. However, well characterized reference materials remain one of the limiting factors for the accuracy and precision of the technique. During the laser ablation process Rb and Sr can fractionate due to their differing element volatilities, which can cause analytical bias and increased uncertainty on calculated ages. The degree of Rb-Sr fractionation is related to the physical and chemical properties of the mineral and developing a range of mineral specific reference materials is required to contraol fractionation behaviour. The most commonly used reference material to date is the Mica-Mg (phlogopite) pressed nano-powder pellet, derived from a phlogopite reference material sourced from the Bekily region, Madagascar and is distributed by CRPG, France. Its advantage is that it is has relatively homogenous ratios which can easily be used for normalization. Its refence age of 519 Ma is the average from associated rocks in the region, however, there remains some uncertainty as to the true age of the Mica-Mg phlogopite. Here we present new solution-based ID-MC-ICP-MS ratios and ages for Mica-Mg (525 Ma, assuming and initial $^{87}Sr/^{86}Sr$ ratio of 0.7261) and GLO glauconite (90.4 Ma, assuming and initial $^{87}Sr/^{86}Sr$ ratio of 0.7073), as well as LA-ICP-MS/MS data from different fractions of GLO grains, plus other potential mica and feldspar reference materials (including SRM 607 potassium feldspar) and discuss strategies for optimal data normalization techniques to minimize elemental fractionation effects for in-situ Rb-Sr dating.

Fluid processes in the early Earth and the growth of continents

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Water is an essential ingredient in transforming primitive mantle-derived (mafic) rocks into buoyant (felsic) continental crust, thereby driving the irreversible differentiation of Earth's lithosphere. The occurrence in Archaean cratons of sodic granites of the tonalite–trondhjemite–granodiorite (TTG) series, high-MgO variolitic basalts, high-Mg diorites (sanukitoids) and diamonds with harzburgitic inclusion assemblages, all require the presence of hydrous fluids in Earth's deep crust and upper (lithospheric) mantle since at least the Paleoarchaean (3.6–3.2 billion years ago). However, despite its importance, where and how water was stored in Archaean crust, and how some water was transported into the upper mantle, are poorly understood. We investigate Archaean crustal fluid budgets through calculated phase equilibria for three protolith compositions — a low-MgO mafic (basaltic) composition, a high-MgO (picritic) composition and an ultrahigh-MgO ultramafic (komatiitic) composition — that are representative of mafic to ultramafic magmatic rocks in Archaean greenstone belts. We show that the mode and stability of hydrous minerals, in particular chlorite, is positively correlated with protolith MgO content, such that high-MgO basalts can store up to twice the amount of crystal-bound H_2O than low-MgO basalts. Importantly, ultrahigh-MgO rocks such as komatiite can store four times as much H_2O, most of which is retained until temperatures exceeding 700 °C. Warmer geotherms in the early Archaean favoured dehydration of hydrated high-MgO and ultramafic rocks in the deep crust, leading to hydration and/or fluid-fluxed melting of overlying basaltic rocks to produce 'high-pressure' TTG magmas. Burial of Archaean mafic–ultramafic crust along cooler geotherms resulted in dehydration of ultramafic material within the lithospheric mantle, providing the source of enriched Archaean basalt that was parental to large volumes of ancient TTG-dominated continental crust.

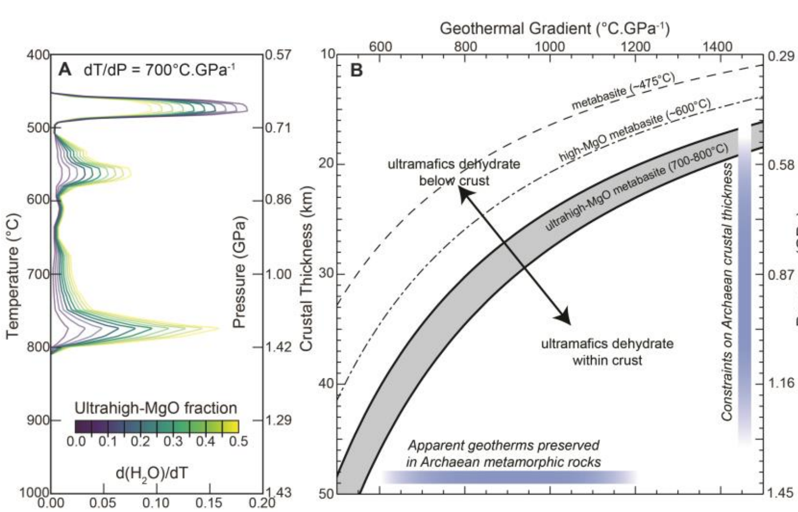

Figure 1:

A. Modelled crustal fluid production versus temperature curves with variable proportions of ultramafic material. **B.** Plot of Archaean geotherms versus crustal thickness with isotherms corresponding to the approximate temperature of chlorite breakdown reactions in end-member mafic rock types

Puzzling Pentlandite: Low-Temperature Alteration and the Effect on Sulphur Isotopes of Pentlandite from the Mawson Prospect in the Fraser Zone, Western Australia.

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Pentlandite ($[Fe,Ni]_9S_8$) is the main sulphide ore mineral for nickel (Ni), an element regarded as a critical metal because it is used in the production of green energy technologies. Pentlandite (Pn) is found in assemblages with pyrrhotite (Po) and chalcopyrite (Ccp) in magmatic sulphide deposits; these deposits form from mantle-derived magmas emplaced into the crust, which interact with and assimilate the country rocks until they may become sulphur-saturated and form an immiscible sulphide liquid separate to the silicate melt.

Sulphur isotopes can be used to interrogate these sulphide minerals to fingerprint the source of the crustal sulphur required for their formation. As Pn, Po, and Ccp exsolve from the same immiscible sulphide liquid, the in-situ sulphur isotope signature ($\delta^{34}S$) of each phase is expected to be consistent. Consequently, a fractionation of the Pn $\delta^{34}S$ (1.02 ‰) from coexisting Po (3.44 ‰) and Ccp $\delta^{34}S$ (3.15 ‰) observed in samples of massive sulphide from the Mawson Prospect is unusual.

Detailed petrological analysis has shown the Pn surface to contain 'freckles' of varying composition between violarite ($FeNi_2S_4$) and greigite (Fe_3S_4). The process of forming these sulphide phases is described as a late, low-temperature, electro-chemical system; the phases form as Fe and Ni cations are lost, and the 'freckle' texture forms as a corrosion pattern. This occurs via deep weathering processes in an open system, where the loss of heavy ^{34}S indicates sulphate ($SO^{2-}{}_4$) is forming elsewhere. The Mawson Fault, a local, shallow-dipping, and long-lived structure, is the likely source for an oxygenated, aqueous fluid (i.e., meteoric water) responsible for this alteration process.

The Mawson Prospect is located within the Fraser Zone, a geologically complex Proterozoic orogenic belt, and part of the Albany-Fraser Orogen of Western Australia.

The interplay between magma source, geodynamic evolution and Cu-Au endowment in convergent margin settings: an example from zircon U-Pb, O and Lu-Hf systematics of the Farallon Negro Volcanic Complex, Argentina

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Insights into the processes that lead to enrichment of ore-forming metals and magmatic-hydrothermal fertility can be constrained by coupling U-Pb, O isotopes and Lu-Hf isotope data from zircon. This study focuses on zircon analyses to unravel the petrogenesis and source evolution of the Farallon Negro Volcanic Complex in the Central Andes of northwest Argentina. A back-arc expression of the Miocene-Pliocene metallogenic belt, it contains the world-class Cu-Au Bajo de la Alumbrera deposit as well as a series of barren to weakly mineralized satellite porphyry intrusions. Ten least altered porphyry samples were analysed: four from the main Bajo de la Alumbrera deposit, and six from satellite systems (Las Pampitas, San Lucas and El Durazno. Whereas the El Durazno porphyry was emplaced at 8.0 ± 0.3 Ma, the San Lucas porphyries formed at 7.4 ± 0.2 Ma and 7.3 ± 0.2 Ma, and the Las Pampitas intrusions between 7.3 ± 0.1 and 7.0 ± 0.2 Ma. The Bajo de la Alumbrera porphyry intrusions are the youngest, forming from 6.9 ± 0.2 to 6.7 ± 0.2 Ma. Zircon from El Durazno exhibits a mantle-like δ18O values (δ18O =5.7 ± 0.1‰) and near a chondritic Lu-Hf isotope signature (εHf= -0.3 ± 0.4); conversely, zircon O-Hf signatures from Las Pampitas and San Lucas indicate input from older supracrustal sources (δ18O >6.7‰, εHf= -4.0 ± 0.8 to -2.8 ± 0.4). Zircon from Bajo de la Alumbrera has relatively radiogenic Hf (εHf= -3.0 ± 0.5 to -2.3 ± 0.3), consistent with late replenishment of the magma chamber that fed the mineralised intrusions. Late magma replenishment, coupled with crustal thickening and subduction of the Juan Fernandez Ridge may play a key role in enhancing Cu-Au endowment at Bajo de la Alumbrera.

New interpreted bedrock geology of the southwest Yilgarn: implications for geodynamics and mineralization

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The 2021 interpreted bedrock geological map of the southwest Yilgarn Craton integrates geophysical data, WAROX and WAMEX data, geochemistry, geochronology, metamorphic data, Nd and O isotope maps, legacy GSWA and company mapping. This universal update changes our understanding of the geology of the Youanmi and South West Terranes and proposes a new location for the boundary between them.

Our new interpretation has the Youanmi Terrane hosting distinctly older crustal and supracrustal rocks than the South West Terrane. The Youanmi Terrane contains magmatic rocks between 3018–2930 Ma and 2820–2710 Ma (Thundelarra, Annean and Austin Downs Supersuites, respectively), all of which appear to be missing from the South West Terrane. Mafic-dominated greenstones, of the 3010–2920 Ma Southern Cross Supergroup and 2820–2710 Ma Murchison Supergroup are found in the Youanmi Terrane and not the South West Terrane. Younger 2697–2600 Ma granitic magmatism in the Youanmi Terrane transitions from High-Ca to Low-Ca geochemical affinity, and has chronological and geochemical similarities within the South West Terrane, however post-2640 Ma granitic rocks are more abundant within the South West Terrane. The South West Terrane contains <2705 Ma greentones at Boddington and Balingup, which are absent from the Youanmi Terrane.

North-trending, lozenge-shaped anastomosing shear zones of the Youanmi Terrane, formed during the Yilgarn Orogeny, are not observed within the redefined South West Terrane. These c. 2660 Ma, structures were re-oriented by c. 2650 Ma, north-northwest trending structures, along the Corrigin Tectonic Zone (CTZ), a zone of intense and pervasive deformation, up to 100 km wide in the hanging wall of the proposed terrane boundary. Interpreted fold vergence and shear sense indicators suggests a sinistral transpressive regime for deformation in the CTZ.

Most known gold deposits in the southwest Yilgarn (e.g. Boddington and Katanning) are proximal to sanukitoid and sanukitoid-like rocks. Corridors of sanukitoid-affiliated shear zones form newly prospective search spaces for mineral exploration.

Orthomagmatic Ni−Cu−PGE and V−Ti mineralization is found in mafic−ultramafic intrusive rocks dated at c. 2665 Ma within the South West Terrane. A tholeiitic high-Fe mafic intrusive suite at Red Hill is possibly coeval with the Coates Siding Gabbro. A high-Mg suite in the far west between Yarrawindah and Julimar (and possibly as far south as Yornup) includes the highly mineralized Gonneville Peridotite.

BOOM … CONTINENT

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Earth is the only planet known to have continents, although how they formed and evolved is not well understood. Using the oxygen isotope compositions (SIMS) of dated magmatic zircon, we show that the Pilbara Craton in Western Australia, Earth's best-preserved Archaean (4.0–2.5 Ga) continental remnant, was built in three stages. Stage 1 zircons (3.6–3.4 Ga) form two age clusters with one-third recording submantle $\delta^{18}O$, indicating crystallization from evolved magmas derived from hydrothermally-altered basaltic crust similar to that in modern-day Iceland. Shallow melting is consistent with giant meteor impacts that typified the first billion years of Earth history. Giant impacts provide a mechanism for fracturing the crust and establishing prolonged hydrothermal alteration by interaction with the globally extensive ocean. A giant impact at around 3.6 Ga, coeval with the oldest low-$\delta^{18}O$ zircon, would have triggered massive mantle melting to produce a thick mafic–ultramafic nucleus. A second low-$\delta^{18}O$ zircon cluster at around 3.4 Ga is contemporaneous with spherule beds that provide the oldest material evidence for giant impacts on Earth. Stage 2 (3.4–3.0 Ga) zircons mostly have mantle-like $\delta^{18}O$ and crystallized from parental magmas formed near the base of the evolving continental nucleus. Stage 3 (<3.0 Ga) zircons have above-mantle $\delta^{18}O$, indicating efficient recycling of supracrustal rocks. That the oldest felsic rocks formed at 3.9–3.5 Ga, towards the end of the so-called late heavy bombardment, seems unlikely to be a coincidence.

Xenotime: A new impact geochronometer?

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Constraining precise ages for impact events is crucial in establishing Earth's history, and several geochronometers have been developed to date impacts. We present electron backscatter diffraction (EBSD), sensitive high-resolution ion microprobe (SHRIMP) and atom probe tomography (APT) data from shocked xenotime [(Y,HREE)PO_4] collected from two impact sites to investigate the potential of xenotime as an impact geochronometer. A detrital xenotime grain from the Vredefort dome (South Africa) contains planar fractures, planar deformation bands and {112} twinning, the latter of which are diagnostic shock microstructures. However, APT analysis from the twin domains and also from the host yielded no evidence of Pb mobility at the nanometer scale during the impact. SHRIMP analysis (n=24) on the grain yielded a discordia with an upper intercept of 3136 ± 110 Ma and an imprecise lower intercept of 1793 ± 280 Ma. These correspond, respectively, to the bedrock age and a post-impact, cryptic terrane-wide fluid infiltration event. Three neoblastic grains from the Araguainha dome (Brazil) experienced partial to complete recrystallisation. The least recrystallised grain yields the oldest $^{238}U/^{206}Pb$ age of 479 ± 26 Ma, whereas a completely recrystallised neoblastic grain gave an age of 257 ± 11 Ma. APT analysis on the latter grain showed different nanoscale features that shed light on Pb mobility during shock deformation and recrystallisation. Based on observations of nanoscale Pb mobility and the correlation between recrystallisation and isotopic resetting, and prior published ages, we interpret 257 ± 11 Ma to date the impact event. These data confirm that recrystallised neoblastic xenotime is a useful impact geochronometer.

PRESSURE–TEMPERATURE–TIME (*P–T–T*) DATASET FOR THE SOUTHWEST YILGARN: SHOWCASING THE GSWA'S ONGOING METAMORPHIC MAP DEVELOPMENT

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The Geological Survey of Western Australia (GSWA) is collecting quantitative metamorphic data across Western Australia, with the initial dataset in the southwest Yilgarn Craton (Fig. 1). The data are available as a GSWA digital layer (see http://www.dmp.wa.gov.au/Geological-Survey/Metamorphic-History-29498.aspx for links to GeoVIEW.WA portal and data download), which is regularly updated as more data are collected and verified. Pressure (*P*)–temperature (*T*)–time (*t*) data, derived via forward modelled phase equilibria calculations and integrated with in situ geochronology (see Fielding et al.), provide powerful insight into the thermal structure of the crust over time. These data combined with the new interpreted basement geology datasets released by GSWA (see Ivanic et al.) are being used to better understand the geodynamic framework of the southwest Yilgarn. The database currently contains 61 data points across with State (Fig. 1), with 33 data points in the southwest Yilgarn, representing one of the most robust, well characterized metamorphic datasets worldwide. The data show that granulite and amphibolite facies conditions dominate the southwest Yilgarn, with apparent thermal gradients ranging between 65 and 225 °C/kbar at c. 2665–2635 Ma. Much of the current dataset is from the northwest-trending Corrigin Tectonic Zone (CTZ), a major sinistral transpressive shear zone system comprising granulite-grade, mid-crustal meta-igneous and metasedimentary rocks. East of the CTZ, within the western Yilgarn, the data suggests that *P–T* conditions are broadly similar to the conditions recorded in the CTZ. West of the CTZ, within the South West Terrane, there is a scarcity of robust *P–T–t* data, but field observations are suggestive of a lower metamorphic grade. These flanking regions have been prioritized for further work as they are critical to better understand the significance of the CTZ, and more thoroughly constrain and underpin geodynamic models for the evolution of the region.

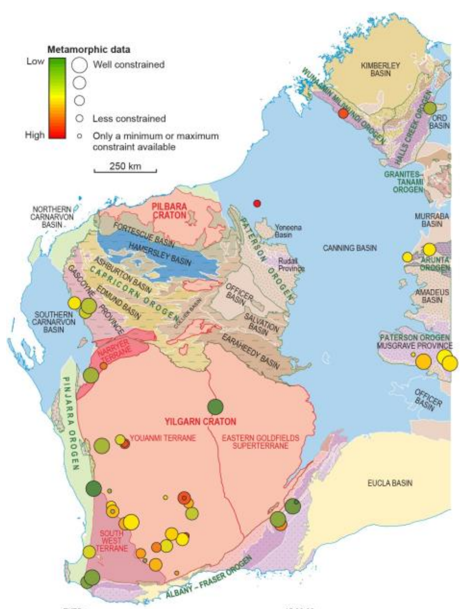

Figure 1. Simplified tectonic map of Western Australia, showing sample locations and metamorphic data as of September 2022. Data plotted are median apparent thermal gradient; temperature and pressure data are also available in the Metamorphic History data layer (https://geoview.dmp.wa.gov.au/geoview/?Viewer=GeoView)

Apatite laser ablation Lu-Hf geochronology: a new tool to date mafic rocks

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Dating crystallization of mafic rocks is challenging since zircon grains do not normally crystallize from low silica magmas, and other U-bearing accessory minerals such as zirconolite, baddeleyite, or titanite are either absent, in low abundance, or often too small to date. Apatite is generally more abundant in mafic rocks, however, the U-Pb system in apatite has a relatively low closure temperature (~350°-550° C) and may therefore be reset in response to post-magmatic thermal or metasomatic events. Here, a recently developed laser ablation Lu-Hf dating method has been applied to mafic apatites, using reaction-cell mass spectrometry. The Lu-Hf system in apatite has a higher closure temperature (~650°-750°C) compared to U-Pb, increasing the chances of obtaining primary crystallization ages. Furthermore, the laser-ablation method allows rapid data collection, compared to traditional chemical-separation Lu-Hf method. Four study areas were selected to compare the apatite Lu-Hf vs. U-Pb systematics of mafic rocks: NE Brazil, the Superior Craton in Canada, the Fennoscandian Shield in Finland, and the Yilgarn craton / Leeuwin Block in Western Australia. In some cases, both isotopic systems reveal primary crystallization ages. In other cases, the apatite U-Pb ages record a secondary overprint while the apatite Lu-Hf system remains undisturbed. Hence, this study demonstrates the power of the novel laser ablation apatite Lu-Hf method by providing a new ability to obtain primary rock crystallization ages for mafic rocks, that lack zircons and reveal regions that may have undergone thermal or fluid overprinting.

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$^{87}Sr/^{86}Sr$ in apatite inclusions in zircon – a window to the early Earth

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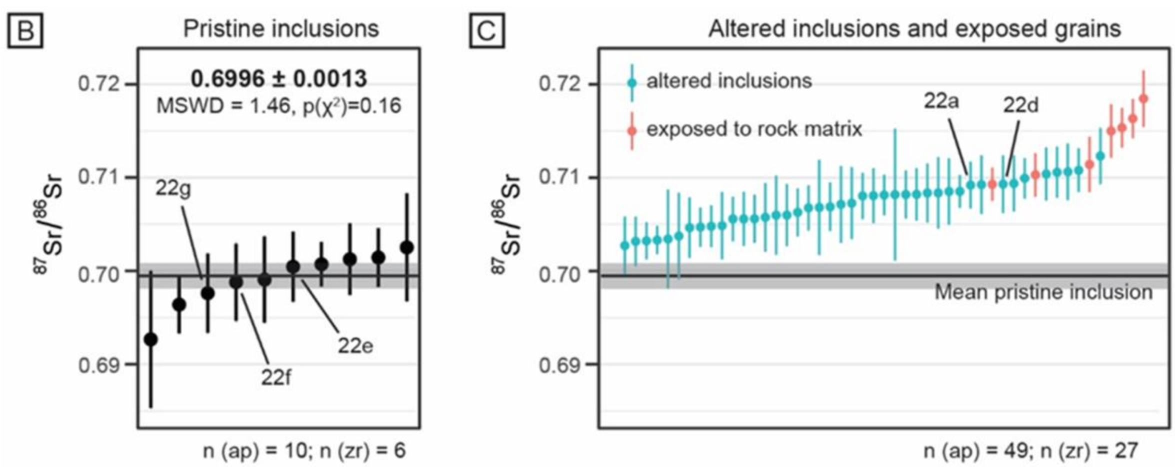
Since the last SGGMP meeting in Devonport we have continued development of a viable SIMS method for Sr isotope analysis of apatite inclusions in zircon. Using the CAMECA 1280, we are able to obtain initial $^{87}Sr/^{86}Sr$ ratios reproducibly from selected inclusions as little as 5 to 10 microns in size. Imaging and chemical analysis of the inclusions by EPMA prior to SIMS analysis, enables us to distinguish those inclusions that have retained their primary isotopic signatures from those that have re-equilibrated with the surrounding rock volume during later events. Typically, the primary inclusions record the lowest measured $^{87}Sr/^{86}Sr$ ratios while the modified ones are more radiogenic and similar to matrix apatite compositions, as per the example below. This has allowed us to investigate for the first time the initial Sr of ancient rocks regardless of any history of open-system behaviour of the Rb-Sr system on the whole rock scale. In early Archean rocks, comparison of initial Sr ratios with contemporary Bulk Silicate Earth evolution, allows us to begin to evaluate the timing of initial formation of significant volumes of differentiated siliceous crust. The data so obtained complements the information from the Lu-Hf isotope system in the host zircons which is less sensitive to intra-crustal processes. By combining the inclusion data with U-Pb and Hf data for the host zircons, we can also obtain insights into the Rb/Sr ratios and hence silica content of precursor crust involved in production of zircon-bearing TTGs.



Apatite inclusion data from the early Archean Meeberrie Gneiss, Western Australia

A GALACTIC TEMPO IN CRUST PRODUCTION?

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The Moon has a pot marked surface clear to see. Earth's gravity well is 80% greater than the Moon's and it has been proposed that extraterrestrial cratering on early Earth was a critical component in the crustal evolution of our planet. Isotopic signatures in zircon have been used to address a wide range of questions on the rates, durations, and timings of Earth system processes. Large compilations of time series data from zircon now exist across most continents. Encoded within this time series data is periodicities linked not only to magma production but also, critically, the source of such melts. Hf time series data, reflecting the relative importance of crustal recycling over mantle production, has statistically significant periodicities for the early Earth on 170-200 Ma^{-1}. Zircon oxygen isotope data resolves a similar periodicity, with episodes of light isotopic signatures corresponding to known early Earth impact events. This oxygen time series appears to support secular episodes when shallow melting dominated crust production, implying a surface, not mantle, derived energy input driving magmatism at those times. This frequency corresponds to the timing of solar system transit through the spiral arms of the galaxy. We suggest the solar systems entry into and exit out of the spiral arms may have triggered more long period comets to lower their perihelion and enter Earth crossing orbits. Whilst, correlation is not causation, it is relevant to note that early Earth spherule beds also correspond to periods of isotopic deviation from crustal averages and also the entry of the solar system into the galactic arms. Impacting appears an important means of forming early crustal nuclei.

IMPLICATIONS OF HIGH-GRADE METAMORPHISM ON DETRITAL ZIRCON DATA SETS FROM THE FRASER ZONE, WESTERN AUSTRALIA

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Detrital zircon grains provide a useful tool to determine the maximum age of sedimentary strata and can elucidate tectonic setting and basin evolution. However, high-grade metamorphism can overprint the mineral chemistry of the detrital cargo, and reset both primary age and compositional information. Here, we use U-Pb geochronology (LA-ICP-MS and SHRIMP), trace element chemistry and detailed textural observations from detrital zircon crystals in the Snowys Dam Formation (Albany Fraser Orogen; AFO) to deconvolve its sedimentary and metamorphic histories. The main detrital cargo was sourced from Mesoproterozoic lithologies from neighbouring regions, with rare Archean Yilgarn crystals. The youngest detrital grains correlate with the Madura Province to the east of the AFO and give a maximum depositional age of c. 1370 Ma. High-grade metamorphism at c. 1310 Ma during AFO (Stage I) caused recrystallization of previous detrital zircons together with neoblastic growth of metamorphic rims. At c. 1250 Ma, anatexis of the metasedimentary rocks produced rare neocrystallized magmatic zircon. Late-stage hydrothermal fluids are indicated by elevated LREE for these grains which also contain hydrous inclusions. Ti-in-Zircon temperatures imply formation temperatures between 650 and 750 °C, which increase during Stage I. U-Pb data collected with LA-ICP-MS shows age peaks shifted slightly compared to SHRIMP analysis. We interpret this as a function of sampling over multiple age domains, some of which have seen radiogenic-Pb mobility, when using LA-ICP-MS due to the larger analytical volume. When rocks have undergone high grade metamorphism, a lower volume sampling technique (e.g., SHRIMP) and verification with mineral chemistry is crucial to accurately resolve age groups.

LIQUID SULFIDE TRANSPORT IN MAGMATIC SYSTEMS

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Magmatic nickel sulfide systems are generally well understood compared to many other commodities' mineral systems. The agreed upon key genetic processes being 1) the source for the metals being the mafic-ultramafic silicate melt and for the S being assimilated crustal rocks, 2) the metal enrichment process linked with kinetically-mediated dynamic interaction between the silicate melt and the sulfide melt, and 3) the trap. This last aspect is by far the least understood, being limited by our understanding of the fundamental physics behind sulfide liquid behavior. Sulfide liquid is usually the last phase to crystallize in these systems and we need to understand how it might migrate in both non-consolidated, semi-consolidated and even consolidated intrusive complexes to understand location of ore.

Interactions between sulfide liquid, silicate melts and crystals relate to the balance between gravitational and capillary (surface tension) forces. We are investigating this balance through analogue modelling of coalescence and infiltration/percolation of sulfide liquid within an unconsolidated crystal mush using salt water (sulfide) and olive oil as analogue materials. Results show different behaviors in function of the proportion of water present in the system.

The presence of volatiles in many magmatic sulfide systems is now well accepted, but the impact it has on the system is still being investigated. High temperature-high pressure experiments have revealed how the association between sulfide melt and a fluid phase may not only facilitate upward transport within the magmatic plumbing system, but also the sulfide accumulation by facilitating the coalescence of the sulfide droplets that are attached to the same fluid bubble. This represents a possible solution to the unsolved problem of how sulfide droplets are deposited from flowing magma.

Finally, we highlight the potential presence of other fluid phases previously unconsidered, such as immiscible volatile-rich alkaline melts. Recent work on Voisey's Bay ore investigated the biotite-hornblende rims developed at the interface between the silicate clasts and the sulfide matrix, and the origin of the volatile component. Another study by Cherdantseva et al., (in review) combining detailed characterisation of the Rudniy sulfide ores (Mongolia) with results of experimental petrology revealed a potential cryptic role of immiscible volatile-rich carbonatite liquid in the transportation of metal-rich sulfides from the mantle to the crust.

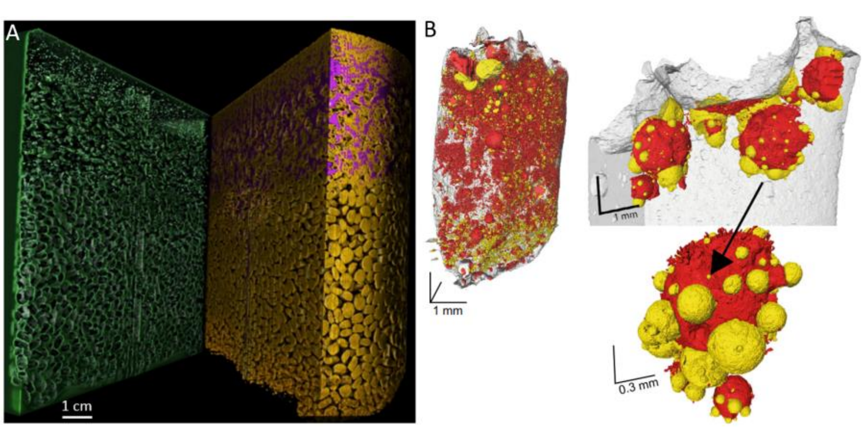

Figure 1:

A) 3D modelling of an analogue experiment studying sulfide infiltrations.

B) 3D modelling of HT-HP experiments studying sulfide coalescence aided by the presence of volatiles (Iacono-Marziano et al. 2022).

PB ISOTOPES OF THE CURNAMONA PROVINCE, AN EXAMPLE OF EXTREME CRUSTAL FRACTIONATION IN THE PROTEROZOIC

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The Proterozoic Curnamona Province, southeastern Australia, hosts several mineral systems, including the world's largest Pb-Zn-Ag ore body (Broken Hill) and important uranium mineralization in the Mount Painter Inlier. Coeval episodes of magmatism, sedimentation, and deformation, suggest a shared Paleo- to Mesoproterozoic geologic history between the Curnamona Province and the highly mineralized Eastern Gawler Craton and Mount Isa Inlier. Constraining the genesis of mineral systems within the Curnamona Province and their genetic relationship to Proterozoic mineralization events in other Australian terranes is challenging. Specifically, high-temperature deformation and metamorphism at 1620-1580 Ma caused widespread isotopic disturbance in the Curnamona province, and large areas of the province are blanketed by a younger sediment cover.

Here we present new Pb isotope data obtained from a suite of (meta-) igneous rocks collected across the Curnamona Province. In-situ K-feldspar laser ablation MC-ICP-MS analyses coupled with whole-rock and K-feldspar/galena TIMS analyses, yield a 1685.01 ± 0.12 Ma isochron, identical to the maximum age of the Broken Hill ore body (1685 ± 3 Ma). Extremely radiogenic Pb isotope ratios ($^{206}Pb/^{204}Pb$ up to 167 in K-feldspar) in the northwestern Curnamona Province imply a source unusually enriched in uranium, similar to the Olympic Dam ore body in the northeastern Gawler Craton. In contrast, relatively unradiogenic Pb isotope ratios in the southeastern Curnamona basement share affinity with Broken Hill galena and granites in the eastern Gawler Craton.

These results indicate a profound magmatic fractionation event linked to crust generation in the eastern Gawler Craton and the Curnamona Province which represent two complementary U and Pb reservoirs, tapped during subsequent magmatism and mineralization. This study investigates the spatial scale and potential mechanisms for this extreme fractionation event.

In-site Rb–Sr dating of lithium pegmatites

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Reliable geochronology of rare-metal pegmatites has been a significant challenge due to the typical dearth of suitable mineral geochronometers (e.g., zircon, baddeleyite) for in-situ techniques. Recent advances in mass-spectrometry now allow for in-situ age determinations of more abundant minerals (e.g., micas) using the Rb–Sr (and potentially K–Ca) decay system. This approach allows for rapid and cost-effective acquisition of geochronometric data with simultaneous collection of in-situ geochemical data that may be useful in advancing our understanding of rare-metal pegmatites.

Analysis of mica specimens from rare-metal LCT-class pegmatites around the world acquired from the South Australian Museum and the Tate Museum, University of Adelaide, demonstrates that many are hyper-radiogenic with negligible initial strontium. These characteristics suggest that single spot ^{87}Rb/^{87}Sr age calculations assuming purely radiogenic growth of ^{87}Sr (akin to U–Pb systems) are often feasible. Preliminary analysis of lithian-micas from Archean pegmatites in WA (Tabba Tabba, Londonderry, Wodgina), Mesoproterozoic pegmatites from the NT, Neoproterozoic pegmatites from Brazil, and Cretaceous pegmatites from California all return precise age data well within the expected age uncertainty for these deposits. We also found that unlike most minerals, crystal orientation of micas has a significant effect on isotopic ratio quantification via LA-ICP-MS, and thus the calculated ages. Caesium-beryl also shows potential as a reliable Rb–Sr geochronometer, though further development is needed. By contrast, our data indicate that neither spodumene nor amblygonite take in appreciable Rb, or Lu, for feasible in-situ Rb–Sr or Lu–Hf dating with current analytical technology.

Carbonates, Sulfides and U-REE-Cu-Au Mineralisation, NW Queensland

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The Cu-Au-U-REE Mary Kathleen deposit, NW Queensland, Australia, is a contentious deposit that has historically been classed as a U-REE skarn deposit. However, recent studies suggest similarities to IOCG deposits. Furthermore, the relationship to controversial occurrences of very coarse-grained carbonates with accessory amphibole, quartz and sulfide in the same area is unclear.

Samples have been analysed for major and trace element compositions, textural features, element zonation, isotopic compositions and age. Our results indicate multiple sulfide mineralisation events all post-dating skarn formation.

Uranium and REE are hosted in skarn-like coarse-grained units dominated by >90 % clinopyroxene or >85 % garnet, respectively. Clinopyroxene-dominated units contain accessory garnet, apatite and REE-rich epidote-group minerals and carbonate while garnet-dominated units contain minor clinopyroxene, REE-rich epidote-group minerals, sulfides, apatite, feldspar and carbonate. Carbonate alteration of variable intensity overprints both units, but is primarily focussed on clinopyroxene-rich rocks.

U-REE mineralisation are hosted in uraninite and REE-rich epidote-group minerals. The main sulfide minerals are pyrite, pyrrhotite and chalcopyrite with minor cobaltite, molybdenite and trace pentlandite. Both U-REE and sulfides are disseminated in skarn-like host rock. U-REE mineralisation also forms feldspar-carbonate ± garnet veins. Sulfide mineralisation forms massive pyrrhotite veins with minor pyrite, stringer veins and sulfide blebs often connected by stringers in carbonate ± feldspar ± quartz ± garnet veins. Sulfide proportions vary between occurrences within the same deposit and between deposits.

Overgrowth sulfide textures of variable trace element concentrations indicate multiple generations of magmatic or hydrothermal origin while drastic changes in Co contents are suggestive of two separate fluids.

Understanding the provenance and mineral paragenesis will help define the origin of these enigmatic deposits and their relationship to the coarse-grained carbonates.

Paleoproterozoic magmatism in the Pilbara Craton: insights from the c. 1.8 Ga hydrous and oxidized Bridget Suite

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The Bridget Suite is a series of undeformed, hornblende-bearing intrusions with a 270 km-long northwest trend within the northeastern part of the eastern Pilbara Craton. The trend is parallel to, and about 130 km west of, the Paleoproterozoic suture zone between the Percival Lakes Province and the Rudall Province. The suite comprises numerous small plutons, stocks and dykes of hornblende- and clinopyroxene-bearing lamprophyre, monzodiorite, monzonite, and monzogranite, commonly with trachytic textures. The intrusions are highly magnetic and can be identified readily in aeromagnetic images. However, the genesis of this distinct magmatic suite is poorly understood. Here we report new geochronology and geochemistry to better constrain the timing, petrogenesis and geodynamic setting of the Bridget Suite.

The age of the Bridget Suite was previously estimated to be 1803–1759 Ma based on discordant U-Pb data from one sample (GSWA 169030). A new geochronology sample of quartz monzonite (GSWA 255830) was collected from the largest Bridget Suite intrusion, in the Mosquito Creek Basin, to better constrain its age by SHRIMP U-Pb dating. The zircons are colourless to dark brown and mainly subhedral to euhedral. Many crystals are dominated by metamict zones, and contain older cores. Seven zircon analyses yield a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1790 ± 7 Ma (MSWD = 0.87), interpreted as the igneous crystallization age. Twenty-two analyses of zircon cores yield $^{207}Pb^{*}/^{206}Pb^{*}$ dates of 3352–2688 Ma, interpreted as the ages of inherited zircons, which are similar to ages of exposed igneous rocks in the East Pilbara Terrane, including the Emu Pool, Cleland and Split Rock Supersuites, and the Bamboo Creek Member of the Hardy Formation. The crystallization age of 1790 ± 7 Ma indicates that the Bridget Suite is contemporaneous with the Yapungku Orogeny and emplacement of the 1804–1762 Ma Kulkan Supersuite in the Rudall Province, the main phase of the Capricorn Orogeny and emplacement of the Moorarie Supersuite in the Gascoyne Province, and deposition of the Ashburton Basin along the northern margin of the Capricorn Orogen.

New geochemistry from 33 samples indicates high-K calc-alkaline compositions with 53–69 wt% SiO_2, and high Sr/Y (35–83) and Eu/Eu* (0.85–0.97), both of which increase with increasing SiO_2. Together with their high V/Sc (9–12), the magmatic evolution can be interpreted to involve suppression of plagioclase crystallization and promotion of hornblende crystallization in hydrous magma, which is consistent with the presence of abundant hornblende phenocrysts. Therefore, the Bridget Suite is essentially a very hydrous and oxidized magmatic suite. We hypothesize that the Bridget Suite was derived from metasomatized mantle or lower crust beneath the eastern Pilbara Craton in an intraplate or distal subduction setting, and the trigger for melting is likely related to Paleoproterozoic convergence of the West and North Australian Cratons.

THE INHIBITED RESPONSE OF ACCESSORY MINERALS DURING HT-UHT REWORKING

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Zircon and monazite are commonly relied on to record meaningful U–Pb geochronology. The isotopic systems of these accessory minerals are renowned for their high closure temperatures, and therefore apparent ability to record high temperature igneous and metamorphic processes. However, recent work in the Warumpi Province suggests that the response of zircon and monazite may be inhibited when ultrahigh-temperature (UHT) metamorphism (> 900 °C) occurs below the solidus. Zircon and monazite from UHT metapelites in the Warumpi Province dominantly record Liebig U–Pb dates of *c.* 1640 Ma, while in-situ Lu–Hf geochronology from peak garnet gives contradictory Musgravian ages of *c.* 1151 Ma. These UHT metapelites are interpreted to have been dehydrated and preconditioned during the Liebig Event, preventing melting and the (re)crystallisation of monazite and zircon during the Musgrave Orogeny. Proximal samples in the Warumpi Province that have been subject to melting record comparatively pervasive Musgravian-aged geochronology. Coarse-grained titanite from a metagabbro gives an age of *c.* 1125 Ma, and monazite and garnet from a migmatised metapelite record U–Pb and Lu–Hf ages of *c.* 1145 Ma and *c.* 1164 Ma, respectively. This study uses U–Pb geochronology from zircon, monazite and titanite, in-situ Lu–Hf dates from garnet, zircon-garnet petrochronology, and mineral equilibria forward modelling to highlight the ambiguity associated with developing geologic interpretations in terranes where rocks have been subject to variable petrological preconditioning. The results from this work demonstrate the potential for dehydrating events to mute the response of accessory minerals, resulting in a decoupling between geochronology and pressure-temperature constraints in polymetamorphic terranes. In the case of the Warumpi Province, this decoupling has led to the Liebig Orogeny previously being assigned significance as a major UHT event associated with the assembly of the Australian continent, when in reality these thermometric constraints belong to a Musgravian age signature instead. Conventional geochronology from accessory minerals should therefore be supplemented by trace element geochemistry and geochronology of peak minerals, such as in-situ Lu–Hf dating of garnet.

MOUNT HAGEN, PNG; A DEEP-ARC CRYSTAL MUSH

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Mount Hagen, a stratovolcano in Papua-New Guinea, resides within a complex tectonic setting and an unclear magmatic history. Samples covering a bulk MgO range from 2 to 11.5 wt.% contain abundant olivine, clinopyroxene, hornblende and plagioclase megacrysts which are clearly out of equilibrium. We interpret this mélange as crystal mush and believe this to be a rare view of a deep arc setting. Despite the incredible complexity of the system, various magma mixing events can be identified by reverse zoning in plagioclase, high-Cr zones in clinopyroxene and two olivine populations, with the most significant occurring at 5.5wt.% bulk MgO.

Within the array of megacrysts, sulfide inclusions were identified across the entire compositional range. These 10 micron sulfide blebs were analysed for trace-element and PGE contents by electron microprobe. These sulfide inclusions record continuous sulfide saturation across the entire sub-volcanic magmatic history. They also provide a temporal axis independent of silicate fractionation trends. The Ni/Cu range generally seen across an entire system is herein recorded within single samples. Despite the abundant silicate compositional reverses, sulfide inclusions evolve to high copper contents through time. This allows an independent relative chronometer. Furthermore, evidence of volatile saturation is found in megacrysts throughout. This study shows that sulfide and volatile saturation was continuous across the entire suite.

Mush zones are very challenging to unravel, however, magmatic sulfides provide an additional chronometer. Additionally, these mushes allow transport of immiscible sulfide within and between phases from great depths, thereby overriding the difficulties of increasing sulfur solubility with decreasing pressure.

Geodynamic transition at 2.7 Ga in Earth's largest craton

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The first ca. 2.2 billion years of Earth history saw significant change; from a water-world dominated by an anoxic atmosphere and tonalitic continents, to the exposed landmasses, oxygenated atmosphere, and granitic crust of the Paleoproterozoic. Precisely when, and how, these major changes occurred, remain some of the most important and controversial questions in modern geoscience. Here, we present an extensive new zircon U-Pb-Hf-O isotopic and trace element dataset from Earth's largest preserved Archean continent, the Superior Craton, Canada. These data record a number of fundamental geochemical changes through time and indicate a major geological and geodynamic transition occurred toward the end of Archean, at ca. 2.7 Ga. Our data show that, at >2704–2695 Ma, the southern Superior Craton had juvenile εHf, light to mantle-like $\delta^{18}O$, low (Eu/Eu*)/Y (drier/shallower crust), reduced ΔFMQ, less continental initial-U (U_i)/Yb, and more mantle-like U_i/Nb. At ca. 2704–2695 Ma, there is a marked transition in multiple datasets, including increases in $\delta^{18}O$, (Eu/Eu*)/Y, ΔFMQ, U_i/Yb and U_i/Nb data, together with more distinct arc-like trace element trends. These data reveal that at 2.7 Ga there was an increase in: (1) continental surface weathering, supported by increased sedimentation at <2.68 Ga, (2) oxidized and hydrous magmatism, and (3) surface material in magma sources. Together, these observations suggest a major geodynamic transition from 'vertical' tectonics (sagduction, drips) to north-dipping subduction at 2.7 Ga. The increase in $\delta^{18}O$ suggests that proximal continental crust, probably in the northern Superior Craton, became emergent at this time, an inference supported by detrital zircon geochronology. Hence, this dataset links major geodynamic change to the emergence of continental crust and the rise of more oxidized magmatism. These fundamental changes to the Earth's surface environment, tectonics, and atmosphere at 2.7 Ga, provide evidence for an Earth systems turning-point at the end of the Neoarchean.

Crustal architecture of Precambrian Australia's south-eastern margin – an isotopic perspective

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The Australian continent comprises a broad dichotomy of crustal settings; from the Archean–Proterozoic cratonic core in the centre and west, to the accretionary margin of the Tasmanides in the east. These continental blocks meet at the Tasman Line, where successive arc systems built the eastern third of Australia in ca. 250 Myrs. This interface represents one of Australia's most fundamental crustal boundaries and is marked by the ca. 520–490 Ma Delamerian Orogen in south-eastern Australia. Despite its first-order crustal control on tectonism, magmatism, deformation, and mineral systems in the area, the Delamerian Orogen remains poorly understood. Here, we present new zircon Hf-O isotopic and trace element data on 32 samples across the south-east Tasman Line. This initial dataset, which will grow over the next 12 months as part of Geoscience Australia's Exploring for the Future program, will be used to constrain the time-space crustal architecture and evolution of Australia's south-eastern Precambrian cratonic margin. These first samples include Paleoarchean to Devonian felsic magmatic rocks from the eastern Gawler Craton, across the Delamerian Orogen, to the Central Lachlan Orogen, and show that the crust of south-east Australia has a significant pre-history, with crustal reworking a major feature across the region. Delamerian arc magmatism appears to have involved significant reworking of Australia's south-eastern Precambrian margin, as recorded by sub-chondritic Hf-isotope data. Assuming a significant mantle-component in the initial arc magmas, contamination by the ancient overlying continental rocks, some as old as ca. 3250 Ma, resulted in less juvenile compositions. This observation suggests Australia's south-eastern Gondwanan margin may have consisted of a west-dipping continental arc, rather than an offshore island arc. The 'heavy' supracrustal $\delta^{18}O$ of magmatic rocks across the area since the Paleoproterozoic is testament to the long-lived terrestrial nature of this continental margin, and its influence on magmatism across >1 billion years of Earth history.

ISOTOPIC ATLAS OF AUSTRALIA – AN UPDATE

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The first iteration of a continental-scale Isotopic Atlas of Australia was introduced by Geoscience Australia at the 2019 SGGMP conference in Devonport, Tasmania, through a talk and poster display. In the three years since, progress on this Isotopic Atlas has continued and expanded datasets are now publicly available and downloadable via Geoscience Australia's Exploring for the Future (EFTF) Geochronology and Isotopes Data Portal.

This poster provides example maps produced from the compiled data of multiple geochronology and isotopic tracer datasets, now available in the EFTF Portal. Available data include Sm–Nd model ages of magmatic rocks; Lu–Hf isotopes from zircon and associated O-isotope data; Pb–Pb isotopes from ore-related minerals such as galena and pyrite; Rb–Sr isotopes from soils; U–Pb ages of magmatic, metamorphic and sedimentary rocks; and K–Ar, Ar–Ar, Re–Os, Rb–Sr and fission-track ages from minerals and whole rocks. Compiled geochronology, which commenced with coverage of northern Australia, is now much more comprehensive across Victoria and Tasmania, with New South Wales and South Australia updates well underway.

This Isotopic Atlas of Australia provides a convenient visual overview of age and isotopic patterns reflecting geological processes that have led to the current configuration of the Australian continent, including progressive development of continental crust from the mantle. These datasets and maps unlock the collective value of several decades of geochronological and isotopic studies conducted across Australia, and provide an important complement to other geological maps and geophysical images—in particular, by adding a time dimension to 2D and 3D maps and models.

ACCESSORY MINERAL STABILITY AND REE MOBILITY DURING WEATHERING

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The trace element character of accessory minerals in the detrital record has been used as a vectoring tool for mineral exploration, a provenance tracer in sedimentary rocks and a means of investigating bulk crustal evolution through time. A key assumption for these applications is that accessory minerals are resistive and can survive weathering and incorporation into the sedimentary cycle. At the same time, ionic adsorption clay deposits are an emerging REE source in Australia and are thought to form via weathering of REE-bearing minerals. The processes that control REE enrichment in regolith include the REE content of the protolith, the resistance of the host phases to weathering and the biochemical processes occurring during the weathering process. Therefore, assessing the stability of common REE-bearing accessory minerals is important to better understand both the detrital record and 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 an opportunity to investigate the changes in whole-rock geochemistry and mineralogy with increasing intensity of weathering. Phosphorus and Ca contents are depleted in the clay-dominated rocks relative to fresh rock, though the transition from fresh to clay-dominated rock is often associated with an interval containing elevated P. There is a demonstrable breakdown of P and Ca-bearing accessory minerals such as apatite and titanite in the early stages of weathering within primary granite. Whole-rock LREE contents are higher in the weathered rock, but are more heterogeneously distributed than in the fresh rock. REEs that could otherwise be released during mineral breakdown are commonly taken up into newly formed phases such as allanite, bastnasite and monazite. This has implications for the proportion of REEs that are available to be adsorbed onto clays. The weathering profiles also highlight potential bias if using detrital minerals such as apatite and titanite for crustal evolution studies.

FROM 'MANY ROCKS TO GET AN AGE' TO 'MANY AGES FROM ONE ROCK' – ON THE AGE-OLD PROBLEM OF DATING A GRANITE

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When we speak of an age of a granite, we mean the event during which melt is injected into and solidifies within the crust. This event is not a single point in time but a period that involves multiple stages of evolution. This evolution involves processes that also "postdate" the solidification of melts and the formation of crystals when fluids are still actively circulating and temperatures are still high enough to allow chemical exchange on an atomic level. A critical complication here is that the temperature at which atomic exchange between phases ceases is variable between minerals, but is also dependent on the presence of fluids and potentially their chemistry, too. For radiometric dating, parent and daughter isotopes must remain closed within a system, and the thermal threshold (*sensu stricto*, i.e., without fluids) when this occurs is termed closure temperature (T_C). Zircon has a high (> 900^{o}C) T_C for U-Pb and is thus often employed as a dating tool for granites. Yet, many granites show zircon age patterns that exceed a single 'event'. The same holds true for U-Pb systematics in monazites or apatites, or Rb-Sr ages derived from mica or K-feldspar, noting that these have potentially lower T_C. To elucidate the cryptic age information from these minerals, we performed a series of experiments with detailed dating approaches of phases within single granite clasts. We analysed various mineral species for their parent-daughter systematics via LA-ICP-MS from the Mt. Buller I-type granodiorite, the Cape Woolamai S-type granite, and the Lysterfield hybrid granite, all of which are part of the Lachlan Fold Belt in Victoria, Australia. We find that the effects of fluids on dating results can be severe, often preventing a conclusive 'age' of the pluton. The combination of a detailed isotope-trace element study from multiple chronometers, however, allows constraints on the true emplacement event. Detailed 'age-mapping' of mineral phases revealed multiple geologic events within a single rock, often spreading tens of millions of years. The wide spectrum of tools now available for dating a granite allows us to decipher a rock's history in unprecedented detail but also forces us to investigate single rocks with much more care, and ultimately to reassess many ages of granitic complexes that we thought are rock solid.

OLDEST MAGMATIC NI-CU DEPOSIT A CONSEQUENCE OF SECULAR CHANGE IN GLOBAL TECTONIC REGIME

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Ore deposit styles have evolved over time due to secular change in an ever-cooling Earth. Prior to this study, intrusive magmatic Ni-Cu-(Co) deposits were not known to exist before 2930 Ma, which may be a function of preservation bias or of geological consequence. Here, we use zircon U-Pb geochronology of the mineralizing gabbro at the Andover Deposit in the Pilbara Craton, WA, to show that it formed at 3015.6 ± 1.5 Ma, ~85 m.y. older than the next oldest deposit (Ruossakero deposit, Finland). Complementary zircon Hf isotopes with more negative initial εHf values than the depleted mantle require assimilation of felsic crust. The interaction of felsic crust is necessary to induce sulfide immiscibility and the development of economic Ni-Cu deposits. At ca. 3.2–3.0 Ga, as part of the transition from dominantly stagnant-lid to plate tectonics, a global extraction of mantle material occurred to produce major felsic continental crust. Prior to this time, the paucity of felsic continental crust may have been a limiting factor in the formation of economically significant magmatic Ni-Cu deposits. Ultimately, we posit that the secular change in Earth's tectonic regime led to the rise of magmatic Ni-Cu deposits in the Mesoarchean.

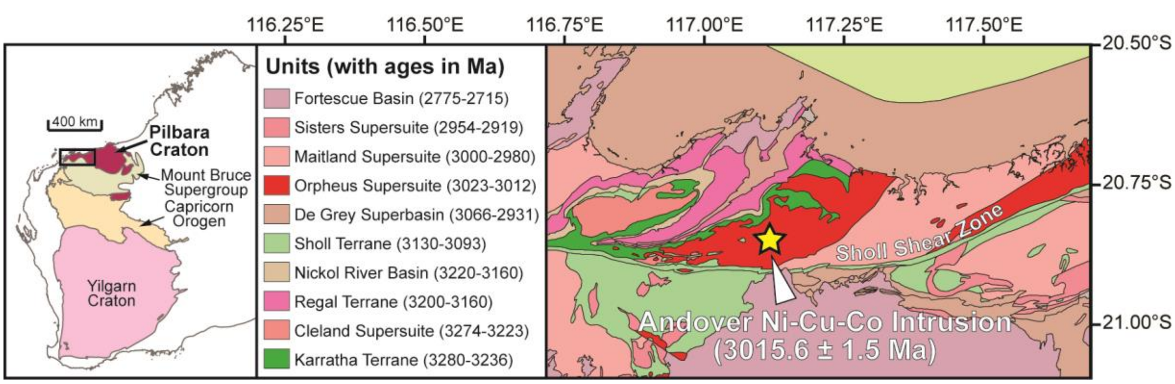

Figure: Location of the oldest magmatic Ni-Cu-Co intrusion

Concordance and chemical abrasion as pathways to improved trace element geochemistry in zircon and other accessory minerals

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Trace element compositions of zircon are increasingly used to understand the petrogenesis of both the analysed zircon grains and their host rock. In most cases the assumption is made that the obtained trace element composition is indicative of the grain composition at the time of formation, with partitioning into the zircon matrix indicative of petrogenetic history. We have used thermal annealing and chemical abrasion of Mesoproterozoic igneous zircon to investigate the utility of these processes for trace element studies of zircon. The chemical abrasion process dramatically improves the quality of the obtained trace element data and removes the majority of otherwise erroneous data influenced by inclusions or metamict and/or altered zircon domains. If chemical abrasion is not undertaken then the results of this study highlight that only U-Pb age concordant analyses should be used for trace element studies in accessory minerals. Concordance provides a simple but highly efficient method for excluding erroneous trace element information and it is recommended that this filter is applied to all accessory mineral studies. Sensu stricto, if an analysis is not age concordant then it indicates that the trace element composition (i.e. Pb) has been modified in some manner since the crystallisation of the grain and the composition information cannot be considered completely reliable.

FANTASTIC SCAPOLITES AND HOW TO MEASURE THEM. ELECTRON MICROPROBE ANALYSIS OF SCAPOLITE: PROTOCOLS AND PITFALLS

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Scapolite is a SO_4^-, Cl^-, and CO_3^- bearing aluminosilicate mineral, that forms in hydrothermal, igneous and metamorphic rocks. In the latter, it is stable from greenschist to granulite facies, and even uppermost mantle conditions. The scapolite group consists of three end-members: marialite ($Na_4Al_3Si_9O_{24}Cl$), meionite ($Ca_4Al_6Si_6O_{24}CO_3$) and silvialite ($\{Ca,Na\}_4Al_6Si_6O_{24}\{SO_4,CO_3\}$). The major element composition of scapolite varies as a function of the physiochemical conditions that it formed or equilibrated at, such as pressure, temperature, fO_2 and rock and fluid composition. Albitisation and devolatilisation of scapolite, and the resulting release of chlorine, carbon dioxide and oxidised sulfur maybe be an important source of highly reactive mineralised brines in the crust.

Under typical electron microprobe operating conditions (15 keV, 15 nA), scapolite grains are strongly affected by beam-induced damage, even when using defocused beams of up to 30 µm diameter. Our literature survey has revealed that commonly reported beam conditions for scapolite analysis employ high current (20 nA), despite the well-known problems of diffusive volatility of light anions such as Cl^- and light cations such as K^+ and Na^+.

For this study, we selected scapolites from locations around the world (Northern Flinders Ranges, Mt Isa, Australia; Grenville Province, Canada; Bolton Quarry, USA; Arendal Mines, Norway; Umba River, Tanzania; Minas Gerais, Brazil). These scapolite samples represent diverse geological environments such as hydrothermal systems, skarns, pegmatite, and various metamorphic grades (calc-silicates subjected to greenschist and amphibolite facies), as well as covering the majority of the solid-solutions of marialite-meionite-silvialite.

This presentation provides an overview of the main challenges of electron microprobe analysis of scapolite, including volatility of certain anions and cations and associated beam damage, along with consideration of standards, analysis time, analysis current and accelerating voltage, detection limits and cathodoluminescence features, ultimately with the aim to define a new protocol for the quantitative analysis of scapolite using electron microprobe.

GEOCHEMISTRY DATA INTEROPERABILITY AND MAKING THE WORLD FAIR THROUGH ONEGEOCHEMISTRY

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Geochemical data is essential to understand the Earth system, i.e., its Geosphere, Atmosphere, Hydrosphere, etc., thereby addressing critical societal issues. Analytical data are produced at astonishing rates and ever greater volumes are being published. As the questions we ask are becoming more complex and require multidimensional analyses, statistics, ML and AI to solve, the data from sophisticated research capabilities and compilations are required to be comprehensive and above all machine-readable, hence, FAIR (Wilkinson et al., 2016). Ideally, data are stored following common, accepted standards from the onset of production. FAIR-compliant data is easy to use by everyone using existing or self-developed computer protocols. Compiling FAIR datasets is still in its infancy and needs to become simple for both those publishing the data and those using the data.

The OneGeochemistry initiative aims to solve this problem through providing catalogued global community-agreed standards, metadata, and ontologies, as well as best practices, and recommend repositories for geochemical analytical data. Achieving this will require the input of international data providers, geochemical societies, data and research infrastructure initiatives, and related stakeholders. OneGeochemistry aims to bring together experts from the international geochemical community to create advice, test and implement best practices in data reporting, methodology and standardisation. The network will simplify the discovery of geochemical data as well as access to it, thereby facilitating faster generation of geoscientific knowledge and discoveries.

Inclusion of OneGeochemistry within the 'WorldFAIR: Global cooperation on FAIR data policy and practice' project, that was funded by the European Commission, provides two years of funding for a project coordinator through AuScope and is a collaboration with major data systems from Australia (AusGeochem), USA (EarthChem, AstroMat) and Europe (GEOROC-DIGIS, EPOS-MSL, NFDI4EARTH, GFZ Data Services). Australian participation will provide hands-on opportunities to test disciplinary and interdisciplinary integration of Australian datasets within emerging global Interoperability Frameworks.

Wilkinson, M., Dumontier, M., Aalbersberg, I. et al. The FAIR Guiding Principles for scientific data management and stewardship. Sci Data 3, 160018 (2016). https://doi.org/10.1038/sdata.2016.18

TIMING AND EFFECTS OF FLUID-DRIVEN METAMORPHISM ON DEFORMATION AND SHEAR ZONE WIDENING

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A mylonitic shear zone that occurs at a high angle to the general structural grain near Mt Boothby, Reynolds Range, central Australia, provides a natural laboratory to better understand the effects of fluid-driven metamorphism on deformation and shear zone widening. Building on an earlier study of U–Pb in apatite and monazite combined with whole rock and mineral chemistry, this study employed $^{40}Ar/^{39}Ar$ analyses of of biotite, muscovite and K-feldspar to understand the age of recrystallisation and further constrain the timing of shear zone activity. Results for the micas are inconsistent with a closure temperature model, with an apparent older date for biotite (c. 380 Ma in central mylonite zone; c. 364 Ma at shear zone margins) than muscovite (c. 344 Ma throughout the shear zone). However, a younger age for K-feldspar (c. 323 Ma) is consistent with closure temperatures. We interpret biotite to record the cessation of shearing in the central part of the shear zone at c. 380 Ma, with shear zone widening continuing laterally until c. 364 Ma. Subsequent retrogression during fluid influx along the weakened and permeable zone caused a K-feldspar to muscovite reaction, explaining the coeval ages of muscovite throughout the shear zone. Further cooling finally closed the Ar diffusion in K-feldspar resulting in the youngest age obtained.

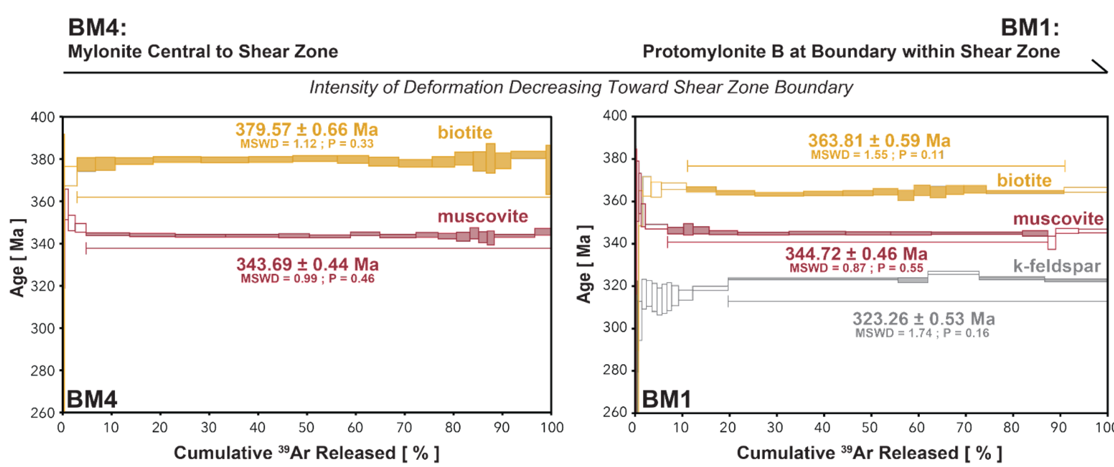

Figure 1; $^{40}Ar/^{39}Ar$ age spectra for biotite, muscovite and K-feldspar of mylonite. Indicated are plateau ages, uncertainties (at 2σ confidence level), MSWD and probability values.

INSIGHTS INTO THE TRANSFER OF METALS BETWEEN MAFIC ENCLAVES WITHIN A HOST GRANITE USING CU ISOTOPE ANALYSIS.

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The transfer of material between mantle-sourced magma and evolved magmatic rocks may provide a mechanism for the transportation of metals such as copper, Cu, to the crust. The Mannum granite provides a case study to examine the isotopic fractionation of Cu (measured as δ^{65}Cu) between these two differing phases. Cu isotope analysis paired with whole rock trace and major element analysis may also reveal the degree to which mixing/mingling have affected metal transport compared to fractional crystallization. Samples of both the host granite and contemporaneous mafic enclaves were taken, covering a broad spectrum of chemical compositions. A high degree of mixing/mingling is present within the Mannum granite as evidenced by Rapakivi feldspars and transfers of both felsic and mafic xenocrysts into both the enclaves and the host granite. δ^{65}Cu values ranged from -0.12 to 2.34‰, this range when modelled with Cu ppm follows a Rayleigh fractionation curve with δ^{65}Cu becoming heavier (more positive) with decreasing Cu this indicates the small range in Cu isotopes indicate that no highly fractionating processes have occurred like fluid interactions. Instead, this distribution shows mixing has most likely produced this distribution. Other stable transition metal isotopes could be paired with Cu isotopes, such as Zn and Fe, to further examine the role of any redox reactions. Three different digestion methods for Cu isotopes ware also investigated, so that Cu isotope analysis become more accessible and economical for exploration companies.

The generation of sodic and potassic granitoids by fluid-fluxed and fluid-absent melting in continental arcs and back-arcs: an example from the Yangtze Block in South China

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Granitoids in modern and ancient active continental margins are dominated by calc-alkaline rocks with subordinate alkaline compositions. However, their petrogenetic relationships and geodynamic mechanisms have not been well addressed. The Neoproterozoic granitoids are subdivided into sodic and potassic rocks along the Panxi continental arc in the western margin of the Yangtze Block, South China. The sodic granitoids (870–740 Ma) are located on the western side of the arc, and consist of tonalite and granodiorite. They have low K2O/Na2O ratios (0.1–0.8), high Na2O contents (3.5–6.7wt%), negative to positive whole-rock εNd(t) values (−1.7 to +2.9), and variable zircon εHf(t) (+0.3 to +12.3) and δ18O values (3.44–8.22‰). The potassic granitoids (820–790 Ma) occur at the eastern side and consist of monzogranite, biotite granite, and syenogranite. They have high K2O/Na2O ratios (0.6–2.2) and K2O (2.6–6.0wt%) contents, but whole-rock εNd(t) (−0.9 to +2.9), zircon εHf(t) (+1.8 to +12.9), and $\delta^{18}O$ values (3.0–6.4‰). Their similar isotopic compositions to those of space-time-associated mantle-derived rocks suggest both granitoids were likely derived from juvenile mafic crust. Phase equilibria modelling shows that the H2O content of the protolith played a key role in their petrogenesis, both in lowering solidus temperatures and in controlling the compositions of partial melts. The sodic granitoids can be formed by H2O-fluxed melting of the juvenile mafic rocks in lower crust (6–10 kbar) at 750–850 °C in which the required H2O was derived from the dewatering of underplating mafic arc magmas. The potassic granitoids can be generated by fluid-absent partial melting at higher temperatures of 800–900 °C. We conclude that the sodic granitoids were derived from partial melting of the newly-formed mafic crust during subduction of oceanic lithosphere. By contrast, the potassic granitoids were likely generated in a back-arc setting induced by upwelling of the asthenospheric mantle.

THE BEHAVIOUR OF RARE EARTH ELEMENTS (REES) IN CARBONATE MELTS AND PHOSPHATE ORE MINERALS

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Rare earth elements (REEs) are critical components for modern electronic devices. REE mineralisation is most commonly associated with carbonatites. However, the processes which lead to REE enrichment in carbonatites are not well understood. Economic REE mineralisation is most commonly hosted in phosphate minerals like monazite or xenotime. This study aims to determine experimentally the favourable conditions for crystallization of monazite from carbonate melt by determining the solubility of monazite in carbonate melts as a function of pressure, temperature and melt composition.

We conducted piston-cylinder experiments at upper mantle pressures of 1 and 2 GPa, and temperatures from 1000 to 1450°C. We prepared a synthetic sintered oxide melt with the composition of a natural monazite and a synthetic sodic dolomitic composition that models a mantle-derived carbonatite melt. The monazite and melt mixes were combined in a 1:1 ratio by weight in most experiments which successfully crystallized monazite, thereby demonstrating saturation of the melt in monazite. We systematically varied the composition of the carbonate melt component by the addition of SiO_2, and CaF_2 to determine their effects on monazite solubility.

Preliminary results indicate that (1) with increasing temperature the solubility of monazite increases in carbonate melt, (2) in fluoride-bearing samples monazite solubility increases relative to the F-free system (3) the solubility of monazite decreases with increasing SiO_2 in carbonate melt and (4) lowering pressure over a range from 2 to 1 GPa increases the solubility of monazite in the carbonate melt.

In future, we will investigate the effect of H_2O on the solubility of monazite and generate a regression model in order to understand monazite solubility as a function of temperature, pressure and different melt compositions, which will allow the conditions where monazite forms in natural carbonatites to be predicted.

CARBON IN MINERALOGIC GRAIN BOUNDARIES

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The causes of electrical conductivity variations in Earth's crust are controversial. The presence of interconnected graphite along mineralogic grain boundaries is a possible explanation. However, deeply buried rocks, now exposed at the Earth's surface, show little evidence of grain boundary graphite at microscopic scales. Here we use APT and correlative analytical techniques to investigate the potential presence of carbon within deformation-related low-angle grain boundaries in monazite from a major zone of tectonic deformation in central Australia. APT data show complex m/q spectra with no significant elemental carbon peaks. However, a peak at 44 Da is interpreted to represent the formation of CO_2^+ molecular species during field evaporation. Reconstructions of these APT data reveal the presence of 5 nm-wide films of carbon within 3-dimensionally interconnected, deformation-related crystal defects. Na shows a similar distribution and this association indicates grain-boundary enrichment is likely associated with the breakdown of NaCl- and CO_2- rich fluid inclusions during tectonic deformation. Geochronological data constrain the timing of deformation to ~530 million years ago, indicating that defect-stabilised carbon is stable over significant geologic timescales. At the time of deformation, crustal temperatures and pressures are consistent with graphite being the stable carbon phase. These previously unobserved defect-hosted graphite films are sufficient to explain electrical conductivity in the deep crust. However, a major SiO^+ peak at 44 Da in silicate minerals would mask any minor CO_2^+ peak and precludes the use of APT to study carbon nanofilms in silicate minerals.

Multiple dates with models; analysing multiple minerals in metapelites to better understand the history of the Proterozoic Fraser Zone, Western Australia

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The Proterozoic Fraser Zone, within the Mesoproterozoic Albany Fraser Orogen, is a fault bound lithologic unit defined primarily by mafic—ultramafic magmatism and granulite facies metasediments. Previous studies were limited to the lack of exposure in this region, but thanks to the associated Ni—Co—Cu mineralization and active exploration in the area, new studies about the associated country rocks have commenced. Metamorphism in the region was coeval with the mafic intrusions, such that the mafic magmatism was the thermal driver, adding high temperatures and overburden pressures to the surrounding sediments. This investigation looks at four metapelites (from drill core derived approx. 10 km outside the Nova-Bollinger deposit) and further quantifies and defines the timeline of the metamorphic history. Key techniques employed are laser ablation dating of monazite (U—Pb) and biotite (Rb—Sr), EPMA and LA-ICP-MS elemental garnet maps and using THERMOCALC to model peak equilibrium conditions. Together, these analysis help detail the evolution of metamorphism, with peak assemblages reaching granulite facies metamorphism (830—875 °C, 7.75—11.75 kbar) at or before 1277± 3 Ma. This inferred peak metamorphic peak is similar to that of previously studied metapelites in the southernmost part of the Fraser Zone, but the garnet elemental maps yielded a new complexity. Yttrium maps of several garnet grains show concentric zoning consistent with heating following multiple pulses of mafic magmatism. Subsequently, the rocks cooled to temperatures at which Sr becomes immobile in biotite (c. 300°C) between 1120—1100 Ma. Combined, we infer the rocks to represent with the birth and death of an ancient backarc during accretionary orogenesis.

Patterns of Tectonic Evolution:Interpolation of Isotopic Data in Yilgarn Craton

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Geologists have been using isotopic and other geochemical data as proxies to map the evolution of craton. For example, Sm-Nd and Lu-Hf isotopic systems which make use of the different in Sm/Nd and Lu/Hf ratios in rocks and minerals resulting from radioactive decay have been used to image the new mantle input and reworking of crustal components and constraint the timing and source of geological events that shape the present Yilgarn Craton. In this study, we present a large Hafnium (Hf) isotopic (246 samples) and Neodymium (Nd) isotopic (517 samples) dataset on zircon and apply it to constrain the evolution of the craton. By using the datasets, we would like to propose an alternative to interpolate the isotope and geochemical datasets from Yilgarn Craton to map the evolution of crust through space and time. For this purpose, we use Kriging, one of the geostatistical methods that uses stochastic models of spatial variation. The samples are grouped and interpolated at three different time – slices, 2.9, 2.76 and 2.6 Ga which represent the major tectonic event in Yilgarn Craton. For each time – slice, we generate three different variogram models to show the spatial dependence degree among samples within the determined area. From this variogram models, we map the Hf and Nd values at each time – slice together with the prediction error maps. Both the Hf and Nd maps show different block of juvenile and reworked crust intermingle with each other either adjacent or enclosed within. The Kriging approach can generate a measure of error or uncertainty thus can avoid misinterpretation on the results. Therefore, this study can help to delineate the juvenile vs reworked crustal block boundaries with high level of confidence and help to understand the architectural control that is responsible for the magma and fluid pathway which contribute to the deposition of minerals in Yilgarn Craton.

The survival of complex Cr-zoning from pyroxene through transformation into amphibole

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Complex chromium and titanium zoning within pyroxene has been suggested as a prospectivity indicator for magmatic sulfide deposits. The complex chemical history, recorded within these pyroxene grains, is interpreted to mark crystallization in a conduit style system, which are preferable for magmatic sulfide mineralization. Thus far, the zoning's usefulness as an indicator has been tested in the binary cases where it was observed within mineralised intrusions (proximal to the mineralisation) and not observed in barren intrusions. If pyroxene zoning patterns are to be a useful and reliable indicator for magmatic sulfide prospectivity, it is important understand how these zoning patterns are affected by alteration to amphiboles, which is a very common process in these long-lived igneous systems.

We examined the Kevitsa deposit from Finland in detail. This deposit consists entirely of disseminated sulfides with widely varying Ni, Cu and PGE tenors, hosted within a mafic-ultramafic intrusion that has significant alteration of the pyroxenite to amphibolite. The clinopyroxene was found to have complex zonation in Cr and Ti. During post-cumulus cooling, spinel exsolves from the pyroxene. Then, during retrograde hydration to amphibole, the pyroxene undergoes patchy replacement, with preference along the (010) face in clinopyroxene and the (100) face in orthopyroxene. The abrupt primary zoning in the pyroxene is preserved as collection of spinel rich regions in the core of the amphibole.

This study shows that, in the case of Kevitsa, the primary Cr zonation in pyroxene can be observed through the alteration to amphibole due to the exsolution of spinel. This strengthens to use of Cr zoning in pyroxene as a practical indicator of conduits style systems which therefore indicates a favourable environment for magmatic sulfide formation.

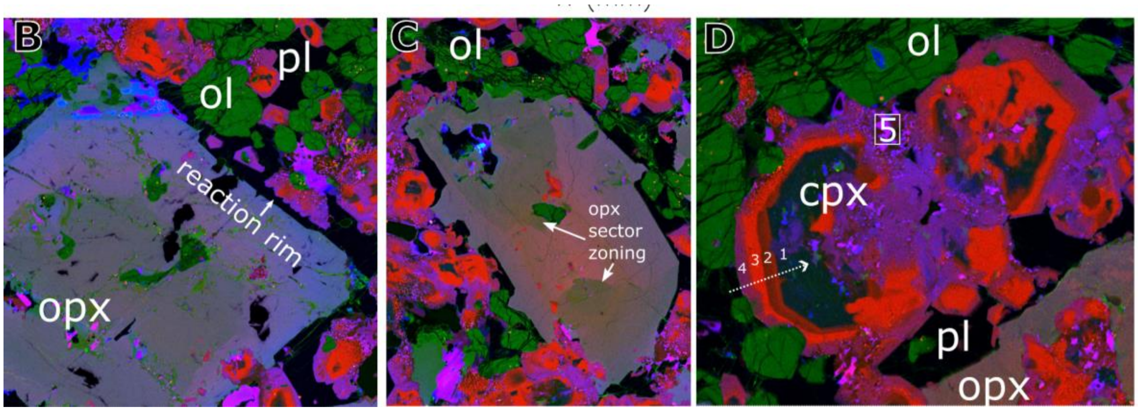

Figure 1: "False Ore" sample i.e sample with high sulfide content with low levels of Ni-Cu and PGE. This sample displays complex zoning of Cr content in clinopyroxene and some alteration to amphibole.

MAGMA CHAMBERS DO EXIST: THE EXAMPLE OF THE MOUNT DROMEDARY MONZONITE COMPLEX

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The concept of magma chambers in which intermediate and felsic magma compositions are generated by removal of early formed crystals is a founding principal of igneous petrology. In recent times models of magma mingling, crystal addition and crustal anatexis in crustal mush zones have largely replaced this traditional concept. However, there are examples of igneous intrusions where the traditional magma chamber models work as the best explanation for an observed association of rock types, one such is the Mount Dromedary monzonite complex.
The Mount Dromedary monzonite complex is a group of small plutons of Cretaceous age intruding lower Paleozoic sediments in southeastern NSW. Rock compositions range from pyroxenite to quartz syenite defining both silica under-saturated and over-saturated lineages. Several plutons show nested systematic compositional zoning that is modelled as the result of side wall crystallization in an essentially static magma chamber at relatively shallow crustal levels. Together these provide evidence for the existence of magma chambers in the conventional sense and for processes that are essentially static crystallization differentiation.
The monzonite igneous association observed at Mount Dromedary differs from the more common granitoid batholiths of eastern Australia in that it is generated by fractional crystallization in shallow magma chambers from mafic magma that is ultimately derived from hydrated upper mantle. Similar rock associations are known from Tertiary and Archean terrains where they are apparently linked to convergent plate tectonic environments.

The depositional window and palaeoenvironment of the economic Proterozoic Glyde Package, greater McArthur Basin, northern Australia

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The greater McArthur Basin is an informal term for a Proterozoic sedimentary system in northern Australia which consists of terranes from the McArthur Basin, Birrindudu Basin, and the Tomkinson Province. These distal basins were interpreted to connect within the subsurface based on geophysical, lithological, and geochronological evidence. Sedimentary units of the greater McArthur Basin were subdivided into depositional 'packages' bounded by unconformities. These packages are called the: Redbank, Goyder, Glyde, Favenc, and Wilton Packages. The ca. 1660–1610 Ma Glyde Package is the focus of this study and hosts the economically important Barney Creek Formation. It holds the world-class, sediment-hosted, Zn-Pb-Ag McArthur River deposit which forms a large part of the Carpentaria Zinc Belt. Notably, the Barney Creek Formation is also a highly prospective hydrocarbon play, and is a key section of the McArthur Petroleum Supersystem. Consequently, identifying similar-aged units and reconstructing their palaeoenvironment would be critical for explorers finding analogous targets elsewhere in the region.

In situ Rb–Sr dating of Barney Creek Formation shales from borehole LV09001 in the McArthur Basin yielded ages of 1634 ± 59 Ma and 1635 ± 67 Ma. On the other hand, Fraynes Formation shales from borehole Manbulloo S1 in the Birrindudu Basin were analysed with the same method and gave ages of 1630 ± 57 Ma and 1636 ± 42 Ma, directly correlating the two spatially distant formations. Similar patterns in $\delta^{13}C_{carb}$, $^{87}Sr/^{86}Sr$, and $\delta^{88/86}Sr$ isotopic signatures from carbonate lithologies further suggests that the Barney Creek Formation and the Fraynes Formation are contemporaneous units. This includes a $\delta^{13}C_{carb}$ excursion of ~+2.0 ‰, a trend towards lower $^{87}Sr/^{86}Sr$ ratios up-section, and a $\delta^{88/86}Sr$ excursion of ~-2.5 ‰ (relative to NIST987). These proxies indicates that the Glyde Package palaeoenvironment became progressively less restricted, and eventually connected to the open ocean, with increasing carbonate deposition.

THE ELEMENTS FOR AN ORIGIN OF LIFE ON LAND: EVIDENCE FROM THE PILBARA CRATON, AUSTRALIA AND IMPLICATIONS FOR THE SEARCH OF LIFE ON MARS

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For decades, deep sea hydrothermal vents have been a preferred setting for the Origin of Life, but ''The Water Problem'' relating to organic molecule polymerization, the diluting propensity and salty nature of oceans, along with other crucial factors suggest that a terrestrial hot spring field with the capacity for wet–dry cycling and element concentration may represent a more likely setting. Here, results from a decades-long research program of the 3.5 billion-year-old Dresser Formation, Pilbara Craton (Australia), show that hydrothermal veins and terrestrial hot spring pools in this ancient system concentrated all of the essential elements required for prebiotic chemistry (including B, Zn, Mn, and K, in addition to C, H, N, O, P, and S).

Translated to early Earth, wet–dry cycling across a range of temporal scales, differential elemental concentration, and information exchange between multiple, geochemically-distinct, springs would lead to "innovation pools" in which complex organic molecules, lipid vesicles, and the systems chemistry required to get life started would develop. Adaptation of life to the salty oceans came later.

An inference of this developing paradigm is that hot spring deposits could be the best target to search for a second genesis on Mars. This is because hot spring deposits represent the "first and last outposts" of primitive life and preserve textural and molecular evidence for life back for 3.5 billion years on Earth.

Nodular hot spring silica sinter deposits with digitate protrusions discovered by the Spirit Rover at Columbia Hills, Mars, are morphologically analogues to hot spring deposits from El Tatio, Chile, where the digitate protrusions relate to microbial activity, raising the possibility that we may have observed a potential biosignature on Mars. The Columbia Hills deposits therefore represent a tantalizing astrobiological target and form the basis of a new sample return Mars mission.

Paleogeographic controls on granitoid chemistry reveal the Mesoarchean diversification of tectonomagmatic regimes

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Plate tectonics has not operated for all of Earth's history. The transition towards a modern-style regime has recently been placed between 3.2 and 2.7 Ga; constrained predominantly by secular changes in geochemical proxies. Whilst providing major advances to our understanding of Archean crustal evolution, these data-rich approaches tend to exclude confounding factors that may be imparted by differences in evolution timescales for various lithotectonic components of cratons. We use a large dataset of granitoid whole rock geochemistry from the Pilbara Craton to focus on the spatial and temporal evolution of geochemical signatures within each of its terranes. Contour maps showing geographical variations in key petrogenetic ratios track depth of melting (Sr/Y, Sm/Yb_{PM}), degree of source melting/fractionation (La/Sm), juvenility and differentiation (Zr/Ti) and relative fluid contribution to the source (Ba/Th). These suggest the Paleoarchean (>3.2 Ga) ancestral Pilbara was characterised by predominantly sodic magmatism associated with drips and upwellings below variably thick mafic crust in a poorly mobile lid regime. A transition to mobile lid behavior occurs at c. 3.2 Ga, coinciding with the East Pilbara Terrane Rifting Event, a change in contour map patterns, and the onset of tectonomagmatic diversification within the craton. Diversification during the Mesoarchean Era consists of variably hydrated sodic magmatism produced at varying depths by episodic asymmetric downwellings in "dripduction" zones, hydrated sanukitoid magmatism produced by transtension-driven melting of metasomatized lithospheric mantle, and potassic magmatism generated by large-scale reworking of pre-existing Paleoarchean felsic crust. Our results indicate the Pilbara experienced tectonomagmatic diversification earlier than most cratons, which clearly demonstrates that the development of a single craton cannot be elucidated solely by compiled data and that associated mobile lid features within individual cratons do not necessarily reflect a global transition towards plate tectonics.

CONSTRAINING THE TIME-STRAIN EVOLUTION OF SHEAR ZONES: INSIGHTS FROM MUSCOVITE TEXTURAL AND ISOTOPIC ANALYSIS

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Although accessory minerals may record the thermal response to mylonitization on isotopes, it fails to track the time of low- to medium temperature fabric reorganization. New methods allowing the high spatial resolution measurement of isotopic ratios in distinct fabric-forming minerals may assist in characterizing the time-strain evolution of mid-crustal shear zones. In order to test this hypothesis, we present high-resolution backscattering diffraction (EBSD), mineral chemistry, and in situ Rb–Sr ages from two distinct muscovite textures in a mid- to upper-greenschist facies granitic mylonite from Top Up Rise, Western Australia. The results indicate that coarse-grained muscovite fish retain a primary magmatic composition, displaying typical microstructures of mechanical (kink and folds) and low-strain crystal-plastic deformation. The muscovite fish yield an age of 1694 ± 54 Ma, indistinguishable from metamorphic garnet Lu–Hf ages in adjacent metapelites (1696 ± 43 Ma and 1670 ± 36 Ma). Conversely, fine-grained muscovite from higher strain shear bands is chemically distinct (related to secondary muscovite growth under fluid influence) presenting microstructural evidence of fluid-assisted dynamic recrystallization and yield a significantly younger age of 609 ± 13 Ma. The Rb–Sr ages from muscovite fish are indistinguishable from regional metamorphic ages and they cannot be unambiguously linked to mylonitization. In turn, the muscovite fish are inferred to have been isotopically reset via thermally activated volume diffusion in response to regional Paleoproterozoic upper amphibolite to low granulite facies metamorphism. This primary muscovite behaved as rigid porphyroclasts during subsequent medium-grade mylonitization, leading to the development of a fish geometry whilst maintaining the Rb–Sr isotopic system intact. However, recrystallized fine-grained muscovite were isotopically reset during medium-grade mylonitization, establishing a direct time–strain relationship. These results highlight the potential for significant diachronicity in mylonitic fabrics, demonstrating the need to establish direct time-strain relationships in order to accurately reconstruct deformation histories.

Facies analysis and multiproxy geochemistry of Tonian to Cryogenian succession in Adelaide Rift Complex, South Australia

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The Neoproterozoic (~1000 to 538 Ma) was one of the most dynamic eras in Earth history and is marked by significant tectonic, biological, atmospheric, and climatic events. These global shifts facilitated the development of a suite of depositional settings under vastly contrasting conditions, from warm shallow carbonate-rich seas to cold, ice-covered continents. The Adelaide Rift Complex in South Australia (SA), preserves thick successions of these Neoproterozoic sedimentary rocks, recording the variability of environments and their respective geochemistry through time.

This study presents a high resolution palaeoenvironmental interpretations from a ~3 km Tonian–Cryogenian succession in the northern Flinders Ranges, SA. Sedimentological analyses record multiple regressive-transgressive cycles in deltaic rippled and cross stratified sandstones; platform intraclastic magnesite, stromatolitic carbonate and subtidal siltstone; and glaciomarine pebbly diamictites, massive sands and turbiditic mudstone with dropstones. Geochemical analyses reveal the fluctuation between restricted to semi-restricted, and dysoxic to suboxic shallow water chemistries, facilitated by the mixing of fresh water and shallow and deep marine waters.

The preglacial succession is represented by the Copley Quartzite, Skillogalee Dolomite, and Myrtle Springs Formation. Carbonate samples indicate low Y/Ho, slight light rare earth element (LREE) depletion, weak negative Ce/Ce* and high Eu/Eu*. Furthermore, δ13C and 87Sr/86Sr demonstrate an inverse trend through time (7.37‰-(-6.68‰) and (0.7088-0.7182, respectively), accompanied by light δ88Sr values (≤0.211‰). This elemental and isotopic data suggests a shift from semi-restricted dysoxic waters in the Skillogalee Dolomite, to a more restricted, continentally sourced setting during deposition of the Myrtle Springs Formation. REE values from carbonate samples in the postglacial Tapley Hill Formation record a geochemical pivot to more open, oxic to suboxic conditions. This is reflected by increased Y/Ho, moderate LREE depletion, slight negative Ce/Ce* and low Eu/Eu*. Our multifaceted approach provides a comprehensive framework for the sedimentological and geochemical control on depositional environment during a critical and unique time in Earth's past.

SULFUR ISOTOPIC VARIABILITY AND PD CONTENT OF PENTLANDITE IN THE MKD5 KOMATIITE-HOSTED NI-CO-CU SULFIDE DEPOSIT, MOUNT KEITH, WESTERN AUSTRALIA

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Komatiites require external sulfur from country rocks to generate immiscible sulfide liquid, which concentrates metals to form economic nickel sulfide deposits. Although signatures related to mass-independent fractionation of S isotopes (MIF-S, denoted as Δ33S) may identify external S sources, their values may not be directly indicative of the S reservoirs that were tapped during the ore forming process, because of dilution by S exchange between assimilated sulfide xenomelt and komatiite silicate melt. To quantify this process and be confident that MIF-S can be effectively used to track S sources in magmatic systems, we investigated the effect of silicate melt-sulfide liquid equilibration, using the proxy of silicate/sulfide mass ratio or R factor, on the resulting MIF-S signatures of pentlandite-rich ore from the Mount Keith MKD5 nickel sulfide deposit, Agnew-Wiluna Greenstone Belt, Western Australia. We carried out in-situ multiple S isotope and PGE analyses on pentlandite from a well characterized drill core through the deposit. The variability in Pd tenor and MIF-S signature suggests that the latter is not controlled by metal-derived R factor. Rather, the observed spread of MIF-S signatures implies that the sulfide xenomelt was initially heterogeneous and that S isotopic composition did not fully equilibrate. It is proposed that chemical equilibration of S isotopes is incomplete as opposed to that of platinum group elements in a komatiite melt. Even in the hottest, most dynamic, and likely fastest equilibrating magmatic systems on Earth, xenomelt sulfides may still preserve to some extent their initial S isotopic compositions, reflecting the range of crustal S reservoirs that were available upon komatiite emplacement.

The elusive trace element pattern in arc lava – New clues from Sn isotopes

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Arc lavas are distinct from mid-ocean ridge basalts (MORB) or intraplate volcanoes through elevated oxidation state, distinct enrichment in magmatic water content, and unique enrichment in some trace elements. These critical aspects of arc lavas are plausibly related to fluids derived from the downgoing slab. The salinity of these fluids (5-10 wt% NaCl) and the high oxidation of arc lavas are key factors for the elements transport but remain a great unknown.

Tin is uniquely sensitive to oxidation state and salinity, and has unusually large spectrum of isotopes. Thus, Sn isotopes have the potential to resolve trace element mobility in deep fluid of supra-subduction zone. Generally, salinity in fluids enhances the mobility of Sn, and the geochemical behavior of tetravalent Sn^{4+} and divalent Sn^{2+}, including respective mobilities in deep fluids, are very different. Sn^{4+} is preferentially transported in oxidized fluid and enriched in heavier isotopes, as opposed to reduced and isotopically lighter Sn^{2+}. Since isotope fractionation occurs between Sn^{4+} and Sn^{2+} at temperatures relevant to arc magmatism, distinctive Sn isotope fingerprint bears memory of these deep processes in erupting lavas.

A great number of arc rock samples including basalts and basaltic andesites had been collected from a systematic arc lava series on the islands of the Sunda and Banda arc, Indonesian. Previous investigations on these samples suggested that they were significantly affected by subducted continental sediment or crust, and are enriched in some trace elements, including Sn. In this study, Sn isotope compositions in these arc rocks are determined using a ^{117}Sn-^{122}Sn double spike technique on the Neptune Plus MC-ICPMS. This novel proxy will be applied to the unresolved issue of elusive trace elements enrichment in arc lavas.

SYENITIC INTRUSIONS WITH ASSOCIATED GOLD: THE SEARCH FOR FERTILITY CRITERIA

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Globally, gold deposits hosted by and/or associated with alkalic intrusions represent an important subclass of gold mineralisation, ranging from Archean to Cenozoic in age (e.g. Grasberg, Dongping, Cadia, Canadian Malartic). In the Archean Kurnalpi Terrane, Yilgarn Craton, many syenitic intrusive centres have been documented but only Wallaby and Carosue Dam are associated with economic gold mineralisation. These belong to the Wallaby and Mt Monger supersuites, respectively, of the Syenitic Group, and porphyry textures indicate a shallow crustal level of intrusion.

At Wallaby, hydrothermally altered monzonite contains no igneous minerals, except rare relict augite. Augite is absent in syenitic intrusions at Karari (Carosue Dam), but the intrusions are pervasively altered, with <5vol% of relict igneous minerals. These are not general features of alkalic intrusions in the Kurnalpi Terrane. Low Cl/OH ratios in relict igneous apatite from Karari suggest that early vapour saturation in the Karari magmas may account for the widespread modification of igneous mineralogy.

Whole-rock compositions of alkalic intrusive rocks at Wallaby and Karari do not plot in the global field of mineralised intrusions, based on immobile elements. They have low SiO_2 compared to other members of the Syenitic Group and are among the most potassic of the Syenitic Group, defined by high K_2O/Al_2O_3 and K_2O/Na_2O. The highly potassic compositions probably result from hydrothermal biotite alteration. The Karari and some Wallaby intrusions plot as sub-alkalic on a Ti/Zr versus Nb/Y diagram, in apparent contradiction of petrographic and major element characteristics. Hydrothermal alteration of igneous titanite to rutile has the capacity to mobilise Nb, potentially accounting for mis-classification as subalkalic.

The search for fertility criteria for alkali intrusions in the Kurnalpi Terrane is ongoing but initial results suggest the following: i) pervasive hydrothermal modification of igneous mineralogy, ii) low Cl/OH of igneous apatite, iii) high K_2O/Al_2O_3 and K_2O/Na_2O, and iv) misclassification as subalkalic on a Ti/Zr versus Nb/Y discrimination diagram.

In-situ S isotopes and Rb–Sr dating of the Cu mineralisation and regolith at Kapunda, SA.

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Kapunda is located 90 km north of Adelaide, South Australia, and is the oldest commercial copper mine in Australia, with insitu weathered regolith reaching depths of up to 100 metres. The mineralisation at Kapunda sits within Neoproterozoic interglacial sediments of the Tapley Hill Formation. This sediment-hosted deposit formed through metal-rich saline groundwaters inundating the carbonaceous siltstone host-rocks of the Tapley Hill Formation, this process, coupled with meteoric influences producing a Cu rich supergene environment. The timing of these mineralisation events remains uncertain. Previously published data from Kapunda display 'super-heavy' sulphides with $\delta^{34}S$ signatures of up to 40‰ in both syn-sedimentary and vein sulphides. These 'super-heavy' sedimentary pyrite values fall within global reported values of $\delta^{34}S$ between the Sturtian and Marinoan glaciations (ca. 715–650 Ma). Novel laser-based isotope techniques on sulphides and sedimentary rocks provide the ability to observe diagenetic redox conditions, fluid sources and weathering alteration of mineralisation through interrogation of coupled S and Rb–Sr dating. This study reports new S isotopes analyses of pyrite and chalcopyrite using in-situ LA-ICP-MS/MS from a range of local weathered regolith and unweathered sediments of the Tapley Hill Formation. Within these super-heavy pyrites an inter-mineral difference in $\delta^{34}S$ of approximately 10‰ is observed between chalcopyrite and pyrite but only in the saprolite of the insitu weathered regolith profile. New ages for Kapunda's mineralisation were constrained by novel in-situ Rb–Sr dating of illite and feldspars associated with sulphide veins, and results show that the pyrite and chalcopyrite were likely precipitated in the time interval between ca. 520–480 Ma, thus coinciding with the Delamerian Orogeny. Overall, this study highlights the usefulness of coupled S and Rb-Sr isotope systems to extract both age and origins of sulphide mineralisation at Kapunda.

The MEX beamlines at the Australian Synchrotron

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The Medium Energy X-Ray Absorption Spectroscopy (MEX) Beamlines have been constructed and commissioned as part of the ANSTO Australian Synchrotron BRIGHT program of new beamline delivery. MEX comprises two beamlines designed to offer high quality XAS measurements of routine, bulk samples with MEX1 covering edges between 3.5 and 13.6 keV, with MEX2 covering the energy range 1.7 to 3.5 keV. To compliment the existing XAS beamline, MEX has been designed to provide a large (up to 1 mm V x 5 mm H), relatively low flux-density beam to facilitate the measurement of beam sensitive samples.

In addition to routine bulk XAFS measurements, MEX1 incorporates a high-resolution Johann-geometry crystal spectrometer based on proven ESRF design. MEX1 further incorporates a microprobe capable of collecting spectroscopic quality data for elements from S to Se, at a spot size down to 2 micron. MEX2 will be equipped with a dispersive Rowland refocussing geometry detector, providing high-resolution spectroscopy at the P, S and Cl K-edges.

Beamline construction commenced in March 2021 with the radiation shielding enclosures; the installation of the photon delivery system in July 2022, followed by user cabins and monochromator installation. First light at MEX1 was achieved in July 2022, and hot commissioning has been underway ever since. First light at MEX2 is planned for Q4 2022. First merit user experiments at MEX1 are scheduled for November 2022, and MEX2 in April 2023. Both beamlines will gradually ramp-up beamline capability offered to users over the subsequent year.

The presentation will include a review of the current status of the beamlines, present results collected during commissioning, and review scientific possibilities for the geochemistry community.

Petrogenesis of carbonatites

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In this talk I will review current ideas about the petrogenesis of carbonatite systems. Carbonatites are mostly plutonic igneous rocks. They consist mainly of carbonate minerals such as calcite, dolomite and ankerite, as well as minor but economically important phosphates, oxides, and silicates. They are emplaced into the crust in continental intraplate settings such as cratonic interiors and margins, as well as rift zones, and very rarely on oceanic islands.

Plutonic carbonatites on the Earth do not represent parental or any other liquid compositions. They are cumulate rocks, formed when phases that crystallized from a carbonate-rich melt physically separated and accumulated. Their parental melts formed either by

1. direct partial melting of carbonate-bearing, metasomatized, lithospheric mantle producing alkali-bearing calcio dolomitic melts, or by
2. silicate-carbonate liquid immiscibility in the deep crust after fractional crystallization of carbonate-bearing, silica-undersaturated magmas such as nephelinites, melilitites, or phonolites, forming alkali calcio carbonatite liquids.

Emplacement of carbonatites into the crust is usually accompanied by fenitization, alkali metasomatism of wall rock caused by fluids expelled from the crystallizing carbonatite.

The evolved melts, complementary to the cumulate component, may be represented on the modern Earth by the only currently active carbonatite volcano, Oldoinyo Lengai, in Tanzania. This remarkable and unique volcano has erupted natro carbonatite in recent times. It has generally been considered an anomaly, as its erupted melt compositions contrast completely with all known plutonic carbonatites. This confusion has been compounded by a long-held view based on early experimental studies, that no liquid line of descent exists in Na_2CO_3-K_2CO_3-$CaCO_3$ systems by which parental alkali-calcio carbonatites could evolve to natro carbonatites similar to those erupted at Oldoinyo Lengai. However, more recent experimental studies have challenged this view with the result that Oldoinyo Lengai may not be anomalous at all and may represent the complementary evolved liquid to plutonic cumulate carbonatites, which is generally not preserved in the ancient geological record due to its instability in surficial environments or loss during fenetization.

New constraints on the origin and post-depositional history of Neoproterozoic Breamar ironstones (SA): Insights from core logging, micro-scale mineral mapping and in-situ Rb-Sr dating

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The Braemar Iron Formation is located in the Yunta-Olary region in South Australia, ca. 400km north-east of Adelaide, and is one of the largest undeveloped Neoproterozoic ironstone formations in the world. The Braemar Iron Formation was deposited during the Sturtian cryochron (717 Ma–660 Ma, Rooney et al. 2015). However, unlike the relatively less altered but coeval Holowiliena ironstone facies in the Flinders Ranges, which are composed mostly of hematite (Lechte & Wallace 2015), the Braemar Iron Formation is made of magnetite. Here we present new in-situ LA-ICP-MS/MS Rb–Sr results from illite that yielded ages ranging from ~450 ± 3.8 Ma to 475 Ma ± 2.4 Ma demonstrating that they were recrystalised/metamorphosed in the Ordovician, similar to late Delamerian deformation reported by Hong et al. (in review). However, the diagenetic and metamorphic history of Braemar Iron Formation and Neoproterozoic Iron Formations (NIF), in general, are complex and still poorly understood. From previous research, one possible depositional model of NIF argues for iron to be deposited in the glaciomarine environment under an ice shelf (Lechte et al. 2019). Under this scenario, the mixing of oxygenated water derived from a melted ice shelf and 'sea ice brines' interacted with deeper ferruginous seawater, resulting in the oxidation of iron and NIF deposition. Future work done as part of this project will employ redox-sensitive metal isotope and REE, coupled with oxygen isotopes, to further test these scenarios, and results from 'pristine' or less altered Holowiliena ironstones will be compared to more recrystalised or metamorphosed Braemar ironstones, to assess the effect of secondary process on ages, metal isotopes and iron enrichments.

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A NEW APPROACH TO GEOCHRONOLOGY IN VERY FINE-GRAINED SEDIMENTS

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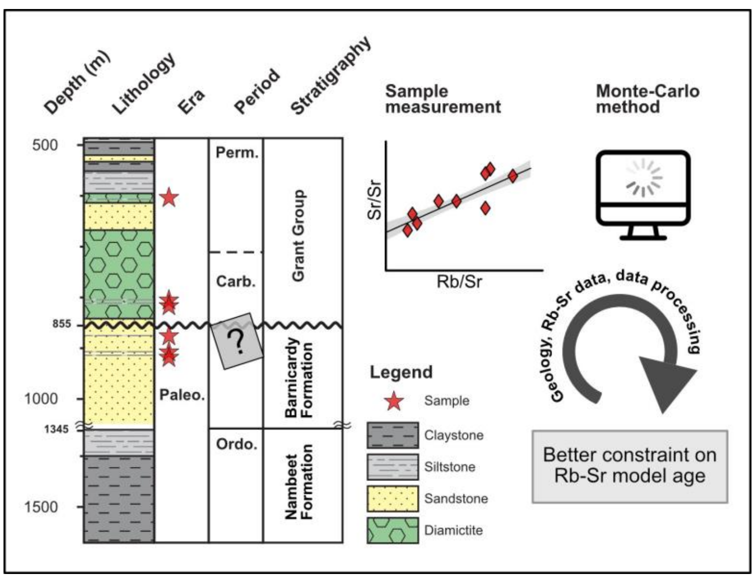
Shales represent a quarter of all sedimentary rocks exposed today, store provenance information and clay minerals in the shales potentially retain greater detail on more distal detritus relative to other conventional provenance indicators (e.g. zircon). Geochronology in sedimentary samples may provide age constraints on deposition or provenance depending on whether authigenic or detrital components are measured. New laser ablation mass spectrometer technology, which allows in-situ Rb-Sr dating, offers several potentially significant advances in the geochronology of certain clay group minerals in particular. However, dating shales is challenged by the inevitable mixing of potentially different generations of Rb bearing minerals within the volume of a laser spot (~90,000 μm^3). Rb-rich phases dominate the isotopic budget of any mixture and may help to constrain age components within the shale. In this study, we present in-situ Rb-Sr data of six variably biostratigraphically constrained Paleozoic shale samples from the Barnicardy-1 drill core (Canning Basin, Western Australia). We develop a new Monte-Carlo modelling approach to improve the constraint on Rb-Sr ages by confining the range of initial Sr-ratios from analysed mixtures via apriori knowledge of the stratigraphy. These findings address the provenance of the shale and help refine stratigraphy of the Barnicardy-1 well.



Sketch shows the approach to improve Rb-Sr model age constraints of mixed Rb-rich phases, using information of geology, measured and modelled data. Such an approach may refine the stratigraphy and yield depositional age or provenance information ("?").

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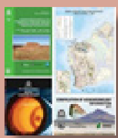

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