SGTSG Armidale 2024

Tectonics on the Tablelands

S*pecialist* **G***roup*
T*ectonics and* **S***tructural* **G***eology*

Geological Society of Australia
18–22 November 2024, Armidale, NSW

Abstract Volume

The University of New England respects and acknowledges that its people, courses, and facilities are built on land, and surrounded by a sense of belonging, both ancient and contemporary, of the world's oldest living culture. In doing so, UNE values and respects Indigenous knowledge systems as a vital part of the knowledge capital of Australia.

We recognise the strength, resilience and capacity of the Aboriginal community, particularly the Anaiwan nation, and pay our respects to the Elders past, present and future.

SGTSG 2023-2024 Committee

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Talks By Day

Monday 18 November 2024

09:00 – 09:15	Welcome
09:15 – 09:30	**Rosenbaum et al.** *Formation of domes and basins by syn-deformational granite emplacement*
09:30 – 09:45	**Zhang et al.** *Magmatic Record of Carboniferous Slab Rollback Along the Australian Tasmanides of Eastern Gondwana*
09:45 – 10:00	**Mahoney et al.** *Crustal architecture and geological evolution of the Central Lachlan Orogen: Insights from new deep crustal seismic imaging of the Yathong-Cobar-Hermidale region, NSW*
10:00 – 10:15	**Henderson** & Fergusson *Detrital zircon ages conflict with an island arc interpretation for older (Silurian-Devonian) rock assemblages of the New England Orogen*
10:15 – 10:30	**Milan et al.** *Reconstructing a cryptic Cambro - Ordovician arc record in the Tasmanides of Eastern Australia*
10:30 – 11:00	*Coffee / Tea Break*
11:00 – 11:30	**Vitale-Brovarone et al.** *Extreme energy from the deep, at convergent margins* (Keynote)
11:30 – 11:45	**Halpin et al.** *Ediacaran-Cambrian high-strain melt-present deformation during gravitational spreading of the ancestral East Antarctic mountains*
11:45 – 12:00	**Musgrave** & Rosenbaum *Can soft collision lead to plate tectonic reorganisation? Revisiting the Ontong Java Plateau paradox*
12:00 – 12:15	**Noorian et al.** *Nitrogen isotope variations in the Mesoproterozoic organic-rich shales (the Velkerri Formation) in Beetaloo Sub-basin, McArthur Basin, north Australia*
12:15 – 12:30	**Collins et al.** *Geological constraints on Proterozoic mountains – reconstructing the largest mountain range of the last billion years*
12:30 – 13:30	*Lunch Break*
13:30 – 14:00	**Wang et al.** *P–T–fluid–deformation evolution of UHP eclogites, Sulu belt, China and implications for exhumation dynamics* (Keynote)
14:00 – 14:15	**Mulder et al.** *Inherited zircon mining refines Cambrian orogenic architecture of southeast Australia*
14:15 – 14:30	**Rodrigues et al.** *Refolding an Orogen: the case of Mossman orogenic curvature in NE Australia*
14:30 – 14:45	**Fergusson et al.** *Late Cenozoic uplift associated with the Lapstone Structural Complex in eastern NSW*
14:45 – 15:00	**Singh et al.** *Topographic Evolution of Active Margins: Exploring the Interplay of Plate Tectonics, Mantle Convection, and Long-Term Climate using Explainable Artificial Intelligence*
15:00 – 15:30	*Coffee / Tea Break*
15:30 – 15:45	**Seton et al.** *The tectonic and volcanic history of Northern Zealandia*
15:45 – 16:00	**Carey et al.** *Cretaceous Basement Rock Dredges from the Louisade Plateau*
16:00 – 16:15	**Keep et al.** *A brief history of the northern Australian margin: from basement inheritance to modern seismology (and a few mass transport deposits)*
16:15 – 16:30	**Zahirovic et al.** *Global ophiolite, large igneous province, and orogenic reconstructions and the implications for deep-time climate and planetary carbon cycling*
16:30 – 16:45	**Rodriguez Corcho et al.** *The tectonic evolution of the western North American margin since the Devonian*
16:45 – 17:00	**Singh et al.** *Topographic Evolution of Active Margins: Exploring the Interplay of Plate Tectonics, Mantle Convection, and Long-Term Climate using Explainable Artificial Intelligence*

Tuesday 19 November 2024

09:00 – 09:15	**Hobbs** & Ord *Non-Andersonian faults, fractures and veins*
09:15 – 09:30	**Ord** & Hobbs *Automatic quantitative analysis and classification of spatial patterns (fabrics)*
09:30 – 09:45	**Finch et al.** *Porosity changes in shear zones during tectonic switching*
09:45 – 10:00	**Olesch-Byrne et al.** *Deformation mechanisms in a shear zone ore fluid conduit*
10:00 – 10:15	**Wilson** & Peternell *Origin of textures in quartz veins: insights from 2D in situ ice experiments*
10:15 – 10:30	**Singh et al.** *Moving to 3D: Constraints on Shape Fabric and Strain in mantle rocks*
10:30 – 11:00	*Coffee / Tea Break*
11:00 – 11:30	**Piazolo et al.** *Signatures of changing deformation rate dynamics in deforming rocks: Examples from the exhumed Slow Earthquake Zone of New Caledonia* (Keynote)
11:30 – 11:45	**Green** & Powell *Phase equilibrium modelling: a frosted window onto geological processes*
11:45 – 12:00	**Volante et al.** *Oxygen isotope shifts during continental anatexis: fingerprints of fluid-fluxed melting*
12:00 – 12:15	**Spier et al.** *U-Pb apatite and zircon ages of dolerite from the Baryulgil Serpentinite, NSW: Insights into the emplacement age of the ultramafic massif*
12:15 – 12:30	**Mayer-Ullman et al.** *Thermal history of the East Antarctic margin recorded in apatite: Campaign-style Lu-Hf, U-Pb, fission track and U-Th-Sm/He results*
12:30 – 13:30	*Lunch Break*
13:30 – 14:00	**Langone et al.** *Reactive and resilient: the behaviour of geochronometers during deformation* (Keynote)
14:00 – 14:15	**Ribeiro** & Kirkland *Challenging the garnet chemical-isotopic reliability under high-temperature deformation*
14:15 – 14:30	**Murphy et al.** *In-situ Lu-Hf dating of garnet: a novel new tool for granulite geochronology*
14:30 – 14:45	**Fitzherbert et al.** *Timing post-peak reactivation episodes in the Broken Hill Block using allanite (and friends) in a shear-hosted REE-IOCG deposit*
14:45 – 15:00	**Durney** *Hypothesis-related systematic uncertainty in radiometric dating of deformation: some cases, arguments and alternative strategies*
15:00 – 15:30	*Coffee / Tea Break*
15:30 – 15:45	**Whittaker et al.** *The Balleny Seamount Trail – A Weak but Persistent Deep Plume*
15:45 – 16:00	**Roy et al.** *Change in the basalt normative mineralogy in deep-time, and possible petrogenetic relations*
16:00 – 16:15	**Kamber** *New insight into the effects of trans-lithospheric magma transfer on the petrology and geochemistry of the lithospheric mantle, lower continental crust and volcanic products*
16:15 – 16:30	**Rodrigues et al.** *Peridotite - komatiite interaction and the origin of orthopyroxene-rich cratonic mantle lithosphere*
16:30 – 16:45	**Tailby** & Chapman *Defrosting the Cowra crystal mush*
17:00 – 19:00	*Posters*

Thursday 21 November 2024

09:00 – 09:15	**Capitanio et al.** *Ishtar Terra highlands on Venus raised by craton-like formation mechanisms*
09:15 – 09:30	**Asimus et al.** *Microcontinents formed during a messy breakup between India and Antarctica*
09:30 – 09:45	**Merdith et al.** *Solid-Earth controls on Phanerozoic icehouses*
09:45 – 10:00	**Williams et al.** *Magnetization of oceanic lithosphere from modelling of satellite observations*
10:00 – 10:15	**Chukwu et al.** *Crustal structure and role of inheritance in the evolution of southeast Australia's triple junction*
10:15 – 10:30	**Zoleikhaei et al.** *A non-arc setting for "Cadomian" magmatism in Iran and Anatolia*
10:30 – 11:00	*Coffee / Tea Break*
11:00 – 11:15	**Evans et al.** *The origin of platinum group minerals in ophiolites, and implications for the Re–Os geochronometer*
11:15 – 11:30	**Babaahmadi** & Saha *Bedding-Parallel Shears in the Upper Permian Coal measures, Bowen Basin, Central Queensland*
11:30 – 11:45	**Gessner et al.** *A rift–transform origin for the East Pilbara Terrane*
11:45 – 12:00	**Zibra et al.** *More than 2 billion years of shearing along the western margin of the Yilgarn Craton (Western Australia)*
12:00 – 12:15	**Rey et al.** *Archean dual geodynamics underneath weak, flat, and flooded continents*
12:15 – 12:30	**Hayman** & Senyah *Reconstruction of a Paleoproterozic Greenstone Belt and comparative study to Late Archean Greenstone Belts*
12:30 – 13:30	*Lunch Break*
13:30 – 13:45	**Betts et al.** *From continental rifting to seafloor spreading. Controversies and insights from the Red Sea*
13:45 – 14:00	**Abdullah** & Pawley *The effect of the original tectonic grain on structural evolution during poly-phase deformation: an example from Mount Woods Domain, Gawler Craton*
14:00 – 14:15	**O'Neill** *Tectonic impact of the boring billion*
14:15 – 14:30	**Armistead et al.** *Mesoproterozoic tectonic and metallogenic link between Tasmania and Laurentia revealed by multi-mineral geochronology*
14:30 – 14:45	**Parui et al.** *Structural reconstruction of the Yeneena Basin, Western Australia – a key for understanding sedimentary-hosted copper mineralization*
14:45 – 15:00	**Subarkah et al.** *The complex chronology of Cryogenian carbonates*
15:00 – 15:30	*Coffee / Tea Break*
15:30 – 15:45	**Deepak et al.** *Multiproxy Analysis of Paleoproterozoic Shales from the Limbunya Group: Insights into Paleoenvironmental Conditions*
15:45 – 16:00	**Noptalung et al.** *Geochronological constraint on the timing of magmatism and sedimentation in the Dajarra region, Mt Isa Inlier, Australia*
16:00 – 16:15	**Cruden** & Robin *Narrow shear zones within broad transpression zones: testing theory with analogue experiments*
16:15 – 16:30	**Withers et al.** *A baseline model for fault development across transpressive plate boundaries*
16:30 – 16:45	**Ozaydin et al.** *Thermomechanical modelling as a tool for decoding geophysical anomalies: A case study of strike-slip pull-apart basins*

Friday 22 November 2024

09:00 – 09:15	**Ubide et al.** *Quiet vs loud arc volcanoes. A microanalytical perspective into magmatic architecture across the Central Andes*
09:15 – 09:30	**Parra-Encalada et al.** *Plagioclase as a mineralization marker in Porphyry Copper Deposits*
09:30 – 09:45	**Ward et al.** *Slab tearing as a driver of porphyry ore deposit formation in island arcs*
09:45 – 10:00	**Yaxley et al.** *The solubility of monazite in carbonate melts – implications for monazite formation in carbonatites*
10:00 – 10:15	**Xing et al.** *REE transport in hydrothermal mineralizing systems: implications from thermodynamic models*
10:15 – 10:30	**Weller et al.** *New thermodynamic models for alkaline-silicate magmatic systems reveal fractionation at a mid-crustal tipping point primes REE-mineralised alkaline igneous rocks*
10:30 – 11:00	*Coffee / Tea Break*
11:00 – 11:15	**Slanislav** Linking magmatism to orogenic gold mineralization through zircon geochemistry
11:15 – 11:30	**Voisy et al.** *Shock Value: Gold nugget formation from earthquake-induced piezoelectricity in quartz*
11:30 – 11:45	**Olierook et al.** *Argyle pink diamonds: a story that involves a super continental break up*
11:45 – 12:00	**Centrella et al.** *Reconstructing the fluid pathways in sedimentary basin using a mass balance approach: example of the Benassal Formation, Spain*
12:00 – 12:15	**Ezad et al.** *Co-existing fenitizing fluids and carbonatite melts derived from ultramafic lamprophyres*
12:15 – 12:30	**Doucet** & Li *Large scale mantle heterogeneity: A legacy of plate tectonic supercycles*
12:30 – 13:30	*Lunch Break*
13:30 – 13:45	**Dyriw** *Managing geological complexity and practical applications: an industry-academic roadblock?*

Talks & Posters By Session

SO1	**Convergent margins and collisional tectonics** *Oral Presentations*
SO1.1	**Rosenbaum, G.**, Barrett, A., Rodrigues, R.T., Allen, C.M., Weinberg, R.F. *Formation of domes and basins by syn-deformational granite emplacement* Monday 18th, 9:15-9:30
SO1.2	**Zhang, Q.**, Buckman, S., Mitchell, R.N., Nutman, A.P., Li, X-H., Bennett, V.C., Beer, C. *Magmatic record of Carboniferous slab rollback along the Australian Tasmanides of eastern Gondwana* Monday 18th, 9:30-9:45
SO1.3	**Mahoney, L.**, Fitzherbert, J., Milz, M., Gammidge, L., Eastlake, M., Simpson, B., Davidson, J., Blevin, P. *Crustal architecture and geological evolution of the Central Lachlan Orogen: Insights from new deep crustal seismic imaging of the Yathong-Cobar-Hermidale region, NSW* Monday 18th, 9:45-10:00
SO1.4	**Henderson, R.A.**, & Fergusson, C.L. *Detrital zircon ages conflict with an island arc interpretation for older (Silurian-Devonian) rock assemblages of the New England Orogen* Monday 18th, 10:00-10:15
SO1.5	**Milan, L.**, Chapman, T., Zoleikhaei, Y., Rosenbaum, G. *Reconstructing a cryptic Cambro - Ordovician arc record in the Tasmanides of Eastern Australia* Monday 18th, 10:15-10:30
SO1.6	**Vitale Brovarone, A.**, Siron, G., Giuntoli, F., Olivieri, O.S., Ressico, F., Peverelli, V., Pastore, Z., Wong, K., Dobe, R. *Extreme energy from the deep, at convergent margins* Monday 18th, 11:00-11:30 (**Keynote**)
SO1.7	**Halpin, J.A.**, Daczko, N.R., Mulder, J.A., Maritati, A., Stål, T. *Ediacaran-Cambrian high-strain melt-present deformation during gravitational spreading of the ancestral East Antarctic mountains* Monday 18th, 11:30-11:45
SO1.8	**Musgrave, R.**, & Rosenbaum, G. *Can soft collision lead to plate tectonic reorganisation? Revisiting the Ontong Java Plateau paradox* Monday 18th, 11:45-12:00
SO1.9	**Noorian, Y.**, Farkaš, J., Collins, A.S., Delle Piane, C. *Nitrogen isotope variations in the Mesoproterozoic organic-rich shales (the Velkerri Formation) in Beetaloo Sub-basin, McArthur Basin, north Australia* Monday 18th, 12:00-12:15
SO1.10	**Collins, A.S.**, Blades, M.L., Merdith, A.S., Hasterok, D., Cameron, F., Gilbert, S., Wilson, K., Boone, S., Clark, C., Makin, S., Morrissey, L., Simpson, A. *Geological constraints on Proterozoic mountains – reconstructing the largest mountain range of the last billion years* Monday 18th, 12:15-12:30
SO1.11	**Wang, L.**, Brown, M., Johnson, T.E. *P–T–fluid–deformation evolution of UHP eclogites, Sulu belt, China and implications for exhumation dynamics* Monday 18th, 13:30-14:00 (**Keynote**)
SO1.12	**Mulder, J.A.**, Halpin, J.A., Morrissey, L.J., Zoleikhaei, Y., Meffre, S., Everard, J.L., Hall, M., Nebel, O., Cawood, P.A. *Inherited zircon mining refines Cambrian orogenic architecture of southeast Australia* Monday 18th, 14:00-14:15
SO1.13	**Rodrigues, R.T.**, Rosenbaum, G., Heaslop, R. *Refolding an orogen: the case of Mossman orogenic curvature in NE Australia* Monday 18th, 14:15-14:30
SO1.14	**Fergusson, C.**, Hatherly, P., Codilean, A.T., Cohen, T.J., Fülöp, R-H., Jansen, J.D., Wilcken, K.M., Knudsen, M.F. *Late Cenozoic uplift associated with the Lapstone Structural Complex in eastern NSW* Monday 18th, 14:30-14:45
SO1.15	**Singh, S.P.**, Seton, M., Zahirovic, S., Wright, N.M. *Topographic evolution of active margins: exploring the interplay of plate tectonics, mantle convection, and long-term climate using explainable artificial intelligence* Monday 18th, 14:45-15:00

SO1.16	**Seton, M.**, Mortimer, N., Williams, S., Mather, B. *The tectonic and volcanic history of Northern Zealandia* Monday 18th, 15:30-15:45
SO1.17	**Carey, R.**, Meffre, S., Seton, M., Duncan, B., Mortimer, N., Orth, K., Williams, S. *Cretaceous basement rock dredges from the Louisade Plateau* Monday 18th, 15:45-16:00
SO1.18	**Rodríguez Corcho, A.F.**, Zahirovic, S., Anthony, M., Tarkyth, D., Alfonso, C., Seton, M., Müller, D., Eglington, B., Tikoff, B. *The tectonic evolution of the western North American margin since the Devonian* Monday 18th, 16:30-16:45
SO1.19	**Babaahmadi, A.**, & Saha, R. *Bedding-parallel shears in the upper Permian coal measures, Bowen Basin, central Queensland* Thursday 21st, 11:15-11:30
SP1	**Convergent margins and collisional tectonics** *Poster Presentations – Tuesday 19th 5-7 pm*
SP1.1	**Zhang, Y.**, Zheng, B., Dai, J., Rosenbaum, G., Wang, J. *Tectonic evolution of the Qiangtang Basin (northern Tibet): constraints from detrital zircon geochronology*
SP1.2	**Zhang, Y.**, & Rosenbaum, G. *Episodic arc behaviour of the eastern Gondwanan margin (New England Orogen): Insights from detrital zircon geochronology*
SP1.3	**Brownlow, J.** *Texas-Coffs Harbour double orocline model, New England Orogen*
SP1.4	**Brownlow, J.** *New England Orogen granitoid diversity and crustal development*
SP1.5	**Scipione, M.**, Knutsen, E., Roberts, E., McCoy West, A., Esterle, J. *Revisiting the Triassic: refining temporal frameworks and provenance in the Bowen Basin through U-Pb detrital zircon geochronology*
SP1.6	**Murray, G.**, Buckman, S., Nutman, A., Saktura, W., Aitchison, J., Bennett, V., Yan, Z., Fu, C. *Age and significance of the Willowie Creek Beds and Gordonbrook Serpentinite, southern New England Orogen*
SP1.7	**Jatupohnkhongchai, S.**, Paterson, J., Milan, L., Payne, J., Betts, M. *Lower Cambrian distal and proximal volcanics from the Arrowie Basin, South Australia and the Gnalta Shelf, western New South Wales*
SP1.8	**Babaahmadi, A.**, & Rosenbaum, G. *Style of thrusting in the Bowen Basin Folded Zone, Central Queensland, eastern Australia*
SP1.9	**Fergusson, C.** *Cambrian-Ordovician Wagonga Group: oceanic rocks accreted to a subduction complex in the eastern Lachlan Orogen, NSW South Coast*
SP1.10	**Verheart, S.**, Glorie, S., Hand, M., Mulder, J.A., Halpin, J.A. *Unravelling the tectonic and metamorphic framework of subglacial East Antarctica using detrital garnet Lu-Hf geochronology*
SP1.11	**Humand M.**, Green, E., Finch, M. *Phase Equilibrium Modelling of Subduction Systems*

SO2	**Critical metals, magmatism and super eruptions** *Oral Presentations*
SO2.1	**Ubide, T.**, Roberts, J., Parra-Encalada, D., MacDonald, A., Ward, J., Rosenbaum, G., Larrea, P., Bustos, E. *Quiet vs loud arc volcanoes. A microanalytical perspective into magmatic architecture across the Central Andes* Friday 22nd, 09:00-09:15
SO2.2	**Parra-Encalada. D.**, Ubide, T., Rosenbaum, G., Cajal, Y., Campbell, I., Tomkins, A. *Plagioclase as a mineralization marker in Porphyry Copper Deposits* Friday 22nd, 09:15-09:30
SO2.3	**Ward, J.F.**, Rosenbaum, G. Ubide, T. *Slab tearing as a driver of porphyry ore deposit formation in island arcs* Friday 22nd, 09:30-09:45
SO2.4	**Yaxley, G.M.**, Ray, S., Miller, L., Berry, A. *The solubility of monazite in carbonate melts – implications for monazite formation in carbonatites* Friday 22nd, 09:45-10:00
SO2.5	**Xing, Y.**, Liu, W., Mei, Y., Etschmann, B., Brugger, J. *REE transport in hydrothermal mineralizing systems: implications from thermodynamic models* Friday 22nd, 10:00-10:15
SO2.6	**Weller, O.M.**, Soderman, C.R., Beard, C.D., Riel, N., Green, E.C.R., Holland, T.J.B *New thermodynamic models for alkaline-silicate magmatic systems reveal fractionation at a mid-crustal tipping point primes REE-mineralised alkaline igneous rocks* Friday 22nd, 10:15-10:30
SO2.7	**Slanislav, I.** *Linking magmatism to orogenic gold mineralization through zircon geochemistry* Friday 22nd, 11:00-11:15
SO2.8	**Voisey, C.R.**, Hunter, N.J.R., Tomkins, A.G., Brugger, J., Liu, W., Liu, Y., Luzin, V. *Shock Value: Gold nugget formation from earthquake-induced piezoelectricity in quartz* Friday 22nd, 11:15-11:30
SO2.9	**Olierook, H.K.H.**, Fougerouse, D., Doucet, L.S., Liu, Y., Rayner, M.J., Danišík, M., Condon, D.J., McInnes, B.I.A., Jaques, A.L., Evans, N.J., McDonald, B.J., Li, Z-X., Kirkland, C.L., Mayers, C., Wingate, M.T.D *Argyle pink diamonds: a story that involves a super continental break up* Friday 22nd, 11:30-11:45
SO2.10	**Centrella, S.**, Hoareau, G., Beaudoin, N.E., Motte, G., Lanari, P., Piccoli, F., Callot, P., Gomez-Rivas, E., Martín-Martín, J. *Reconstructing the fluid pathways in sedimentary basin using a mass balance approach: example of the Benassal Formation, Spain* Friday 22nd, 11:45-12:00
SO2.11	**Ezad, I.S.**, Chattopadhyay, S., Shcheka, S.S., Foley, S.F., Tumiati, S. *Co-existing fenitizing fluids and carbonatite melts derived from ultramafic lamprophyres* Friday 22nd, 12:00-12:15
SO2.12	**Doucet, L.S.**, & Li, Z-X. *Large scale mantle heterogeneity: A legacy of plate tectonic supercycles* Friday 22nd, 12:15-12:30
SO2.13	**Dyriw, N.** *Managing geological complexity and practical applications: an industry-academic roadblock?* Friday 22nd, 13:30-14:45
SP2	**Critical metals, magmatism and super eruptions** *Poster Presentations – Tuesday 19th 5-7 pm*
SP2.1	**Heidari, E.**, Farahbakhsh, E., Shirmard, H., Kohlman, F., Muller, R.D. *AI-Powered Prospectivity Mapping of Porphyry mineralisation in the Macquarie arc, NSW*
SP2.2	**Shirmard, H.**, Mather, B., Farahbakhsh, E., Czarnota, K., Müller, R.D. *Machine learning-assisted mapping of craton boundaries rich in ore deposits using full-waveform seismic tomography*
SP2.3	**Nyakecho, C.**, Sanislav, I., Finch, M. *Structural Control on Cu-Au-REE mineralisation, the relationship between Magmatism, Skarn Formation, and Mineralization at Elaine Dorothy, NW Queensland, Australia*

SO3	**Mantle geodynamics, geochemistry and volcanism** *Oral Presentations*
SO3.1	**Whittaker, J.**, Carey, R., Duncan, B., Orth, K., Seton, M. *The Balleny Seamount Trail – A Weak but Persistent Deep Plume* Tuesday 19th, 15:30-15:45
SO3.2	**Roy, S.**, Hayman, P., Kamber, B.S. *Change in the basalt normative mineralogy in deep-time, and possible petrogenetic relations* Tuesday 19th, 15:45-16:00
SO3.3	**Kamber, B.S.** *New insight into the effects of trans-lithospheric magma transfer on the petrology and geochemistry of the lithospheric mantle, lower continental crust and volcanic products* Tuesday 19th, 16:00-16:15
SO3.4	**Rodrigues, R.F.**, Yaxley, G., Kamber, B. *Peridotite - komatiite interaction and the origin of orthopyroxene-rich cratonic mantle lithosphere* Tuesday 19th, 16:15-16:30
SO3.5	**Tailby, N.D.**, & Chapman, T. *Defrosting the Cowra crystal mush* Tuesday 19th, 16:30-16:45
SP3	**Mantle geodynamics, geochemistry and volcanism** *Poster Presentations – Tuesday 19th 5-7 pm*
SP3.1	**Pasco, J.**, Payot, B., Valera, G.T., Dycoco, J.M., Labis, F.A. *Tectonic origin of peridotites from the Beaufort Ultramafic Complex, central Palawan, Philippines*
SP3.2	**Abersteiner, A.**, Beier, C., Genske, F., Berndt, J., Kamenetsky, M., Goemann, K., Nekrylov, N., Kamenetsky, V.S. *Multi-stage evolution of the oceanic lithosphere recorded by spinel harzburgite xenoliths (Heard Island, southern Indian Ocean)*
SP3.3	**Conway, E.J.**, Kamber, B.S., Murphy, D.T., Emo, R.B. *Revisiting lower crustal xenoliths from northeastern Australia*
SP3.4	**Ominigbo, E.**, Murphy, D., Moore, T.A., Trofimovs, J., Anggara, F., Gaina., C. *Cenozoic tectono-magmatic evolution of southeast Kalimantan (Borneo): New insights from a Late Eocene alkaline magmatic province*

SO4	**Ophiolites** *Oral Presentations*
SO4.1	**Keep, M.**, Holloway, V., Carter, P., Gartrell, A. *A brief history of the northern Australian margin: from basement inheritance to modern seismology (and a few mass transport deposits)* Monday 18th, 16:00-16:15
SO4.2	**Zahirovic, S.**, Viana, R.P.C., Tu, A., Schmaltz, T., Wales, A., Doherty, A., Hao, K., Leonard, J., Salles, T., Shephard, G.E., Dadd, K. *Global ophiolite, large igneous province, and orogenic reconstructions and the implications for deep-time climate and planetary carbon cycling* Monday 18th, 16:15-16:30
SP4	**Ophiolites** *Poster Presentations – Tuesday 19th 5-7 pm*
SP4.1	**Pasco, J.**, Rosenbaum, G., Spier, C., Milan, L., Ubide, T. *Field characteristics of the Marlborough and Rockhampton ultramafic massifs, New England Orogen*
SP4.2	**Zhang, H.**, Rosenbaum, G., Muir, D., Liu, Q. *Inner crystal deformation features and their exhumation significance on the Songshugou Peridotite Massif in the North Qinling Orogen, Central China*

SO5	**Microtectonics and Petrology** *Oral Presentations*
SO5.1	**Hobbs, B.E.**, & Ord, A. *Non-Andersonian faults, fractures and veins* Tuesday 19th, 09:00-09:15
SO5.2	**Ord, A.**, & Hobbs, B.E. *Automatic quantitative analysis and classification of spatial patterns (fabrics)* Tuesday 19th, 09:15-09:30
SO5.3	**Finch, M.**, Tomkins, A., Styles, M. *Porosity changes in shear zones during tectonic switching* Tuesday 19th, 09:30-09:45
SO5.4	**Olesch-Byrne, A.**, Finch, M., Sanislav, I., Riberio, B., Tomkins, A. *Deformation mechanisms in a shear zone ore fluid conduit* Tuesday 19th, 09:45-10:00
SO5.5	**Wilson, C.J.L.**, & Peternell, M. *Origin of textures in quartz veins: insights from 2D in situ ice experiments* Tuesday 19th, 10:00-10:15
SO5.6	**Singh, U.**, Chatzaras, V., Özaydin, S., Rey, P. *Moving to 3D: constraints on shape fabric and strain in mantle rocks* Tuesday 19th, 10:15-10:30
SO5.7	**Piazolo, S.**, Carpenter, M., Chapman, T., Clarke, G., Hawthorne, J., Hansen, L. *Signatures of changing deformation rate dynamics in deforming rocks: Examples from the exhumed Slow Earthquake Zone of New Caledonia* Tuesday 19th, 11:00-11:30 (**Keynote**)
SO5.8	**Green, E.**, & Powell, R. *Phase equilibrium modelling: a frosted window onto geological processes* Tuesday 19th, 11:30-11:45
SP5	**Microtectonics and Petrology** *Poster Presentations – Tuesday 19th 5-7 pm*
SP5.1	**Li, P.**, Chatzaras, V., Rey, P., Özaydın, S. *Structural characteristics of the southeast Australian lithospheric mantle constrained from xenoliths*
SP5.2	**Styles M.**, & Finch, M. *Structural analysis of the Hyde-Macraes Shear Zone hosted gold deposit, New Zealand*
SP5.3	**Olesch-Byrne, A.**, Finch, M., Chapman, T., Beilharz, M., Tomkins, A. *Rheology modification in subduction channels due to eclogite facies metasomatism (Rocky Beach Metamorphic Mélange, Port Macquarie, Australia)*
SP5.4	**Munnikhuis, J.**, Hill, J., Milan, L., Henríquez, A., Cuello, G. *Multi-scale fracture analysis and bedrock mapping of the Galan Ignimbrite near Salar de Hombre Muerto, Catamarca Province, Argentina*

SO6	**Geodynamic Modelling** *Oral Presentations*
SO6.1	**Cruden, A.R.**, & Robin, P-Y.F. *Narrow shear zones within broad transpression zones: testing theory with analogue experiments* Thursday 21st, 16:00-16:15
SO6.2	**Withers, M.**, Eisermann, J.O., Riller, U., Cruden. A.R. *A baseline model for fault development across transpressive plate boundaries* Thursday 21st, 16:15-16:30
SO6.3	**Ozaydin, S.**, Rey, P.F., Chatzaras, V. *Thermomechanical modelling as a tool for decoding geophysical anomalies: A case study of strike-slip pull-apart basins* Thursday 21st, 16:30-16:45
SP6	**Geodynamic Modelling** *Poster Presentations – Tuesday 19th 5-7 pm*
SP6.1	**Withers, M.**, Cruden, A.R., Quigley, M.C. *To splay or not to splay? That is the question*
SP6.2	**Magri, L.**, Whittaker, J., Brune, S., Williams, S., Hochmuth, K., Coffin, M., Neuharth, D., Saniford, D., Glerum, A. *Modes of rifting of oceanic Large Igneous Provinces*

SO7	**Petrochronology** *Oral Presentations*
SO7.1	**Volante, S.**, Pourteau, A., Li, Z-X., Collins, W.J., Doucet, L.S., Olierook, H.K.H., Martin, L., Smit, M. *Oxygen isotope shifts during continental anatexis: fingerprints of fluid-fluxed melting* Tuesday 19th, 11:45-12:00
SO7.2	**Spier, C.**, Milan, L., Rosembaum, G., Armes-Venter, R., Wang, X. *U-Pb apatite and zircon ages of dolerite from the Baryulgil Serpentinite, NSW: Insights into the emplacement age of the ultramafic massif* Tuesday 19th, 12:00-12:15
SO7.3	**Mayer-Ullman, F.**, Glorie, S., Mulder, J., Hand, M., Morrissey, L., Halpin, J. *Thermal history of the East Antarctic margin recorded in apatite: Campaign-style Lu-Hf, U-Pb, fission track and U-Th-Sm/He results* Tuesday 19th, 12:15-12:30
SO7.4	**Langone, A.**, Corvò, S., Piazolo, S., Daczko, N. *Reactive and resilient: the behaviour of geochronometers during deformation* Tuesday 19th, 13:30-14:00 (**Keynote**)
SO7.5	**Ribeiro, B.V.**, & Kirkland, C.L. *Challenging the garnet chemical-isotopic reliability under high-temperature deformation* Tuesday 19th, 14:00-14:15
SO7.6	**Murphy, D.M.**, Glorie S., Gilbert, S., Emo, R.B, Schrank, C.E., Zamora, M.A., Kamber, B.S. *In-situ Lu-Hf dating of garnet: a novel new tool for granulite geochronology* Tuesday 19th, 14:15-14:30
SO7.7	**Fitzherbert, J.**, Hughes, K., Simpson, B., Huiqing, H. *Timing post-peak reactivation episodes in the Broken Hill Block using allanite (and friends) in a shear-hosted REE-IOCG deposit* Tuesday 19th, 14:30-14:45
SO7.8	**Durney, D.** *Hypothesis-related systematic uncertainty in radiometric dating of deformation: some cases, arguments and alternative strategies* Tuesday 19th, 14:45-15:00
SO7.9	**Evans, K.A.**, Reddy, S.M., Tenuta, S., Lodi-Cusani, Merle, R., Fougerouse, D., Rickard, W.D., Saxey, D.W., Park, J-W, Doucet, L., Jourdan, F. *The origin of platinum group minerals in ophiolites, and implications for the Re–Os geochronometer* Thursday 21st, 11:00-11:15
SP7	**Petrochronology** *Poster Presentations – Tuesday 19th 5-7 pm*
SP7.1	**Gomes, I.V.**, Schmitt, R.S., Rosenbaum, G., Armistead, S.E., Mussili, J.V.S. *The triple orogenic junction of central Gondwana*
SP7.2	**Gomes, I.V.**, Rosenbaum, G., Spier, C.A., Ward, J.F. *The elusive tectonic setting of the New England Orogen during the Late Silurian–Early Devonian*
SP7.3	**Laupland, E.**, Caulfield, J., Allen, C.M. *Apatite and zircon: Better together – The case of the northern Ecuadorean Miocene arc*

SO8	**Proterozoic sedimentary basins** *Oral Presentations*
SO8.1	**Armistead, S.**, Meffre, S., Bottrill, R., Cross, A., Huston, D., Cumming, G., Oalmann, J., Berry, R. *Mesoproterozoic tectonic and metallogenic link between Tasmania and Laurentia revealed by multi-mineral geochronology* Thursday 21st, 14:15-14:30
SO8.2	**Parui, C.**, Schmid, S., Spampinato, G., McFarlane, H., Zuchuat, V. *Structural reconstruction of the Yeneena Basin, Western Australia – a key for understanding sedimentary-hosted copper mineralization* Thursday 21st, 14:30-14:45
SO8.3	**Subarkah, D.**, Collins, A.S., Löhr, S.C., Klaebe, R., Gilbert, S.E., Nixon, A.L., Blades, M.L., Farkaš, J., Virgo, G.M. *The complex chronology of Cryogenian carbonates* Thursday 21st, 14:45-15:00
SO8.4	**Deepak, A.**, Collins, A.S., Blades, M.L., Subarkah, D. *Multiproxy Analysis of Paleoproterozoic Shales from the Limbunya Group: Insights into Paleoenvironmental Conditions* Thursday 21st, 15:30-15:45
SO8.5	**Noptalung, S.**, Sanislav I., Flinch, M., Dirks, P. *Geochronological constraint on the timing of magmatism and sedimentation in the Dajarra region, Mt Isa Inlier, Australia* Thursday 21st, 15:45-16:00
SP8	**Proterozoic sedimentary basins** *Poster Presentations – Tuesday 19th 5-7 pm*
SP8.1	**Wyndham, N.**, Collins, A., Blades, M.L., Subarkah, D., Virgo, G.M., Al-Kiyumi, M., Bauer, W., Imbrogno, D. *Controversies of the Cryogenian in Oman: new temporal, chemostratigraphic and palaeomagnetic constraints on the Saqlah, Fiq and Hadash Formations*
SP8.2	**Imbrogno, D.**, Collins, A., Spandler, C., Subarkah, D., Blades, M.L., Bubner, G., Hall, T., Klaebe, R. *Geochemical and Geochronological Insights into Proterozoic Earth Systems in the Batten Fault Zone, McArthur Basin*
SP8.3	**Collins, A.S.**, Blades, M.L., Subarkah, D., Imbrogno, D., Deepak, A., Noorian, Y., Soares, J., Farkas, J., Holford, S., Spandler, C., King, R., and the greater McArthur Basin Linkage Team *The resource-full McArthur-Yanliao Basin of Nuna, its global significance and tectonic evolution*
SP8.4	**Li, R.**, Blades, M., Subarkah, D., Collins, A., Virgo, G., Imbrogno, D. *The Benmara story: geochemistry, geochronology and sedimentology*
SP8.5	**Khazaie, E.**, Collins, A., Farkas, J., Lohr, S., Blades, M.L. *In situ Rb-Sr geochronology of illites in Nifty dolomitic shales, northwest of the Officer Basin*
SP8.6	**Rey, P.F.**, Ibrahim, J., Ozaydin, S., Li, L., Gorczyk, W., Jessell, M., Aitken, A., Nissanka, U., Cruden, S., Betts, P. *A thermal-mechanical framework for Proterozoic basins*

SO9	**Tectonics-early earth, active plate boundaries, planetary** *Oral Presentations*
SO9.1	**Capitanio, F.A.**, Kerr, M., Stegman, D.R., Smrekar, S.E. *Ishtar Terra highlands on Venus raised by craton-like formation mechanisms* Thursday 21st, 09:00-09:15
SO9.2	**Asimus, J.**, Halpin, J., Daczko, N., Whittaker, J., Falloon, T., Coffin, M., Belousov, I., Fox, J. *Microcontinents formed during a messy breakup between India and Antarctica* Thursday 21st, 09:15-09:30
SO9.3	**Merdith, A.S.**, Longman; J., Mills, B.J.W. *Solid-Earth controls on Phanerozoic icehouses* Thursday 21st, 09:30-09:45
SO9.4	**Williams, S.**, Gubbins, D., Seton, M., Whittaker, J. *Magnetization of oceanic lithosphere from modelling of satellite observations* Thursday 21st, 09:45-10:00
SO9.5	**Chukwu, C.**, Betts, P., Munukutla, R., Armit, R. *Crustal structure and role of inheritance in the evolution of southeast Australia's triple junction* Thursday 21st, 10:00-10:15
SO9.6	**Zoleikhaei, Y.**, Cawood, P.A., Mulder, J.A. *A non-arc setting for "Cadomian" magmatism in Iran and Anatolia* Thursday 21st, 10:15-10:30
SO9.7	**Tikoff, B.**, Roberts, N., Kelso, P., Rechtzygiel, N., Vervoort, J., Salerno, R. *Evidence for and against multiple punctuated crustal overturn events in the Pilbara craton, Western Australia* Thursday 21st, 11:00-11:30 (**Keynote**)
SO9.8	**Gessner, K.**, Doublier, M.P., Calvert, A.J., Smithies, R.H., Yuan, H., Hayward, N., Lowrey, J.R. *A rift–transform origin for the East Pilbara Terrane* Thursday 21st, 11:30-11:45
SO9.9	**Zibra, I.** *More than 2 billion years of shearing along the western margin of the Yilgarn Craton (Western Australia)* Thursday 21st, 11:45-12:00
SO9.10	**Rey, P.F.**, Coltice, N., Flament, N. *Archean dual geodynamics underneath weak, flat, and flooded continents* Thursday 21st, 12:00-12:15
SO9.11	**Hayman, P.C.**, & Senyah, G. *Reconstruction of a Paleoproterozic Greenstone Belt and comparative study to Late Archean Greenstone Belts* Thursday 21st, 12:15-12:30
SO9.12	**Betts, P.G.**, Sreenihidi, K.S., Radhkrishna M. *From continental rifting to seafloor spreading. Controversies and insights from the Red Sea* Thursday 21st, 13:30-13:45
SO9.13	**Abdullah, R.**, & Pawley, M. *The effect of the original tectonic grain on structural evolution during poly-phase deformation: an example from Mount Woods Domain, Gawler Craton* Thursday 21st, 13:45-14:00
SO9.14	**O'Neil, C.** *Tectonic impact of the boring billion* Thursday 21st, 14:00-14:15

SP9	**Tectonics-early earth, active plate boundaries, planetary** *Poster Presentations – Tuesday 19th 5-7 pm*
SP9.1	**Tu, A.**, Zahirovic, S., Boone, S.C., Salles, T., Glen, R., Mahoney, L., Bradshaw, M. *Digital plate reconstructions of the Tasmanides*
SP9.2	**Lee, J.**, Sanislav, I., McCoy-west, H. *Adakitic magmatism of the Kennedy Igneous Association in the Georgetown region: implications for the tectonic setting and mineralisation during Permo-Carboniferous period in the northeastern Queensland*
SP9.3	**Barnett, M.**, Collins, A.S., Subarkah, D., Blades. M.L. *Uncovering the Hidden Delamerian Margin: A geochemical and geochronological analysis of an undercover arc*
SP9.4	**Leonard, J.**, Zahirovic, S., Salles, T., Dimitrijevic., D. *Tectonic and paleogeographic reconstruction choice impacts the distribution of simulated ancient reefs*
SP9.5	**Gates, R.**, & Betts, M.J. Which Way Was Up? The Chaos of Ediacaran–Cambrian Tectonic Reconstructions
SP9.6	**Zolikhaei, Y.**, Chaudhuri, T., Cawood, P.A., Mazumder, R., De, S., Nebel, O. *Magmatic maturation of Archean continental crust via a three-step crustal reworking*

Abstracts

Formation of domes and basins by syn-deformational granite emplacement

Gideon Rosenbaum[1], Alana Barrett [1], Raiza Toledo Rodrigues[1], Charlotte M. Allen[2,3], Roberto F. Weinberg[4]

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[4]*School of Earth, Atmosphere and Environment, Monash University, Clayton, Victoria 3800, Australia*

Granitic dome-and-basin patterns have been documented in Archean terranes, and typically attributed to vertical tectonism associated with diapirism and/or “drip tectonics”. Many geologists have suggested that such features formed by gravity-driven processes, involving upward movements of granitic diapirs (forming domes) and downwelling (“sagduction”) of volcano-sedimentary cover sequences. This style of tectonism is generally considered to be unique to the (pre-plate tectonic) Archean era. Accordingly, the recognition of similar structures in Phanerozoic terranes could weaken the assumption that granitic dome-and-basin patterns represent vertical tectonism that dominated crustal processes prior to the onset of plate tectonics.

We show an example of tabular granitic bodies, intruded into the Carboniferous sedimentary succession of the Graveyard Creek subprovince (Broken River, northeastern Queensland). Together with the country rocks, the granitic plutons form macroscopic dome-and-basin fold interference patterns. Field relations indicate syn-kinematic emplacement of the granitic intrusions, which occur as folded sill-like microgranitic bodies, mildly deformed stocks at structural domes, and undeformed granite that cuts across the folded sedimentary sequence. U-Pb zircon ages from the various intrusions yielded an age range of 335–320 Ma, thus constraining the timing of folding. The deformed zone is restricted to a ~30 km wide corridor bounded by two crustal-scale shear zones. Kinematic indicators show that folding was generated by dextral transpression, giving rise to the dominant orientation of folds. The domes and basins are generally concentrated in the proximity of the granitic intrusions, indicating that their development was likely controlled by the syn-kinematic emplacement of these plutons.

To explain our field observations, we propose a model whereby the added volume of granite to the exposed section have altered the local strain regime. In response to the forced syn-kinematic intrusions, the strain in the confined transpressional zone of our study area (dominated by flattening strain) was locally altered to constrictional strain. The fold interference pattern in the proximity of the granite intrusions was not necessarily generated by two distinct phases of folding but may have resulted from a local constrictional strain regime involving two orthogonal orientations of shortening. In the context of these results, which demonstrate a link between Carboniferous granitic dome-and-basin patterns and syn-transpressional magmatism, it is plausible that similar processes were responsible for the development of granitic dome-and-basin patterns in Archean terranes.

Magmatic record of Carboniferous slab rollback along the Australian Tasmanides of eastern Gondwana

Qing Zhang[1,2,3] Solomon Buckman[3], Ross N. Mitchell[2,4], Allen P. Nutman[3], Xian-Hua Li[2,4], Vickie C. Bennett[1], Courtney Beer[3]

[1]*Research School of Earth Sciences, Australian National University*
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[3]*School of Earth, Atmospheric and Life Sciences, University of Wollongong*
[4]*College of Earth and Planetary Sciences, University of Chinese Academy of Sciences*

Slab rollback is a common feature of subduction zones, and it provides key evidence for understanding the evolution of subduction dynamics. However, for ancient orogens, such as the long-lived Australian Tasmanides—one sector of one of Earth's largest orogens in eastern Gondwana—the evolution of the slab dynamics is poorly constrained and the tectonic evolution remains hotly debated. Recognition of ancient slab rollback processes relies on the identification of the progressive migration of magmatic arcs. In this work, we focus on the unique eastward, ~90 km of trans-orogen migration of the Carboniferous Bathurst Batholith, which we reveal was a product of slab rollback and a "missing link" between two orogens.

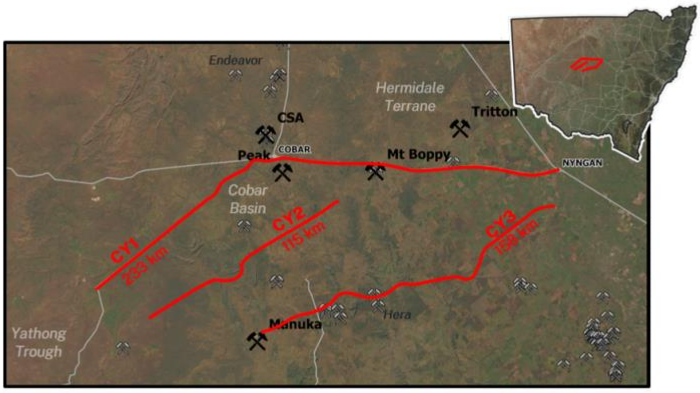
By sampling across the batholith, analysing the U-Pb ages and Hf isotopes of the samples, and compiling the regional Hf database of the neighbouring orogens, we present evidence for Carboniferous–Permian slab evolution along eastern Gondwana, quantify the potential slab steepening rate, and throw light on the tectonic relationship between the key orogens of Australian Tasmandies. It is an example of a study that applies the progressive migration of a magmatic arc, to understand the slab evolution of long-lived orogens and to reveal the trans-orogen tectonic relationship between two orogenic domains.

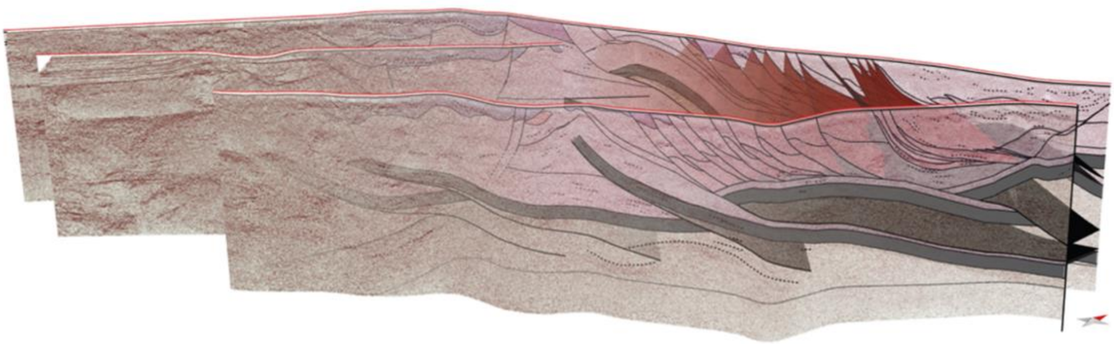
Crustal architecture and geological evolution of the Central Lachlan Orogen: Insights from new deep crustal seismic imaging of the Yathong-Cobar-Hermidale region, NSW

Luke Mahoney[1], Joel Fitzherbert[1], Max Milz[1], Larissa Gammidge[1], Mark Eastlake[1], Brenainn Simpson[1], John Davidson[1], Phil Blevin[1]

[1]*Geological Survey of NSW*

The Geological Survey of NSW recently acquired and processed over 500 km of deep crustal seismic reflection data across the Yathong-Cobar-Hermidale areas in the Central Lachlan Orogen to constrain the subsurface architecture and better understand the metallogeny of the region. The use of a high-density vibroseis-source and best-practice data processing workflows yielded unprecedented subsurface imaging quality for a hard rock setting. Seismic interpretation reveals that the Hermidale Terrane is an archetypical thick-skinned fold and thrust belt, characterised by west-vergent faulting and folding indicative of very significant (> 40%) east-to-west crustal shortening. New geological and geophysical observations distinguish multiple phases of deformation providing important temporal constraints on the geological evolution of the region. Cross-cutting relationships indicate that most of the shortening and major structures within the Hermidale Terrane formed prior to the late Silurian to Devonian Cobar and Yathong basins, highlighting the significance of the late Ordovician to early Silurian Benambran Orogeny in this region. Early formed crustal-scale structures provide important controls on the exhumation of deep mineral accumulations and form conduits for the emplacement of mineralised fluids at shallower levels during the subsequent multi-phased evolution of the Lachlan Orogen.





Detrital zircon ages conflict with an island arc interpretation for older (Silurian-Devonian) rock assemblages of the New England Orogen

Robert A. Henderson[1] and Chris L. Fergusson[2]

[1]*James Cook University*
[2]*University of Wollongong*

Rocks of Silurian -Devonian age comprising the Gamilaroi Terrane and Calliope Province of the New England Orogen have been interpreted by many authors as of island arc association, developed in the Paleo-Pacific Ocean adjacent to east Gondwana to which they were subsequently accreted. Both east dipping and west dipping subduction systems have been suggested for their origin, with interpretation based on geochemical signatures of mafic volcanics and hypabyssal intrusions. Newly acquired detrital zircon age data from the northern New England Orogen indicate a continental provenance and conflict with this interpretation. Spectra of Middle Devonian samples from Erebus Subprovince are dominated by Ordovician ages, indicating a source from the Thomson Orogen then part of continental east Gondwana. Data from samples of the Late Devonian Mount Alma Formation (Yarrol Province) considered by some authors as of island arc association, also indicate a contribution from a continental source. These data, combined with the lithostratigraphic content of the Calliope Province and older elements of the Yarrol Province within the northern New England Orogen, are consistent with their formation in a basinal setting developed adjacent to a continental margin arc. By association, rocks of the Gamilaroi terrane in the southern New England Orogen are best attributed to a similar setting. Geochemical data have overly influenced tectonic interpretation of Silurian – Devonian rock assemblages of the New England Orogen.

Reconstructing a cryptic Cambro - Ordovician arc record in the Tasmanides of Eastern Australia

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This study presents new whole rock geochemistry and zircon U-Pb-Hf data sets on rare igneous clasts extracted from conglomerate horizons within a fault bounded package of sediments. This belt of sediments is known as the Gamilaroi Terrane, interpreted to represent detritus shed from an active Silurian-Devonian exotic intraoceanic arc that formed offshore of the Australian portion of East Gondwana (Aitchison and Flood, 1994). The Gamilaroi Terrane is juxtaposed against the fault bound Great Serpentinite Belt which preserves relics of Cambro- Ordovician subduction. Together, their location within the youngest preserved orogen of the Tasmanides (Carboniferous-Triassic Southern New England Orogen) is attributed to rifting or accretion of an exotic intraoceanic arc. The igneous clasts of this study reveal a diverse spectrum of lithologies from basaltic, intermediate to granite compositions of calc alkaline character. New zircon U-Pb-Hf data from igneous clasts reveal a spread of Cambro-Ordovician ages. The Ordovician magmatism is juvenile in nature with a dominant mantle influence, while Cambrian magmatism shows contamination with continental crust. This is supported by Precambrian aged Inherited zircons in Cambrian aged clasts. Detrital zircons separated from a polymict conglomerate sample also suggest a Precambrian basement source. This discovery prompts a review for the provenance and tectonic setting of the terrane. We review models calling for an exotic terrane and compare our data to existing Cambrian- Ordovician geological records in the New England and Lachlan Orogens.

References

Aitchison, J.C., and Flood, P.G. (1994) Gamilaroi Terrane: A Devonian rifted intra-oceanic island arc assemblage, NSW, Australia.

Extreme energy from the deep, at convergent margins

Vitale Brovarone, A.[1,2,3], Siron, G.[1,4], Giuntoli, F.[1], Olivieri, O.S.[1], Ressico, F. [1], Peverelli, V. [1], Pastore, Z. [1,5], Wong, K.[1], Dobe, R.[1]

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[4]*presently at: Laboratoire Chrono-Environnement, Université de Franche-Comté, UMR 6249, 25000 Besançon, France*
[5]*Norwegian University of Science and Technology (NTNU), Department of Geoscience and Petroleum, S. P. Andersens veg 15a, 7031 Trondheim, Norway*

Interactions between fluids and rocks can produce energy sources life can take advantage of, from microorganisms to modern society. The hydroxylation of olivine-rich rocks, or serpentinization, is known to produce molecular hydrogen that may combine with carbon to form light hydrocarbons such as methane. These natural energy sources are abiotic, i.e. produced without the contribution of biology. Serpentinization is best known at shallow crustal levels such as at mid ocean ridges and on land, at depths largely overlapping with the deep subsurface biosphere. Because microbial life can take advantage of these gases and reprocess them, the identification of abiotic energy sources in these settings is challenging. However, serpentinization can extend to conditions much deeper and hotter compared to the biotic fringe, such as at convergent margins where serpentinization can take place down to at least 70-80 km depth. The genesis of molecular hydrogen and methane through serpentinization at these depths is, however, little studied, even though it may represent an unexplored source region of natural energy along thousands of kilometres of convergent plate margins. This contribution presents an overview of the results of a multidisciplinary study aimed at determining the distribution, formation pathways, signatures, and fluxes of deep energy sources generated at the deepest roots of serpentinization, at convergent margins. The fate and potential chemical and structural implications of the generation of these energy sources at extreme conditions will be also discussed

Ediacaran-Cambrian high-strain melt-present deformation during gravitational spreading of the ancestral East Antarctic mountains

Jacqueline A. Halpin[1,2], *Nathan R. Daczko*[3], *Jacob A. Mulder*[4,2], *Alessandro Maritati*[1], *Tobias Stål*[5,1,2]

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[5] *School of Natural Sciences (Physics), University of Tasmania, Hobart, TAS 7001, Australia*

The assembly of Gondwana involved several well-characterized Pan-African orogens, although their extension into ice-covered Antarctica remains contentious. Particularly problematic is our understanding of the Kuunga orogenic system in East Antarctica, including its eroded architecture and temporal evolution. The remote Charcot Province, at the easternmost extent of the Antarctic Kuunga Orogen, comprises isolated outcrops, which present a key opportunity to test recent tectonic models. Here we investigate the geological history of Alligator Island, a rarely visited exposure of the Charcot Province. Through field relationships, petrography, zircon U-Pb-Hf geochronology, and feldspar Pb-Pb isotopic analyses, we determined that the Alligator Island migmatitic gneisses originated from a Mesoarchean (c. 2.97-2.95 Ga) volcano-sedimentary package. Metamorphism during the Neoarchean (c. 2.76 Ga) was characterised by the channelled migration of anatectic melts. An apparent tectonic quiescence followed for approximately 2 billion years, until the Ediacaran-Cambrian (580–540 Ma) when high-strain melt-present deformation led to pervasive migmatitic textures and tight folding. Zircon Hf-isotopes indicate that melt was externally sourced from crust older than 3.0 Ga. We propose that the melt-present deformation fits within a new tectonic model of Gondwana amalgamation in which gravitational spreading of a mature orogenic system transported high-grade infrastructure rocks of the Charcot Province up to ~10^3 km via a mid-crustal channel from a thickened orogenic core near the ancestral Gamburtsev Subglacial Mountains.

Figure 1. Jacqueline Halpin (foreground) on Alligator Island Dec 2023, looking north across the Shackleton Ice Shelf. Photo credit: Katie Miles.

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Can soft collision lead to plate tectonic reorganisation? Revisiting the Ontong Java Plateau paradox

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Arc polarity reversal constitutes one of two subclasses of induced subduction initiation. The prototypical example is the collision of the Ontong Java Plateau (OJP) with the Solomon Islands Arc. A widely accepted model holds that collision occurred in the Early Miocene, emplacing the Malaita Terrane by obduction, halting arc volcanism, and terminating Pacific Plate subduction, with reversal of subduction polarity delayed until the Late Miocene. The absence of a significant geological response to the collision – ascribed to "soft docking" – appears to be at odds with the substantial far-field consequences that have been ascribed to it, including a slowing of Australian plate motion. Constraints on the timing of the collision are inferential, and an Early Miocene age appears to be inconsistent with a sequence of volcaniclastic-bearing sediments on the Malaita Terrane, which extend from the Late Eocene to the Late Miocene, and with paleomagnetic evidence. Alternative models, which infer a Late Miocene collision closely followed by arc reversal, do not require soft docking, but also appear to be at odds with the Malaita Terrane stratigraphy and paleomagnetism.

ODP drilling on OJP recovered a series of volcanic ashes which peaked in the Late Oligocene and Early Miocene, before decreasing sharply. Despite the inference that these ashes were the product of Melanesian Arc volcanism, no results of any petrological, geochemical or isotopic study have been reported from these ashes.

We propose to conduct geochemical and isotopic analyses on these OJP ashes, to determine whether they represent an arc source or hot-spot volcanism. In parallel, we will sample the on-land record from the Malaita Terrane, conducting isotopic analyses on magmatic zircons for comparison with the plateau ash record. Microfossil biostratigraphy on these Malaita Terrane samples will provide depositional ages, and comparison with zircon magmatic ages will allow a test of whether arc volcanism persisted through the Miocene.

Combining the results from the legacy core study with those from the on-land study, and taking atmospheric circulation models into account when reconstructing the position of the likely source of the plateau ashes, will allow us to test competing hypotheses for the relative positions of the arc and the plateau in the Miocene.

Finding 'Lost Pacifica': Reconstructing Mesozoic northeast Gondwana through sedimentary provenance investigations in the Laura, Capricorn, and Styx basins

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The tectonic setting of north-eastern Gondwana during the Mesozoic remains largely unresolved. Recent sedimentary provenance studies in the Great Australian Superbasin support a continuation of Palaeozoic-initiated subduction and continental arc magmatism along the east Gondwana margin throughout the Mesozoic (Late Triassic to mid-Cretaceous). However, little is known about the northern extent of this system and its relationship with northern Zealandia, which rifted from Australia during the Late Cretaceous. This study used the U-Pb detrital zircon record of onshore and offshore Jurassic-Cretaceous sedimentary successions in the Laura, Capricorn, and Styx basins as a proxy for contemporaneous magmatism in the region. We also utilised sedimentary facies analysis, sequence stratigraphy, and drainage patterns to investigate sedimentary provenance in each basin. Initial results for detrital zircon geochronology on sandstones from the the Laura Basin show pronounced Jurassic to Early Cretaceous age peaks. Additionally, several volcanic pebbles found within Jurassic conglomerates in the basin have yielded Late Triassic (225Ma, 220Ma, 217Ma, 210Ma, 208Ma, 202Ma) and Jurassic (194Ma, 169Ma, and 157Ma) ages. These data strongly support continued magmatism proximal to the Cape York Peninsula from the Late Triassic to Early Cretaceous. Drainage patterns indicate an eastern source for sediments, placing the basin in a back-arc setting during deposition. This challenges current interpretations of formation and infill in the Laura Basin, which typically describe it as an intracratonic sag basin. This study not only contributes to our understanding of the geologic and tectonic evolution of remote north-eastern Australia, but it provides a comparative framework for future quantitative provenance work in a largely understudied region.

Geological constraints on Proterozoic mountains – reconstructing the largest mountain range of the last billion years

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A reconstruction of the shape of the earth surface is essential to test hypotheses and model the solid-earth/earth surface interface in Deep Time. We can only progress our understanding of how the deep earth effected the climate, the budget of bio-available nutrients, the oxidation of earth surface systems and major ecological evolutionary changes by rebuilding the tectonic geography of the planet. The innovation of full-plate tectonic reconstructions back into the Proterozoic is an important development (Merdith et al. 2021; Collins et al. 2021; Cao et al. 2024), but at present, these do not include continental topography.

Here we present the first reconstruction of the changing topography of a trans-Gondwanan mountain belt (the East African Orogen). We inverted metamorphic pressure–time data into a compositional isostatic equilibrium equation. This gives an approximate elevation of the mountain belt relative to the modern-day elevation. There are significant assumptions and simplifications, including the assumption of isostatic equilibrium, no thermal isostatic component included, no post-orogenic modification of the crustal column etc. However, by incorporating these data into a full plate model, a first-pass paleo-geographic topographic reconstruction is presented through the final amalgamation of Central Gondwana. The Arabian Nubian Shield (accretionary orogenesis from ~750–600 Ma) produced elevations of up to ~3 km peak elevation. In the Mozambique and India/Madagascar belts much higher elevations of up to ~8 km, are predicted from ca. 650 –530 Ma; elevations similar to the current day Himalaya.

A major limitation is the lack of good pressure-time data. We present a reconnaissance study to address this using garnets from a well-characterised transect across Southern India, which we dated using the novel laser Lu–Hf LA-ICP-MS/MS technique (Simpson et al. 2021). Quartz inclusions within these were then analysed using RAMAN spectroscopy to determine their trapping pressures. These produced results of up to ~12–15 kbar at ages ~600 to 540 Ma (peak conditions), which agree with conventional pressure-time studies and demonstrate the potential of this workflow.

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P–T–fluid–deformation evolution of UHP eclogites, Sulu belt, China and implications for exhumation dynamics

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We summarize results of the past 14 years of integrated research on eclogites of the Sulu belt, one of the most deeply subducted UHP eclogite localities known globally. Our studies have determined a peak pressure >5.5 GPa (Xia B. et al., 2018: doi.org/ 10.1093/petrology/egy060), confirming that continental crust was subducted to and exhumed from depths exceeding 150 km, and developed a new understanding of the role of fluid and/or melt associated with deformation, with implications for exhumation dynamics in collisional belts.

The eclogites at Yangkou Bay are the only known example of UHP eclogites containing intergranular coesite, indicating a locally strongly fluid-undersaturated environment throughout the exhumation process. The intergranular coesite survived in rootless intrafolial isoclinal F1 fold noses. Comparison of the H_2O content of nominally anhydrous minerals (NAMs), plus microstructural, petrological and structural features indicates that the fold noses have the lowest inherited H_2O content and preserve the largest quantity of intergranular coesite (Wang L. et al., 2018). The drier environment limited fluid connectivity along garnet and omphacite grain boundaries in the fold noses, which themselves acted as rigid low strain sites and remained immune to grain-scale fluid infiltration, allowing coesite to survive. Strain localization in UHP eclogites facilitate different degrees of fluid infiltration, retrogression and evolution of deformation mechanism from brittle, plastic to dynamic recrystallization (Chen Z et al., 2023).

Migmatites formed by partial melting of UHP eclogite and gneiss was first discovered and reported from General's Hill, central Sulu belt (Wang L. et al., 2014). Deeply subducted eclogites in continent–continent collisional belts experience various fluid–melt evolutionary processes during exhumation. The UHP eclogites, whether or not they contain hydrous minerals (e.g. phengite, zoisite), can develop a solute-rich supercritical fluid or melt along grain boundaries by dehydroxylation of nominally anhydrous minerals during the early stages of decompression (Wang S.J. et al., 2020), and/or trigger partial melting by breakdown of phengite and/or omphacite (Feng P. et al., 2021; Wang Z.C. et al., 2024) during the later stages of exhumation. Microstructural and macroscale estimation of the leucosome volume ranges between ~24 vol% and ~10 vol% for partially melted Sulu UHP eclogite, which exceeds the threshold for melt connectivity (5-7 vol.%) and reduces the peak eclogite density by 5-19%. The dominant deformation mechanism of eclogite at Taohang changes from dislocation creep during the near peak metamorphism to diffusion creep with increasing fluid–melt mobility during exhumation. Fluid-weakening activates diffusion creep; the generation of melt promoted dehydroxylation of garnet and omphacite, which enabled deformation by diffusion creep in eclogite. This is consistent with the hypothesis that fluid exsolution and partial melting were important in reducing the strength of parent UHP rocks, facilitating fast exhumation of UHP metamorphic rocks from mantle depths, as suggested by numerical modelling and experimental petrology studies.

Inherited zircon mining refines Cambrian orogenic architecture of southeast Australia

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Accreted terranes are integral components of orogenic belts and their geological records provide insight into the tectonic evolution of convergent margins. The Selwyn Block is one of the few accreted terranes identified in the vast Paleozoic Tasmanides of eastern Australia and its incorporation into this orogen marks a first-order event in the early tectonic evolution of the Pacific margin of Gondwana. Despite being an important component of Paleozoic tectonic models of the Pacific margin of Gondwana, the age, composition, and paleogeography of the Selwyn Block are poorly understood because the terrane is almost completely concealed in the middle and lower crust. The prevailing hypothesis suggests the Selwyn Block is a northern continuation of a Proterozoic microcontinent exposed in the Western Tasmania Terrane, yet Proterozoic continental crust has not been identified in exposures of the Selwyn Block. We test this hypothesis by comparing inherited zircon U-Pb ages (n > 1000) from early Paleozoic granitoids intruding the Selwyn Block and Western Tasmania Terrane. Phase equilibria modelling confirms that if Western Tasmania Terrane-like crust was present at depth in the Selwyn Block, it would have melted and contributed inherited zircon grains to local granitoids. The inherited zircon age signature of granitoids in the Western Tasmania Terrane mirrors detrital zircon ages from local Proterozoic strata with large populations at ca. 1450 Ma and 1600—1800 Ma. In contrast, granitoids intruding the Selwyn Block have ca. 500—600 Ma and 900—1200 Ma inherited zircon populations, likely derived from local Paleozoic strata. Distinct melt sources are also implied by the generally lower initial $^{87}Sr/^{86}Sr$ and higher magmatic zircon initial εHf composition of granitoids from Selwyn Block compared to the Western Tasmania Terrane. Together, these datasets provide no compelling evidence that the Selwyn Block contains Proterozoic continental crust equivalent to that exposed in the Western Tasmania Terrane. Instead, outcrop and inherited zircon evidence are consistent with the interpretation that the Selwyn Block is a fragment of a predominantly mafic, Cambrian intra-oceanic island arc that collided with the Western Tasmania Terrane microcontinent during the Tyennan Orogeny.

Refolding an orogen: the case of Mossman orogenic curvature in NE Australia

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Map-view curvatures are common features of orogenic systems, arising from a variety of processes and mechanisms within active margins systems. Curvatures can develop due to irregularities in subduction zones, localised collisions and indentations, or the interaction of orogenic fronts with pre-existing structures. They may also result from the bending of originally quasi-linear belts, forming what are known as oroclines. Understanding the origin and evolution of such large-scale curvatures is crucial for gaining insights into the tectonic processes and events that have shaped active margin systems over time. In northeastern Australia (Queensland), an enigmatic orogenic curvature is recognised in both the Mossman and Thomson Orogens. Rocks of the Mossman Orogen (Broken River Province) occur in the internal part of the orogenic curvature, where variations in the orientation of the structural grain (e.g., fold traces, foliations, and reverse faults) define a map-view curve with a NE–SW-trending axial plane. The interlimb angle is ~40° and the arc length is ~140 km. Orogenic gold and epithermal deposits are concentrated in the most internal part of the curvature, and in the hinge zone, respectively. Despite the significance of this orogenic-scale structure to the tectonic history of the eastern Australian active margin and its mineral systems, relatively little is known about the architecture and tectonic framework of the orogenic curvature in NE Queensland. To address this gap, we conducted a structural investigation across this map-view curve.

Structural observations show evidence of pre-oroclinal, syn-oroclinal, and post-oroclinal features. Pre-oroclinal structures form a fold-dominated belt with minor associated faults. The folds (F1) are tight to isoclinal, moderately to steeply plunging, and accompanied by well-developed, subvertical axial plane cleavage (S1). The orientation of S1 aligns with the overall trend of the map-view curve, varying from ~N–S (010°) in the northern limb to ~E–W (070°) in the eastern limb. F1 folds are commonly disrupted, and bedding transposition is common. The strike of the reverse faults, which are generally steeply dipping, also changes in accordance with the curvature. The faults show evidence of downdip striations and vergence towards the core of the curvature. Orogenic gold deposits are structurally controlled by the pre-oroclinal structures. Syn-oroclinal structures include moderately to steeply plunging, gentle to open folds with (sub)vertical NE-trending axial planes. These folds, which deform pre-oroclinal fabrics, occur at all scales, from microscopic to regional, and are associated with a poorly developed axial plane cleavage. Post-oroclinal structures are characterised by steeply plunging kink and chevron folds with vertical ~N-S axial planes. These structures are commonly expressed as spaced cleavage or crenulation cleavage, deforming transposed bedding planes and S1 foliations. Fold interference patterns, such as dome-and-basin and boomerang-shaped folds, result from the interaction between F3 folds and older generations of folds. In addition to the fold-related structures, post-oroclinal features also include E-W to NW-SE trending veins, ranging from large-scale veins (>4 km in length) to cm-thick veins.

Our results suggest that the orogenic curvature in NE Queensland involved folding of an originally quasi-linear, fold-dominated belt, suggesting that the curvature is an orocline. The complex architecture of the orocline records at least three distinct tectonic events that affected eastern Australia during the Paleozoic. The first event, related to pre-oroclinal structures, was possibly associated with the development of an accretionary complex along the eastern Gondwana margin during the Devonian. The second event involved bending of the accretionary wedge and related structures. It could have occurred in response to NW-directed contractional tectonism and/or along-strike variations in the dynamics and kinematics of the plate boundary. Post-oroclinal N-S folds were likely associated with tectonic activity during the early Carboniferous, prior to the deposition of the relatively undeformed Carboniferous cover (e.g., Clarke River Group). Finally, the development of veins is attributed to an epithermal system that was possibly associated with felsic magmatism of the Late Carboniferous to Permian Kennedy Igneous Association.

Bedding-parallel shears in the upper Permian coal measures, Bowen Basin, central Queensland

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The presence of bedding-parallel shears (BDSs) in coal seams and burden units of the Moranbah Coal Measures in the western margin of the Bowen Basin have been uncovered. The deformation style of these structures, along with their lithological and tectonic origins, are poorly understood. In this study, we have utilized field observations, 3D photogrammetry data, optical televiewer data, and downhole geophysical data to identify bedding-parallel shears and investigate how they occurred. The BDSs are not confined to coal seams but also extend to the burden units (lithological units above/below coal seams). In coal seams, BDSs are predominantly found in the Upper Harrow Creek seams and P seams, leading to brittle shearing, such as synthetic progressive shears, P-Y shears, dragging folds, and small-scale thrust duplexes within zones of 0.8m to 2m thickness. These BDSs are associated with clay-rich stone bands, such as carbonaceous siltstone or claystone, which are less than 10 cm thick. Furthermore, BDSs are also present in overburden units of Mudstone/claystone, siltstone, and sandstone successions, forming along the boundary of clay-rich and sandstone/siltstone units, marking a rheological contrast. The movement along the BDSs also resulted either in the displacement of vertical dykes (where present) or the propagation of low-angle thrusts. Thrusts are primarily small and confined within the overburden units, displacing lithologies by 5m to 20m. The origin of the BDSs in the Moranbah Coal Measures is unknown. However, the current fission track and K-Ar geochronological dates of igneous intrusions, such as dykes and sills, across the Bowen Basin indicate an Early Cretaceous age. Therefore, if we consider the same age for the displaced dykes, bedding-parallel shears could have occurred synchronously or after the Early Cretaceous. This work underscores the need for further structural investigation of BDSs, which could enhance our understanding of these structures and their implications for geotechnical and coal quality risks impacting mining operations.

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Late Cenozoic uplift associated with the Lapstone Structural Complex in eastern NSW

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The 95 km-long Lapstone Structural Complex consists of north-trending faults and monoclines in the western Sydney Basin between the Cumberland Basin to the east and lower Blue Mountains to the west. It has developed in a compressional regime. At depth, the Lapstone Structural Complex is most likely a deeply penetrating, west-dipping thrust fault that is seismogenic in the brittle middle crust. This structure has propagated upwards into the overlying Sydney Basin in the top ~3 km of the crust and includes an east-facing monocline (Lapstone Monocline) with dips increasing from west to east formed as a fault-propagation fold. It has played a role in landscape development as shown by topography, antecedent meander bends along the Nepean River, uplifted river gravels (Rickabys Creek Gravel) and knickpoints along lower order streams.

Uplift associated with the Lapstone Structural Complex is mainly in the lower Blue Mountains and followed an uplift event associated with Cenozoic volcanism and the broader uplift of the Great Dividing Range in eastern Australia which has been related to Cretaceous Tasman Sea rifting. Evidence for timing and topography for this broader uplift is based on mineral fission-track ages and pre-Cenozoic basalt topography. The second uplift event was followed by rapid erosion shown by the upper Grose River gorge. The Lapstone Structural Complex event was associated with some rejuvenation of the broader uplift to form the Rickabys Creek Gravel which consists wholly of clasts derived ultimately from the Lachlan Fold Belt.

The Rickabys Creek Gravel is widely developed on the Cumberland Plain and is mapped along the dipping limb and even the upper flat limb of the Lapstone Monocline over a north-south distance of 16 km. It is folded by the Lapstone Monocline and finding its age is therefore critical to establishing the timing of the Lapstone Monocline (and hence the Lapstone Structural Complex). A new source-to-sink inversion-based $_{10}$Be-$_{26}$Al age, known as P-PINI (Particle Pathway Inversion of Nuclide Inventories), has been determined for the Rickabys Creek Gravel exposed in a disused railway cutting near the crest of "Lapstone hill" adjacent to the Great Western Highway at Glenbrook. The preliminary burial age is 3 ± 1 Ma (1σ) and indicates an upper Pliocene age of monocline formation and uplift. This result is consistent with the youthful appearance of the Lapstone Structural Complex although in the past age limits of Cretaceous to pre-Quaternary were acknowledged.

The tectonic and volcanic history of Northern Zealandia

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A defining characteristic of the southwest Pacific is the significant amount of continental crust and volcanism distributed throughout the region. This includes the world's largest submerged continent, Zealandia, which separated from eastern Australia and Antarctica in the Cretaceous during the final phase of Gondwana break-up. In addition, together with eastern Australia and Antarctica, Zealandia hosts one of the world's largest intraplate volcanic provinces. Major knowledge gaps exist in our understanding of the tectonic and volcanic history of the northern part of Zealandia, including: the location and continuity of the Mesozoic subduction related magmatic arc; the extent of the Late Cretaceous to Eocene rift-related volcanics, and the enigmatic source of the widely distributed Cenozoic non-plume-related intraplate volcanism. To address these gaps, we conducted research voyages on the *RV Investigator* and its precursor, the *RV Southern Surveyor* [Mortimer et al. 2023; Seton et al. 2016] to unlock the rock record hidden > 1,000 km offshore eastern Australia and beneath 1-3 kilometres of water. We undertook a series of rock dredges, informed by swath bathymetry and/or existing seismic reflection profiles, to target places either where continental basement outcrops at the seabed or at seamounts where volcanic basement could be sampled beneath their carbonate caps. We performed detailed geochronological and geochemical analysis of these samples combined with regional geophysical data interpretation to determine the location and orientation of the Mesozoic Gondwana magmatic arc axis (Median Batholith) from New Zealand through to the northern reaches of Zealandia, at the Fairway Ridge, and mapped the extent of Late Cretaceous to Eocene rift-related volcanics and their relationship to strong positive magnetic anomaly signatures in the region. Spatio-temporal and geochemical analysis of a regional compilation of Cenozoic intraplate volcanics reveals that the stimulation of an enriched mantle reservoir at the transition zone due to changes in subduction flux at the Tonga-Kermadec trench system is the main driver of this volcanism. Our work has provided the first offshore reconnaissance geological mapping of the Zealandia continent and its volcanic record. These findings are of critical importance for interpreting the Mesozoic geological history of pre-breakup eastern Australia, the nature of its asymmetric rifting and for understanding the driver of the regional Cenozoic thermal pulse alongside contemporaneous plume-related activity.

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Cretaceous basement rock dredges from the Louisiade Plateau

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The Paleozoic to early Mesozoic tectonic history of eastern Australia represents a long-lived phase of an active convergent plate margin along eastern Gondwana. This margin involved a continental magmatic arc in at least the Jurassic and Early Cretaceous. The orientation and location of the Early Cretaceous volcanic arc is debated. This study presents lithological, zircon and geochemical data of rocks collected by the RV Investigator in 2019 from an offshore continental fragment of Australia, the Louisiade Plateau, to contribute to this debate.

The IN2019_V04 voyage successfully dredged rocks on the western margin of the Louisiade Plateau. Sedimentary rocks include argillaceous bioturbated mudstone and variably turbated siltstone. Volcano- sedimentary rocks include polymictic volcanic angular lithic sandstone, volcanic angular lithic breccia, welded ignimbrite, and a polymictic pumice fiamme angular lithic breccia. Volcanic rocks included a feldspar-phyric dacite, and a feldspar-quartz-phyric rhyolite. The latter represent a proximal-medial environment to volcanic centres.

Four volcaniclastic rocks have angular volcanic clasts that host zircon crystals together with free zircon grains. Zircons are both broken and euhedral and U-Pb dating shows a well-defined 106-123 Ma age range. Nine small broken detrital zircons in two siltstones had ages between 110 and 591 Ma. Most Louisiade Plateau zircon ages overlap with (1) the biotite granite cobbles (111 ± 1 and 128 ± 1 Ma) collected from the Fairway Ridge on the northern margin of Zealandia thought to be the northern extension of the Median Batholith (130-105 Ma), (2) the main phase of Whitsunday Igneous Province volcanism at 120-105 Ma, with pulses at 118-113 and 110-105 Ma, (3) 130-101 Ma zircon populations in New Caledonia sandstones, (4) New Zealand Early Cretaceous accretionary and fore-arc depositional basement terranes (Waipapa and Torlesse).

On immobile trace element plots, the volcaniclastic rocks are rhyolite to andesite in composition. These compositions match I-type plutons and magmatic arc fields on Rb vs. Nb+Y trace element plots. Pb and Nd isotope data overlap with the Waipapa and Torlesse Terranes. Sr isotopes show lower more mantle derived ratios perhaps explained by the high volcanic component compared to the sedimentary rocks of the terranes.

On Cretaceous paleotectonic reconstructions the 106-123 Ma volcanic and volcanosedimentary rocks from the Louisiade Plateau lie up to 700 km east of the present-day Australian mainland. They support the continuation of a Mesozoic arc and/or forearc from the Louisiade Plateau south into the submerged Mellish Rise and beyond to Zealandia's Median Batholith and accretionary and fore-arc basement terranes. They also support interpretations of the Whitsunday Igneous Province as a product of intraplate or a back-arc setting at this time.

The tectonic evolution of the western North American margin since the Devonian

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The western North American margin records multiple phases of rifting and collisional orogeny, resulting from the interaction between western Laurentia, rifted continental fragments, and intra-oceanic terranes originating in the Panthalassa and Pacific oceanic domains. Previous quantitative plate reconstructions of this margin have prioritised either surface geology or seismic tomography as the first-order constraint for determining the subduction polarity. This approach has led to divergent interpretations of Early Jurassic to Late Cretaceous (175-105 Ma) subduction polarities. Furthermore, seismic tomography cannot constrain paleo-trenches older than 200 Ma, due to thermal assimilation of slab material into the mantle. We present an updated tectonic reconstruction for western North America from the Devonian to present day. Our model reconciles geological histories based on surface geology, detrital and magmatic geochronology, paleomagnetism and isotopic data, with seismic tomography interpretations. The new reconstructions account for the tectonic evolution of Alaska, western Canada and western United States (US), south-western (SW) North America and north-western (NW) Mexico, which have not been implemented in detail in previous tectonic models. Our model suggests that most of the terranes of western North America were rifted off Laurentia and Baltica during Devonian to Triassic extension and trench-retreat. It also shows that terranes in the western USA were rifted from Laurentia, while terranes in northwestern Mexico were rifted from both Laurentia and Gondwana during Jurassic extension (200-170 Ma). Following back-arc rifting and opening, many of the terranes (e.g. Insular, Intermontane, Angayucham, Guerrero) experienced an intra-oceanic subduction phase before accreting to the continental margin of North America between Early Triassic to Late Cretaceous times. The model illustrates the collision of the Intermontane (Early Jurassic) and Angayucham (middle Jurassic to Late Cretaceous) terranes, which caused the formation of the Cache Creek and Alaska oroclines. The model also captures the Late Cretaceous collision of the Insular Terrane, which triggered transpression and northwards terrane displacement for thousands of kilometers in western North America during Late Cretaceous to Paleogene times. Our updated model underscores the importance of surface geology and geochronology in constraining the polarity of ancient subduction zones interpreted from seismic tomography. The approach developed for creating our tectonic model can be applied to regions that have undergone episodes of terrane accretion, such as the eastern Australian margin.

Topographic evolution of active margins: exploring the interplay of plate tectonics, mantle convection, and long-term climate using explainable artificial intelligence

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The processes controlling topography at active margins is highly complex, involving intricate interactions between plate tectonics, mantle convection, and surface processes influenced by climate. In regions of continuing subduction, these interactions create significant feedback, complicating the understanding of the resulting diverse topographies. To address this, we have developed an explainable artificial intelligence (XAI) approach using the Explainable Boosting Machine (EBM) to explore the roles of plate kinematics, mantle dynamics, and climatic factors in shaping topography at subduction margins. Our findings indicate that mountain elevations are predominantly influenced by factors such as subduction flux and trench migration rate, in conjunction with underlying mantle dynamics. We categorise the mountains formed in the region of continuous subduction into three main types based on these factors: (1) mountains with high subduction flux and large-scale mantle convection, like the Central Andes, characterised by very high elevations; (2) mountains with low to moderate subduction flux, retreating trenches with rollback, and small-scale upper mantle convection, resulting in moderate elevations, such as in Calabria in southern Europe; and (3) mountains with very low subduction flux, where high elevation is mainly driven by advancing trenches with rollover, like the Elburz Mountains in Iran. Using the understanding derived from our EBM model, we further developed a Random Forest-based regressor to reconstruct the palaeotopography of mountains and arcs at active margins since the Early Devonian. Our research offers fresh insights into mountain-building dynamics and serves as a valuable tool for understanding the critical role of mountains and active margin topography in shaping Earth's biodiversity.

Tectonic evolution of the Qiangtang Basin (northern Tibet): constraints from detrital zircon geochronology

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The Mesozoic Qiangtang Basin, located in the Tibetan Plateau, holds significant potential for hydrocarbon resources, yet its tectonic evolution is not entirely understood. To understand the tectonic history of the Qiangtang Basin in the context of the subduction history of the Tethyan oceans, we produced new detrital zircon data (U/Pb ICP-MS ages) and a compilation of published geochronological and stratigraphic data from Paleozoic to Mesozoic rocks in and around the Qiangtang Basin. Our findings reveal that the provenance of the Mesozoic strata in the Qiangtang Basin varies significantly both spatially and temporally. In the central Qiangtang region, the Lower to Middle Triassic sequence exhibits unimodal age spectra (300–233 Ma), suggesting a proximal arc source. The trace-element compositions of Permian to Triassic zircons from Lower Triassic strata are indicative of crystallization in arc and back-arc environments. These results support the hypothesis that the Qiangtang Basin formed as a back-arc basin controlled by the southward subduction of the Paleo-Tethys oceanic lithosphere. In contrast, Upper Triassic and Jurassic strata show a more diverse zircon provenance, including sources from Cambrian to Triassic magmatic rocks and Paleozoic strata within central Qiangtang, as well as Triassic flysch deposits from the Songpan-Garze Terrane. This transition, from a unimodal arc source in the Lower–Middle Triassic to varied provenances in the Upper Triassic, marks the closure of the Paleo-Tethys Ocean. Jurassic transgression-regression cycles in the Qiangtang Basin are linked to the evolution of the Meso-Tethys Ocean, especially the first cycle which corresponds to the rapid expansion of the Meso-Tethys Ocean and ends at the Callovian due to its initial subduction. During the Early Cretaceous, the closure of the Meso-Tethys Ocean resulted in uplift and a sedimentary hiatus, ending marine sedimentation in the basin, until the resumption of the terrestrial Upper Cretaceous Abushan Formation.

Episodic arc behaviour of the eastern Gondwanan margin (New England Orogen): Insights from detrital zircon geochronology

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The New England Orogen (NEO) is a non-collisional orogen in eastern Australia that developed along the eastern margin of Gondwana from the Devonian to the Triassic. The spatio-temporal-geochemical evolution of the NEO was possibly governed by changes in the tectonic state of the convergent plate boundary, which was subjected to periods of overriding-plate extension intermitted by phases of contraction and orogeny. These fluctuations in the tectonic regime may have led to arc migration, magmatic flare-ups, and magmatic lulls. However, the pattern of arc modulation and relationships to the geodynamic evolution of the NEO remain poorly constrained. To fill this knowledge gap, we study sedimentary basins in the NEO, which likely received material from the nearby arc, and therefore provide an ideal archive of the arc activity through time. We compiled geochronological data from Upper Carboniferous to Jurassic strata across the NEO. Our compilation identifies periods of enhanced arc activity at 325–310 Ma and 275–240 Ma, and periods of waning magmatism at 300–290 Ma and after 230 Ma. The dataset is incomplete, with crucial data missing. To address these gaps, we are collecting samples from Permian to Jurassic basins, such as the Esk, Tarong, Ipswich, and Lorne basins. Using the new geochronological data, in combination with geochemical constraints, we aim to better understand the spatio-temporal evolution of the New England arc.

Texas-Coffs Harbour double orocline model, New England Orogen

Jeff Brownlow[1]

[1]*Retired*

The Texas and Coffs Harbour Oroclines at the northern end of the southern New England Orogen form steeply plunging folds in an inferred, regional-scale, Z-shaped fold or double orocline. This double orocline was an extraordinarily creative means of welding disparate and anomalous elements into an apparently coherent geological model. However, not all underpinning assumptions have been adequately validated, viz:

1. **Continuity of the Tamworth-Yarrol belt.** Mesozoic cover prevents easy confirmation of the continuity of this belt to the south-west of the Yarraman Block (southern Queensland). Thus, the Yarrol Belt could turn south-easterly and extend beneath Mesozoic cover to the Coffs Harbour Orocline (as claimed). Alternatively, it could turn south-westerly to join the Tamworth Belt directly, and only be in fault contact with the correlatives that extend to the south-east.
2. **Regional scale Z-shaped folding formed through right-lateral shear**. Regional Z-shaped folding is observable in the accretionary complex that abuts the Tamworth-Yarrol Belt. However, right-lateral shear motion is necessary only if the Tamworth-Yarrol belt is a single entity (as claimed), and if the accretionary complex exhibits substantial stratal continuity in the three limbs of the inferred Z-shaped fold. Otherwise, left-lateral shear folding, for which there is sparse but widespread support, needs to be considered as a possible alternative.
3. **Mechanical feasibility.** Devonian-Carboniferous arc/ forearc basement forms the core of the inferred, isoclinal, Coffs Harbour Orocline. Those rocks likely constitute some of the strongest basement in the orogen. The feasibility of folding them isoclinally remains to be demonstrated. Likely effects, such as intense cleavage development and significant crustal thickening, need consideration.
4. **Geophysical anomalies**. Firstly, the inferred Coffs Harbour Orocline is a regional-scale isoclinal fold that is open to the north. However, aeromagnetic images of that area suggest a closed, basin-like shape once attributed to the presence of a Triassic basin. Support for the basin interpretation comes from Triassic basalts that occur in the Mt Barney Complex (Queensland border), within a local extension of the basin-shaped aeromagnetic anomaly. Secondly a U-shaped gravity anomaly, that is open to the SE, occurs south of the Yarraman Block in southern Queensland. This is an area of Mesozoic cover overlying inferred Tamworth-Yarrol belt rocks. Its shape is not explained by the double-orocline model. Thirdly. linear aeromagnetic and gravity anomalies along the “Peel Fault” in the Texas Orocline core occur far closer together than supposedly similar anomalies Tamworth-Bingara area.

Thus, assumptions underpinning the double orocline model need confirmation.

New England Orogen granitoid diversity and crustal development

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Permian-Triassic granitoids of the southern New England Orogen are abundant and diverse. They include the S-type Bundarra and Hillgrove Supersuites, the I-type Clarence River and Moonbi Supersuites, the transitional IS-type Uralla Supersuite, as well as the Triassic "Coastal" Supersuite (mainly reduced, low-K I-types, along with sparse A-types).

Geological factors and fundamental processes significantly constrain their potential origins. The New England Orogen at the start of the Permian, likely comprised a mechanically weak, immature, reduced accretionary complex outboard of a mechanically stronger, oxidised forearc/arc, all overlying an *in situ* Carboniferous slab. Multiple Permian-Triassic regimes, potentially mostly involving flat subduction and slab breakoff, profoundly reworked the arc/ forearc/ accretionary complex assemblage. Most regimes induced contrasting across-"arc" mantle-upwellings: inboard plutons are commonly larger than outboard plutons and sourced all(?) Sn-F mineralisation. Several specific factors potentially contributed to the diversity of New England granitoids.

1. **Basement type**. Arc/ forearc basement (already dryer and oxidised) mainly yielded oxidised, low-K, I-type granitoids (Clarence River type), whereas accretionary complex basement yielded variably oxidised, more potassic compositions (Bundarra, Hillgrove, Uralla, and Moonbi types).
2. **Mafic underplating as a source of I-type granitoids**. Mafic crust of the Carboniferous slab was potentially present beneath the accretionary complex throughout the Permian. A mafic (Gympie-like?) terrain was potentially underthrust from the east in the earliest Triassic, providing a common mafic source for Coastal granitoids across contrasting upper crustal blocks.
3. **Reduced sediments**. The accretionary complex was likely initially reduced, accounting for the reduced nature of Permian S-type and IS-type granitoids. Triassic underplating potentially introduced a small, reduced, sedimentary component to the source of Coastal-type granitoids.
4. **Water content**s. Water potentially controlled the surface tension of melts. Potentially, high contents favoured magma mixing (Hillgrove granitoids), intermediate contents allowed restite retention (Bundarra, Uralla and Moonbi granitoids), and low contents favoured unmixing and fractionation (inboard leucogranites). Water contents in the accretionary complex were likely highest early (inherited) and outboard (replenished?), but reduced by crustal movements. Local dehydration and oxidation by early magmatism potentially influenced later magma compositions.
5. **Crustal movements**. Early Permian crustal movements and associated thermal input likely work-hardened and dehydrated the accretionary complex. Mafic intrusions were potentially able to invade the initially weak accretionary complex in the Early Permian to form S-type granitoids. Later intrusions were likely trapped at the base of that pile, facilitating interaction with underlying mafic crust. Earth movements potentially caused inboard crustal thickening, leading to extending pathways and fractionation opportunities, and facilitating leucogranite formation.
6. **Slab stacking**. The stacking on one flat slab segment beneath an older, active slab segment could potentially delay the descent of the older segment. Age anomalies could thus arise in granite belts defined historically by geological factors, prior to the availability of reliable dating.

Revisiting the Triassic: refining temporal frameworks and provenance in the Bowen Basin through U-Pb detrital zircon geochronology

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Extensive lithological and geochronological studies within the northern Bowen Basin, have primarily focus on the well-documented coal-producing Permian intervals, leaving the post-coal-forming Triassic depositional phase severely underexplored. This study aims to fill this gap by integrating detailed lithostratigraphic interpretations with U-Pb detrital zircon geochronology and chemostratigraphy from outcrop and drill core to refine the temporal and depositional framework across the Bowen Basin. These analyses provide critical age constraints and correlation tie points with coeval units in the adjacent Cooper and Galilee basins.

Our newly defined Maximum Depositional Age (MDA) for the Arcadia Formation, positioned at the top of the Rewan Group in the Denison Trough, date to 231.9 ± 3.0 Ma. Based on detrital zircon MDA control, the Arcadia Formation is significantly younger than previously reported, indicating a late Middle to Late Triassic age rather than an Early to early Middle Triassic age. Further, previous relative age dating using palynology indicated that the foreland loading phase of the Hunter-Bowen Orogeny ceased approximately at 246 Ma, with deposition ending at 237 Ma (Grech, 2001; Campbell et al., 2022). Our revised ages challenge previous interpretations and suggest instead a more prolonged period of tectonic subsidence and sediment accumulation in the Bowen Basin. These findings necessitate a revaluation of geodynamic models to better understand Triassic magmatic sources and clarify the tectonic history of the post-Permian (Triassic) period in Eastern Australia. By utilizing U-Pb detrital zircon dating and paired Hf isotope analysis for sedimentary provenance, our study aims to reconstructs paleofluvial drainage patterns and deciphers the timing and location of Triassic tectonics, including uplifts, volcanic centers, and basin depocenters.

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Age and significance of the Willowie Creek Beds and Gordonbrook Serpentinite, southern New England Orogen

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Remnants of the Paleozoic Panthalassa Ocean are interwoven through the New England Orogen (NEO) in the form of ophiolite and island-arc terranes. Such oceanic terranes remain the most poorly understood elements of many orogens due to the scarcity of datable minerals and their disrupted nature. However, knowledge of their age and the settings and locations in which they formed are critical to accurate tectonic reconstructions. In this study we report new U–Pb zircon ages from the volcanic arc-derived metasedimentary Willowie Creek beds (WCB) (Fergusson 1984) and the largely harzburgitic Gordonbrook Serpentinite in NE New South Wales.

Detrital zircon U–Pb LA-ICP-MS ages from the WCB reveal Middle Ordovician to Middle Devonian age populations with minor Cambrian and Precambrian 'Gondwanan' inheritance. This is consistent with biostratigraphic constraints from sparse fossil localities. A younger population (253-247 Ma) of zircons is associated with localised felsic melt patches and not part of the protolith. Rare zircon grains were also extracted from chromitites and dolerites of the Gordonbrook Serpentinite and dated using the ANU SHRIMP to 254–242 Ma with minor inheritance of Silurian and Precambrian grains.

The youngest Permian-Triassic zircon age populations recognised from the WCB and Gordonbrook Serpentinite are similar to the ~255 Ma age of the Dumbudgery Creek Granodiorite (Waltenburg et al. 2016) that intrudes both formations. We conjecture that during the Permian-Triassic Hunter-Bowen Orogeny anatexis in the Gordonbrook Serpentinite and WCB produced mafic and felsic melts that coalesced and formed the intermediate Dumbudgery Creek Granodiorite.

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Lower Cambrian distal and proximal volcanics from the Arrowie Basin, South Australia and the Gnalta Shelf, western New South Wales

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Lower Cambrian volcanics in South Australia and western New South Wales provide age constraints on sedimentary sequences and fossil deposits within these regions, and potentially provide information on tectonic setting at the birth of the eastern Australia Pacific margin. Single volcanic samples within the Mernmerna Formation and lowermost Billy Creek Formation in the Arrowie Basin have been analysed using CA-TIMS U-Pb zircon geochronology, giving ages of 515.38 ±0.13 Ma and 511.87 ±0.14 Ma, respectively (Betts *et al*., 2018). In addition, the Cymbric Vale Formation on the Gnalta Shelf in western NSW has also been CA-TIMS dated, giving a similar age of 514.96 ±0.16 Ma (Betts *et al*., in press). However, despite these newly acquired radiometric dates, there have been no recent targeted investigations into these lower Cambrian volcanic deposits. Distal volcanics in the Mernmerna Formation in the Arrowie Basin occur as thin (2–3-cm-thick), green, fine-grained layers, with some thicker layers (up to 60 cm) interpreted as ash fall deposits interbedded with marine limestones. Volcanics in the younger Billy Creek Formation also occur as thin (2–6-cm-thick), green, fine-grained layers, in addition to thicker (up to 25 cm) salmon pink beds that occasionally exhibit rippled surfaces, interbedded with shallow marine, clastic sedimentary rocks. In contrast, volcanics in the Gnalta Group are non-bedded and display fiamme structures, more suggestive of a proximal aerial deposit. The Cymbric Vale Formation is a green, coarse-grained, crystal-rich ash with pumice clasts, displaying massive outcrop style, while the underlying Mt Wright Volcanics is fine-grained with felsic to intermediate composition. While the ages of these volcanics are similar, it is clear that they have distinct textural, depositional, and compositional differences. Further work is focused on using a combination of detailed stratigraphic, petrographic, geochemical and precise CA-TIMS U-Pb geochronological analyses to outline the evolution of the volcanism, melt sources and tectonic setting for this part of the Gondwanan margin during the early Cambrian.

Key words: Petrography, Pyroclastic rocks, East Gondwana, Early Cambrian, Tectonics

Style of thrusting in the Bowen Basin Folded Zone, Central Queensland, eastern Australia

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The structural style in fold-and-thrust belts can vary in response to the presence of décollements, the reactivation of pre-existing basement structures, and the shape of older basins. Inversion of the Bowen Basin in eastern Australia during the Late Permian to Triassic Hunter-Bowen orogeny created thrusts with opposite vergences, but the style of thrusting and deformation mechanisms are not fully understood. To examine the geometry and style of thrusting in the Bowen Basin Folded Zone (BBFZ), a comprehensive study was conducted using 2D seismic data and field mapping. The findings reveal that Permian units were displaced by NNW–SSE, southwest-dipping, low-angle thrusts to high-angle reverse faults. Older symmetric folds were also displaced, leading to the development of asymmetric hanging-wall anticlines. The NNW–SSE thrusts in the BBFZ differ from those in the Jellinbah Thrust Zone (JTZ). First, the former thrusts are shorter (~15 km) than the latter. Second, thrusts in the BBFZ dip predominantly towards the southwest, opposite the dip direction in the JTZ. Third, the displacement along the BBFZ thrusts (up to ~130 m) is smaller than that of the JTZ (>300 m and up to ~1000 m). Evidence of displaced Middle Triassic units in the BBFZ indicates that thrusting in this segment of the Bowen Basin occurred during the last phase of the Hunter Bowen Orogeny (at 235–230 Ma).

Based on the structural observations, we suggest that thrusting in the northern Bowen Basin occurred in two stages. The first stage involved the movement along a deep-seated northeast-dipping crustal-scale décollement, which resulted in the southwest-ward movement of the JTZ in the folded Permian-Triassic units. During the second stage, northeast-verging thrusting was accommodated by localized décollements in the BBFZ, along the eastern margin of the basin. Alternatively, it is possible that the BBFZ thrusts and folds were developed simultaneously prior to the movement along the JTZ thrusts. If so, a basal decollement may have caused the development of symmetric detachment folds. Further northeast movement along this basal decollement may have driven southwest-dipping thrusting.

Cambrian-Ordovician Wagonga Group: oceanic rocks accreted to a subduction complex in the eastern Lachlan Orogen, NSW South Coast

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Highly deformed rocks of the Cambrian to Ordovician Wagonga Group are well exposed along the coast around Batemans Bay and Narooma on the NSW South Coast in the eastern Lachlan Orogen. The tectonic setting of these rocks has been debated and several geologists have supported a subduction complex setting. Detailed mapping and other data have been collated on the stratigraphy, structure and age of the Wagonga Group. For the Narooma district and for parts of the Batemans Bay district a radiometric image (RGB, K-Th-U) is available (see MinView https://minview.geoscience.nsw.gov.au/) which has provided constraints on the inland mapping of these complicated rocks. Different hypotheses for the development of the Wagonga Group include the roles of subduction accretion, strike-slip faulting, diapiric melange formation, and olistostrome deposition.

In the Narooma district the stratigraphy of the Wagonga Group is well known from previous detailed work on ages of cherts/black mudstones and a current map compilation based on the radiometric image. The stratigraphy consists of the Kianga Basalt, the Narooma Chert and both are overlain by the mudstone-dominant Bogolo Formation. The Bogolo Formation contains disrupted rocks (melange) with quartz sandstone, chert and greenstone fragments contained in a foliated mudstone matrix. Stratigraphic relationships are complicated and in the Narooma district the Kianga Basalt has been considered the oldest unit and underlies the Narooma Chert but locally Kianga Basalt is injected into adjacent Narooma Chert. Multiple folding has been documented by previous work with an early phase of generally east-west trending folds (with rare axial planar cleavage) overprinted by typically isoclinal, abundant, northerly trending folds with axial planar cleavage and at least two subsequent sets of younger folds. Local dome and basin fold interference patterns are developed. Faulting is widespread and has occurred throughout the deformation history. In contrast to the Wagonga Group in the Narooma district, in the Batemans Bay district the upper part of the Narooma Chert overlies the Adaminaby Group turbidites. At Burrewarra Point 15 km south-southeast of Batemans Bay, Bogolo Formation mudstone and Adaminaby Group disrupted turbidites are adjacent to and locally intermingled with Cambrian shallow-marine limestone and ocean island basalt of the Kianga Basalt.

The complicated deformation history involving early thrust faulting including examples of widespread natural fracking, in addition to the oceanic succession (including ocean island rocks), are consistent with accretion in a subduction complex at the eastern margin of the Lachlan Orogen. Timing of the accretion is loosely constrained to the Late Ordovician – early Silurian Benambran Orogeny.

Unravelling the tectonic and metamorphic framework of subglacial East Antarctica using detrital garnet Lu-Hf geochronology

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East Antarctica remains one of the least understood geological regions on Earth due to its extensive ice sheet cover and remote location. However, given its pivotal position in past supercontinents, understanding the tectonic framework of subglacial East Antarctica is crucial for advancing global plate tectonic models. More than 99% of East Antarctica is ice-covered, and therefore, geological information is primarily provided by geophysical data, satellite imagery, and scarce rock outcrops in coastal areas and the Transantarctic Mountains. Where the basement cannot directly be sampled, alternative methods are needed to probe into the subglacial geology of the continent.

Here, we will report results from laser-ablation detrital garnet Lu-Hf geochronology[1,2] from sediment cores (IODP, DSDP, ODP and R/V Nathaniel B Palmer cruise NB0101) collected offshore and adjacent to major glaciers along the East Antarctic margin. Glacial deposits are important sedimentary archives of detritus that were eroded from the East Antarctic basement; detrital garnet in these deposits can be used to study the complex tectonic and metamorphic histories of the source terranes they were derived from. We compare a preliminary detrital garnet Lu-Hf dataset with published data from other geochronometers such as detrital zircon U-Pb and mica Ar-Ar from four main study areas offshore East Antarctica. ODP hole 1167A was recovered near Prydz Bay and contains two main detrital garnet populations at ca. 950 and 560 Ma., giving us insights into the amalgamation of Indo-Antarctica within supercontinent Gondwana. Detrital garnet from DSDP hole 268, from offshore Wilkes Land, was dated at ca. 1200 Ma and this sample can therefore be used to study the Albany-Fraser-Wilkes Orogeny in Australo-Antarctica. DSDP hole 269 and IODP holes U1358, U1359, and U1361 were retrieved near Terre Adélie, where Archean-Paleoproterozoic basement rocks correlate with the Gawler Craton in southern Australia. Due to their proximity to the Mertz and Ninnis Glaciers, these three cores also include garnets that originated from the Ross Orogen in George V Land. DSDP holes 274 and 273, which contain sediments and erratics derived from the Transantarctic Mountains in Victoria Land, are used to study the timing of metamorphism during the Ediacaran-Cambrian Ross-Delamerian Orogeny, which has recently been proposed to include garnet-grade metamorphism at ca. 590 Ma[2], and the inception of subduction along the Palaeo-Pacific margin of Gondwana.

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Phase Equilibrium Modelling of Subduction Systems

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In geological contexts, phase equilibrium modelling (PEM) refers to any type of effort made to emulate the processes via which rock-fluid assemblages reach thermodynamic equilibrium. PEM methods calculate what mineral and fluid phases are stable at given pressure, temperature, and bulk rock composition (forward modelling), or invert observed mineral assemblages and compositions to infer pressure and/or temperature (inverse thermobarometry). A key component of PEM in modern petrology are the composition-dependent equations of state (x-eos), a set of thermodynamic descriptions of individual mineral or fluid phases.

A subduction channel system is a relatively thin, highly sheared interface formed in subduction zones between a subducting tectonic plate and a relatively less dense overriding plate (

Figure 1). It hosts various poorly understood metamorphic and metasomatic processes, driven by reactive return flow of supercritical fluids rich in aqueous components liberated from the top of the subducting slab.

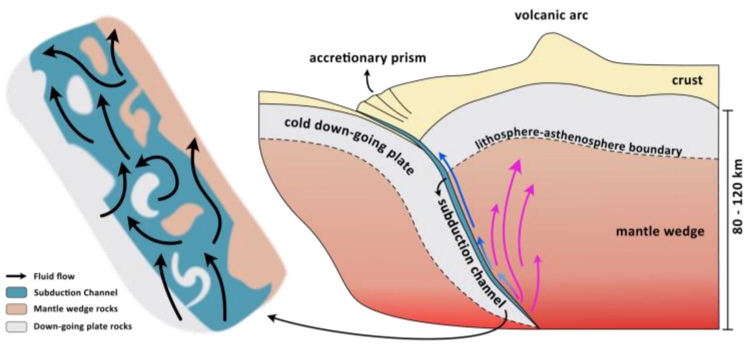

Figure 1. Subduction channel system. Blue arrows: return flow of metasomatic water-rich fluids released from the subducting slab. Purple arrows: flow direction of mantle wedge melts ascending to volcanic arc.

Existing x-eos (1, 2) for phases found in subduction systems are untested under the high-pressure conditions from which material is thought to be exhumed. We seek to improve the mineral and fluid x-eos needed to apply PEM to subduction systems. First, equilibrium calculations using current x-eos for key minerals such as jadeite, chlorite, and lawsonite have been tested against experimental data (3), and the contributing x-eos modified as necessary. Subsequently, once the x-eos for solid phases are well established, we will develop an x-eos for the supercritical slab-fluid with a composition range that runs continuously from aqueous fluid to silicate melt. The new x-eos will provide a quantitative link between the conditions of experiments and their run products, allowing us to interpolate between experimental studies for interpreting field observations and simulating subduction channel processes.

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Quiet vs loud arc volcanoes. A microanalytical perspective into magmatic architecture across the Central Andes

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Current understanding visualises arc magma plumbing systems as complex, vertically extensive, crystal-rich mushes that span the entire crust. The model of transcrustal magma storage is consistent with enhanced geotherms during periods of high magma productivity – ignimbrite flare-up events that lead to caldera forming eruptions. However, these conditions are rare and alternate with major periods of steady-state (quiet) volcanism where erupted magma is relatively more mafic. The transition between 'loud' flare-up volcanism and 'quiet' steady state activity is important because porphyry copper mineralisation is often related to the end of flare-up periods, and because hazards associated with flare-up and steady state eruptions are markedly different.

Here, we explore steady state magma plumbing architecture in active and recent volcanism across the Central Andes. We reconstruct mush systems by deconstructing the petrological information locked in erupted rocks: individual crystals and crystal zones, as well as the host volcanic matrix, which is a proxy for the erupted magmatic liquid. We focus on five volcanoes located at increasing distance from the arc trench, above a deepening subducting slab: El Negrillar monogenetic field and Socompa stratovolcano (slab depth = 92 km), Lascar stratovolcano and Cerro Overo monogenetic cone (slab depth = 111-113 km), and Tuzgle stratovolcano in the back arc (slab depth = 182 km).

When interrogated separately, the petrological components unveil distinct episodes of the magmatic journey from source to surface. The volcanic matrix has relatively evolved basaltic trachyandesite to rhyolite compositions with typical MgO of 1-5 wt.%, indicating that primary melts did not erupt and became strongly modified through the crust. Matrix data reveal differences between the volcanoes that are not apparent from whole rock data alone, including trace element contents that preserve differences in source components and lower crustal differentiation. Mafic phenocrysts record crystallisation in the middle crust (based on clinopyroxene-liquid thermobarometry), with hydrous phases in the arc front stratovolcanoes and olivine restricted to monogenetic volcanoes and the back arc. Plagioclase is the main rock forming mineral and makes a range of crystal populations. Matrix microcrysts are strikingly constant in composition across the arc, consistent with crustal filtering. Phenocrysts are complexly zoned and record fractional crystallisation, mafic recharge and crustal assimilation in upper crustal mushes, providing a connection with flare-up events. Our work shows that deconstructing melt and crystal records can improve proxies into magma generation, differentiation and filtering, potentially helping reconstruct key changes across arc systems in space and time, including transitions between typical steady state arc magmatism, punctuated flare-up events, and porphyry copper mineralisation.

Plagioclase as a mineralization marker in Porphyry Copper Deposits

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The interplay between tectonics and magmatism drives intense volcanic activity known as flare-ups, often culminating in massive caldera formations and ignimbrite eruptions[1]. In the Central Andes, such events occurred at various stages during the geodynamic evolution of the orogen, contributing to crustal growth[2] and allowing the formation of some of the world's largest porphyry copper deposits.

Volcanic records from flare-ups include rocks with both felsic and mafic characteristics. These lithologies deviate from the typical andesitic composition of erupted lavas in continental margins. Felsic melts can remain trapped in the crust for millions of years and, provided favorable conditions ensue, may feed the development of porphyry copper deposits. However, the magmatic processes associated with copper enrichment remain poorly understood.

Here, we explore a new approach to understanding the genesis of Andean porphyry copper deposits by analysing plagioclase in young volcanic rocks, alongside porphyry-related and barren intrusions. Plagioclase is the most abundant mineral in andesitic magmas and has slow lattice diffusion, which allows for the preservation of elemental and isotopic records. It can therefore provide insights into the conditions of magma storage, evolution, and eruption dynamics. Our preliminary results indicate that the geochemical signatures of phenocrysts and mush or lithic fragments in volcanic rocks are similar to those found in the proximity of massive porphyry copper deposits. We explore potential differences between mineralised and non-mineralised intrusions, aiming to detect key distinguishing factors in the origin, development, and maturation of porphyry copper deposits.

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Slab tearing as a driver of porphyry ore deposit formation in island arcs

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Discovering new porphyry ore deposits is vital to address the rapidly rising demand for copper (Cu). On a global scale, porphyry ore deposits are largest and most abundant in mature continental arcs[1,2], such as the Andes, where intra-crustal garnet fractionation may produce oxidised magmas suitable for metal enrichment during fluid saturation in the upper crust[2]. However, giant porphyry ore deposits (>2 Mt contained Cu[3]) have also been discovered in island arcs, where the crust is too thin to fractionate garnet. In many cases, island arc porphyry ore deposits are spatially and temporally associated with 'anomalous' arc volcanoes that display geochemical or spatial characteristics inconsistent with formation via 'typical' metasomatic melting of the mantle wedge[1,4,5]. In this study, we evaluated the possible contributions of slab tearing to forming Pliocene–Holocene island arc porphyry ore deposits in Indonesia, Papua New Guinea, and the Philippines. To do so, we first identified areas of slab tearing by considering lava compositions in the context of local and regional seismic tomography models. We then interrogated geochemical data from the porphyry ore deposits to identify genetic links between slab tearing and metal enrichment. Our multi-disciplinary approach demonstrates that in Indonesia, giant Pliocene–recent porphyry ore deposits are positioned along the edges of slab tears that facilitate melting within the garnet stability field, forming oxidised melts akin to those of mature continental arcs. The compositions of porphyry ore deposits (and associated 'anomalous' volcanoes) in Papua New Guinea and the Philippines are diverse, but these systems are concentrated above torn slab sections. These spatial relationships indicate that slab tearing is likely an important process for forming porphyry ore deposits in island arcs, but the observed geochemical diversity implies that the petrogenetic role of slab tearing in metal enrichment varies within and between arcs.

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The solubility of monazite in carbonate melts – implications for monazite formation in carbonatites

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Rare earth elements (REEs) are essential for the transition to nett zero energy production. Hence an abundant and cost-effective supply is crucial but is threatened by geopolitical factors. REE mineralization is commonly associated with carbonatite systems, yet the mechanisms causing their enrichment remain poorly understood. Monazite ($REEPO_4$) is a key REE ore mineral but its solubility in carbonate melts has not been determined. We have conducted a high pressure-temperature experimental investigation aimed at evaluating the controls on monazite solubility in model carbonatite melts. We ran synthetic mixtures of a natural monazite composition with sodic dolomitic carbonate melt, modelling carbonatite magma. The mass ratio of the monazite mix to the carbonate mix was such that the system was saturated in monazite. Piston-cylinder experiments were conducted at 1.0 and 2.0 GPa and a range of temperatures, replicating upper mantle and deep crustal conditions. We systematically examined the effects on monazite solubility of the addition of variable amounts of SiO_2 and F^- and varying Ca#. Experimental runs crystallised euhedral, primary monazite crystals in equilibrium with carbonate melt. Electronprobe microanalysis, scanning electron microscopy, Ce K-edge X-ray Absorption Near Edge Structure spectroscopy and photo-inducted force microscopy were deployed to fully characterise melt and monazite compositions.

Monazite solubility was expressed as the solubility product derived from the monazite solution reaction $[REEPO_4] = [REE^{3+}] + [PO_4^{3-}]$ where the square brackets denote the mole fraction of REE cations and phosphate anions in the melt. Systematic variation of melt compositions enabled the development of a new multivariant linear regression model to predict monazite solubility based on temperature, pressure, and composition. Our study reveals very high monazite solubility in carbonate melt in general, peaking at >60 wt% $CePO_4$ equivalent at 2 GPa and 1450°C. Experimental findings highlight that monazite solubility (1) increases with increasing temperature, (2) decreases with increasing SiO_2 and to a lesser extent increasing F^-, and (3) is not affected by melt Ca/[Ca+Mg] or pressure from 1.0 GPa to 2.0 GPa.

The results suggest that monazite is unlikely to crystallise directly from natural carbonatite magma until high levels of crystal fractionation have driven the evolved liquid to very high P_2O_5 abundances. However, most crustally emplaced carbonatites probably evolve by crystallising calcite and apatite, which are expected to lower P_2O_5 in the residual liquid. The evolved melt could potentially give rise to monazite formation by partial or complete replacement of earlier apatite, consistent with textural observation of this replacement reaction in some carbonatites (e.g., Prokopyev et al., 2017). Alternatively, reaction of carbonatites with siliceous crust may lower monazite solubility sufficiently to lead to saturation.

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REE transport in hydrothermal mineralizing systems: implications from thermodynamic models

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Hydrothermal fluids play an important role in mobilizing, fractionating and enriching REE in natural hydrothermal systems. A better understanding of the transport behaviour of REE in hydrothermal fluids and during fluid-rock interactions is key to understanding the formation of hydrothermal REE mineral deposits. The knowledge further contributes to exploration, ore processing and recovery of REE.

Despite the overall similar chemical behaviour of REE group elements, their responses to different aqueous complexing agents (e.g., chloride, fluoride, carbonate), and physical-chemical factors (e.g., temperature and pH), can vary significantly. The Olympic Dam deposit in South Australia is the world's largest uranium resource which also hosts significant amounts of REE in the iron oxide ore body. Fluorine is highly enriched in the high-grade ores and is also elevated in the surrounding granites that potentially provide F and REE to the mineralizing system. We evaluated the role of F in the transport of REE at Olympic Dam via thermodynamic modelling and found that the presence of F greatly improves REE mobility in fluids and may contribute to the REE enrichment in the ore body. Alternatively, carbonate is also an effective complexing agent for REE and may contribute to REE transport and mineralization in near-surface low temperature environments. Our thermodynamic model shows that the LREE and HREE can be fractionated in carbonate-rich alkaline fluids depending on the concentration of dissolved CO_2, which may explain the REE patterns observed in regolith REE deposits in South China. Overall, the improvements in thermodynamic properties and modelling techniques for REE aqueous species and solid solution minerals enables more accurate prediction of REE transport in geological fluids and a better understanding of their mineralization processes.

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New thermodynamic models for alkaline-silicate magmatic systems reveal fractionation at a mid-crustal tipping point primes REE-mineralised alkaline igneous rocks

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Alkaline-silicate igneous complexes contain a diversity of rock types and can host significant resources of critical metals, especially rare-earth elements (REEs). At present, the controls on their compositional diversity and REE enrichment are poorly quantified. Here we apply new thermodynamic models to investigate these controls using a case study of the Blatchford Lake Igneous Complex (Canada), which is compositionally-representative of worldwide alkaline-silicate systems and hosts a world-class REE deposit. By modelling fractionation of a primitive mafic melt across crustal pressures, we identify a 'tipping point' at ~4 kbar, about which residual melts become silica-rich or alkali-rich when shallower or deeper, respectively. Therefore, crystallisation both marginally above and below this mid-crustal pressure (within barometric estimates for the Complex) can generate the vast diversity of observed alkali-rich and silica-rich compositions. Furthermore, we show that REE concentrations in the Complex are consistent with residual enrichment via fractional crystallisation at these pressures. Optimal REE enrichment occurs during extensive fractionation immediately deeper than the tipping point. A similar tipping point is also present in other modelled mafic igneous systems, indicating it is a widespread phenomenon. This result implies a key role for mid-crustal mafic staging chambers in priming the world's largest REE-mineralised alkaline-silicate complexes.

Linking magmatism to orogenic gold mineralization through zircon geochemistry

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The metamorphic devolatilization model is commonly used to explain the genesis of orogenic gold systems. However, increasing number of new observations indicate that magmatism may play an important role in the formation of orogenic gold systems. Establishing a genetic relationship between magmatism and gold mineralization is difficult and usually relies on indirect indicators such as spatial and temporal relationships. In this presentation I am going to demonstrate that zircon trace element geochemistry can be used to map the magmatic hydrothermal transition and thus identify areas where these processes have occurred. Trace element geochemistry of zircon grains separated from orogenic gold related porphyritic intrusions have an unusual enrichment in As and Sb. Compositional mapping of these zircon grains indicate that As and Sb are enriched only in specific growth zones. Since As and Sb are highly incompatible elements and tend to concentrate in the fluid phase, we interpret that each growth zone enriched in these elements indicates zircon growth in contact with a magmatic hydrothermal fluid enriched in these elements and each growth zone depleted in these elements indicate fluid exsolution from the magma chamber. Thus, As and Sb compositional zoning in zircon grains can be used to map the magmatic hydrothermal transition and exsolution of fluids enriched in pathfinder elements for gold deposits. This may present a direct link between magmatism and orogenic gold systems.

Shock Value: Gold nugget formation from earthquake-induced piezoelectricity in quartz

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The overall mechanisms that are responsible for the transport and deposition of gold in orogenic deposits are relatively well understood, resulting from an interplay between these geochemical and structural factors. Gold precipitates from dilute (< 1 mg/kg Au), hot, $H_2O±CO_2$-rich fluids due to changes in temperature, pressure, and/or fluid chemistry. However, no widely accepted mechanism can explain the extreme localisation of gold needed to form large accumulations that can occur in orogenic quartz veins. This presents a paradox as to how gold preferentially concentrates to form such large accumulations in an inert host. We show that piezoelectric discharge from quartz may explain the ubiquitous gold-quartz association and the formation of gold nuggets. Quartz is the only abundant piezoelectric mineral on Earth, meaning that when distorted under stress the crystals produce an electrical potential proportional to the applied force. Seismic activity that drives orogenic gold deposit formation means that quartz crystals in veins will experience thousands of episodes of deviatoric stress. We confirm experimentally that stress on quartz crystals can generate enough voltage to electrochemically deposit aqueous gold from solution, as well as accumulate gold nanoparticles. Additionally, since gold is an outstanding conductor, our results show that existing gold grains are the focus of ongoing growth. We suggest this mechanism can help explain the creation of large nuggets and the commonly observed highly interconnected gold networks within quartz vein fractures.

Argyle pink diamonds: a story that involves a super continental break up

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More than 90% of the world's pink diamonds are sourced from Argyle in Western Australia, one of the very few deposits hosted in lamproite and situated at the edge of a continental block. The Argyle mine closed in 2020 and the hunt is on for a new source of these elusive gems. Whilst we knew that pink diamonds required both deep carbon and deformation, how these pink diamonds got to the Earth's surface remained elusive. Through dating detrital zircon and apatite with U-Pb and (U-Th)/He, and dating hydrothermal titanite with U-Pb LA-ICP-MS and ID-TIMS, we constrain the emplacement of the Argyle lamproite between 1311 ± 9 Ma and 1257 ± 15 Ma, coincident with the breakup of the supercontinent Nuna. Extensional forces from continental breakup appear to be the crucial trigger for emplacement of volatile-rich, pink diamond-bearing diatremes at the edge of continental blocks. So, if you ever purchase or receive an Argyle pink diamond, remember that, maybe like you, it once went through a pretty difficult break up to look its best.

Figure 1: A selection of faceted, coloured gems from the Argyle Mine in Western Australia (courtesy of Rio Tinto).

Reconstructing the fluid pathways in sedimentary basin using a mass balance approach: example of the Benassal Formation, Spain

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Dolomitization (i.e. replacement of $CaCO_3$ by $CaMg(CO_3)_2$) and associated MVT deposit is a major mineralogical replacement process that affects limestones in numerous carbonate platforms, basins and fold-and-thrust belts worldwide. This phenomenon makes an important part of the carbon cycle, and large-scale dolomite geobodies that develop in nature are prime targets for greenhouse gas storage, or are related to ore deposit bearing rare metals, oil and gas reservoirs and geothermy. The mass transfer between the original calcite and the newly formed dolomite was quantified in various natural cases of dolomitization, by coupling EPMA and LA-ICP-MS measurements, following a mass balance approach. This approach also allows to estimate the theoretical composition of an aqueous fluid whose element content would be provided by the reaction (i.e., in equilibrium with dolomite), as well as the partition coefficient for most elements involved in the reaction. This approach was tested using three existing datasets obtained from natural dolomite and original limestone in both Jurassic outcrops of the Layens anticline in the Pyrenees (France), and two from the Middle Devonian Pine Point Formation from the Presqu 'ile barrier (Canada). In these areas, dolomitization occurred at different T conditions (~50 to ~300 ◦C), from different fluid sources (seawater, basinal brines), and in different geodynamic settings (Centrella et al. 2023).

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Co-existing fenitizing fluids and carbonatite melts derived from ultramafic lamprophyres

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Fenites are an enigmatic group of rocks formed by high-temperature metasomatism of country rocks adjacent to carbonatite and alkaline igneous intrusions by aqueous fluids. The geological process of fenitization is thought to result from multiple pulses of alkali-rich aqueous fluids expelled from cooling carbonatitic and/or alkaline melts [1-3]. These fenitizing fluids may play an important and unrecognised role in upgrading the Rare Earth Element (REE) contents of carbonatities and have the potential to be used as exploration tools in the search for REE deposits [3]. Descriptions of fenites and their potential utility as exploration tools is currently limited, with insufficient experimental constraints on the compositions and processes of fluid expulsion from carbonatite and alkaline magmatic systems.

We have conducted high-pressure experiments on an ultramafic lamprophyre (aillikite) at conditions in which carbonatite melts are expected to occur; depths between 25 – 90km (~0.5 – 2.5 GPa) and temperatures of 850 - 1100°C. Alkali-poor carbonatite melts were generated in all experiments at temperatures above 900°C, but co-existed with immiscible alkali-rich aqueous fluids. We determined compositions for the dissolved solutes and fluids, establishing that K is the major alkali element present in these fluids. The expulsion of K from carbonatite melts at depth may explain the lack of K-rich, and predominance of Na-rich, carbonatites in the geological record and the propensity for fenite aureoles to be dominated by K-rich phases including phlogopite and feldspar [4]. We find no evidence in our experiments of co-existing immiscible carbonatite and silicate melts.

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Large scale mantle heterogeneity: A legacy of plate tectonic supercycles

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The Earth's mantle is divided by the circum-Pacific subduction girdle into the African and Pacific domains, each featuring a large low shear-wave velocity province (LLSVP) in the lower mantle. However, how does this hemispherical-scale mantle structure link to Earth's plate tectonic evolution remains unclear. Pioneer geochemical work recognised the presence of large-scale mantle heterogeneities in the southern hemisphere, termed the DUPAL anomaly. It was thought to be related to either the enrichment of subducted sediments and/or the mixing of more enriched ancient materials from the primordial lower mantle (i.e., the LLSVPs) formed during Earth's early differentiation process unrelated to the billions of years of plate tectonics. More recent work argued for a subduction-related origin for DUPAL-like mantle enrichment in either the deep plume source or the shallower mantle of the African mantle domain. Here we systematically reanalyse all elemental and isotopic data of mantle-derived oceanic igneous rocks that fingerprint the African and Pacific mantle domains. Data from both mid-ocean ridges and plume-related ocean islands and oceanic plateaus illustrate a consistent chemical dichotomy between the two domains, which can best be explained by tectonic supercycles over the past 1 billion years involving two supercontinents and two superoceans.

Managing geological complexity and practical applications: an industry-academic roadblock?

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Dugald River Zn-Pb-Ag ore deposit is hosted in a structurally complex system associated with the high-strain zone of the Roseby Corridor, 60km north of Cloncurry NW QLD. The Roseby corridor hosts many other mineralized prospects, the most significant being the Little Eva Cu-Au IOCG deposit, a few kilometres to the north.

Despite the interesting and complicated geological setting and abundance of mineral occurrences, published research on Dugald River area is scarce. To remedy this, the Dugald River Geology Team has dedicated a significant plan to support new research with practical applications. The most recently completed project out of JCU focused on the structural complications and controversies of the deposit.

Here I want to highlight two interesting outcomes of this research and the implications to practical use: 1) it subsequently identified the need for further regional geological understanding, and 2) highlighted a challenge in applying the research outcomes to the day-to-day geology team processes and orebody development. The latter is a challenge of particular interest to me. Attempting to align the research with the needs of an operation is hard but important. The resources industry in Australia needs our academic research centers to help them improve understanding of Australian geology. However, the academic sector needs to understand the needs of the industry better – applicable uses of research are key.

Ore body knowledge research of the future should focus on improving project design and the outcomes of research with a practical focus. The current state of Australian geosciences, we must ensure that our resources sector insists on quality research. To achieve improved visibility of the university geosciences sector, we need to show that industry needs this research. Improved practical research will help to build the relationship between academia and industry to force the requirement for a stronger academic landscape and hopefully increasing the numbers of skilled and ready graduates keep this cycle going.

AI-Powered Prospectivity Mapping of Porphyry Mineralisation in the Macquarie Arc, NSW

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The demand for critical minerals is increasing due to their importance in green technologies. However, discovering new resources is becoming increasingly challenging as unexplored deposits are located at greater depths. This heightened demand necessitates more effective methods of mineral exploration. In this study, we employed a machine learning-based framework to address common challenges such as imbalanced training data and difficulty in selecting negative samples, thereby providing efficient mineral prospectivity maps. To create a reliable predictive model for porphyry mineralisation in the Macquarie Arc—renowned for its significant porphyry Cu-Au deposits—we used a random forest classifier with positive and unlabelled bagging, considering the size of the mineral occurrences during the training process. Our study utilised three types of data: geological (e.g., faults and rock units), geophysical (magnetic, gravity, radiometric, and seismic tomography), and remote sensing-derived maps. Raw magnetic and gravity data were processed using filtering techniques such as upward continuation and derivative filters. We then applied grey-level co-occurrence matrix (GLCM) filters, including correlation and dissimilarity, to extract structural patterns from grid data. Additionally, we used principal component analysis and K-means clustering on seismic tomography data at depths of 1 and 70 km to identify crustal structures influencing mineral deposition. Gradient computations were also performed along the x and y axes for elevation data to analyse slope variations and topographical characteristics. Our model incorporated over 300 features, which were narrowed down to 119 after eliminating highly correlated ones. We identified 13 features as most significant for mapping target prospective areas. Key geophysical and geological data layers included the first vertical derivative of total magnetic intensity, reduced-to-pole magnetic intensity, and various faulted rock unit boundaries. The model achieved an accuracy of 0.99, an F1 score of 0.85, and maintained an accuracy of 0.92 for positive samples. These results highlight the model's efficacy in predicting prospective areas and determining essential features. Our prospectivity map reveals a clear spatial relationship between high probabilities and documented mineral occurrences, predicting several potential greenfield areas (Fig. 1a). We found that the boundary between mid-crustal high and low shear wave velocity regions, which separates oceanic and continental fold belt crust, controls the distribution of porphyry deposition (Fig. 1b).

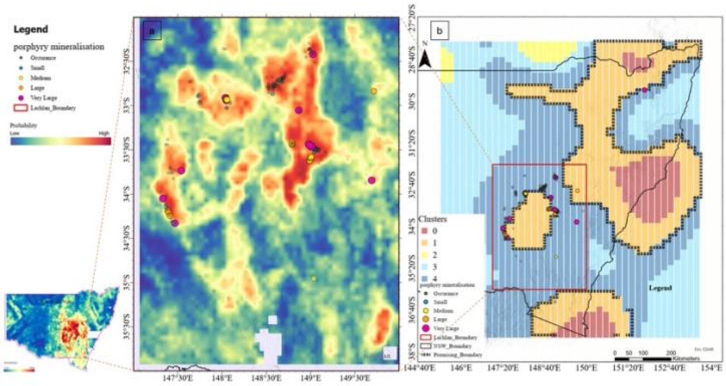

Figure 1. a) Prospectivity map highlighting potential porphyry mineralisation sites in NSW and the Macquarie Arc region; b) Clustered map depicting shear wave velocity variations, created using seismic tomography data.

Machine Learning-Assisted Mapping of Craton Boundaries Rich in Ore Deposits Using Full-Waveform Seismic Tomography

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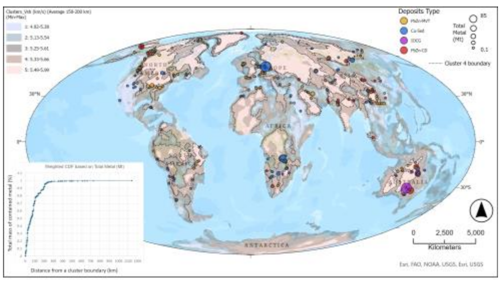
Most sediment-hosted deposits are found in marine sedimentary rocks along the margins of intracratonic or epicratonic rift basins along the edges of anomalously thick continental lithosphere, including cratons. A recent study analysing lithospheric thickness models shows that 85% of these deposits are within 200 km of the thick-thin lithosphere transition. However, a 200 km search radius is inefficient for reducing the exploration area. Additionally, composite cratons often have internal boundaries separating Archean nuclei from Paleoproterozoic to Mesoproterozoic crust. Our analysis of thermal and lithospheric models estimates craton thickness typically ranges from 150 to 200 km, with some exceptions. We use the high-resolution full-waveform seismic inversion model REVEAL to extract horizontal shear wave velocity (Vsh), vertical shear wave velocity (Vsv), and isotropic P-wave velocity (Vp) at depths between 150 and 200 km. Using principal component analysis and k-means clustering, we find that Vsh effectively delineates craton boundaries and similarly thick lithospheric elements, aligning well with target mineral deposits. These boundaries are related to clusters with high horizontal velocity and include cratons, accreted passive margins, orogens, and thick segments of volcanic arcs. Our results show that iron oxide copper-gold (IOCG) and sediment-hosted deposits are within ~125 km of cluster boundaries based on total metal content and around 100 km based on ore tonnage. These deposits have formed both along internal and external craton boundaries, which separate Archean nuclei from Proterozoic craton terranes, as well as along Phanerozoic orogens and associated accreted passive margins. We use published thermal and lithospheric thickness models to separate cratons from other anomalously thick lithospheric features. We isolate craton edges and associated deposits by filtering the cluster boundaries based on the tectonic age of continents. We find that ~85% of associated total metal contents are related to the boundaries of cratons considering ~200 km distance. By selecting these near-craton deposits, we find that approximately 80% of the total metal content is concentrated within a ~90 km distance from the craton boundaries. Finally, we find a consistent gradient of increasing total metal content with proximity to the craton boundaries. The isolated boundaries will serve as a foundational basis for spatio-temporal data mining, enabling the exploration of the drivers of craton edge-related deposits over time.



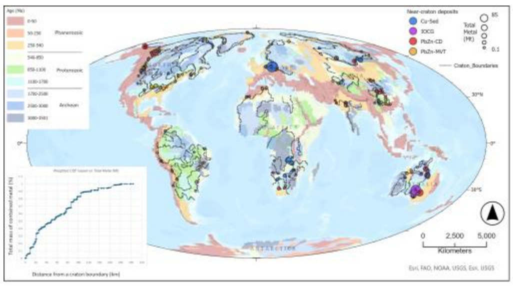


Figure 1. Distribution of sedimentary copper (Cu-sed), clastic-dominated lead-zinc (PbZn-CD), Mississippi Valley-type lead-zinc (PbZn-MVT), and iron oxide-copper-gold (IOCG) base metal deposits near a) cluster boundaries of horizontal shear wave velocity, and b) inferred craton edges.

Structural Control on Cu-Au-REE mineralisation, the relationship between Magmatism, Skarn Formation, and Mineralization at Elaine Dorothy, NW Queensland, Australia

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The worldwide transition to green energy to combat climate change has significantly increased the demand for the critical metals required for renewable energy technologies. The discovery of critical mineral deposits requires deployment of innovative geological concepts and exploration strategies. Skarn deposits are becoming increasingly important as a source of key critical minerals, and have for decades been mined for Fe, W, Sn, Cu, Pb, Zn, Mo, Ag, Au, U, REE, F, and B. Elaine Dorothy prospect, located 60km east-southeast of Mt Isa, has potential for Cu-Au-REE mineralisation. The deposit is hosted in metasediments and calcic skarns of the Palaeoproterozoic Corella Formation, adjacent to a shear zone close to the hinge of a major fold structure, the Mary Kathleen syncline, both of which may have facilitated fluid flow, metasomatic reactions, and mineralisation. Preliminary findings indicate that mineralisation at Elaine Dorothy occur within the hinges of large parasitic folds that are in an orientation that would have opened when the hinge of the syncline rotated. The evidence in the drill cores logged shows that the sulfides are being introduced via the biotite schist shear zone. However, there has been limited work on how these structures affected skarn development and mineralisation. This on-going PhD project aims to explore the connections between deformation, fluid transport, metasomatism, and mineralization at Elaine Dorothy, linking these processes to the region's tectonic history. The study will examine the relationship between the rotation of the syncline and evidence of fluid migration through the shear zone to better understand the metasomatic processes that occurred during shearing within the various lithological units identified at Elaine Dorothy.

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The Balleny Seamount Trail – A Weak but Persistent Deep Plume

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The Balleny seamount trail has long been proposed as an age-progressive line of volcanic islands and seamounts extending from the Australian-Antarctic spreading ridge to the south Tasman Sea, with the present day hotspot location at the Balleny Islands, offshore Antarctica. This study presents new age determinations and geochemical analyses of basaltic rocks dredged from 20 seamounts along the northernmost portion of the chain during a 2018-19 voyage on the RV Investigator, offering insights into the temporal and compositional evolution of hotspot activity.

Most of the seamounts exhibit an age progression, confirming the linear, age-progressive nature of the Balleny seamount trail. Our geochronological results, from ^{40}Ar-^{39}Ar incremental heating of groundmass and plagioclase separates, reveal that hotspot activity commenced around 70 million years ago (Ma), postdating the opening of the Tasman Sea (~84 Ma) and was active offshore Tasmania, forming seamounts over ~35 Myrs. Plate motion modelling shows good alignment between the seamount chain and recent plate motion models using a moving hotspot absolute reference frame, and confirms that this chain of seamounts provides a unique geological record of the movement of the Australian plate over the Balleny plume since the Late Cretaceous.

Geochemical analyses indicate a High U/Pb (HIMU) mantle source for the volcanic samples, aligning with regional characteristics and the Balleny Islands' signature. The basalts are predominantly Ocean Island Basalts (OIBs), with trace element ratios suggesting simple plume chemistry indicative of low degrees of melting and deep melting, or plume-ridge interactions resulting in more depleted melts and shallow melting. The flat-topped morphology of several of the Balleny seamounts (indicating sub-aerial exposure and erosion) corroborates the geochemical findings, indicating that most seamounts formed proximal to the Tasman Sea spreading ridge, with approximately 20 Myr of plume-ridge interaction prior to the cessation of spreading.

Globally, most long-lived seamount trails are associated with plumes sourced from Large Low Shear Velocity Provinces (LLSVPs). Despite being located away from an LLSVP, the ~70 Myr longevity of the Balleny trail suggests a deep mantle source for the Balleny plume. Deeply sourced plumes typically exhibit moderate/high rates of magma production/plume flux but bathymetric mapping of the seamounts, enabling accurate volume calculations, reveals that the Balleny seamounts have lower volumes compared to the seamounts of other deep plumes. The Balleny plume may thus represent a unique example of mantle plume behaviour without the thermal and chemical influence of the LLSVPs.

The seamounts that do not fit the normal age progressive pattern include one that is the youngest of the Tasmantid seamount trail, while a group to the east of the South Tasman Rise likely correlates with continental rifting events between Australia and Antarctica.

Change in the basalt normative mineralogy in deep-time, and possible petrogenetic relations

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Basalt is an invaluable probe into the thermal and physico-chemical conditions of Earth's upper mantle as it forms by partial melting of the asthenosphere. And because basalt is common throughout Earth's history, it is particularly valuable for understanding the secular cooling of Earth, which itself has influenced all four spheres of our planet. Recent efforts to delineate changes in basalt origin from the Archaean to the modern day have focussed mainly on geochemistry and yielded considerable disagreements, particularly regarding major oxides e.g., MgO. While some studies indicate that the MgO content in basalts dropped from 13-14 wt.% in the Archaean to 7-8 wt.% in the modern day, others propose that it has remained relatively constant at 7-8 wt.% over time [1]. These differences primarily arise from the criteria used for sample selection, such as sometimes incorporating ultramafic rocks or the deliberate exclusion of lower-Mg basalts from the analyses. Notwithstanding these differences, agreement is emerging on Glikson (1983)[2] finding that Archaean basalts are much more commonly quartz normative than modern tholeiites (mostly olivine normative). Therefore, rather than revisiting MgO concentration, this study set out to investigate the temporal evolution of normative basalt mineralogy.

We carefully curated a large geochemical dataset from published academic and government sources, precompiled data (GEOROC) and industry data to span the Archaean to Phanerozoic. After removing data that failed tests for Loss on Ignition and Chemical Index Alteration, the final dataset of basaltic rocks in the 5≤MgO wt.%≤18 window consisted of 16,325 samples. Our data confirm the prevalence of quartz normative basalt in the Archaean and demonstrate how normative mineralogy changed through time. From the ~67% quartz normative Archaean basalts, the fraction gradually dropped through the Proterozoic to ~28% in the Phanerozoic. Additionally, our study reveals a gradual increase in nepheline normative basalt from ~3% in the Archaean to ~14% in the Neoproterozoic, with a further rise to ~28% in the Phanerozoic. This could either imply a preservation bias or that alkali basalts became more common with time.

A more detailed analysis of the Phanerozoic basalt dataset shows that most alkali basalts are from oceanic plates, while continental flood basalts have similar normative mineralogy as Archaean greenstone belt basalts. This adds to the growing evidence that greenstone belts are not accreted slivers of oceanic crust. Instead, their magmas were transported through proto-cratonic lithosphere. Transfer through thick cratonic mantle lithosphere dominantly composed of olivine and the much more silica-rich orthopyroxene, offers many petrological ways of affecting normative mineralogy of evolved basalt via melt-solid interaction. Our ongoing work is targeting changing continental lithospheric architecture as a framework to understand normative mineralogy of erupted basalt.

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New insight into the effects of trans-lithospheric magma transfer on the petrology and geochemistry of the lithospheric mantle, lower continental crust and volcanic products

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For most geological history, preserved igneous rocks did not form in the oceanic realm, with only few bona fide Precambrian ophiolites. Instead, preserved Precambrian igneous rocks formed as part of the continental lithosphere, either in convergent, rift or intraplate settings. The comparison of incompatible element concentrations between mid-ocean-ridge-basalts and average continental crust shows that the latter must have formed in a multi-stage process involving enrichment of elements soluble in aqueous fluids. This hallmark feature has directed research interest to mantle melting and magma differentiation in arc settings. However, convergent margins have long been known as sites of continental destruction with many estimates of limited net growth of mass along convergent margins.

Here I will present evidence, from recently published and on-going postgraduate student projects and collaborations. We find that in Phanerozoic bi-modal continental intraplate volcanism, there is a close link between the mineralogy, chemistry, and radiogenic isotopic composition of lower crustal xenoliths and erupted volcanic rocks. A key insight from thermodynamic modelling of interaction between rising parental basalt and resident lower crust is that assimilation-fractional-crystallisation (AFC) cannot be treated as two separate processes of FC of the basaltic melt and 'contamination' with resident crust. This is due to the strongly incongruent nature of the reactions (Emo&Kamber, 2022). Modelling also shows that the density contrast between a crystallising basaltic underplate at the Moho and the solids forming via AFC dictate the MgO wt% of the most buoyant (erupted) basalt (Conway et al., 2024). Model trace element patterns reproduce 'subduction zone 'fingerprints', such as Ti, Nb, Ta depletion relative to U and Sr/Ba fractionation from AFC in evolved intraplate melts.

For the petrology of the tri-modal Archaean intraplate volcanic rocks, basalt, 'rhyolite', and komatiite, preserved in greenstone belts, lithospheric melt transport is probably even more critical because of the deep cratonic mantle through which the erupted melts ascended. A key outcome from thermodynamic modelling (Tomlinson&Kamber, 2021), microstructural and petrological study of cratonic xenoliths, and new targeted high PT experiments (Rodrigues et al., 2024) is the important role that the silica-rich phase orthopyroxene plays in affecting peridotite petrology and erupted basalt and komatiite geochemistry (Roy et al., 2024). We have recently uncovered the first strong evidence for reactive melt flow of komatiite though cratonic harzburgite (Daczko et al., submitted). Collectively, this work suggests that apart from mantle source nature, melt-solid interaction during lithospheric ascent is a major factor influencing the petrology and geochemistry of mafic magmas.

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Peridotite-komatiite interaction and the origin of orthopyroxene-rich cratonic mantle lithosphere

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Excess silica, expressed as modally high orthopyroxene, is a common feature of cratonic lithosphere peridotites. These high Si/Mg rocks are mostly highly refractory orthopyroxene-rich harzburgites. Closed system thermodynamic modelling cannot reproduce this feature, whereas hybridisation of rising komatiite with resident peridotite can yield moderately silica-rich harzburgites (Tomlinson and Kamber, 2021). However, modelling suggests that very orthopyroxene-rich harzburgites require open-system interaction between an evolved komatiite and resident harzburgite. To experimentally test this hypothesis, we performed isobaric (3 GPa) temperature-series (1400-1600 ºC) piston-cylinder sandwich experiments (evolved komatiite + harzburgite) designed to simulate interaction between ascending komatiite melt sourced from great depths (~150 km) with depleted lithosphere. Mineral modal abundances in the experiments were determined using phase maps based on back-scattered electron images and element maps. Pure harzburgite composition runs were also performed and, at 1500 ºC, crystallised an olivine-rich super-solidus assemblage composed of 69.7% olivine, 16.5 % orthopyroxene and 13.7 % melt, with an opx/ol ratio of 0.23. The reaction experiment between komatiite + harzburgite at 1400 ºC crystallised a melt-free orthopyroxene-rich garnet harzburgite, with olivine and orthopyroxene at similar abundances (Ol = 50.3 %, Opx = 46.3 %) and trace quantities of garnet, clinopyroxene and Cr-spinel (Grt = 2, Cpx = 0.7 %, Cr-Sp = 0.6 %). Garnets have anhedral shapes and numerous inclusions of orthopyroxene. The Opx/Ol ratio at this temperature is 0.92. Clinopyroxene and garnet are absent at 1500 ºC, and trace amounts of Cr-spinel and melt were found. Modal abundances of olivine and orthopyroxene are 51.4 % and 47.8 %, respectively, and the Opx/Ol ratio is 0.93. At 1600 ºC, olivine and orthopyroxene abundances decreased significantly (Ol = 42.92 %, Opx = 20.39 %) while the degree of melting increased to 37 %. At this temperature, the Opx/Ol ratio decreased to 0.47. The bulk SiO_2 content of the solids in the komatiite + harzburgite hybrid varied between 46.6 and 48.3 wt.%, overlapping the most silica-rich garnet-bearing peridotites from Kaapvaal, Slave and Siberia cratons (Fig. 1). We proposed that localised enrichment of orthopyroxene is a product of the interaction between channelised, ascending and evolving highly magnesian melts with the already depleted proto-cratonic lithosphere.

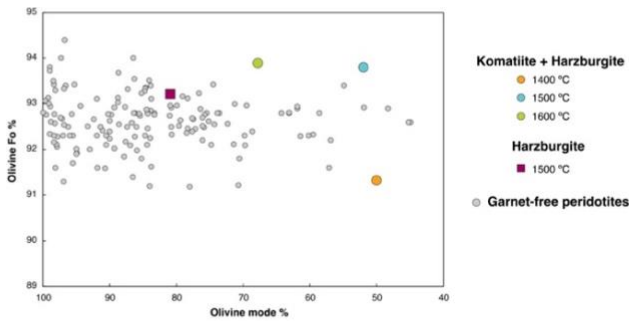

Figure 1. Comparison of modal abundances versus forsterite (Fo) content of natural cratonic garnet-free peridotites (grey circles) (compilation of Tomlinson and Kamber, 2021) and the layered experiment (komatiite + harzburgite) (circles) and harzburgite alone (square).

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Defrosting the Cowra crystal mush

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Granites record protracted episodes of crystallization that can involve mixing histories from different magmatic pulses. Locations near the Cowra lookout, and within the Japanese gardens of Cowra, are well-known for containing an abundance and an array of surmicaceous enclave types. Since the pioneering work of Stevens (1952) first identified five enclave types in the Cowra granodiorite (pelitic, psammitic, calcareous, igneous and granitized), various workers have used a range of geochemical, mineralogical and isotopic observations to help study their origin (Vernon, 1991; Chappell et al., 1993; Waight et al., 2001; Vernon, 2011). This study aims to build on the existing body of work by using an approach that combines cathodoluminescence profiles, Ti-in-quartz thermobarometry and volume diffusion calculations from chemical boundaries observed within individual crystals. The style of zonation imaged from different quartz populations (i.e., "step function-type" boundaries versus "error function-type" boundaries) appear to indicate different enclave groups likely formed under different titania and alumina activities, while also likely recording different time-integrated thermal histories. Several enclave populations also appear to show internally consistent compositions – such that quartz geochemistry (say magmatic quartz versus peltic enclave quartz versus "quartz ocelli") all appear to be unique and distinguishable from one another. In this way quartz geochemistry and zonation profiles help to define the time-temperature history observed in the different rocks at Cowra, while also allowing meaningful estimates of the P-T history (spoilers – it is a complex story). The observations from quartz also demonstrate that like zircon, quartz can have inherited cores from a diversity of sources (e.g., metamorphic quartz and hydrothermal quartz).

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Tectonic origin of peridotites from the Beaufort Ultramafic Complex, central Palawan, Philippines

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Palawan island represents one of the few areas in the Philippines where both continental and oceanic materials are exposed, as the island records the obduction of ophiolitic units onto a continental margin. These ophiolitic units are composed of pillow lavas, layered and isotropic gabbros, and a mantle section known as the Beaufort Ultramafic Complex. In central Palawan, the Beaufort Ultramafic Complex is composed mostly of massive dunites and harzburgites. Rare exposures of basal lherzolites and harzburgites are juxtaposed with the metamorphic sole of the ophiolite in Ulugan Bay. This work combines petrological and geochemical data to determine the tectonic origin of the peridotites in central Palawan.

Most of the peridotites in central Palawan plot within the olivine spinel mantle array (OSMA) of residual peridotites. Ultramafic rocks from Ulugan Bay follow a vertical trend of increasing spinel Cr# from dunite to lherzolite with minor changes in olivine Fo. This signature is associated with influx melting with a fluid rich in Fe relative to Mg. Mobile elements Al, Na, Ti, and REEs are notably more enriched in the clinopyroxenes of the lherzolites relative to the harzburgites and dunites, suggesting a fertile origin. Negative Ti and Zr anomalies in chondrite-normalized REE patterns of clinopyroxenes of the lherzolites further imply an abyssal origin. Low concentrations of mobile elements, and depleted clinopyroxene REE patterns recorded in the harzburgites and dunites are typical of more depleted peridotites. These petrological and geochemical signatures suggest that the harzburgites and dunites in central Palawan represent supra-subduction zone peridotites. Meanwhile, the abyssal signatures observed in the lherzolites indicate that fertile mantle fragments can also be exposed along the subduction interface.

Multi-stage evolution of the oceanic lithosphere recorded by spinel harzburgite xenoliths (Heard Island, southern Indian Ocean)

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The Heard and McDonald Islands (southern Indian Ocean) are situated in the Kerguelen Plateau, which is the second biggest large igneous province (LIP) on Earth. Although products of mantle melting (e.g., mid-ocean ridge basalts and ocean island basalts) have provided some insights into the lithospheric mantle source(s) of the Kerguelen LIP, the number of mantle-derived xenolith occurrences available to directly study the composition, evolution and processes occurring within the lithospheric mantle are comparatively far fewer.

This study presents petrographic and geochemical data for a suite of spinel-bearing harzburgite xenoliths hosted within basanite lavas from Heard Island. We present detailed constraints for distinguishing *in-situ* mantle metasomatism from post-entrapment modification of the xenoliths following their entrainment and interaction with the host magma. The mineral compositions and textures of the xenoliths preserve a complex multistage history, recording different types of modal and cryptic transformations in the mantle due to: i) high degrees of partial melting that produced highly refractory whole-rock and mineral compositions, ii) solid-state re-equilibration reactions that caused exsolution of clinopyroxene and Cr-spinel from xenolith orthopyroxene to form symplectite intergrowths, iii) infiltration of the mantle by siliceous melts that formed crosscutting veins that consist of metasomatically-formed olivine, pyroxene and sulphides. These crosscutting veins also show evidence of re-equilibration with the mantle host-rock, and iv) cryptic metasomatism that modified the composition of xenolith clinopyroxene due to the interaction with carbonatitic melts in the mantle.

These mantle fragments, which were entrapped by ascending basanite magmas as xenoliths, were further modified by reactions with the host magma. This resulted in the partial dissolution of mantle orthopyroxene and replacement by compositionally and texturally distinct assemblages of clinopyroxene, olivine and Cr-spinel (i.e., 'wehrlitisation' of the xenoliths). This study highlights the utility of combining petrography and mineral chemistry to decipher the complex and sometimes overprinting and masking effects that different processes (e.g., melting events, metasomatism) exert on the lithospheric mantle, as well as constrain the processes that modify the xenoliths during transport towards the surface.

Revisiting lower crustal zenoliths from northeastern Australia

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Cenozoic intraplate basaltic volcanism in eastern Australia has exhumed a rich suite of mantle peridotite and rarer lower crustal xenoliths (LCXs). They provide a great opportunity to explore deep-seated processes in the Australian mantle lithosphere, Moho and lower crust as direct, rapidly exhumed samples of otherwise inaccessible portions of the lithosphere. Past studies on LCXs from Queensland have majorly featured in attempts at constructing the composition of the lower continental crust (LCC) (e.g., Rudnick & Taylor, 1987; Sutherland & Hollis, 1982).

The Queensland LCXs are overwhelmingly mafic and represent two granulite-facies assemblages: two-pyroxene-plagioclase-ilmenite and clinopyroxene-garnet-plagioclase-rutile. They have been revisited through combined geochemical and petrological modelling in work by our group (e.g., Emo & Kamber, 2022) confirming that the local LCC is very refractory, strongly depleted in incompatible and heat producing elements (HPE), having experienced melt extraction at very high temperatures (950-1050°C). The LCXs are sampled directly from the deep crust and differ markedly in mineralogical variety and HPE depletion from terrain granulites. They are not predisposed to the same tectonic complications and slow exhumation as lower crustal terrain granulites.

Our recent work has highlighted the role of melt-solid interaction in the formation of the LCXs, whereby basaltic under- or interplates apparently interacted with existing resident LCC near the Moho. The resulting process is a form of Assimilation-Fractional-Crystallisation (AFC), whereby both the resident LCC and the basalt are modified in mineralogy and chemistry, respectively. Thermodynamic modelling indicates that at P >10 kbar, AFC leads to clinopyroxene-garnet-plagioclase-rutile residues that potentially delaminate. The current work set out to study a rarer 'garnet websterite' xenolith population which co-occurs with granulites. Their mode is dominated by garnet and clinopyroxene, with some orthopyroxene, plagioclase, oxides and minor scapolite. These rocks have only received limited attention but have been compared to 'pyroxenites' from Salt Lake crater in Hawaii, even though they could also be mafic granulites.

In our ongoing study, we are determining the geochemistry and formation processes of these rocks. The aim is to establish whether they are cumulates (e.g., Lu et al., 2018), deep AFC products or foundered, originally more plagioclase-rich granulites to compare them with "arclogites" (Lee & Anderson, 2015). Constraining their origin is important for understanding whether garnet-pyroxenite delamination is possible in intraplate settings as a tectonic environment of net continental growth.

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Cenozoic tectono-magmatic evolution of southeast Kalimantan (Borneo): New insights from a Late Eocene alkaline magmatic province

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The island of Borneo is located between several active tectonic plates, making it an important site for studying and understanding local, and regional geodynamics. Despite its positional and tectonic significance, many aspects of the geology of Borneo remain poorly constrained. The Indonesian province of South Kalimantan was previously presumed to be devoid of Cenozoic magmatism. A recent study (Murphy et al., 2024) has identified the occurrence of a Late Eocene (37 Ma) alkaline lamprophyre in peninsular Senakin, southeast Kalimantan. The spatio-temporal extent of this alkaline magmatism and its relationship with other Cenozoic igneous provinces in the region is still unclear. Interestingly, the current SE Kalimantan lithosphere is too thin for lamprophyre petrogenesis. Thus, Murphy et al. (2024) proposed thicker lithosphere for that region in the Eocene.

Here, we investigate further mafic rocks that intruded Eocene sediments in SE Kalimantan for their petrology, geochemistry and geochronology. We aim to assess if these rocks represent a regional or local scale Eocene alkaline magmatic province in SE Kalimantan.

Furthermore, reconstructing the petrogenesis of the mafic rocks, including their magma plumbing systems, will provide more constraints on the lithospheric thickness across the area. Thus, understanding the petrogenesis of this alkaline lamprophyre may provide a window into local magmatic evolution and magma genesis that will inform on local to regional crustal evolution. Findings from the study will help situate the reported Eocene alkaline magmatism in Senakin within the framework of regional tectono-stratigraphy which will inform on overall regional Cenozoic geodynamic evolution.

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A brief history of the northern Australian margin: from basement inheritance to modern seismology (and a few mass transport deposits)

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Over nearly 30 years our research group has documented styles of deformation around the North West Shelf, across a >2,200 km transect from the Bonaparte Basin in the NE to the Carnarvon Basin in the SW. Starting with the Neogene collision of the Australian Plate with the Banda Arc in the Miocene, we've documented multiple locations and periods of related reactivation and inversion. In seeking to understand the multiple reactivations, we looked to the basement to identify the controlling faults, their distribution, and what regional tectonic events they might have been related to. Backstripping and restoration of multiple deep seismic cross sections exposed distinct extensional styles inboard and outboard of the margin, and hyper-extension at the base of the crust. Proterozoic listric faults from hyper-extension act as loci for Neogene reactivation and inversion Reactivation events are correlatable across basins, forming margin-wide deformation phases. Deformation is onoing, and there are strong links between our calculated strike-slip focal mechanism solutions and locations of strong basement inheritance. We can show strong basement control and fault renucleation and reactivation of Miocene-Pliocene faults, and can also link this reactivation to the drowning of Miocene reefs. Our fault population and fault throw analyses show distinct periods of Neogene fault displacement up to and including the present-day. This young deformation strongly controls collapse of vast sections of the passive margin, especially around the Exmouth Plateau, where we have documented at least 14 regional mass transport deposits captured in dozens of 3D seismic data sets. We present a overview of the structural history since the Proterozoic, including the first attempt at rationalising the many mass transport deposits and link them to seismicity.

Global ophiolite, large igneous province, and orogenic reconstructions and the implications for deep-time climate and planetary carbon cycling

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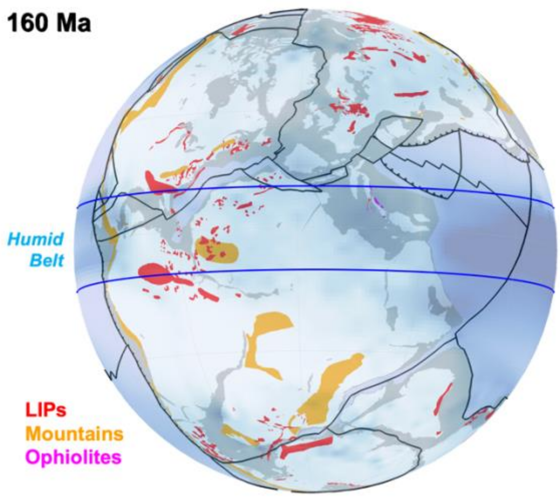
Major perturbations to the planetary carbon cycle in deep time have been driven by massive outgassing events (via tectonism, mantle plume eruptions, and other processes) as well as episodes of significant carbon sequestration through silicate weathering and other processes (including biology, etc.). Related swings in the planet's climate, between greenhouse and icehouse states, are well-documented in the geological record and represent an important in-built thermoregulation and life-support system on our planet.

In this work, we explore the role of silicate weathering from mountains, sub-aerial large igneous provinces, and the obduction of ophiolite belts. Importantly, we present a new global ophiolite dataset in which we document more than 3,000 ophiolite geometries and capture key metadata of ophiolite crystallisation and obduction ages. We use the cross-platform and open-source GPlates software (www.gplates.org) to reconstruct the orogens, LIPs, and obducted ophiolites in a paleomagnetic reference frame. We use the residence time of these features in the near-equatorial humid belt as forcings for biogeochemical modelling using COPSE to show their effects on surface temperature and atmospheric CO2. Our analysis focuses on the Phanerozoic, but our reconstructions enable insights into planetary carbon cycling for the last two billion years of Earth's history.

The analysis demonstrates the dominance of these processes during Pangea assembly in the late Carboniferous, as well as the Cenozoic closure of the Tethyan ocean gateways. The results also highlight the importance of using recent and data-constrained forcings for the biogeochemical box models like COPSE, which had traditionally relied on pre-1990s obscure (and sometimes unpublished) tectonic degassing, uplift and silicate weathering parameters. These new results also provide insights into the relative contributions of each of the components of the silicate weathering system, which has not been attempted before. More broadly, the approach and results help us quantify perturbations to planetary carbon cycling in deep time and the effects on global climate and the biosphere.



Field characteristics of the Marlborough and Rockhampton ultramafic massifs, New England Orogen

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Ultramafic rocks such as peridotites, pyroxenites, and chromitites are typically lithologies found in the Earth's mantle. To expose ultramafic massifs at the surface, major plate tectonic processes must play out, such as continental breakup and the development of rifted margins, or the obduction of ophiolitic complexes in convergent plate boundaries. Determining the tectonic origin of ultramafic rocks is thus essential for understanding the formation of orogens and their evolution through time.

A north-south-trending belt of ultramafic rocks occurs in the New England Orogen in eastern Australia, but the tectonic origin of this, potentially ophiolitic, belt is poorly understood. The ultramafic rocks occur approximately at the contact between Devonian–Carboniferous forearc basin and accretionary complex units and may represent an ophiolitic suture. The largest exposures of ultramafic rocks occur near Marlborough and Rockhampton in central Queensland. Smaller, isolated exposures are found along the Yarrol Fault and farther south in New South Wales (Baryulgil and Peel Fault). This work presents preliminary field observations from the Marlborough and Rockhampton ultramafic massifs to provide context for further petrological and geochemical studies.

The ultramafic rocks occurring in the Marlborough region are predominantly massive serpentinites and serpentinised peridotites. The serpentinites range from fresh, indurated, dark-coloured varieties to extremely friable, brownish exposures cut by magnesite veins. Blocks of metamorphosed gabbros also occur with the serpentinites along the Bruce Highway in Kunwarara. The gabbros preserve relict cumulate texture of pyroxene and plagioclase. The ultramafic rocks in Marlborough are also closely associated with mica schists and amphibolites. In the Rockhampton area and along the Yarrol Fault, the ultramafic rocks are mainly massive to sheared serpentinites and serpentinised peridotites. These ultramafic rocks display varying degrees of shearing and deformation. Several exposures of greenish metagabbros and pyroxenites also occur as blocks surrounded by sheared and friable serpentinite. Spinel is typically the only primary mineral observed in the serpentinites, although some samples preserve bastite pseudomorphs after orthopyroxene. Further petrological and geochemical analyses will be done to further constrain the tectonic origin of the ultramafic rocks.

Inner crystal deformation features and their exhumation significance on the Songshugou Peridotite Massif in the North Qinling Orogen, Central China

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Identifying anisotropic behavior during the evolution of orogenic peridotite units remains a significant challenge. This study conducts mappings at various scales, from section to regional, of the Songshugou Peridotite Massif (SPM) in the Central China Orogen. It utilizes fabric types through an investigation of olivine crystal-preferred orientations (CPOs), building upon earlier related studies. We discover that olivine specimens can exhibit multiple textures; notably, fine grains may encapsulate relatively recent textures when subjected to a high strain rate in brittle deformation, while coarse grains may retain older textures. The results indicate that the AG (010) and A (010)[100] fabrics may represent the early general passive extension stage (D0); the B (010)[001] fabric appears to have formed at the onset of subduction, with evidence from the northwest part (D1); the C (100)[001] fabric suggests the conclusion of subduction, peak metamorphism, and slab break-off (D2); and the D (okl)[100] and E (001)[100] fabric types in SPM peridotite signify events that occurred during the arc extension period upon entry into the lower crust, potentially related to deformation within strike-slip and thrust stress fields, respectively (D3).

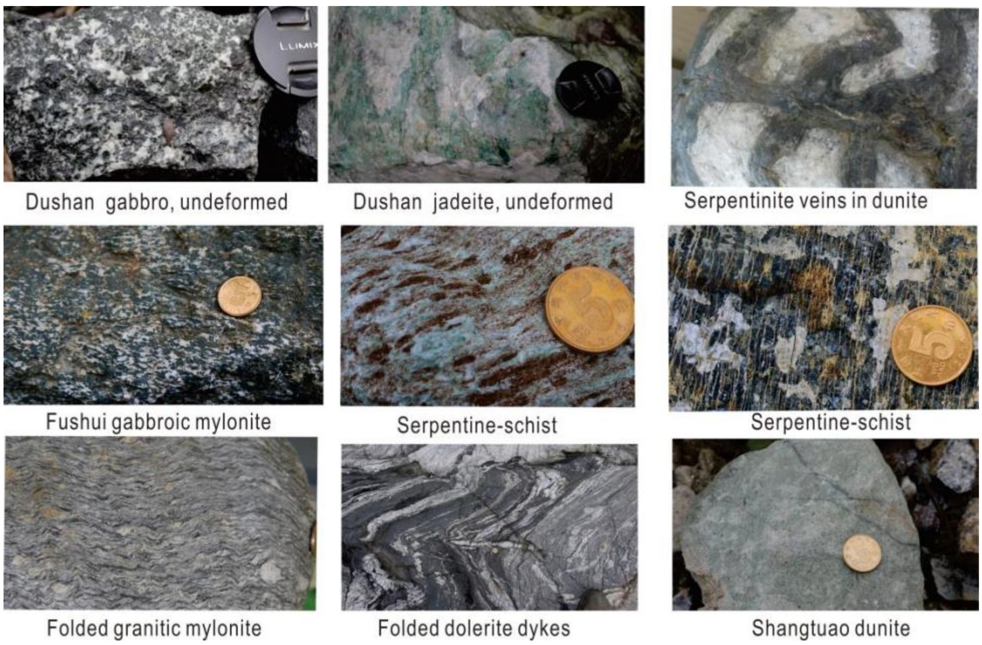

Figure 1. Outcrop deformation features in or surrounding the Songshugou Peridotite Massif

Non-Andersonian faults, fractures and veins

Bruce E Hobbs[1] and Alison Ord[2]

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Thermodynamic arguments and a large amount of experimental work indicate that the failure envelope for rocks is capped at large mean stresses instead of being open ended as in the classical Mohr-Coulomb (M-C) failure envelope. The cap is important in representing hardening and softening associated with volume changes during deformations and chemical reactions. For a given elastic stress state, classical failure can be achieved by increasing the differential stress or by increasing the fluid pore pressure; at the cap end failure is achieved by increasing the differential stress or by *decreasing* the fluid pore pressure. Andersonian kinematics correspond to classical M-C failure whereas non-Andersonian kinematics correspond to the capped end of the failure surface. The brittle-ductile transition represents a transition from Andersonian to non-Andersonian kinematics. Failure to recognise this means people propose erroneous switches in stress fields or reactivation of older structures. Typical non-Andersonian structures are axial plane veins and laminated veins with parallel stylolites and solution seams. Small changes in mean stress at the brittle-ductile transition can result in a switch from Andersonian to non-Andersonian kinematics. This includes changes in s_2. Archean tectonics commonly represents non-Andersonian kinematics. Relatively shallow faults (e.g., the Ida Fault in the Yilgarn of WA) and approximately horizontal ‘bright spots’ form during slight fluctuations in horizontal extension.

Automatic quantitative analysis and classification of spatial patterns (fabrics)

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Spatial patterns of interest in structural geology and in mineral exploration include the distribution of structure and mineralisation at regional scales, the characterisation (fingerprinting) of structure and mineral distributions at the bench and core scale, and the characterisation of deformed rocks, breccias and vein/fracture systems. Since these spatial distributions are heterogeneous, the characterisation problem must be grounded in statistics. A goal is that any statistical approach be based on principles related to nonlinear dynamical systems so that some contact with the physics and chemistry of the processes that operated to produce the spatial structure might be established. Ultimately the aim is to make contact with the predictive and analytical power such systems have to offer. This suggests that statistical methods related to correlations in the spatial patterns have priority over classical methods. For this reason, we concentrate on n-point correlation functions. We apply such functions to several examples including deformed quartzites and breccias. The probability distributions of grain size for all breccia samples and the entropies of the probability distributions are very similar indicating that very similar breakage mechanisms operate in all samples. However the correlation functions are quite variable indicating that n-point correlation functions are powerful means of characterising breccias and other microstructures in deformed rocks. Possible applications are in distinguishing, for example, sedimentary versus structural textures, and with a view to prediction of the mechanical behaviour of rock materials.

Porosity changes in shear zones during tectonic switching

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Switching between extension and shortening on tectonic plate boundaries is linked to hydrothermal ore deposit formation within shear zones. During tectonic switches, shear zone structures that accommodated deformation before the switch reconfigure to accommodate the new shearing direction. Through numerical modelling and observation of structures and porosity in naturally deformed rocks, we show evidence for the generation of new fluid pathways during tectonic switching, which may have implications for the formation of ore deposits.

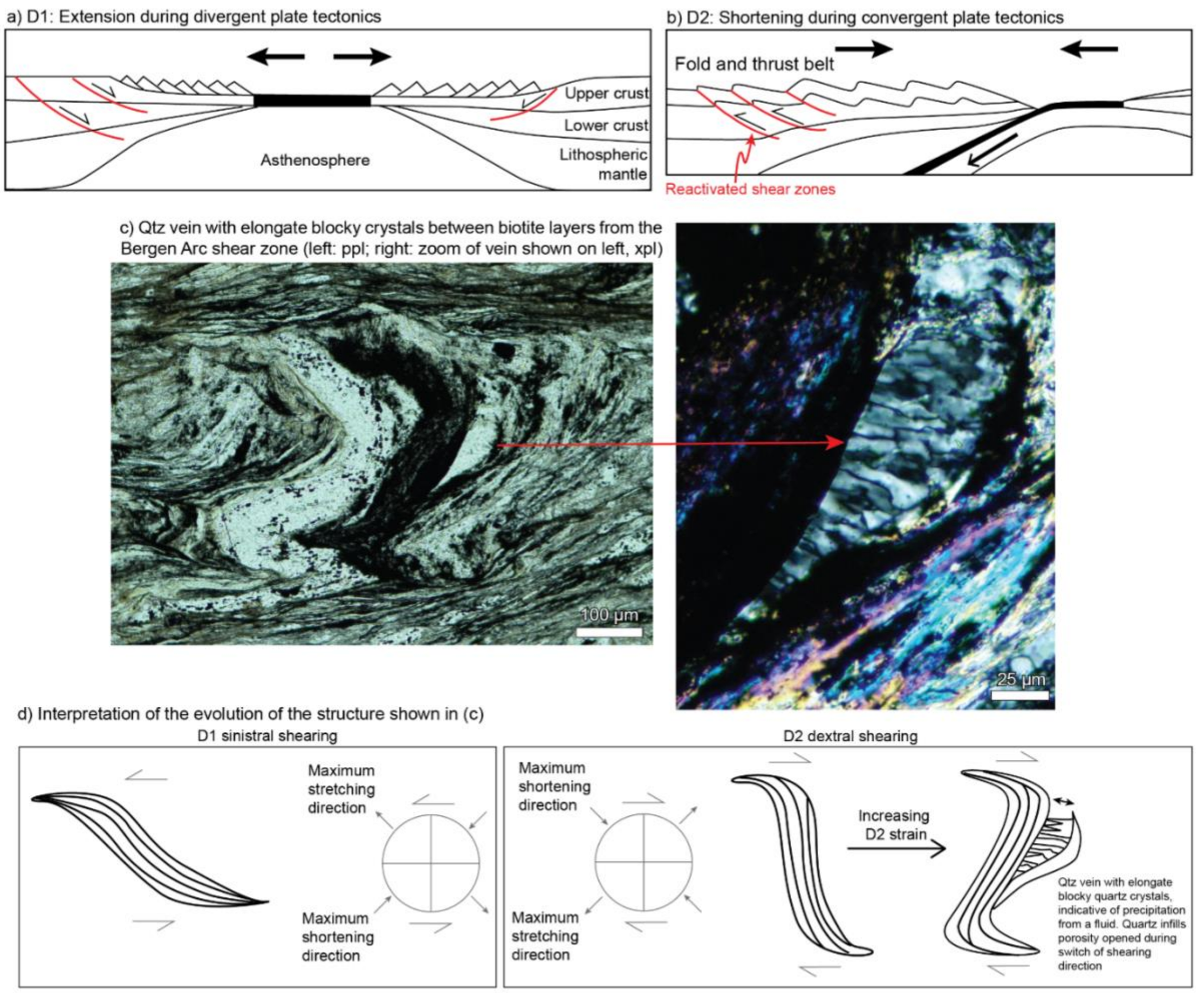

Figure 1. (a) During an extensional D1 event, shear zones nucleate with normal shear sense. (b) During tectonic switching, D1 extensional shear zones are inverted to accommodate D2 thrusting. (c and d) In rocks that underwent tectonic switching we observe veins forming as the microstructures are reconfigured to accommodate D2 shearing.

Deformation mechanisms in a shear zone ore fluid conduit

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Hydrothermal Rare Earth Element (REE) ore deposits form when REEs are mobilised from source rocks by hydrothermal fluids and are transported through structural conduits such as shear zones or faults to the ore deposit site. The Mary Kathleen REE ore deposit, located adjacent to a ductile shear zone, presents a compelling example where the shear zone likely functioned as a primary fluid conduit. This study investigates the ore genesis of the Mary Kathleen deposit by examining the relationships between host rocks, skarn alteration, and cross-cutting ore veins to understand the factors influencing the deposit's location. Highlighting the interplay between rheological properties, deformation mechanisms, and fluid dynamics, the research focuses on the Eastern (EMKSZ) and Western Mary Kathleen Shear Zones (WMKSZ) to understand how deformation processes control fluid migration. EBSD data will be presented focusing on the difference in deformation mechanisms between the different rock types in the two shear zones and the implications for ore fluid migration.

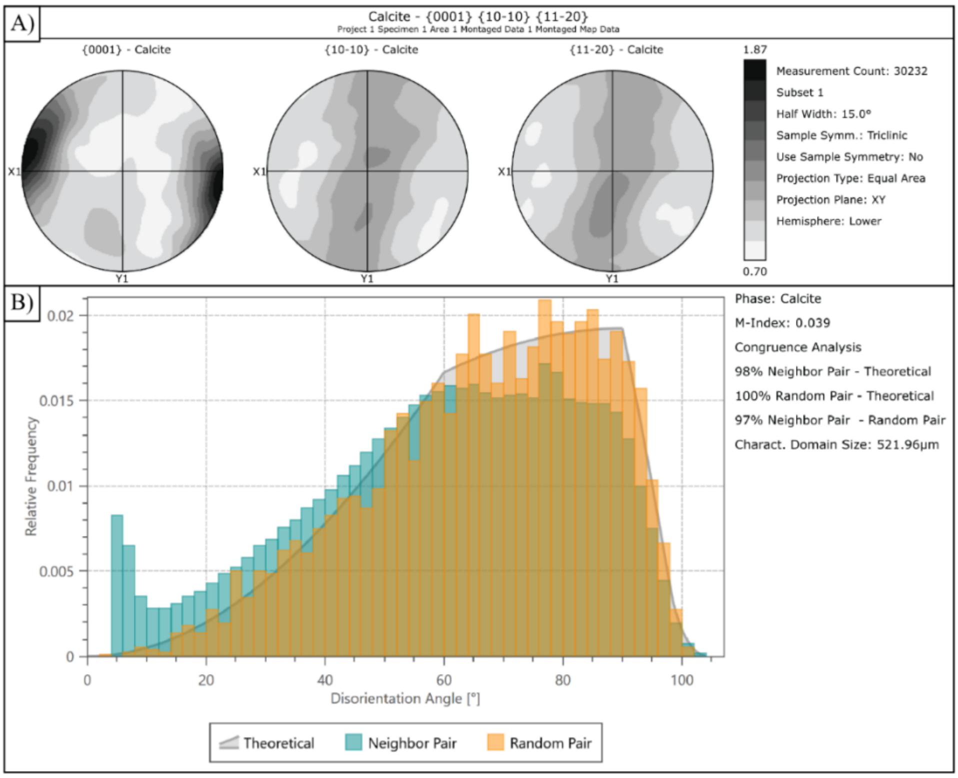

Figure 1. A) The CPOs of the marble mylonite, demonstrating dynamic recrystallisation of the marble mylonite presented as pole figures (equal-area, upper-hemisphere stereo plots). B) Calcite misorientation histogram, showing small uniform calcite grain size indicative of recrystallisation.

Origin of textures in quartz veins: insights from 2D in situ ice experiments

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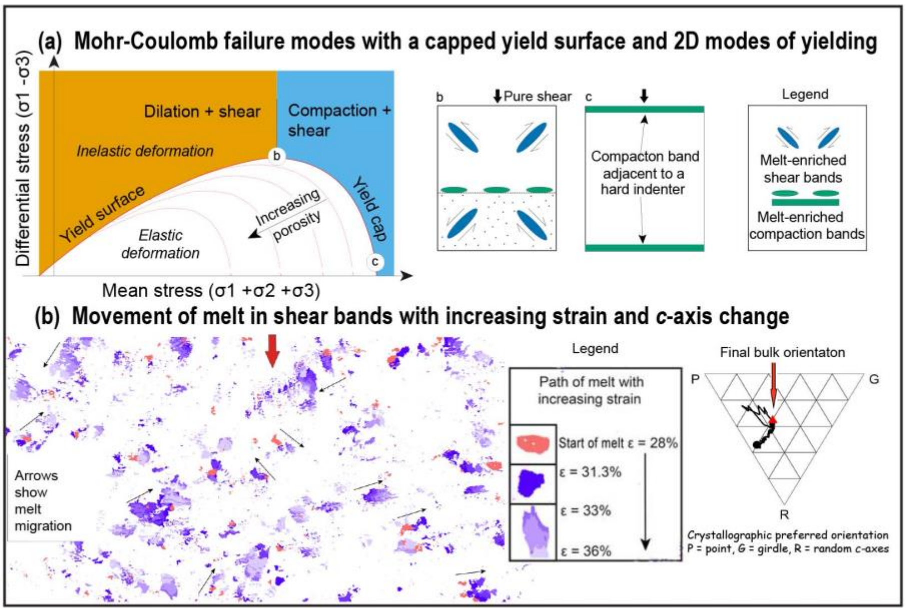
Reactions between solids and fluids are commonly recognized in the evolution of quartz-rich quartz veins in orogenic gold deposits. This is particularly seen in quartz-rich dilatant laminated compaction veins oriented perpendicular to the maximum principal stress (σ_1) and in quartz-rich shear veins. These veins generally have coarse interlocking quartz crystals and have a random or weak *c*-axis crystallographic orientations unlike crack seal veins. We have been able to explain the origin of the textural evolution in such veins from a series of see-through in situ and 3D deformation experiments (Wilson *et al*., 2024). Where an interstitial fluid, generated by melting, is transported and localized in low-pressure areas as dilatational compaction and shear bands (Fig. a). During the evolution of the veins coarse grains are produced that grow from the free surface of matrix grains that are open to pore space. The starting material for the experiments was composed of 90% polycrystalline deuterium-ice (D_2O, T_m = +3ºC) and 10% water-ice (H_2O. T_m = 0ºC). The deformation was performed at ~5.24 x 10^{-6} s^{-1} at –7 °C. During deformation the temperature was raised to +2 ºC, and H_2O meltwater which became an interstitial fluid was then moved obliquely through the deforming matrix (Fig. b). This fluid reacted with strained grains in the matrix and was accompanied by extensive grain boundary migration, inheriting the *c*-axis orientation of the neighboring matrix grains via rapid grain boundary migration. The inferred processes are an example of dissolution-precipitation creep that is governed by three processes: the melting or dissolution of material, the transport and precipitation of material. Transport of material may be by diffusion of DHO through a fluid phase or by advection with a moving fluid.



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Moving to 3D: Constraints on Shape Fabric and Strain in mantle rocks

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Three-dimensional (3D) shape preferred orientations of mineral grains or grain aggregates are used to constrain models of the formation and deformation processes in rocks. Despite being an inherently 3D problem, the fabric ellipsoid is commonly estimated by data collected on 2D sections because of limited access to 3D data. X-ray microscopy, however, offers access to the tensors that describe the full 3D orientation and shape of individual grains, as well as the spatial distribution of neighbouring grains within a rock matrix. This study expands existing 2D shape fabric analysis techniques in 3D and presents applications on mantle xenoliths from Southeast Australia.

We extend the mathematical frameworks of the Fry method (Fry, 1979), the normalized Fry method (Erslev, 1988), and Delaunay Triangulation (Mulchrone, 2003), into 3D. The new framework allows for fitting a fabric or strain ellipsoid into a central vacancy of a point distribution. The performance of these 3D methods is validated against simulation of synthetic samples with grains in a 3D matrix, subjected to known deformation regimes, combining pure shear and simple shear. The resulting fabric ellipsoids are compared to those derived using the tensor averaging method of Brandon (1995).

Our results indicate that the mean ellipsoids generated from the 3D Fry and 3D Delaunay triangulation methods exhibit similar orientations with the tensor averaging method; a maximum angular discrepancy of ~13° is observed in the long and intermediate axes, and ~10° in the short axis between the three methods. Notably, these methods demonstrate varying sensitivities to different shear conditions, yet consistently reflect the distinction between oblate and prolate ellipsoids. Applying these 3D fabric analysis techniques to mantle xenoliths reveals significant variations in the degree of anisotropy and shape of fabric ellipsoids within and between volcanic centres. Spinel lherzolite xenoliths from Mt. Noorat show moderate anisotropy with both prolate and oblate shapes, while those from Gnotuk display high anisotropy and an oblate shape, indicative of flattening. By adapting the methods of shape fabric analysis to 3D, we enable the calculation and fitting of fabric ellipsoids, which are essential for accurately capturing the geometric characteristics of deformed rocks.

Acknowledgments: We thank Sue O'Reilly and Olivier Alard for sharing with us xenolith samples.

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Signatures of changing deformation rate dynamics in deforming rocks: Examples from the exhumed Slow Earthquake Zone of New Caledonia

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[5] University of Minneapolis, USA

Deformation on planetary bodies is characterized by processes that act at strain rates of more than 15 orders of magnitude difference. With the advent of advanced geophysical techniques with ever increasing resolution in time and space, we are now able to detect some of these intriguing dynamics. It is now recognized that despite extreme differences in rates of deformation, there must be a wealth of interaction between processes of vastly different strain rates. However, advancing from observations of apparent dynamics and links between geophysically detected deformation events to in-depth understanding of the underlying physical processes remains one of the unsolved challenges faced by the tectonics research community. One "type" example of a deformation phenomenon encompassing deformation events acting at different rates are Slow Earthquakes (SEs). In SEs, slip occurs more slowly than in regular earthquakes, but significantly faster than can be attributed to normal plate motion. SEs have been shown to be closely associated with a range of deformation processes active at different deformation rates. Although SEs are abundant, their geophysically observed characteristics cannot be reconciled with current understanding of how rocks deform: New evidence of slip processes need to be discovered in the geological record.

Rock outcrops from an example of exhumed subducted crust in New Caledonia are interpreted to contain zones of former SEs. Microstructural characterization combining EBSD and EDS analyses deciphers controlling deformation processes, while phase petrology is used to evaluate stages of fluid ingress, production or egress. Rocks are hydrous, exhibit high porosity and individual layers show strong shape preferred orientation associated with crystallographic preferred orientation of epidote and glaucophane but not quartz or rutile. Mineral chemistry varies between grain tails and cores while grain boundaries are aligned over several grain lengths. Asymmetrically zoned, disaggregated garnets are present while crosscutting replacement veins are characterized by localized replacement textures with high abundance of inclusions and defect rich crystal growth. "Interstitial-like" mineral growth is inferred along boundaries of individual grains and grain clusters. We interpret that several deformation processes which are directly associated to the presence and movement of fluids governed rock behaviour. Relative "slow" dissolution-precipitation creep is the main "background" deformation process responsible for the shape and crystallographic preferred orientations, in-grain compositional variations and grain boundary alignment. Transient fast brittle, hydrofracturing and local granular flow is enabled by transient high fluid pressures induced by mineral dehydration reactions. Such high fluid pressures trigger (i) intermittent fluid escape inducing fluid filled fractures to form replacement veins, and (ii) disaggregation of layers along porosity gradients, loss of cohesion and friction between grains and grain clusters. These transient deformation processes act at much faster strain rates but occur for only short time periods.

Phase equilibrium modelling: a frosted window onto geological processes

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Petrological phase equilibrium modelling can be used to simulate magmatic or metamorphic processes, or to constrain geotherms via thermobarometry, often in the form of pseudosection calculations (e.g. Baldwin et al., 2007). The uncertainty in such calculations is, however, difficult to evaluate. How reliable a contribution might mineral equilibrium modelling make to our understanding of planetary processes?

A new tool within the THERMOCALC software, av*PT*+ (Green & Powell, in revision), promises to make this uncertainty less opaque. The method is implemented for calculations based on the Holland & Powell (2011) end-member dataset and associated thermodynamic models for mineral phases (*x*-eos: composition-dependent equations of state). Like its predecessor method, av*PT* (Powell & Holland, 1994), av*PT*+ is formally a method of inverse thermobarometry: the user provides the analysed compositions of minerals thought to represent an equilibrium assemblage, and the algorithm returns an optimised estimate of the equilibrium pressure and/or temperature recorded by the observed assemblage. Unlike the older av*PT* method, however, av*PT*+ makes this optimisation at fixed bulk composition, and in this sense resembles a pseudosection calculation. The optimisation is subject to uncertainties derived from (1) the calibration of the *x*-eos, (2) from the recalculated mineral analyses and their conversion into THERMOCALC's internal composition variables, and (3) from the bulk composition. Av*PT*+ output sometimes reveals large errors in the modelled partitioning of elements between minerals. By comparing av*PT*+ output with a pseudosection calculated for the same bulk rock composition, it may be possible to infer which phase-out boundaries on a pseudosection are highly uncertain, resulting in a misleading comparison between the calculated most-stable assemblage and the assemblage observed in the rock.

We advocate re-evaluating key samples, using a combination of av*PT*+ and equivalent pseudosection calculations, to characterise typical uncertainties in petrological phase equilibrium calculations. This process will also establish targets for improving the *x*-eos, and the contributions that petrological modelling can make towards our broader understanding of the Earth.

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Microstructural characteristics of the southeast Australian lithospheric mantle constrained from xenoliths

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The geological interpretation of the geophysical datasets (e.g., passive seismic and magnetotellurics) available for the Australian continent relies mostly on theoretical approaches rather than observed physical mantle properties. In southeast Australia, the thermal structure and composition of the lithospheric mantle are well-constrained (O'Reilly and Griffin, 1985), however, its microstructural and petrophysical properties are poorly understood. To address this gap, we studied a suite of xenoliths, predominantly spinel peridotites with some pyroxenites, entrained in Cenozoic (ca 4.5 Ma - 5 ka) volcanic rocks erupted in three volcanic centres (Mount Leura, Mount Anakie, and Mount Wiridgil) within the Newer Volcanic Province in southeast Australia. Combined X-ray and electron microscopy analyses of the xenoliths provide direct constraints on the deformation processes and structural heterogeneity of the lithospheric mantle.

We used X-ray computed tomography to quantify the xenolith fabric defined by the three-dimensional shape preferred orientation of spinel grains, as well as their spatial distribution. Spinel shows significant variation in both shape and degree of anisotropy of the mean fabric ellipsoid within each volcanic centre. While the range of anisotropy degree is similar between centres (P': ~1.1 to ~2.6), fabric geometry differs notably among them. Xenoliths from Mount Leura exhibit a wide range of shape fabrics from prolate to oblate (T values: -0.82 to 0.38). In contrast, spinel lherzolite xenoliths from Mount Wiridgil show predominantly oblate shape fabric. Preliminary results from Mount Anakie also suggest oblate shape fabric. We used electron backscattered diffraction (EBSD) to determine the modal composition, and crystallographic preferred orientation of the major mineral phases, as well as to estimate the differential stress and seismic properties (i.e. velocities and anisotropy) of the lithospheric mantle. Our results contribute to a better understanding of the three-dimensional microstructural variations and deformation geometry in the lithospheric mantle in southeast Australia.

Acknowledgments: We thank Sue O'Reilly and Olivier Alard for providing us with xenolith samples.

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Structural analysis of the Hyde-Macraes Shear Zone hosted gold deposit, New Zealand

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The Macraes orogenic gold deposit is located in the Otago goldfield in the South Island of New Zealand. Hosted in the Otago Schist belt by the Hyde-Macraes Shear Zone, the deposit formed due to convergence along the Pacific margin of Gondwana, with the earliest stages of deformation linked to gold mineralisation. The ore deposit consists of interlayered feldspathic and micaceous schists, with mineralisation hosted in different structures within each lithology. In competent feldspathic layers, gold is found within quartz veins, whereas in less competent micaceous layers, gold is hosted in high strain zones.

Despite extensive studies on the geology and mineralisation of Macraes, a detailed structural analysis is yet to be conducted. This study provides a structural review of the shear zone, focusing on the relationship between specific structures and mineralisation and between the highly mineralised shear zone and less deformed, unmineralised adjacent rocks. Understanding why strain and fluid flow are localised to certain zones provides deeper insight into the structural controls on the formation of the deposit. This offers new perspectives on similar shear-hosted deposits globally.

Rheology modification in subduction channels due to eclogite facies metasomatism (Rocky Beach Metamorphic Mélange, Port Macquarie, Australia)

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The rheological properties of the interface between subducting and overriding plates in subduction zones are important for understanding plate convergence and the mechanisms behind seismic and aseismic slip. This interface, known as the subduction channel, is studied through exhumed samples that provide insight into deformation and metamorphism that affects rheology. The focus of this study is the Rocky Beach Metamorphic Melange in Port Macquarie, which contains eclogite, blueschist, and greenschist facies blocks encased within a mélange matrix. Previous studies suggest that high-pressure blocks were subducted to depths of around 100 km and then retrogressed during return flow. Our research shows that metasomatism, a process involving fluid-rock interaction, alters the rheological properties of these blocks, with varying effects depending on the pressure and temperature conditions of metasomatism. Unmetasomatised eclogites remained rigid, while metasomatised eclogites were affected by significant strain, forming isoclinal and refolded folds. Deformation began under eclogite facies conditions and continued during return flow to blueschist facies, where metasomatised rocks developed mm-scale isoclinal folds that underwent shearing parallel to fold limbs resulting in rootless isoclinal folds. As these rocks continued to greenschist facies, pressure solution became the main deformation mechanism, particularly in lawsonite-bearing layers, leading to mineral dissolution precipitation and mass loss. The metasomatism at eclogite facies reduced the strength of the blocks, decreasing the heterogeneity of the subduction channel during return flow. We suggest that extensive eclogite facies metasomatism in subduction channels may reduce the likelihood of seismic slip during exhumation due to the reduced strength and proportion of rigid blocks.

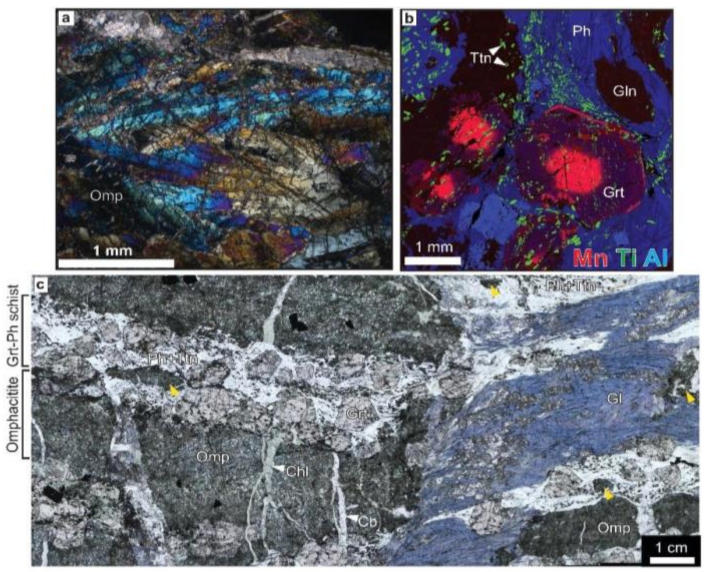

Figure 1. A) Examples of mineral relationships from the southern section of the RBMM. (a) Microfolds in omphacite from an omphacitite (XPL). (b) Element map of manganese (red), titanium (green) and aluminium (blue) in a Grt-Ph schist. Titanite is included in Grt and is in the Grt-Ph matrix that wraps around Grt. (c) Layers of omphacitite, Grt-Ph schist and blueschist. Blueschist and Grt-Ph schist include pieces of omphacitite layer (yellow arrows) (PPL).

Multi-scale fracture analysis and bedrock mapping of the Galan Ignimbrite near Salar de Hombre Muerto, Catamarca Province, Argentina

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The Hombre Muerto West lithium-brine project, one of the world's most significant sources of lithium brines, is situated near the northern edge of Catamarca Province in northern Argentina. The Salar del Hombre Muerto is located at 67.1° W and 25.4° S, at an elevation of 3,972 MSL within the arid Puna Plateau. This salar is an approximately 600 km2 rectangular dry salt pan, surrounded by faults that trend both northeast-southwest and northwest-southeast. The salar is divided into a debris-covered eastern section and an evaporite-dominated western section. Forty kilometres south of Hombre Muerto West, there is a structurally controlled basin measuring 15 km by 4 km, infilled with sediments containing lithium-bearing brines. This basin is flanked by the massive 2 – 7 Ma Galan Ignimbrite.

Bedrock fractures and faults were compared to regional lineaments and basins to assess the impact of fracture networks in Hombre Muerto West and evaluate their influence on the lithium-bearing brine resource. These fractures can create complex networks of planar discontinuities, serving as pathways for the movement of lithium-bearing brines. Using drones in the field provided high-resolution nadir photography of highly fractured outcrops that serve as proxies for regional structural patterns observed during bedrock mapping. The drone images were processed using open-source software, and the fractures were digitised using QGIS. Digitised fractures and lineaments were analysed using the Fractopo Python package (Ovaskainen, 2023). The package provides statistics of the 2D outcrops, including fracture densities, orientations, mean lengths, and topological parameters.

The primary fracture sets identified exhibit an N-S and E-W orientation, evident at both the map and outcrop scales. This observation contrasts with the regional fault-controlled geomorphology trending NW-SE and NE-SW, indicating that most fractures were formed in an N-S transtensional regime. This finding underscores the importance of integrating drone technology with traditional bedrock mapping to enhance efficiency at both metre and kilometre scales. The resulting bedrock maps and fracture analyses can support future lithium-brine exploration by combining this data with past drilling results and geophysical surveys.

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Narrow shear zones within broad transpression zones: testing theory with analogue experiments

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In obliquely convergent margins the entire upper plate may be subjected to regional transpression. Within this broad region of transpression, deformation may become localised into margin-parallel shear zones due to magma-related thermal softening, reaction weakening or reactivation of inherited structures. In this scenario, we can expect the margin-parallel component of non-coaxial deformation to become partitioned into narrow (0.1 – 1 km) shear zones, while the margin normal component of coaxial strain is distributed across a broad transpression zone (10 – 100 km). Here we investigate a model of ductile transpression in which a thin, low-viscosity layer (the shear zone) is sandwiched in the middle of a higher viscosity zone (the broad transpression zone). Material in the transpression zone is free to extrude vertically but is confined laterally. Because the thickness of the shear zone is small compared to its other two dimensions, it is constrained to match the in-plane strain of the surrounding rocks. The strain response of such models is examined analytically and with analogue experiments. The significant parameters are bulk convergence angle, α, and viscosity ratio, m. We aim to predict how both the instantaneous and finite strains vary in both the shear zone and the surrounding transpression zone in time and space, as a function of α and m. The resulting strain and vorticity patterns can be used to interpret complex fabric and kinematic relationships in exhumed oblique convergent margins.

Analytical modelling deals with small strains and strain rates within zones of infinite extent and idealised geometry. Analogue experiments are used to confirm the analytical models and to study the consequences of finite strain accumulation over time. As expected, the horizontal shear strain is concentrated in the low viscosity shear zone, but that zone is also stretched vertically, to match the vertical extension of the wall rock. Varying α and m leads to a number of interesting situations. For example, lineations (i.e. the directions of maximum principal strain and strain rate) in the narrow shear zone can be horizontal, while those in the adjacent domain are vertical, or the deformation in the surrounding rocks can be dominated by vertical stretching, whereas almost pure flattening strain occurs in the shear zone.

Three-dimensional finite strains measured in the experiments are consistent with theoretical predictions at relatively low levels of deformation. However, they start to diverge from theory at higher strain, recording a greater degree of flattening in the shear zone than predicted. This can be explained by imperfections in the experimental machine, such as maintaining perfectly parallel side walls and some horizontal extrusion at the ends of the transpression zone. However, the main factor arises from challenges in controlling the initial width of the low viscosity shear zone, which if too thick results in more vertical extrusion and volume loss than assumed in theory. This enhanced volume loss results in stronger than predicted flattening strains in the central shear zone, as might also be expected in nature due to dehydration reactions or partial melting and melt extraction.

A baseline model for fault development across transpressive plate boundaries

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Transpression is an encompassing term for vertical deformation zones that may include all potential ratios of combined boundary normal shortening (press) and boundary parallel simple shear (trans) (Sanderson and Marchini 1984, Dewey *et al.* 1998). Fault networks which develop to accommodate strain across transpressive systems can therefore differ substantially depending on the tectonic boundary conditions. Such fault networks have a strong control on hydrothermal fluid migration and associated mineralisation, and therefore the distribution of commodities such as Gold, Silver, and critical metals such as Molybdenum, Lithium and Scandium. Here, we present the results of a transpressive analogue experiment series, conducted at the Universität Hamburg Experimental Tectonics Laboratory, using the unique *MultiBox* apparatus (Eisermann *et al.* 2021). The experiment series is designed to provide a baseline model of the development and spatial distribution of faults across all possible transpressive boundary conditions. The experiments sequentially alter the trans/press ratio, beginning with 100% boundary parallel shear and ending with 100% boundary normal shortening as end members. The experiment series is repeated twice, once where the boundary parallel shear is localised over a basal discontinuity, and once where the boundary parallel shear is distributed over a much larger area using four-way stretchable fabric taped to the base of the *MultiBox* (Withers *et al.* 2023). In this presentation we will review the full range of structural geometries that arise in the upper crust from systematic variations in the lateral and basal boundary conditions of transpression zones.

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Thermomechanical modelling as a tool for decoding geophysical anomalies: A case study of strike-slip pull-apart basins

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Interpreting electrical conductivity anomalies in magnetotelluric (MT) models is often difficult. Researchers face challenges due to the inherent non-uniqueness of MT modeling and the open-ended nature of interpretations caused by limited knowledge of Earth's subsurface. One method to interpret conductivity anomalies involves using experimental measurements of electrical conductivity in minerals or rocks to estimate composition and mineral structure. However, this approach can overlook the complex geometries present in real geological environments and how these complexities are represented in MT models. To bridge this methodological gap, we developed a new toolkit called 'pide' that can transform thermomechanical models into geophysical observables, including electrical conductivity.

Using the new pide toolkit, one can create an efficient workflow to analyze anomalies: (1) Develop a thermomechanical model for the tectonomagmatic environment in question, (2) translate the model into geophysical parameters, (3) generate synthetic magnetotelluric (MT) data from these models that mimic real-world data sets, (4) invert this synthetic data, and (5) compare it with actual MT models from similar environments. This iterative approach was first applied to study anomalies in pull-apart basins formed by strike-slip faults, with a comparison to real-world examples from the North Anatolian and San Andreas Fault Zones. By presenting these examples, we aim to demonstrate a new methodological framework for interpreting geophysical anomalies.

To splay or not to splay? That is the question

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Geologists use the term 'splay fault' to refer to a secondary fault which branches outwards at an acute angle from a primary fault (Fossen 2010, Perrin *et al.* 2016). The word 'splay' is defined as 'to cause to spread outward' and therefore splay faults are often associated with assumed kinematics where the secondary fault propagates outwards from the primary fault. The assumed kinematics have implications for geological interpretations, including development of 3D models (Bond *et al.* 2007b, Grose *et al.* 2020, Grose *et al.* 2021). We present the results of analogue modelling experiments that investigate the development of branching strike-slip fault systems with 'splay fault' surface geometries (Withers *et al.* 2023). We show that fault networks within regions of ~100 km wide distributed simple shear develop as sub-parallel arrays that approach and intersect the primary fault, creating an abutting relationship. The geometries resemble splay fault systems that develop within regions of ~10 km wide localised simple shear, however the mode of formation is not consistent with the kinematic interpretation of splay fault development. We therefore suggest the term 'splay fault' be used with caution when interpreting branching strike-slip fault systems and should be restricted to describe secondary faults which form by branching away from primary faults. This study highlights that scale is an important factor when interpreting fault networks.

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Modes of rifting of oceanic Large Igneous Provinces

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Oceanic Large Igneous Provinces (LIPs) are scattered over the global seafloor. Their formation is typically attributed to mantle plumes and they can develop in both divergent plate boundary and intraplate settings. The inaccessibility of these predominantly submarine, thickly-sedimented igneous oceanic LIPs has resulted in limited understanding of their post-formation evolution, particularly regarding the role of extension following formation.

Significant lithospheric weakening, and sometimes successful breakup of oceanic LIPs, is fostered through a combination of plume-driven thermal weakening and extension from divergent plate boundaries. Oceanic LIPs that fragmented in the Eocene appear to be linked to the ~50 Ma major plate reorganization, which likely triggered spreading ridge jumps, leading to breakup. Oceanic LIPs that separated in the Cretaceous are associated with plume-driven thermal weakening, rapid extension rates, warm LIP lithosphere, and the ~100 Ma plate reorganization in the Southwest Indian Ocean. Some oceanic LIPs have not undergone any rifting, which appears to be due to their distance from mantle plumes and plate boundaries, or mantle plume-driven thermal weakening too limited to significantly influence the LIP crust.

Corroborating ASPECT numerical models and observational data from the Kerguelen Plateau-Broken Ridge rift system support the above observations, and can be used as a reference to explain the rift processes undergone by oceanic LIPs. After being emplaced and subsequently subsiding below sea level, during the early stages of rifting, the conjugate flanks of many oceanic LIPs are uplifted to be exposed subaerially or to shallow marine conditions, before subsiding further. Under the continuous influence of extensional stresses, the rift evolution can result in either failed rifts or successful rifting followed by seafloor spreading. These results show that extension plays a critical role not only in the formation of oceanic LIPs, but also in controlling their breakup. Like its impact on continents, plume-driven thermal weakening affects the strength and deformation patterns of oceanic LIP crust during post-emplacement rifting.

Oxygen isotope shifts during continental anatexis: fingerprints of fluid-fluxed melting

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Fluid-fluxed melting is increasingly recognised as a mechanism for continental crust growth and recycling, but the abundance and sources of external fluids remain uncertain. Zircon and garnet oxygen isotope data, supported by geochronology and petrological analysis of mid- to lower-crustal (6-9 kbar), 1565–1440 Ma rocks from the Georgetown Inlier, Australia, reveal the composition and origin of anatexis-triggering fluids. Tonalite veins and associated residual garnetite show zircon $\delta^{18}O$ values (~6‰) that are distinctly higher than in their amphibolite source (~2–3‰), while sediment-derived (S-type) granites yield similar values (6‰), which are lower than typical siliciclastic sources (10–20‰). Mantle-like $\delta^{18}O$ values of ~5‰ for the garnetite residue are considered the most appropriate geochemical proxy for the ingressed fluids. Statistical mass balance calculations of fluid–rock interaction explain the contrasting isotopic shifts to a relatively uniform 5-6‰ during partial melting induced by the mantle-like hydrous fluids. Post-collisional asthenospheric mantle upwelling beneath the Georgetown crust as the subducting slab either broke off or rolled back provided the heat and fluids to generate young hydrous mafic underplates that exsolved mantle-derived water, thereby generating crustal-derived magmas from both metasedimentary and metaigneous (amphibolitic) sources. These findings underscore the critical role of mantle-derived fluids in promoting anatexis and influencing continental crust evolution.

U-Pb apatite and zircon ages of dolerite from the Baryulgil Serpentinite, NSW: Insights into the emplacement age of the ultramafic massif

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The Baryulgil Serpentinite, the largest known ultramafic massif in New South Wales, is part of a serpentinite belt that occurs sporadically along the length of the New England Orogen, from Marlborough (central Queensland) to Port Macquarie (NSW). The emplacement age of the protoliths of the Baryulgil Serpentinite, and the tectonic settings in which the ultramafic melts crystallised, are unknown. Elsewhere in the New England Orogen, constraints on the ages of the dismembered ophiolite blocks range from Neoproterozoic (~560 Ma, basalt Sm-Nd), Cambrian (535–500 Ma, plagiogranite U-Pb zircon ages), Silurian - Devonian (~420 – 377 Ma, Plagiogranite U-Pb zircon ages) to Early Permian (~280 Ma, plagiogranite U-Pb zircon ages). To address this tectonic enigma, we investigated the age and composition of dolerite dykes and inclusion that intrude on the Baryulgil Serpentinite.

Eight samples of dolerite collected from several locations revealed variations in texture, mineralogy, and metamorphic alteration. The samples are anisotropic at both macro and microscopic scales. Most samples are phaneritic, but ophitic and porphyritic textures were also observed. The dolerite is metamorphosed and comprised primarily of fine- to very fine-grained amphibole crystals set within a plagioclase matrix. Augite crystals were locally observed in the groundmass, partially altered to chlorite. Plagioclase is variably altered to albite. Relict augite and hornblende phenocrysts were locally observed. Altogether, the mineral assemblage is indicative of greenschist to lower-amphibolite metamorphic conditions.

Apatite occurs as a trace mineral in most dolerite samples. One sample (BRG23-16) yielded a 379 ± 24 Ma $^{207}Pb/^{206}Pb$ age (n = 20, MSWD = 2), which we interpreted as the crystallisation age of the dolerite dyke, based on textural relationships of apatite with relict plagioclase and augite. Apatite from other samples (20BY15 and 20BY03) yielded much younger $^{207}Pb/^{206}Pb$ ages (248 ± 19 Ma, n = 56, MSWD = 1.2, and 257 ± 44 Ma n = 11, MSWD = 1.2, respectively). Considering that apatite grains from these samples exhibit complex patterns on SEM-CL images, we interpret these ca. 250 Ma ages to represent the timing of contact metamorphism by Triassic I-type granites. In one sample (20BY09), we found euhedral and bipyramidal zircon grains, with marked oscillatory zoning in CL images typical of magmatic zircons. Some of these zircon grains contain inherited cores with complex CL patterns. LA-ICP-MS spot analyses on magmatic domains yielded a 444 ± 17 Ma concordant age (n = 20, MSWD = 5.9). We interpret these zircon grains as xenocrystic grains extracted from the magmatic pathways or wall rocks when the mafic melt was emplaced.

The combined U-Pb apatite-zircon ages of dolerites from Baryulgil rules-out an early Permian emplacement of ultramafic melts for the Baryulgil serpentinite. The dolerites constrain the massif to be likely older than ~379 Ma. The occurrence of ~450 Ma magmatic xenocrystic zircon grains indicates the presence of Ordovician aged crustal rocks occur at depth.

Thermal history of the East Antarctic margin recorded in apatite: Campaign-style Lu-Hf, U-Pb, fission track and U-Th-Sm/He results

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Antarctica was the centre of Gondwana for most of the Phanerozoic and holds key information on the tectonic evolution of our planet. Its location and extensive conjugate margin make it a pivotal puzzle piece for reconstructing the evolution of supercontinents. Yet, largely due to its remoteness and outcrop scarcity, the tectonic history of Antarctica remains poorly constrained.

Thermochronology can provide time constraints on the process of amalgamation and breakup of Gondwana and the impact of these processes on the conjugate margin of East Antarctica. While high-temperature radiometric clocks can be used to constrain deep crustal processes related to amalgamation (i.e. metamorphic history), low-temperature chronometers can advance our understanding on the landscape evolution during continental breakup.

In this study, we present new apatite U-Pb, Lu-Hf and fission track results for the East Antarctica margin, with the aim to reconstruct its thermo-tectonic evolution during an entire super-continent cycle. The higher temperature apatite chronometers (U-Pb ~ 350 – 550 °C, Lu-Hf ~ 650 – 730 °C) record the Proterozoic cratonization in the Antarctic continuation of southern Australia (1.7 – 1.5 Ga) as well as the 2nd phase of the Albany-Fraser orogeny (1200-1150 Ma). In the Indo-Antarctic sector early Phanerozoic metamorphism, time-equivalent to the Kuunga orogeny (550 – 500 Ma), is recorded.

Low-temperature thermochronology (fission track ~60 – 120 °C, U-Th-Sm/He ~ 75 – 40 °C) reveals rapid Late Carboniferous and Permo-Triassic cooling of the passive margin, preceding continental breakup. New thermal history models indicate that Palaeozoic – Early Mesozoic pre-breakup 'cracking' of the Gondwana supercontinent, may have led to vertical adjustment along the intercontinental margin without major horizontal displacement. Proto-Pacific subduction along the Gondwanide orogeny and perhaps additional rifting of the Cimmerian Terranes in the Meso-Tethys may have extended intercontinental margins of Gondwana, forming a failed rift that acted as a breaking point for later extension. Given the absence of Cretaceous rapid cooling in the models, Gondwana breakup at 160-80 Ma may have only affected the upper 2km of earth's crust without leaving a deeper imprint that can be accessed by thermochronology.

Hence, the multi-method `campaign-style` approach characterizes the thermal history of the East Antarctic basement, revealing regional differences between the Indo- and Australo-Antarctic domains. Further, it provides time constraints for the late Palaeozoic – Mesozoic denudation history leading to the eventual supercontinent breakup and continental drift.

Reactive and resilient: the behaviour of geochronometers during deformation

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Technological advancements, such as higher spatial resolution and sensitivity of in-situ techniques, have made it easier to constrain the timing of deformation, yet significant challenges remain (e.g., Villa, 2022). One major limitation is the small size and low modal abundance of syn-kinematic minerals and overgrowths. Shear zones often exhibit apparent lithological heterogeneity, with compositionally distinct layers alternating at the millimeter scale. Additionally, the prolonged activity of shear zones, which can culminate in brittle deformation leading to comminution and fluid-induced retrograde reactions, adds further complexity. The behavior of geochronometers during deformation is still not well understood and remains a critical area of ongoing research (e.g., Mottram and Cottle, 2024).

This study focuses on the behavior of accessory minerals such as zircon, monazite, and titanite, commonly found in basement rocks, during mylonitic deformation under high to medium-temperature conditions in the continental crust. We examine the Ivrea-Verbano Zone (Italian Alps), a continuous section of low- to mid-Variscan continental crust that experienced rift-related extensional deformation during the Triassic-Jurassic period. To elucidate the behavior of different geochronometers, we employ a combination of mineral-scale microtextural characterization, petrochronological analysis (U-Th-Pb isotopes and trace elements), and petrological characterization of microdomains. This integrated approach allows us to explore the interactions among key factors influencing geochronometer reactivity, including microdomain composition, intracrystalline deformation, metamorphic conditions, fluid flow, and dissolution-precipitation mechanisms. We demonstrate how geochronometer reactivity is affected by strain intensity (e.g., protomylonites vs. mylonites), local variations in mineral assemblages (mm-scale compositional layering), and metamorphic conditions ranging from high to medium temperatures.

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Challenging the garnet chemical-isotopic reliability under high-temperature deformation

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Garnet is a common mineral in metamorphic rocks, prized for its chemical-isotopic systems that are sensitive to changes in pressure and temperature. This sensitivity makes garnet a valuable tool for constraining the conditions and timing of metamorphic and associated geological processes. However, the reliability of garnet's chemical-isotopic systems can be challenged by additional processes often associated with metamorphism, such as mineral intracrystalline deformation. Although garnet is typically considered a rigid and stable mineral, nanoscale studies have shown that dislocations within the crystal can cause segregation of major and trace elements like Ca, Mg, Fe, Na, and Ti into intracrystalline defects. Yet, the full extent of these processes on grain-scale garnet geochemistry remains underexplored. In this study, we investigate the impact of intracrystalline deformation on garnet chemistry and the Lu–Hf isotopic system. We use an array of microstructural mapping techniques and in situ Lu-Hf isotopic analysis on garnet porphyroclasts from high-temperature mylonite in the Alem-Paraíba shear zone (SE Brazil).

Our findings reveal that garnet recrystallization, leading to subgrain formation due to grain boundary gliding, does not significantly promote grain-scale element mobility. However, when the dislocation network exceeds the threshold needed to form a low-angle boundary network, major and trace elements are mobilized on a grain scale, facilitating re-equilibration during retrograde shearing. This dislocation network also enables the syn-kinematic diffusion loss of radiogenic $^{176}Hf^{*}$, directly affecting the garnet Lu-Hf geochronometer and thus the timing of intracrystalline deformation. Our results suggest that chemical perturbations and isotopic resetting in garnet under high-temperature deformation are more complex than previously assumed.

In-situ Lu-Hf dating of garnet: a novel new tool for granulite geochronology

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Geochronological studies in high-grade metamorphic terranes are essential for the temporal reconstruction of tectonic and associated magmatic events and to understand uplift histories. Typically, these studies deploy a variety of radiogenic isotope chronometers with different closure temperatures to reconstruct time-temperature evolution paths. Geochronometers based on rock forming minerals, such as garnet, are particularly attractive because of the wealth of petrological and geochemical information that can be gleaned from them.

Conventionally, garnet has been dated by hand-picking, digestion, chemical separation, and analysis of the U-Pb, Pb-Pb, Sm-Nd, and Lu-Hf isotope systems. Important tectono-metamorphic information has been obtained with garnet geochronology, particularly for constraining the timing of relatively high-temperature processes that are preserved thanks to the high closure temperatures (~600°C or higher) of these systems. However, solution-based garnet geochronology is not only time- and labour-intensive but the resulting multi-chronometer dates are also often complex. Complexities arise from mineral inclusions, elemental zoning, multiple generations of garnet growth, isotopic disequilibrium with the whole rock, and unexpectedly low parent/daughter ratios, yielding insufficiently radiogenic isotope ratios for precise dating. These factors can result in datasets devoid of chronological information, and, in the worst situation, potentially untrustworthy spurious age dates.

The development of Laser-Ablation Inductively-Coupled-Plasma tandem mass spectrometry (LA-ICP-MS/MS) has opened new opportunities for in-situ dating. The advent of Q-ICP-MS with reaction gas technology allows beta decay radiogenic isotope systems to be utilised for in-situ isotope analysis. For Lu-Hf, where Lu is effectively separated from Hf through reaction with NH_3, this allows for in-situ analysis of garnet (Glorie et al. 2024) and apatite and other rock forming and accessory phases. The technique is fast, and conventional LA-ICP-MS can be used to screen samples into those with sufficiently high Lu concentration and low common Hf, thereby avoiding the disappointment of unradiogenic Hf besetting the solution-based approach.

In this study, we present Lu-Hf data for large (>5 mm) chemically zoned garnets from Palaeoarchean granitoid gneisses from the East Pilbara Terrane (Wiemer et al. 2016) to assess if the garnet grew in one or more tectono-metamorphic event and to understand the post-magmatic history of deformed gneisses on the margin of a typical Archaean granitoid dome.

More broadly, we are participating in efforts to characterise a wider suite of garnet-bearing granulites, including lower crustal xenoliths from eastern Australia, to better understand the conditions that lead to favourable Lu/Hf systematics for dating. Our on-going work has highlighted the propensity of clinopyroxene, ilmenite, and rutile to sequester Zr and Hf and the strong incorporation of heavy REE into garnet, certainly in the absence of zircon, which is typical for refractory lower crustal mafic xenoliths. Study of these contrasting garnet-bearing lithologies is expected to provide useful constraints on expected garnet age and concentration of Lu and Hf in garnet that can provide reliable geochronological information.

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Timing post-peak reactivation episodes in the Broken Hill Block using allanite (and friends) in a shear-hosted REE-IOCG deposit

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The upper greenschist to granulite facies field array of the Broken Hill Block of NSW is crosscut by a network of biotite-muscovite-rich retrograde schist zones that are the primary record of post Olarian Orogeny (<1600 Ma) evolution in the eastern Curnamona Province. The Copper Blow Schist Zone south of Broken Hill township is unique in that it hosts an allanite-rich REE-IOCG prospect (copper blow) that preserves an unprecedented history of shear zone reactivation to the Carboniferous. Allanite U-Pb dating and trace element chemistry from the mineralised shear zone records initial LREE-rich allanite crystallisation associated with IOCG mineralisation between 1430-1340 Ma. Subsequent recrystallisation/neocrystallisation of allanite (±titanite and mica) records events at ~800 Ma, ~500 Ma, 440 Ma and 320 Ma, with younger events associated with limited, but distinctive HREE-rich allanite as rims surrounding Mesoproterozoic allanite. The initial Mesoproterozoic (1430-1340 Ma) timing of LREE-rich allanite and IOCG mineralisation is previously unknown in the Borken Hill Block, while ~800 Ma coincides with Neoproterozoic magmatism/sedimentation in the Adelaide Rift Complex, ~500 Ma with the Delamerian Orogeny, 440 Ma with the Benambran Orogeny and 320 Ma with the Kanimblan/Alice Springs Orogeny. The crystallisation of limited, but distinctive HREE-rich allanite primarily at ~500 Ma times extensive biotite-muscovite retrogression of the garnet-rich host sequences and the main phase of schist zone formation during the Delamerian Orogeny, with recrystalised granulite facies garnet representing the mostly likely, local HREE source.

Hypothesis-related systematic uncertainty in radiometric dating of deformation: some cases, arguments and alternative strategies

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While significant advances have been achieved in radiometric dating techniques in recent times, the often low analytical and statistical uncertainties which are reported may not always reflect a probable or possible time range of an event, especially in *orogenic systems* where several factors may be involved (e.g., Schaen et al., 2021, p. 478). In applications to *ages of rock deformation*, further systematic uncertainty may arise from the choice of hypothesis of formation of a *cleavage or schistosity fabric*. This presentation examines some published examples from the Swiss Alps and the Cobar Mineral Field with a view to increasing awareness of how this can affect the results. Two main hypotheses are considered, which have been current for over a century, and a common third one.

- The 'crystallization' hypothesis: synkinematic growth of minerals, particularly phyllosilicates, in or parallel to cleavage surfaces. Proposed cracks or channelways for transport of fluid along cleavage planes subject to maximum normal stress under formative conditions, as well as necessary expansion of the deposits against such stress, are the *least* likely directions. So *rejected* on mechanical grounds. Similarly, bent and differently oriented micas with different interlayer components, including 'chlorite-mica stacks', appear not be distinct new phases but modifications of earlier micas.
- The 'pressure-solution' hypothesis: dissolution of 'mobile' minerals on surfaces parallel to cleavage, and solution residues of 'immobile' minerals in cleavage-parallel domains. Widely observed in impure arenites and siltstones. Explains strong orientation of clays and white micas in the residues and is physically realistic. So *works*. However, not useful for dating appreciably below closure T owing to retention of primary material. Chiefly important if neglected such that a residual origin of cleavage-domain minerals is overlooked.
- The single event hypothesis: utilised for interpretation of Ar/Ar data on 'Cobar type' mineral deposits assuming mineralisation during convergent deformation. Does not recognise a possible higher-T basin-related hydrothermal event prior to regional deformation, with possible continued Ar loss during cooling afterwards, and/or partial Ar loss during later sub-closure-T regional deformation, thus not clearly defining the deformation.

As may be seen, such assumptions may result in significant over-estimation of convergent deformation ages in terrains well below closure T. Accordingly, an alternative in such situations is to analyse minerals which *are* known to have grown during convergent deformations, such as in flat veins and steep 'fringe' structures. Examples where this may be possible are (1) low- to intermediate-T feldspars and biotite in small cracks in plagioclase kinematically related to solid-state S-structure in granite (Lennox et al. 2016), and (2) well-preserved post-mineralisation quartz-carbonate 'fringes' on pyrite, and similar growths in vertically stretched pyrite veins, from the former Elura mine, Cobar.

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The origin of platinum group minerals in ophiolites, and implications for the Re–Os geochronometer

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The highly siderophile elements (HSEs), which include Re and Os, are geochemical tracers and geochronometers that have been used to constrain the formation and evolution of Earth's crust and mantle. Rocks from the Earth's mantle on the surface of Earth are commonly serpentinized, but the effect of serpentinization on the distribution of HSEs is poorly understood, partly because a large proportion of the HSE budget is hosted by rare, micrometer- to sub-micrometer-scale grains of platinum group minerals (PGMs). These grains are difficult to find, characterise, and interpret. Atom probe tomography (APT) provides the necessary nanometer-scale spatial resolution to characterize complex PGMs and was applied to PGMs from Macquarie Island, Australia, and the Oman Ophiolite.

The APT data reveal an extraordinary level of complexity that has been used to derive insights into the origin of a complex Cu–Pt alloy grain (average composition ~ Cu_4Pt). The grain hosts Fe-, Ni-, and Pt-rich sub-grains that are associated with Rh, variably overlapping Pd- and Cd-enriched networks, and OH-rich volumes that are interpreted as fluid inclusions. An idioblastic laurite (RuS_2) grain hosts Os and Ru. The compositions and textures of the alloy grains, combined with phase diagram constraints, indicate that the PGMs formed prior to serpentinization but were modified by serpentinizing fluids. Implications for the Re–Os geochronometer are discussed.

The Triple Orogenic Junction of Central Gondwana

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Three distinct continental collisions during the Neoproterozoic tectonic history of central Gondwana produced the East African Orogen (late Cryogenian), the West Antarctica Orogen (early Ediacaran), and the Kuunga Orogen (late Ediacaran). These orogens have intricate geometries which frequently overlap one another geographically and retain the evidence of multiple metamorphic processes that resulted from successive collisions. We used Sm-Nd and Lu-Hf isotope data, thermobarometric P-T peak estimations, and zircon and monazite U-Pb ages (from igneous, detrital, and metamorphic rock samples) to reconstruct the tectonic history of central Gondwana. Our dataset includes information from eastern Africa, southern India, central-southern Madagascar, Sri Lanka, and East Antarctica. The analysis of 2208 concordant U-Pb metamorphic zircon ages, ranging from 700 to 450 Ma, indicates that a peak metamorphic event, recognisable amongst different terranes, occurred at c. 550 Ma. We consider several possible scenarios for the evolution of the three orogens. Specifically, we reassess previous tectonic reconstructions based on geochronological and isotopic data from a potentially contiguous province named TNASH (Trivandrum and Nagercoil terranes in southern India, Androyen and Anosyen terranes in southwestern Madagascar, Skallevikshalsen terrane in East Antarctica, and Highland Province in Sri Lanka). These Paleoproterozoic terranes exhibit comparable U-Pb igneous ages, isotopic signatures (Lu-Hf and Sm-Nd), and metamorphic conditions. Our study provides an extensive review into the complex tectonic history of central Gondwana, and a better understanding of the strengths and limitations of previous hypotheses.

The elusive tectonic setting of the New England Orogen during the Late Silurian–Early Devonian

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The New England Orogen, which is dominated by Late Devonian to Triassic units, includes several older successions, such as the Calliope, Silverwood, and Gamilaroi provinces. Rocks in these provinces are dominated by immature siliciclastic lithological assemblages that have been interpreted as Silurian and Early Middle Devonian supra-subduction units, but their exact tectonic setting remains controversial. Several studies have suggested an island arc origin, which would have major implications on plate tectonic reconstructions. Alternatively, these units have been attributed to a continental margin arc or a backarc. To unravel the tectonic origin of the Calliope and Silverwood provinces, we obtained detrital apatite and zircon ages from different stratigraphic levels and localities. Based on the texture and composition of the samples, we infer that the rocks represent undissected to transitional arcs. Most samples indicate an Early Devonian maximum depositional age. However, the samples also exhibit older U-Pb ages, including prominent age peaks at the Silurian, Ordovician, and Cambrian, and minor contributions from the Neoproterozoic, Mesoproterozoic, and Meso- to Neoarchean eras. The trace-element compositions of the apatite and zircon grains suggest that the early Paleozoic ages were predominantly derived from mafic sources, indicating a possible affinity with oceanic rocks. The rocks from the Calliope and Silverwood provinces share similar maximum depositional ages, peak contributions of older grains, and geochemical characteristics. Based on these findings, we interpret the Calliope and Silverwood provinces, and potentially also the Gamilaroi province, as part of the same arc system. The results allow us to reassess tectonic models previously proposed for this segment of the Tasmanides during the Cambrian to Devonian timeframe.

Apatite and zircon: Better together – The case of the northern Ecuadorean Miocene arc

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Zircon and apatite compositions are increasingly used in petrogenetic studies of plutonism and associated porphyry copper mineralization where key magmatic signatures may be obscured by hydrothermal overprinting. Useful in fingerprinting magmatic processes, apatite and zircon can retain petrogenetic information on the magmas from which they crystallized. Zircon is a highly robust mineral which provides reliable age constraints, whereas apatite provides constraints on magmatic volatile, major, and minor element contents. Within the northernmost Andes of Ecuador, Late Oligocene to Miocene intrusions and porphyritic units intrude through Late Cretaceous accreted oceanic crust. Late Miocene porphyry emplacement coincides with Oligocene-Miocene increasing compression and deepening of magmatism observed within the arc (Schütte et al., 2010). Compressive arc environments may cause ascending magmas to stall at depth, undergoing progressive recharge, enriching magma volatile contents allowing extensive amphibole fractionation and inhibiting plagioclase. In contrast, magmas formed in non-compressive arc segments may experience shallower crustal evolution where plagioclase is stable. In compressive arc segments where magmas stall at depth and become H_2O rich, plagioclase inhibition may cause certain accessory minerals to precede or accompany it in the crystallization sequence (Loucks and Fiorentini, 2023), imparting these petrogenetic signatures to accessory phases.

Apatite and zircon geochemistry and U-Pb ages were obtained using LA-ICP-MS on samples from suites of intrusive and porphyritic units within the arc. Zircon U-Pb ages provide a timeframe for the intrusive pulses while preliminary trace element results identify two trends in zircon and apatite behaviour diverging in the Late Miocene. Late Miocene trend 1 apatite include depleted MREE and variable HREE well as high and variable Sr content at constant low Y. Combined, these features may indicate extensive amphibole fractionation prior to plagioclase saturation ramping up magmatic Sr contents and depleting Y. Rapid and concurrent plagioclase, apatite, and potential zircon saturation may have been triggered by H_2O exsolution, imparting the observed chemical trends. Early Miocene trend 2 samples show evidence for lower pressure evolution, with zircon and apatite crystallization after plagioclase fractionation, but during amphibole crystallization, supported by a range of apatite Y contents at low Sr. Zircon trace elements from Trend 1 samples define a zircon-dominated trend of increasing Dy/Yb with decreasing Zr/Hf whereas trend 2 zircon show decreasing Dy/Yb with decreasing Zr/Hf, indicating co-crystallizing amphibole or titanite. Further work may clarify the relationship between tectonic regime, plutonism, and porphyry formation within the northernmost Andes of Ecuador as well as the use of accessory minerals in mineralized deposit exploration.

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Mesoproterozoic tectonic and metallogenic link between Tasmania and Laurentia revealed by multi-mineral geochronology

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Plate tectonic reconstructions suggest a connection between Laurentia and eastern Australia during the Mesoproterozoic. Detrital zircon studies have linked the Belt-Purcell Basin in the USA and Canada with the Rocky Cape Group in northwest Tasmania [1, 2]. The Belt-Purcell Basin is known for its rich deposits of Cu, Pb, Zn, and critical metals such as Co, formed during the Mesoproterozoic. Similarly, the Rocky Cape Group hosts several sediment-hosted Cu-Pb-Zn±Co prospects, previously thought to be Devonian in age.

New LA-ICP-MS in situ U-Pb monazite, xenotime, and apatite data, along with SHRIMP in-situ U-Pb monazite data and LA-ICP-MS galena Pb isotope data, were collected from these prospects. By analysing multiple minerals with different closure temperatures, we have uncovered a complex history of thermal events in the Rocky Cape region associated with Cu-Pb-Zn±Co mineralisation. Our data indicate primary sulphide mineralisation at approximately 1350 Ma, with subsequent resetting or remobilisation events at around 1250 Ma, 1100 Ma, and 950 Ma. These ages align with previously published authigenic and metamorphic monazite ages from the Rocky Cape Group, suggesting that mineralisation is broadly syn-sedimentary and related to basin development. Additionally, new Lu-Hf garnet data (using LA-ICP-QQQ-MS) and monazite data indicate that metamorphism may have coincided with some mineralisation events.

Our new data suggest a correlation between mineralisation ages, particularly with the Idaho Cu-Co Belt, including the Merle Cu-Co and Spar Lake Cu-Ag deposits. This presents new exploration targets for northwestern Tasmania and potentially southeastern Australia. These findings further support a tectonic link between northwest Tasmania and Laurentia during the transition from the breakup of supercontinent Nuna to the assembly of supercontinent Rodinia. The high metal endowment of age-equivalent rocks in the Belt-Purcell Basin highlights the potential for new discoveries of base and critical metals in southeastern Australia.

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Structural reconstruction of the Yeneena Basin, Western Australia – a key for understanding sedimentary-hosted copper mineralization

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The Neoproterozoic Yeneena Basin hosts the only mined sediment-hosted copper deposit (Nifty) in Western Australia (WA). However, the very limited exposure of the basin makes it challenging to discover new economic deposits. The data presented here are part of a MRIWA-funded (M10502) research project which integrates sub-regional to regional scale basin analysis with a mineral systems approach. This study investigates the following questions: (1) What is the present-day structural architecture of the Yeneena Basin? (2) How did the basin kinematically evolve through time and space?

Most of the known exposures of the Yeneena Basin can be found along the Pilbara Craton's north-eastern margin. Its sedimentary succession is subdivided into the Throssell Range Group (Coolbro Sandstone, Broadhurst Formation, and Isdell Formation) and the Lamil Group (Malu Formation, Puntapunta Formation, and Wilki Formation). The sediments are of Tonian age and comprise a fluvial to marine succession, reaching >5 km in thickness. The marine Broadhurst Formation hosts the Cu mineralization. The basin underwent two NE-SW directed shortening events: Miles Orogeny (~680-650 Ma) and Paterson Orogeny (~580-530 Ma).

We used seismic, gravity, and magnetic datasets to map subsurface structures and constrain the basement topography. We compiled mapped legacy bedding, tectonic foliation, mineral lineation, and hinge line orientation datasets from the Geological Survey of WA. We structurally logged ten oriented drill cores and combined these results with published structural data from seven drill cores. Integrating these various datasets, we constructed three ~47-49 km long, transport-parallel regional balanced cross-sections at the 1:500K scale to determine the Yeneena Basin's present-day structural architecture, pre-deformed basin geometry, and kinematic evolution.

Based on bedding data, we estimated the regional transport direction to be 045-225°, and hinge line orientations corroborate this interpretation. Bedding data measured from drill cores indicate that the rocks are folded along gently plunging NW trending hinge lines at the core scale. Using the line-length balancing method, we calculated a minimum shortening percentage of ~28-30% from these sections, with ~85-90% of the shortening accommodated by regional scale folds and the remainder by reverse faults. 2.5-D basin reconstructions suggest that the deformation generally progressed from the NE part to the SW part with folding pre-dating reverse faulting. Our pre- and post-shortening basin geometries will serve as the basis for upcoming stratigraphic and fluid-flow modeling exercises.

The complex chronology of Cryogenian carbonates

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The Cryogenian period represents a critical interval in Earth's history, characterized by drastic tectonic, geochemical, and environmental changes. Evidence of low-latitude glacial deposits from this interval have been recognized globally and points to the most extensive icehouse regimes known in Earth's history. The consecutive global freezing and subsequent warming conditions during the Neoproterozoic have been dubbed 'Snowball Earth' events (Hoffman and Schrag., 2000). In addition to such extreme icehouse conditions, the Cryogenian may have also played a key role in the accelerated evolution of early life, as microorganisms became more complex and abundant after this period (Och and Shields-Zhou., 2012). Consequently, it is important to constrain the absolute timing, duration, and termination of these glacial and interglacial events. Despite their geological significance, robust, direct dating of Cryogenian sections remains challenging. The most accurate way to constrain these units is through dating interbedded volcanics but they are not present across all sections globally, making correlations difficult to establish.

In order to address these issues, we present a novel strategy by directly dating a broad array of Cryogenian carbonates through an in-situ U-Pb mapping approach (Drost et al., 2018). Our case study includes inter-glacial and post-glacial carbonates from sections in Greenland, Australia, and Namibia. The examples in this presentation encompasses the Islay-Russøya Anomaly, the Trezona Anomaly, and a Marinoan cap carbonate. We show that this method allows for the concurrent collection of petrological, geochemical, and geochronological information at sufficient precision to separate key geological events. Geochemical proxies such as elevated Mn/Sr ratios and Al or Si can be used to filter areas affected by alteration or detrital input, respectively. Secondary phases such as veins, rims, and replacement textures can also be petrographically avoided as an advantage of the spatially coherent mapping technique. Regions that yield enrichment in U and best spread in U–Pb ratios can be preferentially selected. Triaging such datasets and spatial information can help identify subdomains within a sample that is most suitable for dating, maximizing the success rate of this approach.

Multiproxy Analysis of Paleoproterozoic Shales from the Limbunya Group: Insights into Paleoenvironmental Conditions

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The Proterozoic Birrindudu Basin, spanning an area of 36,000 km² in northwestern Northern Territory, remains one of the least explored basins in the region, lacking a comprehensive chronostratigraphic framework. The Birrindudu Basin shares lithological and chronological similarities with the McArthur Basin and the Tomkinson Province. These three Paleo-Mesoproterozoic, intra-cratonic basins are believed to have been interconnected at the time of deposition to form a superbasin system, informally referred to as the greater McArthur Basin. To describe such regionally extensive multiphase systems, the sedimentary successions of these basins have been divided into five basin-scale, non- genetic depositional packages. In stratigraphic order, they are: - the Redbank, Goyder, Glyde, Favenc, and Wilton packages.This study focuses on the Limbunya Group of the Birrindudu Basin, which has been placed within the Glyde Package (ca. 1660–1610 Ma) based on geophysical and sedimentological correlations. The Limbunya Group comprises cyclic successions of carbonates and siliciclastic rocks deposited in a marine shelf environment setting, influenced by multiple transgressions and regressions. This research aims to reconstruct the sedimentary environment of the group through petrography and bulk geochemistry of the shales. Given the predominance of shales in Earth's sedimentary record, utilizing clay minerals as paleo-climate proxies becomes imperative. Clay minerals have long been indicators of paleo-climatic conditions due to their chemical composition and structure, which vary with the depositional environment. However, clay mineralogy alone cannot distinguish between clays of different origins (e.g., continental-derived detrital, hydrothermal, burial, authigenic), each of which exhibits distinct particle morphology.

In this study, we petrographically identify the authigenic origin of clay within the shales of the Limbunya Group and use geochemical signatures to infer the paleo-environmental conditions at the time of their in-situ precipitation. Additionally, we utilize the authigenic clays to provide Rb–Sr ages (LA-ICP-MS/MS) from these Limbunya shales, sampled from wells DD90VRB2 and DD90VRB1 in the Birrindudu Basin. The geochronological data obtained help establish age correlations with other Glyde Package sequences within the greater McArthur Basin.

Geochronological constraint on the timing of magmatism and sedimentation in the Dajarra region, Mt Isa Inlier, Australia

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The stratigraphy of the Mount Isa Inlier is generally interpretated to reflect the superposition of three major superbasin events, marked by discontinuities and deformed and metamorphosed during the Isan orogeny. The superbasin model proposes continuation of stratigraphy along the length of the inlier and the existence of corelative units across the inlier. According to this model the stratigraphy in the Dajarra region consists of a series of units that are either continuous with or can be corelated along strike with units that occur further north. The oldest units are the Bottletree Formation and Lower Haslingden Group, characterized by bimodal volcanic and siliciclastic rocks which were deposited during 1800-1780 Ma Leichardt Superbasin. These units were unconformably overlain by the Warrina Park Quartzite and the Moondarra Siltstone accumulated during the 1690-1670 Ma Calvert Superbasin. However, there is no geochronological data available from the sedimentary units in the Dajarra region and these correlations remain speculative. In this study, we reported new LA-ICP-MS ages from magmatic and detrital zircons that can help constrain the magmatic and sedimentary history of the rocks occurring in this region and evaluated the existing stratigraphic correlations. The results indicate that (1) siliciclastic rocks mapped as the Mount Guide Quartzite have the youngest detrital populations between 1885 Ma and 1850 Ma; (2) siliciclastic sediments from the Eastern Creek Volcanics and the Jayah Creek Metabasalt have the youngest detrital zircon populations between 1870 and 1850 Ma; (3) siliciclastic rocks mapped as the Timothy Creek Sandstone and as the Mount Isa Group have the youngest detrital populations between 1820 and 1780 Ma. The detrital ages obtained in this study are significantly older compared to the same stratigraphic units mapped to the north indicating either a different source or that these units are indeed much older and represent a different stratigraphy not previously recognized in the Mount Isa Inlier.

Controversies of the Cryogenian in Oman: new temporal, chemostratigraphic and palaeomagnetic constraints on the Saqlah, Fiq and Hadash Formations

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The Neoproterozoic is unparalleled in the extent and frequency of earth system fluctuations occurring in this time. The development of our present-day habitable planet and the subsequent evolution of our animal ancestors are attributed to the changes that occurred during this era. The Cryogenian period lies within the Neoproterozoic and records two global-scale glaciations, the older 'Sturtian' and the younger 'Marinoan', separated by an interlude of extreme hothouse climate. Despite the significance of this time in earth history, there still remains contention over the causes and implications of such dramatic climatic shifts. Prior studies of upper Cryogenian and early Ediacaran sedimentary sequences from north Oman have been the source of two major controversies provoking reconsideration of the "Snowball Earth" hypothesis. Firstly, it is proposed that the Fiq Formation of north Oman records several distinct episodes of glacial advance and retreat within a supposedly-singular (Marinoan) glaciation. Secondly, the presence of magnetic reversals occurring within the Hadash Formation, the end-Cryogenian "cap carbonate", undermines the mechanisms attributed to their formation. Given the frequency of magnetic reversals during the Cryogenian was comparable to that of today, the proposed mechanisms for cap carbonate formation cannot account for the high number of reversals recorded in these ubiquitous deglacial relicts. Thus, evidence of such reversals implies cap carbonate deposition is an order of magnitude more prolonged than the current interpretation, or that we have little understanding of the earth's magnetic field at this time.

Our study applies a range of sedimentological, geochemical, geochronological and palaeomagnetic analyses to the Saqlah, Fiq and Hadash Formations of north Oman to address the aforementioned discrepancies. Traditional and novel dating techniques, including direct dating of sediments via Rb–Sr in shales and U–Pb in carbonates, will be used to constrain deposition and deformation of these Neoproterozoic strata. Trace element concentrations coupled with carbon isotope data ($\delta^{13}C$) in shales of the Fiq are used to reconstruct salinity, redox and palaeogeography of the Cryogenian basins in north Oman. This will serve in assessing the validity, or inadequacy, of claims that the Marinoan glaciation was marked by several episodes of glacial advance and retreat. Additionally, post-Marinoan deglaciation dynamics are elucidated through a combination of high resolution sedimentology, palaeomagnetism, and $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ chemostratigraphy on the end-Cryogenian Hadash Formation cap carbonate. Ultimately, the synthesis of geochemical analyses, prospective new temporal constraints, and novel palaeomagnetic results bolsters our understanding of the Cryogenian in Oman and globally. Studies such as this highlight the prominent uncertainties relating to the cause, extent, and aftermath of Neoproterozoic glaciations and the need for further research.

Geochemical and Geochronological Insights into Proterozoic Earth Systems in the Batten Fault Zone, McArthur Basin

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The McArthur Basin covers much of the Northern Territory, Australia, and comprises multiple stacked siliciclastic and carbonate sedimentary sequences of Proterozoic age. Despite being labelled as 'the boring billion' due to the perceived stability of Earth systems, this period exhibits significant and geochemically traceable fluctuations in paleo-water chemistry and tectonics. These rocks are of interest for due to their hosting of economically significant hydrocarbons, world class base metal deposits, and preserving one of the oldest known biomarker records.

The Batten Fault Zone within the McArthur Basin is a broad, structurally complex corridor with structural depocenters and sub-basins. This study uses litho-stratigraphy, geochronology, and sedimentary geochemistry over three of these sub-basins to correlate depositional sequences and highlight post-depositional alteration characteristics. Shale and carbonate geochemical data collected for this project focuses on the middle McArthur Group (ca. 1650-1630 Ma) stratigraphy, aiming to fill gaps in literature surrounding Earth systems and tectonic processes during deposition and basin evolution.

The middle McArthur Group succession has predominantly been deposited under deep subtidal to slope conditions, and the combination of carbonate and siliciclastic samples sequence has produced Total Organic Carbon (TOC), $\delta^{13}C_{org}$, and $\delta^{13}C_{carb}$ profiles for sub-basins in the central and northern Batten Fault Zone. Notable trends observed in these profiles, such as the ~+2.0 ‰ $\delta^{13}C_{carb}$ excursion transitioning from the Barney Creek Formation into the overlying Reward Dolostone, are valuable tools for local, regional, and possibly global stratigraphic correlation. In-situ Rb–Sr geochronology ages of ~ 1485 Ma within the economically significant Barney Creek Formation raise questions about the possible resetting of the isotope system by fluid interactions or its reflection of burial timing. The combined data set will build a solid framework for the sedimentological, environmental, hydrological, and structural evolution of each sub-basin, which, in the scope of the "mineral systems framework" can then be used to examine models for Pb-Zn-Ag ore mineral formation processes in the McArthur Basin.

Nitrogen isotope variations in the Mesoproterozoic organic-rich shales (the Velkerri Formation) in Beetaloo Sub-basin, McArthur Basin, north Australia

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The middle member of the Velkerri Formation (Mesoproterozoic in age), known as the Amungee Member, has three cyclic organofacies with dominated organic-rich black shales. These intervals are separated by two organic-lean layers. The lower part of the Amungee Member (A-organofacies and A−B interval) represents positive and constant values (av. 2.2 and 2.3 ‰ in A-organofacies and A−B interval, respectively). These values suggest that partial denitrification may have controlled nitrogen cycling in these two intervals. In addition, the positive $\delta^{15}N$ values are accompanied by moderate total organic carbon contents in both intervals and constant organic carbon isotope in the A−B interval (around -34 ‰), while that of A-organofacies is less than the former interval (≈ -35 ‰). It appears that nitrogen fixation has become the main contributor in nitrogen cycling at the same time with the highest primary productivity in B-organofacies, as reflected in the lowest $\delta^{15}N$ (av. 1.9 ‰), less negative $\delta^{13}C_{org}$ values (av. -33 ‰) and higher TOC contents in this interval. However, the overlain B−C interval displays a decrease in organic content coinciding with the constant $\delta^{13}C_{org}$ (av. -33 ‰) and $\delta^{15}N$ (av. 2.4 ‰) values. This suggests that a high rate of detrital influx into the basin, as also reflected in high clay minerals such as chlorite, is likely to inhibit organic matter accumulation in this interval. Interestingly, the organic matter accumulation was likely developed after the dramatic decrease in dilution in response to the declined detrital influx during the deposition of the last organofacies of the Amungee Member (C-organofacies). This high primary productivity level is reflected in high TOC, values along with higher positive $\delta^{15}N$ values (av. 2.6 ‰) in this interval.

The resource-full McArthur-Yanliao Basin of Nuna, its global significance and tectonic evolution

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The north Australian part of the McArthur-Yanliao Gulf is a vast frontier exploration province for basin-hosted resources, both hydrocarbons (oil and natural gas) and metals (critical metals [e.g. rare earth elements, Co], Cu, Pb, Zn and Au). This basin system covers much of northern Australia and extends as the Yanliao Basin across much of North China, which lay off northern Australia when the basin formed—ca. 1820–1325 Ma.

In order to better understand the basin evolution we follow a number of approaches, including:

1. Developing new techniques to date sedimentary rocks, rapidly and economically, to assist with intra-basinal correlation, thermal and hydrothermal overprint history, and to help build a basin chronostratigraphic framework. Innovations in laser mass spectrometry have been used to date shales and carbonates from the McArthur Basin and triage the resulting data to separate ages interpreted as dating deposition or early diagenesis, from those reflecting later hydrothermal overprints.

2. Characterizing the source areas for the basin system through detrital petrochronology and shale geochemistry. Detrital minerals (zircon, rutile, muscovite) from the main 'packages' in the greater McArthur Basin have been dated to build a spatial and temporal database of source material that has been interpreted based on the tectonic evolution of the basement terranes around the greater McArthur Basin during the amalgamation of the Australian continents within Nuna/Columbia.

3. Investigating the ancient basin water chemistry through chemical proxies that relate to bio-productivity, salinity/restriction, and redox—temporally and spatially. Proterozoic basin waters were extremely heterogeneous in dissolved oxygen. We are developing and building basin-wide elemental (e.g. U, V, Cu, Co, Mo, Fe, organic geochemistry) and isotopic (Cr, Cd) proxies for the reconstruction of paleoredox and paleobioproductivity conditions at different sites in the ambient water columns. These will be coupled with elemental and isotopic proxies for restriction/salinity (including coupled $^{87}Sr/^{86}Sr$ and $^{88}Sr/^{86}Sr$ datasets from carbonates) and proxies for biological activity (e.g. Cr/Cd, as well as C and N isotopes). These are being interpreted in a sequence stratigraphic framework to understand the dynamics between basin water chemistry, tectonics and basin water level variations.

4. Building a reconstruction of the basin, and of the tectonic geography of the basin and its environs through the ca. 1.8–1.32 Ga history of its existence. This has been facilitated by constructing a full-plate tectonic reconstruction for the Proterozoic. Here we present a full-plate tectonic reconstruction from 1.8 Ga to present, focussed on the region of the Australian continental lithosphere. The greater McArthur Basin is considered as part of the McArthur-Yanliao Gulf of Nuna/Columbia and the nature of the basin will be addressed at different times/places.

The Benmara story: geochemistry, geochronology and sedimentology

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The Benmara region of the northern South Nicholson Basin lies south of the highly mineralised Ba7en Fault Zone (McArthur Basin), it borders the Murphy inlier and lies directly east of the newly defined Brune7e Downs RiE Corridor. Here we present new research focussing on the exploration potential of this part of the northern South Nicholson Basin using data from a newly drilled ca. 1km deep core, which samples a series of Proterozoic sedimentary and volcanic rocks. We applied a comprehensive suite of exploration techniques, including sedimentary logging, chemostratigraphy, isotopic stratigraphy, and in-situ Rb–Sr laser dating, alongside seismic interpretation, to be7er understand the stratigraphy in the region, to help link the sequences of the greater McArthur Basin to those of the Isa Superbasin and to further help de-risk the region for exploration for sedimentary-hosted mineral deposits.

In situ Rb-Sr geochronology of illites in Nifty dolomitic shales, northwest of the Officer Basin

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The Nifty deposit is hosted by the Neoproterozoic Yeneena Supergroup of the Paterson Orogen, which is a 2000 km long orogenic belt from the Paleoproterozoic to Neoproterozoic that stretches from northern Western Australia to northwest South Australia. The Nifty copper deposit is situated within the folded carbonaceous shale of the Broadhurst Formation, which is particularly, the focus of this study. This formation comprises four members: footwall beds, the Nifty member, a pyrite marker bed, and hanging-wall beds. Despite its significance, the timing of mineralization at Nifty remains poorly constrained due to the region's complex geological history, which suggests multiple fluid flow and mineralization phases. A SHRIMP zircon dating of the mafic intrusion within the Broadhurst Formation, northeast of the Maroochydore copper deposit defines a minimum age of 816 ± 6 Ma. Moreover, based on detrital zircon grains from the Coolbro Sandstone, the maximum deposition age of the Broadhurst Formation is ~ 910 Ma, constraining the Nifty deposit within these two dates. Our study employs a texturally controlled geochronological approach using in situ Rb-Sr geochronology on illites to address this challenge. Rb–Sr geochronology of authigenic clay minerals such as illite, which results from fluid-rock interaction during migration of tectonically-driven fluids, can determine the timing of fluid flow events associated with active tectonism. This method aims to provide insights into the timing of deposition or mineralization, ultimately enhancing our understanding of the geochemical processes that shaped the Nifty copper deposit. Based on this method, our Rb-Sr dating of illite in carbonaceous shales of Broadhurst Formation produced the age of 640–740 Ma for the Nifty deposit, presumably associated with a hydrothermal event at 670-640 Ma, which is assumed to be linked with granite magmatism in the Paterson Orogen around 650-630 Ma. This may have reset the Rb-Sr isotope system in pre-existing illites in the host-rock matrix. The findings from this research are expected to contribute to the broader geological understanding of the Paterson Orogen and inform future exploration strategies in the region.

A Thermal-mechanical Framework for Proterozoic Basins

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Owing to the strong temperature dependence of the rheology of rocks, and the enhanced rock content in heat-producing radiogenic elements back in time, we can expect that tectonic processes in Proterozoic times may have been significantly different from those of today.

Our numerical experiments show that under a warmer geotherm, and despite steady-state kinematic boundary conditions, extension leads to a bimodal tectonic history involving a transition from a long period of wide-rift extension with a low strain rate to a shorter period of narrow-rift extension with a high strain rate leading to breakup. This transition is due to the progressive cooling and strengthening of the lower crust, enabling the mechanical coupling of the brittle upper crust and the stronger upper mantle. During the wide-rift cycle, connected shallow basins are broadly distributed over a homogeneously thinned continental crust and lithosphere. In the early stage of the wide-rift cycle, decompression melting may be pervasive underneath the extending lithosphere. Translated to the real world, this suggests that some shallow Proterozoic basins may have been largely intra-continental, therefore poorly connected to the open ocean, and prone to the deposition of shales rich in organic carbon and evaporites, interlayered with volcanics.

Following an episode of wide-rift extension, which may last tens of millions of years (Myr), the outcome of tectonic inversion depends on the delay between the end of extension and the start of contraction. When inversion follows soon after the cessation of extension (less than a few tens of Myr), contractional deformation affects a very broad region with an overall low strain rate. In contrast, when inversion occurs after several tens of Myr of thermal relaxation, cooling, and thickening of the lithospheric mantle, contractional deformation is more localized, delivering narrower mountain belts. Interestingly, little topography develops due to the enhanced thickening of the lithospheric mantle (tectonic thickening is enhanced by thermal thickening) compared to that of the crust, which keeps the Earth’s surface close to sea level.

In northern Australia, Palaeoproterozoic to Mesoproterozoic polyphase extension resulted in the formation of stacked shallow intracontinental basins (Birrindudu, McArthur, South Nicholson, Fitzmaurice, Tomkinson, Davenport, Lawn Hill). Though some sub-basins have accumulated up to 12 km of sediments over hundreds of millions of years and several extensional episodes separated by tectonic inversion, each extensional episode delivered no more than a few kilometers of sediments (e.g., Tawallah Group, McArthur Group, and Roper Group of the McArthur Basin) with lateral thickness variations suggesting growth-faulting. Our numerical experiments suggest that these basins may have developed under wide-rift mode and a geotherm delivering a Moho temperature greater than approximately 650-700ºC. Some of the volcanics could be explained in terms of decompression melting under a warmer lithosphere. This volcanism may have led to the formation of Cu-rich cumulates, the remelting of which would deliver ore deposits during orogenic periods.

Ishtar Terra highlands on Venus raised by craton-like formation mechanisms

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The Ishtar Terra highlands on Venus consist of Lakshmi Planum, an Australia-sized crustal plateau with an average elevation of ~4 km that is comparable to that of the Tibetan Plateau, surrounded by elongated mountain belts with elevations of around 10 km, taller than the Himalayas. The region is floored by thick crust that is comparable to that of cratons on Earth. On Earth, plateaus and mountain belts result from the collision of tectonic plates. However, the origin of Ishtar Terra remains enigmatic because Venus lacks Earth-like plate tectonics. Here we use three-dimensional thermo-chemo-mechanical computational simulations of Venus-like mantle convection to show how magmatism and tectonics emerge from mantle dynamics. The simulations show that a lithosphere weakened as a result of high initial hydration or high surface temperatures enhances convective thinning and decompression melting, favouring the emplacement of a thick magmatic crust on top of a deep residual depleted mantle. The stiffer residual root deflects mantle flow outwards, leading to the formation of fold belts around the buoyant lithosphere that are consequently uplifted into a plateau and preserved from further deformation. The modelled topography, crustal thicknesses and gravity is consistent with observational constraints of Ishtar Terra. Our findings suggest that plateau formation on Venus may operate similarly to craton formation on the hot early Earth, before the onset of plate tectonics

Microcontinents formed during a messy breakup between India and Antarctica

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Submerged microcontinents are increasingly being recognised with our enhanced capabilities to investigate the seafloor, but these features are commonly identified using indirect geophysical and geochemical techniques. Such techniques have been used to interpret microcontinental fragments within sections of the Kerguelen Plateau, a large igneous province in the southern Indian Ocean. These interpreted microcontinents are controversial due to the complex crustal structure of the Kerguelen Plateau, and none have been verified by direct sampling, leading some workers to dispute their existence entirely. We present our investigations of continental rocks from the Central Kerguelen Plateau trawled by *FV Southern Champion* (SC26) and continental rocks from William's Ridge and Rig Seismic Seamount dredged by *RV Investigator* (IN2020_V01). Petrography and geochronology (zircon and apatite U-Pb) of the recovered continental rocks were used to investigate their affinity in a full-fit reconstruction of Gondwana. The Central Kerguelen Plateau microcontinent comprises Archean (*c.* 3.3 Ga) tonalites and Mesoproterozoic granitoids and gneisses (*c.* 1.44 Ga, *c.* 1.19 Ga). These correlate with provinces in NE India; the Archean tonalites best matching the Singhbhum Craton and the Mesoproterozoic rocks best matching the Shillong Plateau. Continental rocks from William's Ridge comprise Mesoproterozoic (*c.* 1.6 Ga, *c.* 1.48–1.44 Ga, *c.* 1.1 Ga) orthogneisses, also matching the Shillong Plateau. Rig Seismic Seamount is composed of Archean (>3 Ga) and Palaeoproterozoic (2.4 Ga) orthogneisses, Mesoproterozoic paragneisses, and Mesoproterozoic (*c.* 1.17 Ga) and Cambrian (*c.* 490 Ma) granites, correlating best with the Vestfold/ Prydz provinces in East Antarctica. All discussed microcontinents likely rifted and separated from the Indian continent via ridge jump(s) between 115–102 Ma. We relate their formation to neighbouring microcontinents: Elan Bank (to the west), and Gulden Draak Rise and Batavia Rise (to the east), thus forming a ribbon of microcontinents along the East Indian margin that calved during the breakup of Gondwana.

Solid-Earth controls on Phanerozoic icehouses

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Earth's climate during the Phanerozoic has switched between greenhouse and icehouse intervals, where the expanse of polar-ice caps reached mid-latitudes, once during the late Palaeozoic, and a second time during the Cenozoic. While these cold intervals correspond well to lower atmospheric CO_2, causal mechanisms for understanding why CO_2 fell low enough to trigger ice growth remain unclear. Hypotheses range from changes in solid-Earth degassing, changing palaeogeographic configuration of the Earth, growth of mountain ranges, and exposure of more weatherable lithologies (e.g. arcs, LIPs). We constructed a long-term Earth System model that can integrate these proposed cooling mechanisms to test their effect on global temperature. Our model switches between icehouse and greenhouse states and can reproduce the broad geological record of ice cap expansion. Our results suggest that Phanerozoic icehouse climates required a combination of different solid-Earth cooling mechanisms acting simultaneously, and neither were driven by a single mechanism.

Magnetization of oceanic lithosphere from modelling of satellite observations

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Measurements of variations in Earth's magnetic field strength have made fundamental contributions to our knowledge of planetary evolution. Mapping of magnetic anomalies across the oceans, primarily by marine research voyages, has played a key role informing our knowledge of past plate motions, as well as the long-term evolution of the geodynamo. However, recent satellite missions are providing data which fills many remaining gaps in terrestrial coverage. This presentation will illustrate novel applications of lithospheric magnetization models derived from satellite data. One set of examples focusses on the oceans – here, long-wavelength magnetic anomalies reveal the nature of sloping magnetisation boundaries and allow reinterpretation of past plate tectonic motions and seafloor age maps. The second set of examples focuses on subduction zones defined by seismicity and seismic tomography to understand the nature of magnetization within these domains. Anomalies at many subduction zones are well modelled by magnetization distributed across both the slab and mantle wedge, providing clues to the distribution of temperature and magnetic minerals deep within the Earth.

Crustal structure and role of inheritance in the evolution of southeast Australia's triple junction

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Southeast Australia's triple junction, where divergent, failed rift, and transform arms converge, is a natural laboratory to understand the complex evolution and structure of a divergent tectonic system. This research, which focuses on the divergent arm that lies along Otway Basin, is based on a comprehensive dataset that includes legacy seismic data, well information, gravity data, and velocity models. The study reveals significant variations in fault orientations, magmatic activity, and overall margin architecture, reflecting a complex interplay of pre-existing structures, thermal dynamics, and extensional stress direction. Gravity models show a transition crust as a hybrid zone, exhibiting characteristics of both continental and oceanic crusts, with evidence of serpentinisation, particularly near the transition zone. The continent-ocean transition is marked by a continent-dipping breakout fault and significant mafic underplating, which is most pronounced at Discovery Bay High. Additionally, the study shows that the evolution of the triple junction was heavily influenced by pre-existing structural features, such as deep lithospheric faults, which guided the formation of rift and transform arms. The thermal impact of thick mafic underplating, while contributing to crustal thinning, was not solely responsible for rift evolution; rather, the interplay with inherited structural conditions dictated the tectonic development. Understanding these pre-existing conditions is vital for predicting the evolution of rifted margins, especially in regions where a divergent arm interact with aulacogens and transform arms. This study significantly contributes to a broader understanding of passive margin formation and highlights the crucial role of structural inheritance in shaping complex tectonic environments like Southeast Australia's triple junction.

A non-arc setting for "Cadomian" magmatism in Iran and Anatolia

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Establishing the type and position of plate boundaries is crucial for paleogeographic reconstructions. The northern margin of Gondwana (NMG) is inferred to have been a convergent, Andean-style, plate margin for much the late Neoproterozoic to early Paleozoic (i.e., the Avalonian-Cadomian Orogen), based largely on the presence of igneous rocks with arc-related geochemical affinities. However, a major segment of the margin that fringed the Arabian Plate includes bimodal Ediacaran—middle Cambrian (ca. 600—500 Ma) igneous rocks, more typical of continental rift settings, which has led to ambiguous and contradictory interpretations of magma tectonogenesis. Here, we employ an alternative approach to investigate the tectonic setting of the NMG by studying the evolution of sedimentary basins that developed in Iran, Anatolia, and the Arabian Plate simultaneously with the ca. 600—500 Ma magmatism. The Ediacaran—middle Cambrian successions in this segment of the NMG consist of laterally continuous siliciclastic and carbonate sequences, which have been broadly correlated across the region. The consistent northward and eastward paleocurrent directions and decrease in clastic sediment grain-size from proximal (the Arabian Plate) to distal (Iran and Anatolia) successions suggest a northward and eastward deepening basin with relatively flat topography. The new detrital zircon (n = 2870) and apatite (n = 1178) U-Pb ages from the Ediacaran—middle Cambrian siliciclastic strata of Iran are mostly older than 600 Ma. Detrital apatite trace element compositions indicate that most grains are sourced from I-type granitoids and mafic igneous rocks, low- and high-grade metamorphic rocks, with a minority from ultramafic rocks. Together with published detrital zircon U-Pb age data from correlative strata in Anatolia and the Arabian Plate, these data suggest the pre-existing Arabian-Nubian shield as the main source. Importantly, detrital zircon and apatite grains with ages < 600 Ma are rare in these strata, suggesting that they received little input from contemporaneous Ediacaran—middle Cambrian (ca. 600—500 Ma) igneous rocks. We suggest that the very small sediment contribution from the ca. 600—500 Ma igneous rocks argues against the tectonic model that considers the development of a large Andean-style magmatic arc at this segment of the NMG. Integrating these constraints from the sedimentary record with geochemical data from the ca. 600—500 Ma igneous rocks in Iran and Anatolia favors an extensional continental margin setting that may be related to escape tectonics or post-collisional relaxation during Ediacaran—Cambrian following Gondwana assembly.

Evidence for and against multiple punctuated crustal overturn events in the Pilbara craton, Western Australia

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The dome-and-keel structures of the Paleoarchean East Pilbara Terrane of Western Australia are thought to record some type of vertical tectonics. 'Partial convective overturn', in which granitic domes diapirically rose through a dense, foundering mafic supracrustal sequence, is most often invoked. Our work on the Mt Edgar and Coruna Downs batholiths, and the interleaving Warrawoona belt, can address this issue.

What works about the partial convective overturn model are the internal fabrics of the plutons (using AMS or Anisotropy of Magnetic Susceptibility) and recent garnet geochronology. The AMS results reveal a consistent structural pattern: 1) Migmatitic gneisses, which represent the oldest granitic component of the dome, are folded and flattened against the margin of the dome in two distinct lobes; and 2) Sub-vertical lineations plunge towards the center of the dome and foliations generally strike northwest. Recent geochronology indicates two distinct phases of garnet growth, at 3.42-3.39 Ga and 3.34- 3.30 Ga (Salerno et al., 2023). These ages are consistent with U-Pb zircon ages for two of the granitic supersuites and mafic volcanism lithostratigraphic groups, and are interpreted as magmatism-associated overturn events.

What does not work about the convective overturn are shear sense indicators at the dome boundary and recent gravity results. First, shear sense indicators along the edge of the Mt Edgar pluton show dome-up shear sense along its margin, particularly prominent on the southwest margin of the dome. Second, a “zone of sinking” model was proposed by Collins et al. (1998), in which vertical lineation and constrictional strain occurred in the Warrawoona belt was thought to correlate to a zone of sagduction. To test this idea, we conducted a ground-based gravity survey with 535 new stations with a 0.5-1 km station spacing. A maximum of a 20 mGal positive Bouguer anomaly is observed over the zone of sinking on a ~NS-oriented transect from the Mt Edgar batholith to the Coruna Downs batholith. On a transect along the axis of Warrawoona syncline, we observed no closed contour Bouguer gravity anomaly above the proposed zone of sinking. These results do not rule out convective overturn for the Pilbara craton, but suggest that a key line of evidence for convective overturn is not supported by geophysical results.

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A rift–transform origin for the East Pilbara Terrane

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The East Pilbara Terrane in Western Australia has been a benchmark for numerous studies on the formation of Earth's early continents. These studies by and large have been based on surface data of variable spatial extent, or on numerical simulations. By combining and integrating geological and high-resolution trace element geochemistry data with geophysical imaging we are able to better constrain the structural and spatial evolution of the East Pilbara Terrane. Our study suggests that rather than being a product of density-instability driven, crustal scale convective overturn, the East Pilbara Terrane more likely originated as a Paleoarchean rift structure.

Active and passive source seismic imaging and 3–D gravity inversion models show that the East Pilbara Terrane's iconic ovoid–curvilinear granite–greenstone geometry is confined to the present-day upper crust, whereas deeper levels have a layered, predominantly felsic composition. We further show that geochemical mapping of trace elements in felsic igneous rocks reveals common magmatic source domains that are spatially coincident with terrane-scale density variation trends imaged by seismic velocity-constrained 3–D gravity inversion models. These observations are at odds with the predictions of crustal scale convective overturn models.

We propose that the imaged linear trend originated as a pre-plate tectonic, segmented Paleoarchean rift in Earth's primeval crust, with similarities to present-day oceanic ridge-transform systems. In our model the original structural blueprint constrained shape and extent of volcano-sedimentary basins, and of emerging granite-gneiss domes in an overall hot rift setting. Sustained by a weak lower crust with a significant horizontal flow component, the coeval emergence of granite-gneiss domes and deepening volcano-sedimentary basins accommodated an overall extensional growth of hot Paleo– and Mesoarchean continental crust.

More than 2 billion years of shearing along the western margin of the Yilgarn Craton (Western Australia)

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Craton margins are anticipated to focus the development of large-scale shear belts, which may have experienced repeated episodes of reactivation and reworking, as rigid cratonic blocks drifted on the Earth's surface colliding with each other. With this contribution, I test these concepts by investigating the tectono-thermal evolution of the high strain, ≥100 km long Chittering Metamorphic Belt (CMB), along the western margin of the Archean Yilgarn Craton. This margin is today marked by the Darling Fault (DF), a ≥1500 km long structure that formed through Permo-Cretaceous rifting of Greater India and Australia. The footwall of the DF exposes ductile fabrics subparallel to the fault itself, which have been considered to have formed primarily during the Proterozoic Pinjarra Orogeny. The CMB exposes a layered sequence of felsic migmatites predating the emplacement of the 2648–2626 Ma Darling Range Batholith. It is then intruded by two sets of late-Archean (c. 2615 Ma) and Mesoproterozoic (c. 1210 Ma) gabbro–dolerite dykes, which predate the pervasive, regional scale (i.e. ≥ 100 km along strike) and north-striking ductile shear fabrics. Two sets of north-striking, steep ductile structures are recognizable throughout the CMB: (i) an oblique-slip (normal–sinistral) shear zone, the Swan Gorge Shear Zone, marks the eastern boundary of the CMB; (ii) a network of anastomosing, strike-slip sinistral shear zones, which are associated with constrictional fabrics, collectively belong to the Lady Springs Shear Zone. Microstructural data, supported by quartz c-axis crystallographic preferred orientation (CPO) data, indicate that these shear zones show a comparable tectono-metamorphic evolution, which include an early shearing stage characterised by the occurrence of synkinematic kyanite, overprinted by localised, sillimanite-bearing high-strain zones. These amphibolite-facies fabrics are overprinted by greenschist-facies fabrics, along which synkinematic white mica replaced the earlier aluminosilicates. These retrograde fabrics are geometrically and kinematically consistent with the earlier, higher-grade ones, suggesting progressive fabric development during exhumation and cooling of the CMB. A variety of geochronology techniques is being implemented to constrain the tectonothermal evolution of the CMB. Preliminary Lu–Hf, in-situ garnet geochronology on pre-kinematic garnet porphyroblasts from two samples collected along the Protozoic shear zones, together with in-situ Rb–Sr dating of biotite from seven samples, indicate that the regional-scale shear fabric developed in the 740–640 Ma time span. Field and geochronology relationships suggest that the belt-scale compositional layering of the Archean migmatite sequence was already in the current north-striking, steep orientation by the end of the Archean. Such fabric played a fundamental role in controlling the orientation of the Proterozoic ductile fabrics, and of the Mesozoic fabrics associated with the Darling Fault. The CMB preserves the record of tectonomagmatic and metamorphic events that span more than two billion years of Earth's history, making it the ideal target for structural studies focused on structural inheritance.

Archean Dual Geodynamics Underneath Weak, Flat, and Flooded Continents

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The composition of Archean fine-grained sedimentary rocks and marine carbonates suggests that the emerged crust transitioned from dominantly mafic to more felsic compositions no earlier than ~3.0 Ga. Yet, proxies for mantle depletion suggest that 70-75% of the crust had been extracted from the mantle by 3.5 Ga. This raises the question of why there is little discernible evidence for felsic sources in the pre-3.0 Ga sedimentary record. To address this paradox, we have proposed that the felsic reservoir was buried under thick layers of basalt emplaced onto flooded continents, and therefore isolated from the surface until ~3.0 Ga. On a hotter Earth, flooding can be explained by the reduced water storage capacity of a warmer mantle and a shallower seafloor, forcing oceans to overspill onto continents. The hotter continental lithosphere was much weaker and unable to sustain significant orogenic topography, making Archean landscapes flatter. Overall, no more than 3 to 4% of the Earth's surface was above sea level before the late Archean. The hypothesis of weak, flat, and flooded continents reconciles the early extraction of a significant volume of continental crust with its late appearance in the sedimentary record.

Over the past decade, a second major paradox has emerged. Increasing $\delta^{18}O$ values above 7.5 ‰ in zircon after 2.5 Ga indicate a shift toward a growing contribution of supracrustal lithologies to the production of felsic crust. The shift towards higher εHf(t) at 3.8-3.6 Ga in zircon points to increasing recycling of juvenile basaltic crust into TTG magmas. The initiation of subduction and plate tectonics has been invoked to explain both shifts. This raises the question of why no $\delta^{18}O$ shift is observed at 3.8-3.6 Ga. To solve this paradox, a process is needed that can explain the recycling of basaltic crust without leading to a significant increase in the $\delta^{18}O$ in crustal magmas. We propose that sagduction could explain the shift towards higher εHf(t) in TTG zircon from 3.8-3.6 Ga onwards without a corresponding shift towards higher $\delta^{18}O$. This is because the volume of buried felsic sediments during sagduction was much more limited compared to modern subduction zones, and sagduction buried greenstones that evolved over a protracted period under higher geothermal regimes, leading to high-temperature fluid-rock interactions that may have lowered the $\delta^{18}O$ of rocks.

We suggest that the early Earth had a dual-mode geodynamics where intra-crustal tectonics, driven by sagduction, was independent from the evolving geodynamics of the global lithosphere-mantle system. The onset of sagduction and modern subduction is marked by positive shifts of εHf(t) and $\delta^{18}O$ in zircon.

Reconstruction of a Paleoproterozic Greenstone Belt and comparative study to Late Archean Greenstone Belts

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Constraints on early earth processes are largely based on geochemistry and numerical modelling, rather than physical volcano-sedimentology because of poor preservation, yet the physical data can provide many important constraints. In this study, we present mapping, geochemistry and geochronological data from the 2.35-2.10 Ga Toumodi-Houndé Greenstone Belt (Ivory Coast & Burkina Faso, West Africa) to reconstruct the stratigraphy and paleo-depositional environment, as well as track geochemical changes in arguably the best-preserved post-Archean greenstone sequence. We then compare results with a typical 2.7 Ga greenstone belt (Norseman-Wiluna, Kalgoorlie Terrane, Yilgarn Craton, Western Australia) and highlight what we consider are some of the key differences and relate these to secular changes.

The Toumodi-Houndé Belt is represented by several discontinuous belts that altogether total >800 km long and ~10-20 km wide and preserves a sequence ~5-10 km thick that is correlated based on stratigraphy, geochemistry, geochronology and distinctive rock types. U-Pb zircon and Sm-Nd whole rock data indicate the succession is juvenile and built on crust <2.35 Ga. The stratigraphy consists of three main stages: I) an initial (ca. 2.35 Ga) tholeiitic lava and sill succession (1-3 km thick?) intercalated with cherts and black mudstones, representing a mafic event in an open, anoxic and deep-water setting; II) a diverse middle volcano-sedimentary package (ca. 2.20-2.16 Ga) of porphyritic basalt/andesite lavas and turbidites that formed in deep water, as well as porphyritic pyroclastic (scoria/tuff cones) and epiclastic deposits that formed in a subaerial setting; and III) an uppermost (ca. 2.15-2.10 Ga) sequence of felsic effusive and pyroclastic (including ignimbrites) deposits associated with fluvial rocks that formed in a subaerial setting, as well as turbidites, which represent distal and coeval subaqueous mass flows. Stages II and III form a synclinal sequence, while stage I occurs only on one side of the greenstone belt, hinting at an accretionary origin. Similarities with 2.7 Ga greenstones include transitions from mafic to felsic volcanism, geochemistry of mafic and intermediate rocks, and overall transition from subaqueous to subaerial environment. Important differences include the protracted history (>100 vs 70 Myrs), belt asymmetry, absence of a stacked sequence of widely correlated mafic rocks, prevalence of porphyritic textures, and abundance of emergent stratigraphy (especially during stage II). In the Paleoproterozoic belt, these differences reflect: arc construction and accretion; stiffer/buoyant continents that become emergent more quickly in their evolution; and volcanoes with more complex magmatic plumbing systems. In contrast, the typical Late Archean greenstone belt reflects intra-plate LIP-style magmatism on weaker and less buoyant crust that was rarely emergent.

From continental rifting to seafloor spreading. Controversies and insights from the Red Sea

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The Red Sea is the archetype example of a continental rift transitioning into a juvenile oceanic basin, providing one of the few places on Earth to understand this transition. However, investigating the evolution and architecture of the Red Sea presents significant challenges. Active spreading occurs underwater, often obscured by sedimentary cover and salt glaciers. There are distinct geological differences between the northern and southern ends of the sea, with the latter intersecting with a plume channel and plume. Additionally, local geological observations have often been inappropriately generalised across the entire region, and the resolution of geophysical and geochemical data varies greatly, complicating longitudinal comparisons.

Single versus Dual Opening Stages: The prevailing view is that seafloor spreading initiated around 5 million years ago during the Pliocene. However, evidence from the southern Red Sea suggests an earlier phase of oceanic crust formation during the Miocene, characterised by seafloor stripes in magnetic data buried under Miocene sedimentary rocks. This indicates that the Red Sea might have opened in two distinct stages.

Synchronous versus Propagating Opening: There is a debate over whether the Red Sea opened synchronously along its entire length or via a propagating or unzipping process. Potential field geophysical data from various studies present divergent models of seafloor spreading, leading to conflicting interpretations.

Direction of Seafloor Spreading Propagation: While the central part of the Red Sea shows clear signs of spreading, there is evidence that the extremities of the basin are still floored by continental crust and that rifting is ongoing. This raises questions about the direction and nature of seafloor spreading propagation.

Influence of crustal and lithospheric Heterogeneities: Lithospheric and crustal heterogeneities are crucial in determining the location of rift propagation and the shift in extension locus. Pre-existing structural features correspond with segment boundaries and areas of high elastic thickness, suggesting these are preferred sites for weakness and deformation.

Potential Jumping of Spreading Centres: Recent studies speculate that the Red Sea spreading centres may soon jump to the northern and southern interior regions of the Arabian Plate and the Danakil Block. If this occurs, the current seafloor spreading observed in the Red Sea could represent just a segment of what might develop into a larger ocean basin.

Although often considered a relatively straightforward tectonic system, the complexities of the Red Sea are increasingly evident, and there are more intricate dynamics underlying its development than previously understood.

The effect of the original tectonic grain on structural evolution during poly-phase deformation: an example from Mount Woods Domain, Gawler Craton

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The Gawler Craton in the South Australia has a complex geological history of poly-phase deformation, magmatism, metamorphism, and sedimentation since the Mesoarchean. This complexity is particularly obvious in the northern Gawler Craton where the Mount Woods Domain, which is located along the northern boundary of the Archaean Christie Domain, preserves the Palaeo-to Meso-proterozoic processes that affected the craton. However, despite numerous recent studies, there is still uncertainty about the tectonic evolution of the region. Solving this knowledge-gap may help in understanding the tectonic processes and deformation history of the entire craton. Therefore, as part of the GSSA's SA Discovery Mapping project, we aimed at generating a systematic, high-resolution (1:25,000) geological compilation of the poorly exposed Mount Woods Domain using remote-sensed data, scattered outcrop, and drill hole constraints. Using this map, we establish overprinting geological processes to constrain the timing and kinematic histories of the major shear zones which allow us to relate these structures to different tectonic events.

Results show that the ~E-W-trending regional structures (e.g., Southern Over Thrust) preserved the Early Paleoproterozoic (ca. 1850-1750 Ma) extensional deformation and sedimentation to the north of the Archean Christie Domain. A major tectonic switch from extension-related basin formation processes to a deformation-metamorphism-magmatism dominating processes in the Gawler Craton was initiated with the Kimban Event (ca. 1730-1690 Ma). The event is poorly defined and is only preserved in the central and western Mount Woods, possibly represented by open to tight folds with variable axial orientations. Subsequently, a NNE-SSW to N-S shortening linked to the Olarian or Kararan Event (ca. 1600-1540 Ma) affected the entire Mount Woods, led to the refolding of the earlier Kimban-aged structures and reactivation of major shear zones. These include sinistral movement along the ENE-trending Karari and Bulgunnia shear zones; sinistral-normal movement along the NE-trending Moonlight-Panorama shear zones; dextral movement along the WNW- to NW-trending Skylark-Spire Hills Shear Zone and Kennedy's-Taurus Fault Zone; reverse movement along the E-W-trending Cairn Hills Shear Zone and inversion along the E-W-trending Southern Over Thrust. Some of these shear zones were further reactivated in response to the NW-SE trending shortening linked to the Coorabie Event (ca. 1470-1450 Ma). This event resulted dextral movement along the E-W structures (e.g., Cairn Shear Zone) and a possible reverse movement along NE-trending shear zones (e.g., Bulgunnia Shear Zone).

Holistic interpretation from the new structural mapping suggests that the orientation of the pre-existing structures played a key role in style of deformation, kinematics, and activation/reactivation history in the Mount Woods Domain. A detailed structural evolution provides the framework with which to test the tectonic models applied to the area and help understand the controls on mineral systems.

Tectonic impact of the boring billion

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The Mesoproterozoic "Boring Billion" from 1.8 to 0.8 Ga exhibited long-lived extreme environmental stability. This included stagnated oxygen levels, and limited phosphorous input into the oceans. However, at the same time, the metamorphic and magmatic history recorded singular occurrences, such as massif-type anorthosites not seen at any other time in the geological record, widespread Rapakivi anorogenic granites, and the highest thermobaric gradients record in the metamorphic record.

The subdued surface conditions and limited erosional influx of oceanic nutrients is suggestive of a plate slow-down, with subdued rates of orogenic and volcanic activity, and associated erosion. This idea has support in the passive margin record, which indicate the longest-lived passive margins occurred in the middle of this period. This can be explained by a slowing of plates, and subsequent increase in the time taken for oceanic crust to reach subduction zones, with concomitant increases in period between Wilson cycles and oceanic closure.

Here we benchmark passive margin lifetimes for Phanerozoic examples, for which we have independent plate velocity records. We use these relationships to calculate plate speeds for the Mesoproterozoic and show these estimates – as low as 1 cm/yr – are on par with existing paleomagnetic data and hotspot tracks from this period.

These slow velocities have geodynamic consequences. We use parameterised convection models with melt transport modules to demonstrate such slow velocities predict high mantle temperatures during the Mesoproterozoic. These temperatures are consistent with existing petrological databases, and predict hotter mantle melts, with higher densities. Our models show this results in an increase in intrusive:extrusive ratios of magma emplacement. This would result in large volumes of dense melts being emplaced in the lower crust, resulting extremely hot lower crust, high thermobaric gradients, widespread lower crustal melting, driving the formation of anorthosites. This is the first explanation tying the subdued (and boring) surface conditions of the Proterozoic with its anomalous lower crustal extreme thermal and magmatic regime, via the slow pace of geodynamics in the boring billion.

Digital plate reconstructions of the Tasmanides

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The geological evolution of eastern Australia during the Phanerozoic, collectively known as the Tasmanides, has been extensively studied, resulting in multiple schematic tectonic reconstructions. However, the lack of detailed numerical reconstructions has hindered the development of Earth Science-related computational models of the Australian continent in deep time. Here we aim to address this crucial need by developing a new numerical tectonic reconstruction using the open-source and cross-platform GPlates software. This reconstruction, covering the entire Phanerozoic era, will be based on existing literature and various geological evidence, including incorporating recently-collected and published geochronology systems, isotopic geochemistry, ophiolites, and geophysical surveys. The kinematic model we present for discussion favours simpler active margin configurations, following an Occam's Razor and ribbon terrane philosophy, and involves the accretion of the West Tasmania, Selwyn, and Proto-New England (Calliope-Gamilaroi Arc and older xenoliths) terranes. Importantly, we consider the regional model in the context of the surrounding tectonic domains and the global tectonic context, including links to Antarctica, North America, and the proto-Pacific tectonic domains. This proposed numerical tectonic reconstruction will provide a basis for further computational modelling in Earth Sciences, filling the current gap in our understanding of the Tasmanides and enabling future work to refine and test end-member interpretations and scenarios.

Adakitic magmatism of the Kennedy Igneous Association in the Georgetown region: implications for the tectonic setting and mineralisation during Permo-Carboniferous period in the northeastern Queensland

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The Kennedy Igneous Association (KIA) is composed of widespread intrusive and extrusive, dominantly felsic and silicic magmatism during the Carboniferous to Permian throughout northeastern Queensland. Magmatism of KIA can be divided into 3 groups: >310 Ma, 310-290 Ma, and <290 Ma. As ages of granitoids become younger, the location of magmatism changed from inland region toward current coastal region. Numerous and significant mineralisation related to the Kennedy Igneous Association are hosted in northeastern Queensland including Sn-W, epithermal Au(±Ag), porphyry/skarn Cu-Au, and intrusion-related gold deposits (IRGDs). Interestingly, Sn-W deposits related to highly fractionated magmas are dominantly located in the Herberton and Hodgkinson provinces, which are closer to coastal region, while IRGDs are concentrated in the Georgetown and Charters Towers provinces. Geochemical graphs with the Kennedy Igneous Association are delineated to see transitions or changes of geochemical features from the Kidston, Tate, and Herberton to the Daintree subprovince (from inland to coastal region). I-type rocks of KIA in the Herberton and Tate subprovinces are subdivided into the Almaden, Ootann, and O'Briens creek Supersuites. O'Briens creek Supersuite has been reported to be related to Sn mineralisation, Ootann Supersuite is associated with W mineralisation, and S-type granitoids in the Daintree subprovince are related to Sn and/or W mineralisation. Even though I-type granitoids in the Kidston, Herberton and Tate subprovince show similar geochemical features such as high potassic calc-alkaline series and metaluminous characteristics, the O'Briens creek Supersuite is the most fractionated among the I-type Supersuites. S-type Supersuites in the Daintree subprovince are highly fractionated and peraluminous, which could be related to Sn-W mineralisation. However, some samples from the Kidston subprovince have high Sr/Y ratios, compatible with an adakitic signature.

Granitoids rocks collected from the Georgetown region include granodiorite, granite and rhyolite. The granodiorite group is mostly porphyritic or medium grained whereas the granite and rhyolite are dominantly medium to fine grained. Ages of granodiorite range from 294 to 284 Ma, while granite and rhyolite group show older ages between 360 and 330 Ma. Younger granodiorite group shows high Sr/Y ratios, steeper LREE/HREE trend, no or weak Eu anomaly, and high La/Yb ratio, consistent with an adakitic signatures. Thus, the granodiorite group shows closer affinities to porphyries related to Cu(-Au) mineralisation unlike the granite and the rhyolite group.

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Uncovering the Hidden Delamerian Margin: A geochemical and geochronological analysis of an undercover arc

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The Delamerian Orogen sits eastwards of the Adelaide Hills in South Australia and contains a preserved volcanic arc consisting of the Stavely Arc in Victoria, and the Mount Wright Volcanics in the Koonenberry Belt in New South Wales. It is the westernmost portion of the Tasmanides and was the first orogenic event associated with the west-dipping subduction system that formed on the palaeo-Pacific Ocean margin with Australia while part of the Gondwana continent. The Loch Lilly-Kars Belt (LLKB) is located south of Broken Hill and is the central portion of the Delamerian Orogen. The LLKB contains the buried rocks of the Delamerian Orogen and sit under the Cenozoic cover of the Murray Darling Basin. Due to this cover, the LLKB is understudied and poorly constrained despite its potential for mineral endowment.

To better understand the formation and evolution of the LLKB, this research sampled from 6 diamond drill holes drilled in 2023 by Geoscience Australia and MinExCRC as part of the National Drilling Initiative which intersected the arc undercover. Geochronological constraints on low-grade metamorphism, alteration, and magmatism were obtained using in-situ LA-ICP-MS Rb-Sr and U-Pb age mapping of altered igneous suites and cross-cutting calcite veins. A depositional window of sedimentary samples within the section have also been deduced using Rb-Sr and U-Pb spot analyses of deep-water shales and carbonate beds, respectively. Geochemical analysis of igneous samples was undertaken in the form of solution ICP-MS to obtain major & trace element data along with TIMS analysis of Nd-Sm isotopes to further understand the tectonic setting of the Delamerian at the time of these intrusions.

Results from the LLKB have shown that the volcanic arc was an active margin of the Delamerian Orogen and contains intrusion ages equivalent to those present in the Stavely Arc and Koonenberry Belt. Furthermore, our study also records significant evidence for continuing episodic hydrothermal activity in the region ca. 200 Ma after the conclusion of the Delamerian Orogeny. This periodic tectonism may be linked to wider evolution of the collision margin as the subduction zone rolled back eastwards.

Tectonic and Paleogeographic Reconstruction Choice Impacts the Distribution of Simulated Ancient Reefs

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The last three decades have seen significant advancement in plate tectonic reconstructions over deep time resulting in a diverse array of models, each with their respective strengths and weaknesses. Recent work has sought to work towards better assessments of plate reconstructions through quantitative intercomparisons and testing. However, limited progress has been made towards exploring the implications on modelled surface and climate states that arise through variations in paleogeographies.

Here, we compare two widely used, but different plate and paleogeographic reconstructions by simulating global tropical coral reef evolution since the rise of scleractinian corals in the early Triassic. Tropical reefs have shifted in their latitudinal extent throughout the Meso-Cenozoic and are sensitive to key climatic variables such as sea surface temperature, making them a suitable candidate for assessing differences between reconstructions.

We use an efficient coupled atmosphere-ocean general circulation model (plasim-genie) alongside a species distribution model (biomod2) to reconstruct paleo-climatic conditions and estimate tropical paleo-reefs evolution. In addition, differences in model-dependent CO_2 sensitivity are accounted for by simulating climate over a range of atmospheric carbon dioxide levels and fitting it to a global mean-temperature reconstruction curve.

Our findings indicate that not only does the choice of reconstruction impact ancient coral reef distribution by altering the latitudinal distribution of marine shelves, but also through differing regional climactic and oceanic conditions. We argue that researchers in matters of the ancient Earth's surface and atmosphere should carefully consider which tectonic and paleogeographic reconstruction/s they use in the analysis of their work, and ideally consider a range of proposed models to explore uncertainties.

Which Way Was Up? The Chaos of Ediacaran–Cambrian Tectonic Reconstructions

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The 'Cambrian Explosion' was one of the most important biological events in Earth's history, and the Ediacaran–Cambrian transition remains one of the most fundamental and enigmatic research frontiers in Earth science. The development of a robust tectonic model for the Ediacaran–Cambrian interval (635–485 Ma) is fundamental to understanding how plate positions and dynamics affected Earth's surface systems during the evolution of the first complex life. However, reconciling relative plate positions for this interval is challenging, which has resulted in a wide variety of tectonic and palaeogeographic models, often with little consensus between them. While palaeomagnetic data universally underpins modern global tectonic plate models, a key hurdle is that Ediacaran–early Cambrian palaeomagnetic data are often anomalous and challenging to interpret, possibly due to—as yet not fully understood—processes that were operating in the deep Earth. In lieu of unambiguous palaeomagnetic data, various other proxies must be employed in order to reconcile Ediacaran–Cambrian plate tectonic reconstructions. Key among these are climatically sensitive lithofacies, fossil occurrences, zircon dating and isotope data, in addition to other important geological information such as distribution of large igneous provinces and metamorphic terranes. This work reviews the range of proxies essential for reconciling palaeocontinental position in the Ediacaran–Cambrian (and ultimately for calibrating difficult to resolve palaeomagnetic data), and champions a multi-proxy approach as a pathway toward resolving the chaos caused by low resolution tectonic and palaeogeographic models at the dawn of complex life.

Magmatic maturation of Archean continental crust via a three-step crustal reworking

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The western part of the Singhbhum Craton preserves Paleo-Mesoarchean mafic greenstone lava flows, felsic tonalite-trondhjemite-granodiorite (TTG)-granite associations, and high-K granite and volcanic suites, similar to other Archean cratonic blocks. These successions are crucial components of early continental crust, and unravelling their respective petrogenetic relations is important for understanding the evolution from mafic to felsic crust. This study presents detailed investigations of zircon U-Pb age and Hf isotope data from the Bonai TTG/gneiss-granite Suite, and the overlying Tamperkola high-K granite and rhyolite Suite. Our results indicate concurrent crystallization of the Bonai TTG gneiss (3316 ± 9 Ma), associated porphyritic high-K granite (3299 ± 9 Ma), and their amphibolite enclaves (3325 ± 9 Ma) with older, inherited zircon grains intercepting at 3586 ± 25 Ma. The entire Bonai Suite yields an overall juvenile Hf isotope composition ($\varepsilon Hf_{(t)}$ = −1.7 to +4.6, 94 % $\varepsilon Hf_{(t)}$ > 0). Combined with the mantle-like Hf isotope signatures of the inherited zircons grains ($\varepsilon Hf_{(3685\ Ma)}$ = +2.5 to +6.2), this indicates a Hf isotope evolution array with a mafic crustal $^{176}Lu/^{177}Hf \approx$ 0.022. Considering that these grains represent the source of the TTGs, this implies lower crustal residence of ca. 300 Myr of the mafic precursor rocks. The Tamperkola high-K magmatic suite yield a crystallization age of 2810 ± 8 Ma with subchondritic Hf isotope composition ($\varepsilon Hf_{(t)}$ = −3.2 to −0.6). This Tamperkola Suite plots on the Hf isotope evolutionary array defined by the Bonai Suite and its mafic precursor, suggesting remelting of the Bonai (transitional) TTGs to produce these high-K granitoids in an internal reworking process. Our new and published data yield a threefold crustal evolution with (i) initial formation of the mafic crust at ca. 3685 Ma, (ii) subsequent residence for ca. 300 Myr and crustal reworking at ca. 3316—3299 Ma to form TTGs and (iii) their melting at ca. 2810 Ma to form high-K magmas. This succession of re-melting of igneous rocks drove the transition from mafic to felsic continental crust in the Singhbhum Craton. This Paleo-Mesoarchean process reflects the order of crustal maturation in the Archean continental crust and is not confined to late Archean cratonization.