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The effect of craton margin geometry on deformation at the edge of the North Australian Craton: Insights from analogue modelling

Fatemeh Amirpoorsaeed*, Anindita Samsu*, Peter Betts*, Alexander Cruden*, Robin Armit*

**School of Earth, Atmosphere, and Environment, Faculty of Science, Monash University*

Craton margins experience intense deformation that is influenced by rheology, strain rate, kinematics, and crustal and lithospheric architecture. However, how the geometry of the craton margin affects deformation has not been examined thoroughly. The purpose of this study is to examine the influence of craton margin geometry on upper crustal deformation by considering if the margin dips inward towards the interior of the craton or outward away from the craton. We focus on deformation observed along the eastern margin (inward dipping) and southern margin (outward dipping) of the North Australian Craton (NAC). These margins have well understood geometries and structures that are imaged in crustal-scale seismic reflection data. We implement these known geometries in crustal-scale analogue experiments to investigate the impact of the craton margin on rifting and subsequent inversion. An inward dipping craton margin geometry prevents the formation of a major rift, similar to what we observed on Mount Isa (i.e., the eastern margin of NAC). In contrast, the outward dip geometry contributes to the formation of a main rift. Furthermore, the outward dipping geometry shows a more widespread rifting than inward dipping. During the inversion phase, deformation along the inward dipping edge is localised at the edge of the craton, while in the outward dipping scenario, deformation occurs away from this edge. We can therefore conclude that the geometry of the craton margin exerts a first order control on deformation of the upper crust related to rifting and subsequent inversion.

New timing constraints on the metallogenic and tectonic evolution of western Tasmania

Sheree E Armistead[1], Sebastien Meffre[1], Ralph Bottrill[2], Andrew Cross[3], David Huston[3], Jacob Mulder[4], Jeff Steadman[1], Jacqueline Halpin[5]

[1]*Centre for Ore Deposit and Earth Sciences, Department of Earth Sciences, University of Tasmania*
[2] *Mineral Resources Tasmania*
[3]*Geoscience Australia*
[4]*Department of Earth Sciences, University of Adelaide*
[5]*Institute for Marine and Antarctic Studies, University of Tasmania*

The tectonic evolution of western Tasmania has a protracted history spanning the Mesoproterozoic to present. Despite this long-lived history, ore deposit formation in western Tasmania has so far only been found to occur between the Cambrian to Devonian time periods. Understanding the source and timing of mineralisation in western Tasmania is important to understanding mineral system evolution in this region, and for potentially opening up new areas of exploration in previously unknown mineral systems. Western Tasmanian deposits are affected by multiple phases of deformation, alteration and recrystallisation making attempts to date the deposits challenging. We will use novel geochronological and thermochronological techniques to help constrain the timing of mineralisation in western Tasmania. These techniques will include monazite U–Pb, apatite U–Pb and apatite Lu–Hf. By dating minerals using isotopic systems that have different closure temperatures, we can begin to build a thermo-tectonic evolution model for western Tasmania and constrain the origin and formation of ore deposits. Of particular interest are deposits that are potentially older than the known Cambrian–Devonian mineral systems, such as the Alpine deposit, which is hosted by the Neoproterozoic Oonah Formation [1], and the Interview River and Strickland prospects, which are hosted by the Mesoproterozoic Rocky Cape Group [2].

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AusGeochem - a novel geochemistry data platform for enabling big-data geochemical studies into Earth's composition and evolution

Sheree E Armistead[1], Samuel C. Boone[2,8], Bei Chen[3], Hayden Dalton[2], Florian Dux[4], Andrew Gleadow[2], Yoann Gréau[5], Sally-Ann Hodgekiss[5], Halimulati Ananuer[5], Fabian Kohlmann[6], Barry Kohn[2], Brent McInnes[7], Angus Nixon[8], Wayne Noble[6], David Philips[2], Alexander M. Prent[7], Tim Rawling[9], Moritz Theile[6], Xueying Wang[10], Bryant Ware[7], Renjie Zhou[11]

1 - Centre for Ore Deposit and Earth Sciences, The University of Tasmania, Hobart, Australia
2 - School of Geography Earth and Atmospheric Sciences, The University of Melbourne, Melbourne, Australia
3 - Research School of Earth Sciences, Australian National University. Canberra, Australia
4 - School of Earth, Atmospheric and Life Sciences, University of Wollongong, Wollongong, Australia
5 - Centre of Excellence CCFS & GEMOC, School of Natural Sciences, Macquarie University, Sydney, Australia
6 - Lithodat Pty Ltd, Melbourne, Australia
7 - John de Laeter Centre, Curtin University, Perth, Australia
8 - School of Physical Sciences, The University of Adelaide, Adelaide, Australia
9 - AuScope, The University of Melbourne, Melbourne, Australia
10 - School of Earth, Atmosphere & Environment - Science, Monash University, Melbourne, Australia
11 - School of Earth and Environmental Sciences, University of Queensland, Brisbane, Australia

Geochemical data is essential to our understanding of the formation, composition and evolution of the Earth and its environment. Despite the significant investment of public funds into the generation of high-value geochemical data by the research sector, a large proportion remains relatively inaccessible to the public. Over the last few years, a key theme arising within the geochemical community is the importance of geochemical data infrastructure to facilitate data production, management and storage. The importance of data transparency and management through the adoption of FAIR (findable, accessible, interoperable, reusable) data principles is paramount.

The AuScope Geochemistry Network (AGN) is a collaboration between 11 Australian universities and Museums Victoria to foster collaboration and professional development between laboratories/end users as well as maintain and strengthen the operations and growth of Australia's research infrastructure (laboratories and staff). Together with collaborator Lithodat Pty Ltd, the AGN has developed the AusGeochem data platform to provide a powerful cloud-hosted multi-purpose geochemistry research tool. The platform allows users to upload and publish their own geochemical data in a format that complies with the increasingly strict requirements of many leading peer-reviewed journals. Directly within the AusGeochem platform, users are able to visualise and plot various geochemical data, enabling on the fly integration of their own datasets together with all public data.

Difficult dates with rocks: complex geochronology at the Entia Dome

Jeremy Asimus[1], Nathan Daczko[2], Isra Ezad[2], Jean-Antoine Gazi[2]

[1] *Institute for Marine and Antarctic Studies, University of Tasmania, Private Bag 129, TAS 7001, Autsralia*
[2] *ARC Centre of Excellence for Core to Crust Fluid Systems and GEMOC, School of Natural Sciences, Macquarie University, NSW 2109, Australia*

Across all scales, fluid-rock interactions facilitate metamorphism, increase chemical mobility, disturb geochronological systems and change the rheological properties of rocks. In regions affected by fluid activity, determining the nature of fluid-rock interaction, i.e., fluid type (aqueous fluid or silicate melt), scale of fluid migration and the proceeding reactions, is required to better understand the region's geological history. The Entia Dome in central Australia is well-studied, but lack of a comprehensive understanding of fluid-rock interaction has limited previous interpretations. This thesis uses microstructures to implicate silicate melt as the key fluid present during dome formation. Syn-tectonic melt migration, reaction and metasomatism in major shear zones modified the chemistry of precursor rocks. Melt-rock interaction at the mineral scale modified zircons via coupled dissolution-precipitation and disturbed their U-Pb ages. Although, new apatite U-Pb dates (~312 Ma) confirm the Carboniferous age of doming. This study finds tectonic extrusion of melt-weakened lower crust is critical in forming the extensional dome structure during the contractional Alice Springs Orogeny. We further demonstrate that fluid-rock interaction is intimately tied to all aspects of the Entia Dome's formation. Therefore, it is essential that fluid-rock interactions at all scales are considered when building robust histories of geological regions.

Tectonics of Eastern Indonesia: Lessons for Tasmania

Peter Baillie

University of Western Australia

Eastern Indonesia has some of the most complex geology on Earth lies within a highly complex and dynamic plate tectonic setting at the meeting of three major tectonic plates – the oceanic/continental Indo-Australian, the predominantly continental Eurasian Plate, and oceanic Pacific/Philippine Sea plates. Rapid geographic changes have occurred over the last 80 million years; biogeographic complexity reflects significant changes in vertical and horizontal distribution of land and sea during the Neogene which in turn reflects the complex geological history, largely driven by subduction and strike-slip fault movements.

The region is a tectonic laboratory and offers unique insights of ongoing geological processes which have implications for the study of older areas, including Tasmania.

The talk will discuss aspects of the geological development of the region and utilise modern petroleum industry seismic and high-resolution bathymetric data.

Multiple Events along the Shear Zones of King Island, Tasmania

Ron Berry[1], Ralph Bottrill[2], Grace V Cumming[2], John L Everard[2], Karsten Goemann[1]

[1]*University of Tasmania*
[2]*Mineral Resources Tasmania*

The Mesoproterozoic Surprise Bay Formation and Neoproterozoic granites are exposed along the west and north coast of King Island (Calver and Everard 2014). The metasedimentary rocks were deformed at 1300 Ma and again during the granite intrusion (~760 Ma). Numerous mylonitic and cataclastic zones have been reported from within the granites (Streit and Cox 1998) and along the west coast of King Island from Currie to Surprise Point (Blackney 1982, Streit 1994, Everard 2011). We used electron probe microanalysis to collect the composition of monazite grains in the mylonites and applied chemical U-Th-Pb dating methods to constrain the age of these shear zones.

The mylonites in King Island shear zones have textures typical of formation above 400^0 C and probably formed very soon after granite intrusion while the metamorphic temperature was still high. Monazite analyses from this event were identified by their low Y (<1 wt%) and small Eu anomaly (average Eu/Eu*= 0.99) consistent with the metamorphic conditions and albitisation of plagioclase. These grains indicated the primary mylonite event occurred at 740 ±9 Ma (MSWD=1.0).

The Disappointment Bay West and Currie shear zones were reactivated as sinistral faults in the Cambrian (511 ±25 Ma, MSWD =0.69), probably at the same time as the NE striking cleavage was formed in the Grassy Group. There was further reactivation of the faults in the Devonian.

A later brittle movement on the Disappointment Bay West Shear Zone was associated with pyritic veins. The monazite recrystallised during this event has an average chemical U-Th-Pb age of 293 ±15 Ma (MSWD=2.1). The Grassy River Fault 50 km to the south had a large sinistral offset after 350 Ma, and we speculate these two events are related. The Grassy River Fault and late brittle reactivation of the Disappointment Bay West Shear Zone may correlate with early Permian sinistral transpression in the New England Fold Belt.

Throughout the shear zones of western King Island there are multiple generations of rhabdophane with apparent ages from 350 to 10 Ma. We interpret this data as evidence for several hydrothermal events in the shear zones that post-date the last ductile deformation.

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Does the Afar Triple Junction conform to idealised magma-rich divergent R-R-R triple junction models?

Peter Betts[1], Khalid Almalki[2], Radhakrishna Munukutla[3], Sreenidhi Kuruvamana Satheeshbabu[3], Fabio Capitanio[1], Alexander Cruden[1], Hany Khalil[1], Nicolas Molnar[4]

[1]*Monash University, Melbourne*
[2]*King Abdulaziz City for Science and Technology (KACST), Riyadh, Saudi Arabia*
[3]*Indian Institute of Technology Bombay, Mumbai, India*
[4]*RWTH Aachen University, Aachen, Germany*

The Afar Triple Junction is considered the archetype modern example of a juvenile magma-rich triple junction and is associated with the separation of the Arabian and African plates. The development of plume-driven passive rift models was derived from this region because of the relationship between the plume-related magmatism, and associated domal uplift in the Afar region coupled with the development of three rift arms, the Red Sea, the Gulf of Aden, and the Main Ethiopian rift, which converge towards the Afar region. Plume models for the Afar triple junction have persisted for many decades, although there is increasing recognition of the role of external tectonic forces associated with the convergence of the Arabian and Eurasian plates contributed to extension in the region.

New geological and geophysical data, and geodynamic models challenge plume-related models for the development of the Afar triple junction and associated rifts. Numerical simulations that produced triple junction geometries require boundary conditions that are not compatible with geological understanding of known triple junctions on Earth.

Furthermore, despite more than 50 years of research there is little consensus about: whether the Afar region and associated rift arms represent a passive or active triple junction; the timing of the transition from rifting to ocean spreading; whether the ocean initiation involved wholesale rupturing of the lithosphere or propagation of sea-floor spreading; the role of pre-existing crustal and lithospheric heterogeneities for controlling rift geometry; the timing of ruptures; the role of plume-related asthenospheric mantle channel flow in rift evolution; or even whether a plume actually impinged beneath the Afar region.

We present magnetic and gravity data from the Gulf of Aden and the Red Sea that reveals insights into some of these controversies. The data reveals domains that suggest diachronous and heterogeneous transition from rifting to sea-floor spreading. In these juvenile oceans, sea-floor spreading propagates towards the Afar region. We speculate that this pattern of rupturing was dictated by variations in the integrated strength of the Afar region and the rifting triple junction arms. The weaker lithosphere and thinner crust in the Afar resulted in wide rifting mode, whereas the stronger lithosphere away from the Afar region promoted narrow rifting mode. As the juvenile ocean basins evolved they propagated from narrow rift domains through a transition zone to a wide rift domain as lithospheric extension increased. If these concepts are correct then magma-rich triple junctions should demarcate the location of final continental break-up and they are not the nexus of extension and continental break-up as presented in many models.

Laser ablation Lu–Hf dating reveals Laurentian garnet in subducted rocks from southern Australia

Dillon A Brown[1], Alexander Simpson[1], Martin Hand[1], Laura J Morrissey[2,1], Sarah Gilbert[3], Renée Tamblyn[1], Stijn Glorie[1]

[1]*Department of Earth Sciences, University of Adelaide, Adelaide, SA, Australia*
[2]*Future Industries Institute, University of South Australia, Mawson Lakes, SA, Australia*
[3]*Adelaide Microscopy, University of Adelaide, Adelaide, SA, Australia*

Garnet is a fundamental expression of metamorphism and one of the most important minerals used to constrain the thermal conditions of the crust. Here, we use innovative in-situ laser ablation ICP–MS/MS Lu–Hf geochronology to demonstrate that garnet in metapelitic rocks enclosing Cambrian eclogite in southern Australia formed during Laurentian Mesoproterozoic metamorphism. Garnet porphyroblasts in amphibolite-facies metapelitic rocks yield Lu–Hf ages between c. 1285 and 1240 Ma, revealing a record of older metamorphism that has been partially obscured by mineralogical overprinting during c. 510 Ma Cambrian subduction along the East Gondwana margin. Existing detrital zircon age data indicate the protoliths to the southern Australian metapelitic rocks were sourced from western Laurentia. We propose the metapelitic rocks of southern Australia represent a fragment of western Laurentian crust, which was separated from Laurentia in the Neoproterozoic and incorporated into the East Gondwana subduction system during the Cambrian. The ability to obtain Lu–Hf isotopic data from garnet at acquisition rates comparable to those for U–Pb analysis of detrital zircon means, for the first time, the metamorphic parentage of rocks as expressed by garnet can be readily accessed to assist palaeogeographic reconstructions.

Profiles across a fossil congested subduction zone – is the Governor Fault in Victoria a ~5 km thick megathrust progressively superimposed on a probable Rodinian-age passive margin, and a control on the distribution of subsequent mantle-derived dykes and orogenic gold mineralisation?

Ross A Cayley[1], Phil B Skladzien[1], Cameron P Cairns[1], Suzanne Haydon[1], Mark A McLean[1], David H Taylor[1], Tanya Fomin[2], Ross D Costelloe[2], Alison Kirkby[2], Duan Jingming[2], Michael P Doublier[2], Robert J Musgrave[3], Ned Stolz[3], Giovanni Spampinato[3], Phil Gilmore[3], John Greenfield[3], Astrid A Carlton[3], Tim J Rawling[4]

[1] Geological Survey of Victoria (past and present); [2] Geoscience Australia (past and present); [3] Geological Survey of New South Wales (past and present); [4]AuScope Limited

The Governor Fault coincides with a major Ordovician-Early Devonian paleogeographic discontinuity that separates the Ordovician-Early Devonian Melbourne Zone of central Victoria resting unconformably on Proterozoic-Early Cambrian Selwyn Block continental crust, from the adjacent Tabberabbera Zone of conformable Early Cambrian–Late Ordovician deep marine mafic igneous and sedimentary rocks of oceanic–intra-oceanic arc–accretionary character. The Lachlan Orocline hypothesis interprets the Governor Fault as a mega-thrust, the terminal Siluro-Devonian collisional phase of an Ordovician subduction zone that became progressively congested and oroclinally folded from northwest (dipping north) to southeast (dipping northeast) by the northern and eastern flanks of buoyant Selwyn Block crust drawn obliquely into the subduction zone on the down-going plate. The Governor Fault is exposed at Dookie where basal-Tabberabbera Zone mafic metavolcanics overthrust the Melbourne Zone succession, imaged as sub-horizontal to north-dipping in adjacent N-S oriented deep 2D seismic reflection line 06GA-V4. The Governor Fault is also exposed south along-strike at Howqua where structure-contouring the fault trace and fault klippes implies an ~10° northeast dip for the thrust. The E-W oriented Southern Lachlan Crustal Transect (SLaCT) deep 2D seismic reflection line 18GA-SL1 was positioned between these key control points to study the Governor Fault in more detail and test depth extent. The SLaCT data is spectacular, imaging the Governor Fault as a complex zone of intercalated alternately highly reflective and unreflective rocks ~5 km thick that apparently dips east overall at 20-28° beneath the Tabberabbera Zone, virtually unchanged in geometry and appearance from surface to base of crust (Moho, at 12-13 s TWT / ~38 km depth). The fault zone separates crust of markedly contrasting overall reflective character, consistent with fundamentally different geological affinity and history. Within the fault zone a number of kilometres-thick eye-shaped regions of non-reflective crust that look similar to adjacent Selwyn Block crust are stacked in systematic en-echelon fashion, separated by tracts of highly reflective crust that extend to surface as mafic igneous Tabberabbera Zone rocks. We interpret these 'eyes' as Selwyn Block mega-boudins fragmented and rotated into a foreland-dipping domino configuration within the fault zone during east-over-west shear, with interstitial antithetic slips incorporating reflective Tabberabbera Zone material. The planar fault zone base projects to surface as the mapped Fiddlers Green Fault within the Melbourne Zone. Thus, Selwyn Block windows exposed at Jamieson, Whiskey Knob, Licola, Glen Creek are reinterpreted as fault-slices, 'eyes' in map view uplifted within the Governor Fault Zone. The Fiddlers Green Fault bounds the Woods Point Dyke Swarm and the Woods Point-Walhalla-Tallangalook Goldfield, implicating the Governor Fault megathrust base as a plumbing system that 1: facilitated mantle-derived magmatism to surface during extensional reactivation, and then 2: scavenged metamorphic fluids from a thickening Tabberabbera Zone to form co-located orogenic goldfields during the Mid-Devonian Tabberabberan Orogeny, with big implications for Mineral Systems Analysis and mineral exploration under cover.

Contributions of metamorphic volume changes to mineral equilibria and the generation of tectonic tremor

Timothy Chapman[1], Geoffrey L. Clarke[2], Luke Milan[1], Julie Vry[3]

[1]School of Environmental and Rural Science, University of New England, NSW, 2351, Australia
[2]School of Geoscience, The University of Sydney, NSW, 2006, Australia
[3]School of Geography, Environment and Earth Sciences, Victoria University of Wellington, 6040, New Zealand

Volume changes during metamorphic reactions are key contributors to the physical changes of crystalline rocks. The production of H_2O during metamorphism along active plate boundaries is inferred to contribute to low-frequency tectonic tremor. Assessing dehydration or hydration reactions in terms of conjugate *V*–*T* pseudosections provides indicators of transient departures in hydrostatic pressure and their impact on observed mineral equilibria. The expansion in volume of major dehydration events such as the breakdown of lawsonite or chlorite delineate zones of fluid overpressure that generate connectivity via fracturing. Net compressional reactions represent sinks for fluid consumption and the focussing of strain. The capacity of metamorphic rocks to generate or consume fluid along portions of the *P*–*T*–*V* path exerts a fundamental control on the distribution of stresses in the crust and the observed mineral assemblages. Coupling a phase equilibria approach to mechanical modelling provides a quantitative framework to assess these changes in fluid pressure. The results can be compared to case studies in rocks from New Caledonia and New Zealand and the links to tremor episodes in specific tectonic environments.

The effect of reactive melt percolation on upper mantle structure, composition, and seismic anisotropy in West Antarctica

Vasileios Chatzaras[1], Seth C. Kruckenberg[2]

[1]The University of Sydney, School of Geosciences, NSW, Australia
[2]Boston College, Department of Earth and Environmental Sciences, MA, USA

West Antarctica hosts one of the largest rift systems on Earth, the West Antarctic Rift System (WARS), and supports the West Antarctic ice sheet. Constraining the deformation, composition, and seismic structure of the West Antarctic mantle is important for unravelling the dynamics of intracontinental extension within the WARS, and for accurately modelling glacial isostatic adjustment processes and global sea level rise. The aim of this contribution is to understand the processes that control the seismic properties (velocities, anisotropy) of the West Antarctic upper mantle, in the context of Marie Byrd Land (MBL) and WARS tectonic evolution. Using an integrated study that combines analysis of the petrology, microstructure and seismic properties of 44 peridotite xenoliths extracted from the upper mantle beneath MBL, we demonstrate the effect of melt-rock reaction and refertilisation on seismic anisotropy. The xenoliths are predominantly lherzolite (n = 30), with lesser occurrences of harzburgite (n = 4), wehrlite (n = 3), dunite (n = 3), olivine websterite (n = 1), websterite (n = 1) and clinopyroxenite (n = 2). Variations in modal compositions, enrichment of clinopyroxene in lherzolite, discrepancies between the estimated degrees of partial melting inferred from geochemical trends in orthopyroxene and clinopyroxene, and microstructural relationships, suggest that the lithospheric mantle beneath MBL may have experienced some degree of diachronous reactive melt percolation and refertilisation. Olivine shows three main CPO patterns, the A-type, axial-[010], and axial-[100] texture types. Olivine CPO is controlled by the finite strain geometry, rather than the deformation conditions and strain magnitude. The maximum P-wave and S-wave anisotropy show positive correlation with olivine CPO strength, and negative correlation with increasing modal abundance of pyroxene. Reactive melt percolation and refertilisation likely modified the average seismic properties of the MBL mantle lithosphere by decreasing the CPO strength and increasing the pyroxene content. The seismic properties of the MBL mantle xenoliths are heterogeneous between individual samples and volcanic centres, however, at larger spatial scales (>100 km) they are dominated by the anisotropy resulting from the A-type olivine CPO. In contrast to other major rift systems, the polarization of fast shear waves in the WARS is oriented perpendicular rather than subparallel to the rift trend. This relationship suggests that the maximum P-wave anisotropy, and thus the alignment of olivine [100] axes and the lineation orientation, are parallel to the extension direction in the WARS. Assuming that WARS rifting and modification of the lithospheric mantle affected the majority of the MBL xenoliths, the weighted average seismic properties of the MBL xenoliths that are dominated by A-type olivine textures suggest that lithospheric thinning was accommodated primarily by pure shear deformation. Variations within and amongst individual volcanic centres, however, attest to variations in local strain geometry and heterogeneous mantle deformation, likely resulting from the protracted history of deformation that has affected MBL and West Antarctica.

Localisation at constant strain rate and changing stress in the upper mantle of an extended plate margin

Vasileios Chatzaras[1], Julie Newman[2], Basil Tikoff[3], Jan R. Wijbrans[4], William M. Lamb[1], Martyn R. Drury[5]

[1] *The University of Sydney, School of Geosciences, NSW, Australia*
[2] *Texas A&M University, Department of Geology and Geophysics, TX, USA*
[3] *University of Wisconsin-Madison, Department of Geoscience, WI, USA*
[4] *Vrije Universiteit Amsterdam, Department of Earth Sciences, The Netherlands*
[5] *Utrecht University, Department of Earth Sciences, The Netherlands*

In this contribution we test whether strain along a plate boundary localises at constant strain rate or constant stress conditions. Deformation experiments of monomineralic olivine show localisation of strain under constant stress rather than constant strain rate conditions [1,2]. We test these results in naturally deformed rocks, which are usually polymineralic and heterogeneous. We present results from a natural deformed mantle shear zone in the Turon de Técouère massif of the French Pyrenees. The Turon de Técouère peridotite is composed of spinel- and plagioclase-bearing lherzolite. The massif is composed of protomylonites, mylonites, and a layer of ultramylonites (25–40 m thick), which transects the mylonite domain at a low angle. An $^{40}Ar/^{39}Ar$ date of 127.30 ± 6.70 Ma was obtained on amphiboles within veins that crosscut the dominant foliation within the Turon de Técouère massif. This age is consistent with the interpretation that deformation occurred during the mid-Cretaceous, associated with hyperextension between the Iberian peninsula and the European continental margin. The peridotite microstructures record deformation during lowering deformation temperatures (1000, 850, and 750 ◦C). Olivine-based paleopiezometry indicates that differential stresses are variable both spatially across the zone, and temporally during exhumation. Calculated strain rates from olivine flow laws, however, remain relatively constant despite changes in differential stress. Specifically, differential stresses and strain rates were estimated to be: 60 MPa and 10^{-11} to 10^{-10} to s^{-1} at 1000 ◦C; 83 to 634 MPa and 10^{-12} to $10^{-10}\cdot s^{-1}$ at 850 ◦C; and 70 to 478 MPa and 10^{-12} to $10^{-11}\cdot s^{-1}$ at 750 ◦C [3]. This result appears to be at odds with the results of the deformation experiments, which indicate that strain localization occurs dominantly as a result of constant stress. We hypothesize that in the Turon de Técouère massif—and many natural shear zones—strain localization occurs as a result of reactions, which decrease the grain size and promote the activation of grain size sensitive deformation mechanisms. From a tectonics perspective, this study indicates that the deformation rate in a particular plate boundary is relatively uniform while stress varies to accommodate this deformation. This viewpoint is consistent with deformation at a plate boundary, but it is not the typical way in which we interpret strain localization.

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Out of Antarctica or not? Where did the Tasmania dolerites come from with implications for Jurassic Gondwana breakup

Alexander R Cruden[1], Andrew Gordon[1], James Barter[1]

[1]*Monash University*

Ca. 182 Ma Jurassic dolerite sills in Tasmania overlap in age with dolerite sills and basaltic lavas in the Ferrar province, Antarctica, and the Karoo, South Africa. Hence, the Tasmanian dolerites have long been considered to be part of a major Large Igneous Province that extended parallel to the Jurassic margin of Gondwana from what is now southern Africa, the Transantarctic Mountains, to Tasmania and South Australia. Two hypotheses have been proposed for the Ferrar and Tasmanian dolerites. 1) They are related to a mantle plume emplaced in the present-day Wedell Sea region, implying long-range, shallow-crustal transport of magmas in sills and dykes over distances of up to 4,000 km. 2) They are sourced from the mantle below Tasmania and Antarctica, implying only short-range lateral transport at the level of emplacement. We report results from a combined structural and anisotropy of magnetic susceptibility (AMS) study of the Tasmanian dolerites conducted to evaluate these hypotheses by differentiating between flow patterns and structural architectures in sills that are indicative of local versus distal sources.

Detailed structural mapping and 3D modelling indicate that no more than a few individual large sub-horizontal dolerite sheets were emplaced parallel to bedding in Permian sedimentary host rocks. They are offset by map and outcrop scale steps that we interpret to be NW-SE-trending, steeply dipping broken bridges. The AMS of dolerite was measured in oriented samples collected from 126 sites across Tasmania. Their mean bulk magnetic susceptibility is ~0.01 SI units, which together with high-temperature susceptibility measurements indicate that the AMS is carried by magnetite, which occurs as skeletal grains with morphologies controlled by the petrofabric of plagioclase and pyroxene. These observations, and scant microstructural evidence for solid-state deformation, indicate that the AMS records a magmatic fabric that formed during emplacement and crystallization of the dolerite sheets. Magnetic lineations are dominantly subhorizontal, trending mostly NW-SE. Steeply-moderately inclined magnetic lineations are rare and mostly plunge SE. Subsets of shallow N-S and NE-SW lineations are associated with sites with subvertical E-W and NW-SE striking magnetic foliations. Magnetic foliations are dominantly subhorizontal, parallel to bedding in the surrounding Permo-Triassic sedimentary rocks, and the upper and lower contacts of subhorizontal dolerite sheets. Anomalous subvertical E-W and NW-SE striking magnetic foliations are associated with steps or broken bridges observed in the field and cross sections.

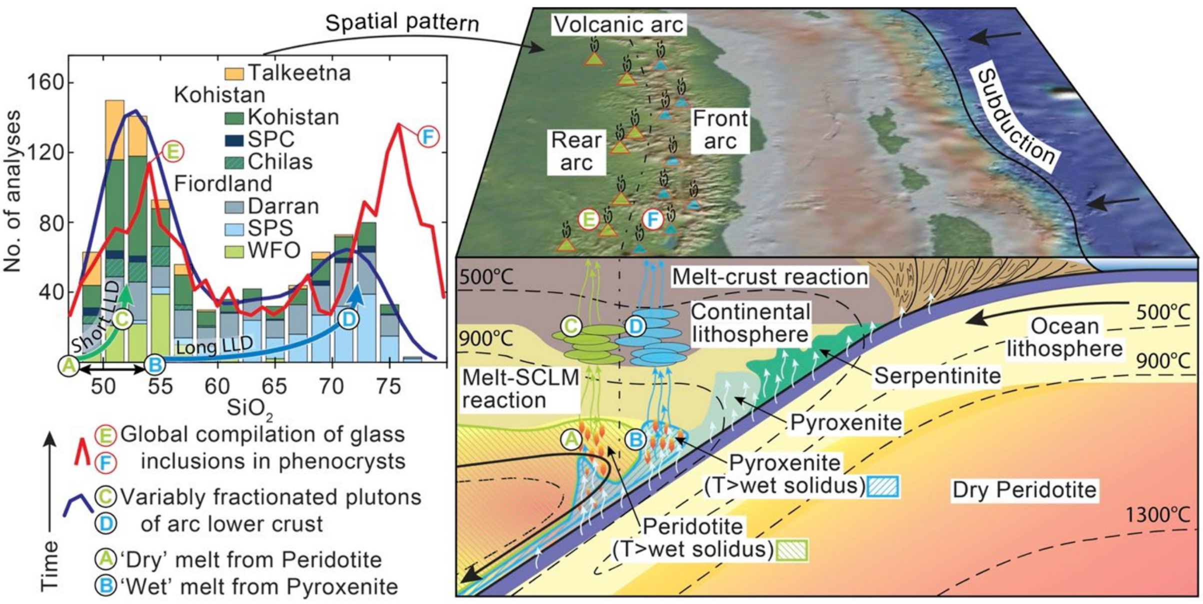
The AMS results are consistent with dominantly NW-SE magma flow within subhorizontal sheets, which is supported by the NW-SE orientation of steps and broken bridges. The architecture of segmented sheet fronts indicates that the polarity of sill propagation was from SE to NW. This finding is inconsistent with a magma source immediately below Tasmania and implies lateral transport from another location. However, the magma flow vector does not point back to the Ferrar dolerites in Antarctica, and therefore does not support the long-range Ferrar-Tasmania LIP hypothesis. Rather fabrics in the Tasmania dolerite are consistent with lateral flow from the present SE, perpendicular to the Gondwana margin with a source in the back-arc of the associated subduction zone.

A mantle-source solution to the enigma of bimodal arc volcanism

Nathan R Daczko[1], Timothy Chapman[2], Michael W Förster[1], Heather Handley[1], Stephen Foley[1]

[1]*Macquarie University*
[2]*University of New England*

Silicate melts in arc environments are dominated by mafic (low-silica) and silicic (high-silica) compositions, often generating a characteristic bimodal pattern. We investigate the whole arc crust and show that the plutonic lower crust shares the bimodal pattern of melts from volcanoes. This key observation reveals that, contrary to some explanations of bimodal volcanism, variation in mantle source and mantle processes must fundamentally control bimodalism. We also recognise bimodalism in Th/La composition of the whole arc crust and suggest a new working hypothesis: bimodalism originates by melting of distinct sub-arc mantle sources, one dominated by relatively dry peridotite and the other by hydrous pyroxenite. The two groups of primary melts fractionate along distinct liquid lines of descent that lead to relatively dry mafic melts (Th/La~0.1) versus hydrous silicic melts (Th/La>0.2) by 65–80% fractional crystallisation. Common crustal processes such as crystal fractionation, assimilation, reactive flow and/or magma mixing may also lead to differentiation of both groups.



Overturning paradigms: Detailed field observations from the Himalayan Main Frontal Thrust and frontal foldbelt, Nepal

Nicholas G Direen[1,2,3]

[1] *School of Earth Sciences / CODES, University of Tasmania*
[2] *Mitre Geophysics Pty Ltd*
[3] *FrOGTech Pty Ltd**
**deceased*

The Main Frontal Thrust of the Himalayan Orogen is part of a tectonic system that is actively converting a Miocene-Recent intracontinental foreland basin, its underlying Mesozoic and Palaeozoic pre-orogenic continental passive margin system, and its basement, into a fold and thrust belt. This orogenic belt includes an active petroleum system.

As part of a commercial hydrocarbon exploration reconnaissance program, detailed structural and stratigraphic observations from field work were compiled along a series of 7 orogen-orthogonal dip lines, and balanced and restored cross sections were constructed. These observations detail heretofore unrecognized complexity at the Himalayan Main Frontal Thrust, the hinterland-ward thrusts, and within the orogenic foreland deposits of the Miocene-Recent Siwalik Group. These results contrast with (and falsify) published governmental maps, and generalised results and models presented in widely distributed and cited academic literature. As a consequence, they call into question published estimates of shortening within the overall Himalayan foldbelt, and possibly the published postulated mechanisms of shortening within a "text-book" foreland fold and thrust belt orogen.

These outcomes are consistent with a long and successful history of industry resource explorers undertaking pioneering fieldwork motivated by commercial outcomes, rather than solely academic considerations, in advancing the geological understanding of complex geological phenomena e.g. Dahlstrom (1969).

References:
Dahlstrom, C., 1969. Balanced cross sections. Canadian Journal of Earth Sciences, 6(4): 743-757.

Metamorphic diamonds discovered along the Northeast margin of Gondwana – Tectonic Implications

Alexander Edgar[1], Ioan Sanislav[1], Paul Dirks[1], Carl Spandler[2]

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

The identification of ultrahigh pressure (UHP) metamorphism is important for the tectonic reconstruction of ancient terranes. The existence of coesite and in-situ metamorphic diamonds in continental and oceanic rocks is widely regarded as evidence for UHP metamorphism. UHP metamorphism is typically described in arc-continent or continent-continent collision terrains where oceanic or continental material is subducted to >70 Km depth, prior to exhumation and emplacement along plate margins.

Paleozoic tectonic models for the northeastern margin of Gondwana describe an accretionary environment with continent growth occurring without the addition of exotic terranes. We present evidence of UHP metamorphism along the northeastern margin of Gondwana, preserved in garnets from quartzites within the Ordovician Running River Metamorphics of northeast Queensland. These garnets preserve textural evidence of former coesite inclusions and contain inclusions of metamorphic diamonds, indicating minimum peak metamorphic conditions of 3.5 GPa at 800 ºC. The discovery of ultrahigh pressure metamorphism within the Running River Metamorphics strengthens interpretations of arc-continent collision, which cannot be attributed to the traditional accordion tectonics model. Arc-continent collision would require either a westward dipping double subduction complex, or an eastward dipping subduction complex to accommodate intra-oceanic arc formation and westward migration. We conclude that the tectonic processes operating in the northern Tasmanides differ from those of the southern orogens during the early Paleozoic.

Comparing plate motion models and crustal thickening in the central Andes using time-series analysis and data analytics

Alex Farrar[1], Matthew J. Cracknell[1], Thomas Schaap[1], David R Cooke[1]

[1]*Centre for Ore Deposit and Earth Sciences (CODES), University of Tasmania*

Cordilleran orogenic systems, such as the Andes, form adjacent to oceanic-continental convergent margins due to compressional and mass transfer events associated with plate tectonic processes. There are many investigations that link plate convergence parameters with Andean orogenic processes and *vice versa*. However, such studies tend to focus on only one or few plate tectonic or orogenic models, with little explanation as to why potentially dozens of alternate models were omitted from the analysis. It is conceivable that allowing for alternate plate tectonic or orogenic models might have led to different conclusions regarding the hypothesised causal relationship between plate tectonics and orogenic processes. However, the causal relationship between plate convergence parameters and orogenic uplift indicators has, until now, not been assessed using a data-driven approach.

Unresolved fundamental questions relating to orogenic processes in the central Andes include the effect, if any, that upper plate deformation has on plate convergence, triggering mechanisms for flat slab subduction and temporal lag between plate convergence changes and Andean orogenic responses. In this study, we conduct the first data-driven analysis to identify statistical correlation and “causation” between plate tectonic models and orogenic processes. We conduct Granger-causality time-series and statistical analysis of published central Andean orogenic proxies over the last 70 million years: Sr/Y and La/Yb ratios from volcanic rocks, low-temperature thermochronology, paleoelevation and flat-slab subduction events, and find that they are statistically correlated to each other - in some cases with a temporal causal link, and in other cases synchronously.

Statistical and time-series analysis of five plate motion models of the oceanic Nazca-Farallon and continental South American tectonic plates with the central Andean orogenic proxies demonstrates the significant variability between published plate motion models. Granger causality analysis is used to investigate bi-directional “causality” between orogenic processes and plate convergence rate and obliquity. From our analyses we identify a tectonic convergence model that most adequately fits orogenic modeling, and we utilize our data-driven method to identify causal linkages between plate tectonic and orogenic processes that yield critical insight into the bi-directional causal relationships between plate tectonics and orogenesis.

Tectonic switching in ductile shear zones

Melanie Finch

Department of Earth and Environmental science, James Cook University, Townsville, QLD

Ductile shear zones that accommodate periods of deformation with different stress axes are common in weak regions that localise strain over multiple tectonic events, such as mobile belts. Co-planar, opposite shear sense due to a reversal in shear direction produces unique, hybrid microstructures that can be difficult to decipher. While such zones are relatively common, lack of understanding and familiarity with hybrid microstructures may mean that they are underreported and misunderstood. A comprehensive study of microstructural evolution after shear sense reversal is needed to guide studies of naturally deformed rocks. Our work uses the numerical modelling platform *Elle* to fill this gap. We simulated dextral shear in a three-phase microstructure and then switched the shear sense to sinistral and determined how the microstructure evolved through a range of hybrid structures towards full transposition. In order to investigate the effect of the pre-existing structures on the development of hybrid structures, the length of the period of dextral shearing was manipulated, producing seven different models with a dextral finite strain (γ) from 2 to 14 ($\Delta\gamma$ between models =2). We found that in models with low dextral finite strain ($\gamma_{dextral}$ = 2) S-C fabric simply rotated from a dextral shear sense to a sinistral shear sense via anticlockwise rotation of S planes. In models with moderate finite strain ($\gamma_{dextral}$ = 4-12), transitional hybrid microstructures formed. $S_{dextral}$ planes showed the most complex evolution with initial anticlockwise rotation into parallelism with the direction of maximum shortening, followed by folding with axial planes perpendicular to the maximum shortening direction. These folds rotated until axial planes approached parallelism with the shear zone boundary. During rotation, folds tightened and their amplitude increased until they were isoclinal and hinges were sheared away from limbs, forming rootless isoclinal folds and 'hooks'. Finally, the microstructure was completely transposed to sinistral S-C fabric. Models that start at high dextral finite strain ($\gamma_{dextral}$ = 14) show a different evolution because the microstructure at the time of the switch (i.e., at the end of dextral shearing) is dominated by C planes, which are parallel to the shear zone boundary. When the shear sense reverses many C planes can accommodate sinistral shearing without rotation, since shearing is co-planar. However, some C planes are impeded by strong grains and undergo folding. Results from modelling are compared to microstructures in the naturally deformed Zanskar shear zone, NW Himalaya, an extension of the South Tibetan Detachment System. Here normal shearing overprinted a pre-existing thrust shear zone, producing complex hybrid microstructures that are similar to those revealed in our numerical models.

Fingerprints of melt flux in oceanic core complexes

Robyn Gardner[1], Nathan Daczko[1], Sandra Piazolo[2]

[1]*Macquarie University*
[2]*University of Leeds, UK*

Core complexes form in both continental and oceanic environments, usually in extensional tectonic settings, causing deep crustal rocks to be exhumed. Numerous oceanic core complexes on slow spreading ridges have been drilled by the International Ocean Drilling Program (IODP) in the Atlantic, and Indian Oceans. The rocks in these cores are complex and heterogeneous in their fabric and assemblage with evidence of deformation and fractionated melt-rock interactions. The drilling programs have generated vast amounts of data, including extensive cruise reports, on-board core descriptions, whole rock and mineral chemical analyses, thin section images and descriptions.

Investigating melt flux through oceanic crust has usually depended on observing mineral microstructures and reaction textures indicative of melt-rock interactions. Here, we show that coupling these observations with quantification of mineral and whole rock chemical variations can highlight the sites and the degrees of melt flux throughout the complex. We investigate melt flux in samples from the 735B core, Atlantis Bank, on the South West Indian Ridge in the Indian Ocean. We also re-analyse the legacy data provided by the cruise scientific teams with a view to simplifying the data and finding chemical "fingerprints" indicative of melt flux by diffuse and channelized porous melt flow. The observations we make on the 735B core are then applied to two core complexes in the Atlantic Ocean – Kane Bank and Atlantis Massif, both situated on the Mid Atlantic Ridge.

Our comparison underscores the importance of melt flux in the formation and evolution of oceanic core complexes.

Zircon Pb-loss arrays result from melt-mediated coupled dissolution-precipitation recrystallisation

JEAN-ANTOINE GAZI[1], NATHAN DACZKO[1]

[1]*Department of Earth and Environmental Sciences, Macquarie University, Sydney, New South Wales 2115, Australia.*

Pb-loss arrays resulting from the mobilisation and escape of radiogenic Pb are a common feature of zircon, yet the mechanisms that drive and facilitate Pb-loss can be ambiguous and difficult to interpret. Such is the case for the Macklin Island gabbro, where previously published zircon geochronology produced a near concordant Pb-loss array spanning 550 million years despite relatively simple igneous textures, low amounts of radioactive elements and no evidence of crystal-plastic deformation. In this study, multiple spot analyses (up to 7 per grain) are combined with high-resolution electron back-scatter imaging to characterise the isotopic (U-Pb) and trace element variability of three selected grains from the Macklin Island gabbro. Using this approach, we identify microstructures indicative of zircon recrystallisation via coupled dissolution-precipitation including abundant micro- to nanoscale porosity, preservation of the parent grain morphology and sharp compositional reaction interfaces. Melt-mediated coupled dissolution-precipitation is supported by the presence of common host rock minerals such as biotite, plagioclase feldspar and orthoclase feldspar pseudo-morphing former porosity in zircon grains and the stability of pyroxene in recrystallised domains of the (meta-)gabbro. In each grain, several analyses produced an array of near-concordant dates ranging from 1100 Ma to 530 Ma. Non-essential cations (REE, Y, Ti, U and Th) are increasingly depleted and Hf is enriched with younger measured $^{206}Pb/^{238}U$ dates (apparent ages). Our observations show that variable REE, Y, Hf, Th, U and Pb mobility resulted from melt-mediated coupled dissolution-precipitation and produce an array of concordant apparent ages, of which the oldest and youngest ages may be geologically meaningful.

Structural aspects of the Tasmanian Tyennan nucleus with tectonic and dynamic implications

David R. Gray[1], Michael J. Vicary[2]

[1]*Consultant to Mineral Resources Tasmania*
[2]*Mineral Resources Tasmania*

The Tyennan nucleus, the geological core of Tasmania, consists of a structurally complex, litho-tectonic stack of low-grade Early Proterozoic quartzite and phyllite and high-grade garnetiferous schist-quartzite ± amphibolite. It extends from Cradle Mountain in the north to Southwest Cape in the south. A re-examination and re-appraisal of the structure of these rocks in the context of early Cambrian (~515-510 Ma) continental margin subduction to depths of ~20-60km has shown:

1) The Tyennan nucleus structural architecture consists of:

- stacked, obducted, metamorphosed slabs of allochthonous high-grade schist (uppermost unit), overlying low-grade quartzite, overlying low-grade pelite (basal unit), overlying para-autochthonous? low-grade dolomitic pelite and phyllite.
- a ~200km length fold-nappe at the leading edge and highest structural level of the composite obducted stack of metamorphic sheets.
- mega-sheath folds with 20-25km sheath-tube widths ('y' dimension) and 20-30km sheath-tube lengths ('x' dimension) in the quartzite core (Southern Tyennan).
- Isoclinal macro-fold stacks within the composite stack with 20-30km axial trace lengths, pinched lateral terminations and doubly-plunging "augen" form at the regional scale (Central Tyennan and Southern Tyennan).
- a regional scale 'shear-lozenge' of isoclinal, asymmetric fold-pairs (~500m wavelengths) with the lozenge bounded by high-strain zones (Southern Tyennan).

2) The early Cambrian deformation is partitioned through the composite obducted "slab" into domains of isoclinal macro-folds transitioning into regional scale sheath folds bounded by zones of higher strain. These zones are characterised by transposition foliation, rootless mesoscopic isoclinal folds, sheath-folds, overprinting crenulation cleavages and platy mylonitic to schistose zones.

3) The positions, extent and geometries of these early Cambrian macro-fold structures reflect a complex interaction between i) facies variation within the continental margin stratigraphy, ii) shear-strain gradients within the subducted-obducted margin, and iii) the boundary conditions of a subduction-obduction channel involving buoyant expulsion coupled with tractional forces along the tops and bottoms of the ascending sheets. Post-metamorphic bottom to the west footwall extrusion or footwall uplift occurred beneath the advancing ophiolite sheet. The timing and comparative rates of ophiolite advance versus sheet ascent potentially dictate extrusion beneath an essentially "static" or fixed hanging wall.

4) Post-collisional E-W extension (~508-492 Ma) led to development of a linked rift system essentially orthogonal to the stretching lineation in the Tyennan nucleus and was followed by a period of E-W compression in the Late Cambrian.

5) The fanning nature of i) the stretching lineation (Lm) orientation pattern within the Tyennan nucleus, ii) the Early Cambrian transport direction pattern (based on restored Lm and shear band data), and iii) the mid- to Late Cambrian rift-basin pull-apart directions all support **oroclinal bending** as part of the Palaeozoic tectonic development of Tasmania. These structural relationships require a post Cambrian but pre- Middle Devonian timing of orocline formation.

6) The mechanics of oroclinal bending are largely by vertical-axis, broad-scale crustal bending facilitated by scissored movements on oblique slip, sub-vertical faults.

7) The younger Devonian deformation is partitioned within and around the oroclinal form of the Tyennan nucleus into a series of variously oriented, open to tight folds, cleavage and reverse faults. This pattern was largely controlled by reactivation of the Middle Cambrian rift architecture.

Alps-style recumbent Isoclinal macro-folds in quartzite sequence, Frenchmans Cap, Tasmania

David R Gray[1], Michael J Vicary[2]

[1] *Consultant to Mineral Resources Tasmania*
[2] *Mineral Resources Tasmania*

The Frenchmans Cap region belongs to the Central Tyennan domain, within the Proterozoic core of Tasmania. It is made up of three west-dipping, stacked metamorphic sheets with the high-grade schists of the Franklin-Joyce metamorphic sheet at the highest structural level on the western side. These overlie the quartzite of Frenchmans Cap (Fincham-Mary metamorphic sheet) and the low-grade dolomitic schist of the Scotchfire metamorphic sheet at the lowest structural level on the eastern side.

Structure includes two oppositely-closing, regional-scale recumbent isoclinal folds with lower limbs transitional into intensely foliated high-strain zones (The southwest-closing Frenchmans Cap-Lions Head Ridge recumbent fold and the east-closing Agamemnon recumbent fold). These are part of two quartzite outcrop belts that attenuate and merge to the northwest, a pattern related to the recumbent fold cores and refolding by more open Devonian folds (the Clytemnestra Anticline, the Philps Peak Anticline and the Lake Vera Syncline). The associated younger Devonian brittle reverse faulting offsets the high strain contact between the quartzite and underlying dolomitic phyllite.

The significant relief of the east and northeast faces of Frenchmans Cap itself show structural variation and zonation in the low-grade quartzite sequence as well as high-strain contact with the underlying dolomitic schist. Three structural zones include:1. An upper zone with recumbent macro-isoclinal folds in apparent “bedding”, 2. A middle strongly foliated zone with mesoscopic, isoclinal folds within transposed layering and 3. A lower intensely foliated zone overprinted by brittle faulting above the faulted contact with the underlying dolomitic schist/phyllite.

Quartzites in the Frenchmans Cap region commonly show a quartz mineral elongation lineation (Lelong or Lm), a rodding lineation (Lrod) and crenulation lineations (Lcren). In the high-strain parts, particularly in the lower limb transition to the basal zone of the recumbent Frenchmans Cap and Agamemnon macro-folds, the fabrics are typified by strong to intense foliation and transposition layering/foliation (Sm), rodding fabrics within the transposition layering, mesoscopic isoclinal folds, rootless isoclinal fold pairs and multiple crenulation cleavages (Scc).

Transport direction vectors calculated from shear bands and macro-shear band boudins indicate the quartzite sheet was emplaced from west-to-east towards 110°-120°. Shear bands in the high-strain upper part of the Scotchfire dolomitic phyllite also show west-over-east shear emplacement.

The oppositely closing Frenchmans Cap (southwest-closing) and Agamemnon (east-closing) recumbent folds at the same structural level, combined with the convergence of the quartzite outcrop belts containing the hinge lines to the north, support a possible macro-sheath pod geometry within this part of the Mary-Fincham metamorphic sheet. The proposed structure is ~6 km wide with a strike length of ~10 km and a sheath-closure at around the Franklin River. Pod thickness is estimated at ~500 m in the position of Frenchmans Cap.

Cambrian Recumbent macro-folds and Devonian thrusts, The Arthur Ranges, Southwest Tasmania

David R Gray[1], Michael J Vicary[2]

[1] *Consultant to Mineral Resources Tasmania*
[2] *Mineral Resources Tasmania*

The Arthur Ranges lie in the northeast corner of the Southern Tyennan domain. They consist of a Proterozoic low-grade quartzite-pelite sequence dominated by a series of Cambrian regional-scale, recumbent-isoclinal folds. The northeast flank of the Arthur Ranges is defined by a Devonian reverse fault system that truncates and offsets these Cambrian recumbent folds. The faults are associated with a sub-parallel series of open, upright northwest-trending Devonian folds that swing to a more east-west trend towards the eastern end of the Western Arthur Range. Spacing of the Devonian axial surface traces is on the order of ~1.5km. This younger folding refolds the older Cambrian large-scale recumbent folds that are also northwest-trending.

The spine of the Western Arthur Range consists of a major northeast-closing recumbent macro-fold that extends the length of the range (~21km) and is folded by the younger open Western Arthur Anticline. An oppositely, southwest-closing recumbent fold sits in the footwall to the Devonian reverse fault system, but to current knowledge this is only preserved at Mt Hayes, Dorado Peak and Mt Scorpio along the north flank of the range.

The Eastern Arthur Range consists of a fold-pair of regional-scale, Cambrian recumbent-isoclinal macro-folds, with a structurally higher southwest-closing closure overlying a structurally lower northeast-closing closure. Hinge zones of these folds can be seen at "The Needles" and Devils Thumb (southwest-closing hinge zones) and at Geeves Bluff and Federation Peak (northeast-closing hinge zones).

Lithofacies of the Arthur Ranges include quartzite (both thick and thin bedded), banded quartzite-pelite (interlayered quartzite, quartz schist and schist) and pelite (carbonaceous schist/phyllite). These lithologies dictate the geometry and character of the early recumbent isoclinal folding. Most of the structural profiles show 1) a thin-bedded, chevron folded quartzite in the macro-fold core (exposed on the eastern flanks of the range), and 2) more thick-bedded quartzites within the north-closing macro-fold hinge (exposed in the central to northern part of the range). Chevron folding is dominant in thinner-bedded quartzites whereas the transposition layering is more associated with the intercalated black carbonaceous siliceous pelite/phyllite.

In the Western Arthur Range cross-bedding was observed in quartzites above Alpha Moraine and on ridgeline south of Lake Cygnus. Both indicate right-way-up, bedding-parallel foliation (So/Sm) on the upper limb of the northeast-closing recumbent fold.

Shear sense indicators in the low-grade metamorphic sheet indicate recumbent macro-fold evolution and internal sheet deformation involves south-southwest-over-north-northeast transport, with shear displacement to the north (003° to 013°)in the Western Arthur Range and to the north-northeast (022° to 026°) in the Eastern Arthur Range. The Devonian fold and thrusting is also south-southwest-over-north-northeast, with transport towards ~025° in the Western Arthurs and towards ~035° in the Eastern Arthurs (assuming transport is approximately orthogonal to fault strike-traces).

Mega-sheath fold core of the southern Tyennan domain: The De Witt-Propsting and South West Cape Sheath-Fold Systems

David R Gray[1], Michael J Vicary[2]

[1] *Consultant to Mineral Resources Tasmania*
[2] *Mineral Resources Tasmania*

The Southern Tyennan Domain of southwest Tasmania is dominated structurally by two regional-scale sheath-folds that have 25km length scales (sheath 'y' dimension). They are the east-closing De Witt-Propsting mega-sheath fold and the west-closing South West Cape mega-sheath fold, that together form a complimentary isoclinal fold pair within quartzite and platy quartzite/quartzite respectively. The mega sheath folds are north-south trending and are bisected by a broadly west-south west trending mineral lineation Lm. The associated mesoscopic isoclinal folds have variable orientation and geometry but overall reflect position in the mega-sheath folds.

Two oblique sections through the De Witt-Propsting mega-sheath fold mega-fold result from tilting on the limbs of the younger Devonian anticline. The western, west-dipping anticline limb exposes the largest section as the De Witt-Propsting sheath profile. The eastern, east-dipping limb provides the Davey River profile as the nose or eastern termination of the mega-sheath fold. Unfolding or removing the effects of the younger enables reconstruction of the mega-sheath fold to give a projected sheath length ('x' dimension) of ~20km, a maximum width ('y' dimension) of ~29km, an apical angle of 50° and an interlimb angle of 10°.

The De Witt-Propsting mega-sheath fold has cats-eye-fold sheath geometry indicative of folding within a simple or general shear deformation. It consists of three shells, an outer 1.5km thick shell of alternating intensely banded So/Sm and platy to mylonitic quartzite with Sm dominant, a middle shell ~3.5km in thickness constituting a folded domain of asymmetric isoclinal fold pairs in compositional layering So/Sm, and an inner shell or core of ~1.7km thickness consisting of refolded isoclinal folds and multiple fabrics reflecting successive overprinting in progressive deformation. The inner shell projects across the younger anticline as the complexly deformed Davey River nose to the mega-sheath fold.

The South West Cape mega-sheath fold is en echelon with the De Witt-Propsting mega-sheath fold as part of a regional-scale oppositely closing fold-pair. It has a minimum length ('y' sheath dimension) of 25km and a half-width ('z' sheath dimension) of 8km. By closing out a possible oval or eye-shaped form of the inner shell it is likely that half of the mega-fold is offshore. Map geometry is typical of a regional-scale mushroom-style Type 2 fold interference pattern where F1 macro-isoclinal folds are coaxially refolded by upright, north-south trending isoclinal F2 macro-folds. These are the same geometrical relationships seen in the inner shell of the De-Witt-Propsting fold and the Davey River sheath nose. Component folds in the South West Cape mega-fold have inclined plunging to reclined geometry with west-plunge in contrast to the northeast plunge in the Davey sheath nose, a plunge-change related to the younger Devonian refolding.

Sheath-like Fold nappes and bounding high-strain zones in the Central Tyennan of Tasmania

David R Gray[1], Michael J Vicary[2]

[1] *Consultant to Mineral Resources Tasmania*
[2] *Mineral Resources Tasmania*

The large-scale structure of the Central Tyennan region is a laterally tapered, bulbous, macro-fold “wedge” elongated in the direction of the fold plunge. It is cored by high-grade schists and garnet quartzite of the Franklin-Joyce metamorphic sheet, in-folded and bounded by low-grade quartzites and phyllites of the Fincham-Mary metamorphic sheet. The gross geometry is that of a series of regional-scale, recumbent isoclinal folds (fold-nappes) bounded by high strain zones of platy quartzite, quartz-mica phyllite and phyllite. The structurally highest Franklin fold-nappe dominates the macro-fold “wedge” with a ~40km axial surface strike-length, a maximum ~7km thickness and a minimum down-plunge extent of ~20km. It has an extremely attenuated, flattened and elongated form towards the south and some apparent attenuation to the east. Much of the macro-fold geometry shows a reclined fold form (i.e. fold plunge in the dip direction of the axial surface). Scarce younging data suggests the western limb of Fincham Quartzite is overturned.

Three apparent fold-nappes involving high-grade Franklin-, Joyce and low-grade Fincham-Mary Metamorphic sheets sit on the underlying low-grade Scotchfire Metamorphics. The most continuous recumbent fold is the structurally highest south-facing and closing Franklin synformal fold-nappe to the west, underlain by a north-facing and closing antiformal closure of the Redan Hill recumbent fold, and then the south-facing and closing synformal Collingwood Plain recumbent fold to the east. The structurally lowest recumbent fold is segmented into a series of high-grade fold hinge-cores as pods bounded by intensely foliated, retrograde quartz-mica phyllite. These include the Collingwood Plain and Joyce Creek closures.

The Franklin fold-nappe shows an along strike transition from 1) an isoclinal fold stack in a thicker bedded quartzite-schist sequence (Raglan Range) to 2) a higher strain, hinge domain with conical, sheath-like hinges (closed loop outcrop patterns at Mt Madge and Mt Maud), to 3) attenuated tapering hinge form (Engineer Range and Mt McCall). The closed loop outcrop patterns and curvilinear fold hinges reflect bulbous hinge projections of downward penetrating, synformal closures in the high-grade Franklin-Joyce metamorphic sheet interpenetrating with upward projecting, antiformal hinges in the underlying low-grade Fincham-Mary metamorphic sheet.

Both the high-grade (Franklin-Joyce metamorphic sheet) and the low-grade (Fincham-Mary metamorphic sheet) sheets are internally isoclinally folded and show a consistent west-northwest to northwest mineral stretching lineation and marked rodding to mullion structure in fold hinges.

Restored shear sense indicators (shear bands) give calculated Central Tyennan transport directions of towards 110° (Mt McCall), 115° (Frenchmans Cap) and 136° (Collingwood Plains). In all cases data have been rotated to 1) remove the plunge of the younger Devonian folding, and 2) return the foliation Sm to the horizontal.

Southern Tyennan Domain. Overview, Synthesis and Implications.

David R Gray[1], Michael J Vicary[2]

[1] *Consultant to Mineral Resources Tasmania*
[2] *Mineral Resources Tasmania*

The Southern Tyennan Domain occupies the southwest part of the Proterozoic core of Tasmania. It has a complex structural architecture consisting of a stacked series of isoclinal macro-folds within a composite, layered metamorphic "sheet" made up of high-grade schist, low-grade phyllite, low-grade quartzite and platy quartzite. Contacts between the high-grade and low-grade units are high-strain, mylonitic zones (HSZ) that in many cases have brittle/cataclastic overprints from Devonian and younger deformations. Shear sense indicators suggest a complex movement picture with the overall emplacement shear sense towards the southwest (~250°).

Structurally the Southern Tyennan domain is dominated by two regional-scale isoclinal, mega-sheath folds that have ~25 km length widths (sheath 'y' dimension) and ~20km sheath lengths (sheath 'x' dimension). They are the structurally higher, east-closing De Witt-Propsting mega-sheath fold and the underlying west-closing South West Cape mega-sheath fold. Together they form a complementary isoclinal sheath-fold pair within quartzite and platy quartzite/quartzite respectively. In map view, the mega-sheath folds have approximately north-south-elongated elliptical sections, or sheath shell profiles, that are bisected by the broadly west-south west trending mineral lineation Lm. The sheath character of the De Witt-Propsting and South West Cape mega-sheath folds are defined by doubly plunging, closed-loop outcrop patterns. The apparent antiformal form of the De Witt-Propsting sheath core reflects an east-closing geometry, whereas the apparent synformal, downward facing form of the South West Cape sheath core reflects a west-closing geometry. Both mega-sheath folds show complex refolding and overprinting fabrics within their cores reflecting decoupling of the inner sheath shell(s) accompanied by shear-related translation relative to the outer sheath shells.

The overlying high-grade Nye Bay fold-nappe and the Mulcahy Bay-Port Davey isoclinal fold stack form an outboard carapace to the De Witt-Propsting structure. The high grade schist occurs within the core of the fold-nappe with the map pattern indicating attenuation of the schist to the north beyond the Lawson Range. The Nye Bay fold nappe is interpreted as a leading-edge, bending fold formed by roll-over of the sheet edge caused by tractional forces at the base of the overlying ophiolite sheet (toe-stub mechanism).

The eastern part, incorporating the asymmetric-fold domain and including the Arthur Range, represents the structurally lowest part of the structural architecture. It shows a reverse stacking of low-grade platy quartzite overlying quartzite overlying low-grade pelite and consists structurally of an S-vergent, asymmetric, isoclinal third-order macro-fold pair. It is interpreted as the lower limb of the Red Point macro-fold transitional into a regional scale shear zone that bounds the asymmetric isoclinal fold pair. In the far eastern part including the Solly River Valley and Crest Range, the asymmetric-fold domain structurally overlies, with a high strain transition, a low-grade pelite sequence. This low-grade sequence consists of dolomitic phyllite and dolomite of a Scotchfire-equivalent, para-autochthonous metamorphic sheet.

Structure of the southwest high-grade coastal belt, southern Tyennan domain, Tasmania

David R Gray[1], Michael J Vicary[2,] Andrew W McNeill[2]

[1] *Consultant to Mineral Resources Tasmania*
[2] *Mineral Resources Tasmania*

The southwest high-grade coastal belt of the Southern Tyennan domain appears to consist of a simple, overall west-dipping sequence of fault-bounded and structurally intercalated high grade albite and garnet bearing schists and gneiss, low-grade quartzite, phyllite and graphitic phyllite. The belt forms a structural carapace to the underlying quartzite dominated Propsting-De Witt mega-sheath fold.

In the northern part, the regional structure of the Southwest Coastal Belt is dominated by a major south-closing, west-plunging, reclined to recumbent macro isoclinal fold (Nye Bay fold-nappe) cored by high-grade schist and flanked by phyllite and low-grade quartzite. The upper, overturned western limb has a map width of ~7km and extends from Top Rocks to Nye Bay. The fold-nappe lower eastern limb from Mulcahy Bay southwards is transitional into a series of second-order, structurally lower, isoclinal macro-folds defined by alternating high-grade and low-grade layers. These have axial trace length of ~26km and extend from Mulcahy Bay to Port Davey.

In the southern part, from Alfhild Bay to Port Davey the map pattern is dominated by a classic "mushroom" fold interference pattern where early, northwest trending, reclined isoclinal macro-folds are refolded by younger, open Devonian northeast trending and southwest-plunging folds.

Due to the overall west-dip of the West Coast succession the northern and most western part at Top Rocks is structurally higher than the macro-fold sets at Port Davey. The fold-nappe in the north is therefore at the highest structural level. It has an overturned western limb, is south-closing, west-plunging and approaching reclined geometry, and has a high-grade schist core (hinge zone). All these relationships are identical to those of the Franklin Fold-nappe that dominates the structurally highest part of the Central Tyennan domain to the north. The Franklin fold-nappe has been mapped to Mt McCall, some 75km to the north, and now with potential continuation beneath the Cambro-Ordovician of the Elliot Range suggests that the highest levels of the Tyennan structural unit has an markedly asymmetric over-fold (fold-nappe) that extends the entire western margin of the Tyennan massif on the order of 200km.

The current macro-structure and regional structural geometry was established from form-lines in the dominant foliation Sm and So/Sm, the mapped distribution of lithologies, and early isocline (F1/F2) fold axis and lineation Lm attitude data. Changes from clockwise to counter-clockwise rotation of early isocline axes towards the mineral lineation Lm occur at Nye Bay, Mulcahy Bay, Brier Holme Head-Svenor Point, and Sandblow Bay. These define the axial surface trace positions of major folds and match the positions of the axial surface traces of the inferred macro-folds.

Contacts between the high-grade and low-grade units are high-strain, mylonitic zones (HSZ) that in many cases have brittle/cataclastic overprints from Devonian and younger deformations. This part of the Southern Tyennan consists of a high-grade metamorphic sheet overlying composite low-grade sheet of phyllite overlying quartzite. Shear sense indicators suggests complex movement picture with the overall emplacement shear sense towards the southwest (~250^{o}).

Between a Dome and a Duplex: a Palaeozoic Tectonic Model for the Ruby Gap Duplex and the Entia Dome in Central Australia

Youseph Ibrahim[1], Patrice Rey[1], Christian Teyssier[2], Donna L. Whitney[2]

[1]*University of Sydney, School of Geoscience*
[2]*Department of Earth and Environmental Sciences, University of Minnesota*

In the eastern central Australian intracontinental orogen, the Entia Dome, the Ruby Gap Duplex and the intervening north dipping Illogwa shear zone are interpreted as a compressional thrust stack formed during the Alice Spring Orogeny (ASO, 450-300 Ma)[1]. However, extensional deformation in the dome has been overlooked.

The Entia Dome is a high-grade gneiss dome structured into a double-dome with a median high-strain zone separating the sub-domes. The dome comprises a Paleoproterozoic igneous core underneath a Neoproterozoic cover sequence - the Harts Range Group, which has been deformed and metamorphosed in the amphibolite to granulite facies during the ASO. To the south, the Ruby Gap Duplex consists of greenschist-grade Neoproterozoic sedimentary rocks deformed into a south-verging fold-thrust belt during the late ASO[2]. The intervening Illogwa shear zone consists of sheared and retrogressed Paleoproterozoic gneiss. On the southern section of the shear zone, near Ruby Gap, Ar-Ar on muscovite reveals a cooling age of 327 Ma[3].

Structural analysis of the Entia dome suggests a syn-partial-melting double-dome structure and an exhumation history involving an extensional setting. Recumbent to sub-recumbent folding and horizontal boudinage in and around the sub-domes suggest a strong vertical shortening, post-dating upright folds and foliation. The architecture of the double dome with a median high strain zone can be reproduced by 2D and 3D coupled thermo-mechanical numerical modelling of continental extension in the context of a hot geotherm. Age-dating of syn-exhumation leucosome veins in metatexite from the Entia Dome points to ASO ages, including late ASO ages[4] coeval with Ar-Ar ages on the Ruby Gap Duplex, and the Illogwa shear zone.

Structural data shows a structural coherence from the dome to the duplex, with the Harding Springs slide acting as a south dipping normal detachment connecting to the north dipping Illogwa shear zone across a broad synform of Bruna gneiss. Existing late ASO geochronology data from the dome to the duplex supports a tectonic model documenting a genetic link between the Entia Dome and the Ruby Gap Duplex.

The juxtaposition of a mid-Carboniferous extensional domain to the north and a mid-Carboniferous contractional domain to the south suggests a possible geodynamic model in which the exhumation of the deep crust in the dome contributes to contractional deformation to the south. In this model, the south-dipping Harding Springs detachment on the southern margin of the Entia Dome is structurally linked to the north-dipping Illogwa shear zone on the north of the Ruby Gap duplex, which functions as the roof-thrust of the Ruby Gap Duplex.

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Metamorphic Belts in the New England Orogen: hallmarks of extension?

Kim Jessop[1], Nathan Daczko[1]

[1]*Macquarie University*

The New England Orogen (NEO), the youngest of the orogens of the Tasmanides of eastern Australia, is defined by two main cycles of compression–extension. Within these two cycles, six accepted and distinct tectonic phases are defined and reviewed. A compilation of zircon data and maps of each tectonic phase reveal the centres of magmatic activity, and the degree of diachronicity along the length of orogen.

Rocks representing a range of metamorphic facies have been identified and their relationships to the tectonic phases are discussed. They include high P/T blueschists and eclogites, mid P/T orogenic metamorphism and low P/T contact metamorphism and regional aureoles.

Two north–south-trending belts of high-temperature–low-pressure (HTLP) sub-regional metamorphism have been identified. Metamorphic complexes in the ~1300 km long Early-Permian Inland belt have ages ca 300–290 Ma, and those of the ~400 km long Mid-Permian Coastal belt ca 275–270 Ma. These periods correspond to the beginning and end of an extended (early–mid Permian) phase of subduction rollback and crustal thinning in eastern Australia. A significant number of characteristics are shared between the complexes including: their location at the higher-temperature end of broad areas of very low-grade to greenschist facies metamorphic rocks, indicative of tilted crustal blocks; their association with major shear zones; the presence of migmatite at the high-temperature end of a steep metamorphic field gradient; the presence of two-mica granite formed by the melting of the local sedimentary pile; and temporal association with S-type granites. A common extension-related mechanism of formation for these HTLP belts is implied. The connection with major faults and shear zones suggest the belts trace major crustal-scale extensional structures that migrated eastwards from ca 300 to 270 Ma.

ISOTOPIC ATLAS OF AUSTRALIA: An Update

Jones, S.L.[1], Cumming, G.V.[2], Waltenberg, K.[1], Everard, J.L.[2], Vicary, M.J.[2], Duncan, R.[4], Bodorkos, S.[1], Champion, D.C.[1], Huston, D.L.[1], Meffre, S.J.[3], Bottrill, R.S.[2], Waugh, S.[4], Fraser, G.L.[1]

[1]*Geoscience Australia*
[2]*Mineral Resources Tasmania*
[3]*University of Tasmania*
[4]*Geological Survey of Victoria*

An Isotopic Atlas of Australia (Fraser et al., 2020) provides a convenient visual overview of age and isotopic patterns reflecting geological processes that have led to the current configuration of the Australian continent, including progressive development of continental crust from the mantle.

This poster provides example maps produced from compiled data of multiple geochronology and isotopic tracer datasets from this Isotopic Atlas, now publicly available and downloadable via Geoscience Australia's (GA) Exploring for the Future (EFTF) Geochronology and Isotopes Data Portal and Mineral Resources Tasmania's Listmap. These datasets and maps unlock the collective value of several decades of geochronological and isotopic studies conducted across Australia.

Compiled geochronology, which commenced with coverage of northern Australia (Jones et al., 2018), is now much more comprehensive across Victoria (Waltenberg et al., 2021) and Tasmania (Jones et al., in press), with New South Wales and South Australia updates well underway. Available data include: Sm–Nd model ages of magmatic rocks; Lu–Hf isotopes from zircon and associated O-isotope data; Pb–Pb isotopes from ore-related minerals such as galena and pyrite; Rb–Sr isotopes from soils; U–Pb ages of magmatic, metamorphic and sedimentary rocks; and K–Ar, Ar–Ar, Re–Os, Rb–Sr and fission-track ages from minerals and whole rocks.

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Constraining the Cambrian to Early Ordovician tectonic history of the Lachlan Orogen.

Sebastien Meffre, Umer Habib and Ron Berry

Centre for Ore Deposit and Earth Sciences, The University of Tasmania, Hobart, Australia

The orogenic events that formed the continental crust of southeastern Australian during the Cambrian and Ordovician are poorly constrained. A lack of understanding of these events hinders our knowledge of the crustal architecture of this area, which then impacts our ability to model other aspects of the geology, including the metallogenesis. New zircon isotopic data from PhD students working on an ARC-funded Linkage project placed some constraints on the tectonic evolution of the area. These are summarised as follows:

- Zircon Hf isotopes show that Tasmanian and Victorian ophiolitic rocks are derived from a juvenile mantle source, confirming an intra-oceanic magmatic arc origin.
- Zircon Hf isotopes show that the Mt Read Volcanics are sourced from melting Proterozoic sedimentary rocks, confirming an intra-continental rift setting for this magmatism and excluding a magmatic arc origin.
- Detrital zircon geochronology and geochemical data from western Tasmanian Late Cambrian to Early Ordovician sedimentary rocks confirm that the Tasmanian micro-continent began interacting with Gondwana-derived sediments during this time.
- Detrital zircon geochronology, geochemical data and Hf isotopes show that the sediments deposited immediately above the ophiolitic rocks at Waratah Bay have mixed provenance, which can be interpreted as being derived mostly from Gondwana sources, with a small component from the Mesoproterozoic quartz-rich sedimentary rocks of Tasmania and another from the Early Ordovician volcanic rocks of the Macquarie Arc.
- Magmatic and inherited zircons from the western belts of the Macquarie Arc in NSW show that Late Cambrian diorites with juvenile Hf signatures underlie the earliest rocks in the Macquarie Arc.

These findings support a continent-arc collision tectonic setting for the Cambrian rocks in Tasmania, a passive margin-arc collision setting for the late Cambrian-Early Ordovician rocks in central Victoria and an arc-reversal setting for the Early Ordovician rocks in NSW.

A new reconstruction for Permian East Gondwana driven by the discovery of Early Permian Ophiolite blocks in the Great Serpentinite Belt

L.A. Milan[1], E.A. Belousova[2], R.A. Glen[2], T. Chapman[1], J. Kalmbach[1], B. Fu[3], and P.M. Ashley[1]

[1]*Division of Earth Sciences, School of Environmental and Rural Science, University of New England, Armidale, New South Wales 2351, Australia*
[2]*CCFS/GEMOC ARC National Key Centre, Department of Earth and Environmental Sciences, Macquarie University, NSW 2109, Australia*
[3]*Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia*

The Australian sector of the eastern Gondwana margin was the site of Cambrian to Cretaceous convergent margin orogens that now comprise the Tasmanides. In Eastern Australia the New England Orogen (NEO) is the easternmost of these orogens. Outcropping in the southernmost portion of the NEO is a ~1500 km belt of dismembered ophiolite, known as the Great Serpentinite Belt (GSB). For much of its length, the GSB consists of schistose serpentinite that hosts uncommon meter scale tectonic inclusions of ophiolitic affinity. The age of the GSB was generally considered to be Cambrian (Aitchison et al., 1992). This is despite contrasting Cambrian to Devonian ages and the complex P-T histories of small (typically <50 m^2) exotic meta-igneous inclusions embedded in schistose serpentinite (Aitchison & Ireland, 1995; Manton et al., 2017; Phillips et al., 2015; Tamblyn et al., 2019). To circumvent the contrasting reported ages from these small inclusions of the GSB, we have instead focused on a coherent block of dismembered ophiolite that provides robust geological context to sampling. Zircon U-Pb-Hf-O isotope and trace analyses from three plagiogranite dykes cutting massive gabbro confirm ~283–277 Ma ages and a mantle source (Milan et al. 2021). By establishing an Early Permian age for the large blocks of coherent ophiolite we argue the older inclusions were Cambrian to Devonian plagiogranites and subducted meta igneous blocks inherited from previous subduction events in eastern Australia. This discovery allows us to match the Great Serpentinite Belt with the contemporary Dun Mountain ophiolite (New Zealand) and the Koh ophiolite (New Caledonia), thus supporting a new, integrated Pacific Gondwana margin paleogeography involving multiple arcs and subduction zones.

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Influence of Deep Structures on Orientations of Shallow Features: A Central Victorian Perspective

David H Moore[1], Anindita Samsu[1], Alexander R Cruden[1]

[1]*Monash University*

The Lachlan Orogen is dominated by fabrics that strike more or less north-south. These structural elements include the orientation of bedding and cleavages in Ordovician to Devonian metasedimentary rocks and the trends of elongate granitic intrusions. However, some granites of the Middle to Late Devonian Central Victorian Magmatic Province in the Melbourne Zone and adjacent areas are exceptions to this trend. These plutons have long axes that strike approximately 080°, although others of similar ages conform to the north-south orientation. We argue that subtle strain patterns mapped in the Melbourne Zone and seen in isostatic gravity anomaly data can be used to determine the wider strain field in the region at the time of granite intrusion.

The Mesoproterozoic to Neoproterozoic Selwyn Block underlies the Melbourne Zone and adjacent areas. Previous analogue experiments of extension have indicated that this block may have locally reoriented the strain in the overlying Melbourne Zone rocks during Cretaceous rifting along the Australian southern margin. Similarly, we infer that Selwyn Block fabrics may have also influenced upper crustal deformation and magma emplacement during and after the Tabberabberan Orogeny. This changed the preferred extension and dilation directions that facilitated granite pluton emplacement, so that 080° long axis orientations were sometimes favoured, in contrast to the dominant north-south orientations seen outside of the Melbourne Zone. We also note that the retention of remnants of the post-orogenic collapse sedimentary and volcanic rocks of the Howitt Province may also have been controlled by the localised strain reorientation along the eastern boundary of the underlying Selwyn Block.

A xenocrystic zircon perspective on the composition of the Selwyn Block: Testing the Tasmanian connection

Jacob A. Mulder[1,2], Jacqueline A. Halpin[3], Oliver Nebel[2]

[1] School of Earth and Environmental Sciences, University of Queensland
[2] School of Earth, Atmosphere and Environment, Monash University
[3] Institute for Marine and Antarctic Studies, University of Tasmania

The Tasmanides comprises a series of Paleozoic accretionary orogens that built the eastern third of the Australian continent. In comparison to many other accretionary orogens, the Tasmanides are notable in their scarcity of accreted continental terranes, with most of the orogenic system inferred to be underlain by late Neoproterozoic—Cambrian crust of oceanic or island arc affinity.

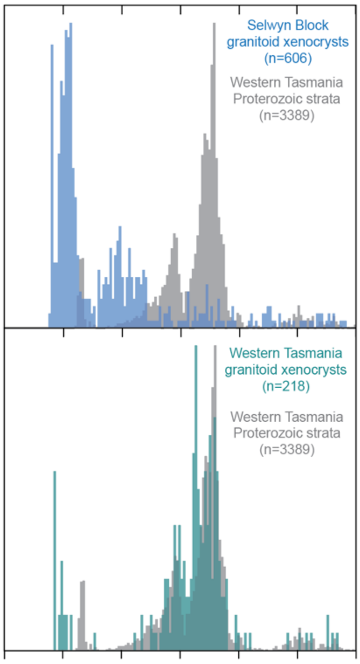


Fig. 1 | Xenocrystic zircon ages from Devonian granitoids in the Selwyn Block and WTT

A possible exception is the Selwyn Block— an almost completely concealed crustal terrane beneath central Victoria. Tracing of magnetic lineaments across Bass Strait has led to the suggestion that the Selwyn Block represents the continuation of the Proterozoic Western Tasmania Terrane (WTT). However, the only directly dated exposures of the Selwyn Block are (meta)mafic and intermediate rocks of Cambrian age.

Here, we test the link between Selwyn Block and the WTT by comparing xenocrystic zircon ages from widespread Devonian granitoids that intrude both terranes. Interpretations of regional seismic sections across the Selwyn Block suggest strongly layered units at depths of 10—25 km represent the buried Proterozoic crust of the WTT[1]. Petrogenetic modelling of typical Mesoproterozoic pelites that make up most of the exposed geology of the WTT demonstrate that these lithologies are both melt-fertile and would have been above the solidus at depths of 10—25 km during the Devonian due to the elevated regional geothermal gradient. Therefore, any Proterozoic crust of the WTT present in the Selwyn Block would have been primed to melt and contribute to the Devonian granitoids of central Victoria.

The majority of the ~600 xenocrystic zircons recovered from 14 Devonian plutons in central Victoria define age peaks at 800—1200 Ma and 400—600 Ma (Fig. 1). In comparison, xenocrystic zircons from 9 Devonian plutons in western Tasmania define age peaks 1450 Ma and 1600—1800 Ma, mirroring the distinct detrital zircon age distribution of the Mesoproterozoic strata they intrude (Fig. 1). Therefore, our new xenocrystic zircon ages provide no clear evidence that Devonian granitoids intruding the Selwyn Block sampled Proterozoic continental crust comparable to the WTT. Rather than a block of continental crust, we speculate that the majority of Selwyn Block comprises Cambrian mafic and intermediate rocks, comparable to those exposed at the surface, and may represent the buried remnants of an intraoceanic that collided with the WTT during the Cambrian Tyennan Orogeny.

[1] Moore et al., (2016), Tectonophysics, v. 687, p. 158-179.

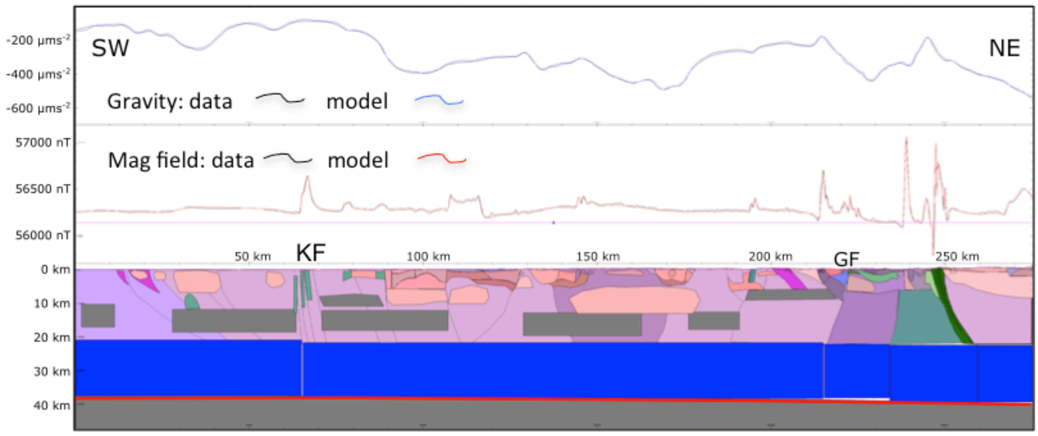
Potential-field modelling of a crustal section across the Central Lachlan Orogen

Robert J Musgrave[1,2], Phil Gilmore[3]

[1] *PALM Laboratory, School of Environmental and Life Sciences, University of Newcastle*
[2] *School of Geosciences, University of Sydney*
[3] *GEMS Geoscience, Exploration and Mineral Systems*

The East Riverina area of the Central Lachlan Orogen comprises the NSW portion of the Wagga - Omeo Zone, dominated by Ordovician metaturbidites and Silurian to Early Devonian S- and I-type granites. East of the Gilmore Fault Zone lie elements of the Eastern Lachlan Orogen including the Ordovician to Silurian Macquarie Arc and the Silurian Tumut Trough; west of the Kancoona-Bootheragandra Fault Zone are the Tabberabbera and Hay-Booligal zones. Detailed geological mapping conducted by the Geological Survey of NSW over the East Riverina area provided the geological constraints for a new joint inversion of aeromagnetic and gravity data by iterative forward modelling. The reference model for the inversion was a ~250-km-long cross-section normal to the NW-SE structural grain and extending to a depth of 10 km. Several features in the magnetic and gravity anomalies over the length of the section have wavelengths in the range of 10 to 50 km, requiring the geophysical model to extend to the upper mantle. Geophysical modelling involved multiple phases of iterative refinement and interaction between the geophysicist and geologist. The resulting profile, incorporating the entire crust and extending west to the Tabberabbera Zone and east to the Tumut Trough, not only builds a cross-section which honours both geological mapping and geophysical data, but also suggests significant tectonic and magmatic elements which could not be detected by surface mapping. These include: the extent of granite under younger cover in the Wagga Zone (much larger than inferred from outcrop); the inferred presence of substantial mafic intrusive systems in the middle crust (likely to have provided at least part of the heat required to generate shallow crustal S-type granites); and likely links between these mid-crustal intrusions and a suite of strongly magnetic, poorly-outcropping features that have been interpreted as mafic intrusions, which intrude major shear zones in the area. In common with an equivalent whole-crust model further north in the Forbes-Bathurst region (Musgrave, 2021), this inversion supports a distinct contrast between a highly magnetic lower crust below the Wagga-Omeo Zone and an order-of-magnitude less magnetic lower crust below the Eastern Lachlan Orogen.

Musgrave, R.J., 2021. Structure of an accreted intra-oceanic arc: potential-field model of a crustal cross-section through the Macquarie Arc, Lachlan Orogen, southeastern Australia. Australian Journal of Earth Sciences, doi: 10.1080/08120099.2021.1939158.



Deformation and ore fluid migration in the Mary Kathleen Shear zone and ore deposit

Alanis Olesch-Byrne[1,2], Melanie A Finch[1,2], Andrew G Tomkins[2], Peter Betts[2] & Ioan Sainislav[1]

[1]Department of Earth and Environmental science, James Cook University, Townsville, QLD
[2]School of Earth, Atmosphere and Environment, Monash University, Clayton, VIC.

The global demand for Rare Earth Elements (REE) is increasing, and Australia is likely to become a key supplier in the future. However, new deposits have not been discovered for decades, and it is thought this is because the geology of existing REE deposits is not well understood. Hydrothermal REE ore deposits can form when REE are scavenged from source rocks by fluids, mobilised along shear zones and faults, and precipitated at structurally and chemically favourable sites. REE have low solubility in typical hydrous fluids, but solubility increases when the fluid is enriched in ligands including alkalis, chlorine, fluorine, hydroxide, or carbonate. Fluid migration and ore deposition are usually structurally controlled, as seen at the Mary Kathleen U-REE ore deposit in Mount Isa, which formed in a hydrothermal breccia adjacent to Mary Kathleen ductile shear zone. The shear zone is thought to have transported ore fluids, but links between the ore deposit and the shear zone have never been demonstrated. If the shear zone was the conduit for ore-forming fluids, it may also have been the source of REE, since fluid migration through ductile shear zones is a relatively slow process where chemical reactions between fluid and rock are unavoidable. Interestingly, the high strain zone in the Mary Kathleen shear zone consists of a 40 m thick marble mylonite, which is >90% calcite: a major REE host mineral. Adjacent to the high strain zone are mica-schists and quartzofeldspathic rocks that are similarly strongly deformed and folded, but strain localized preferentially to the marble layers. During fieldwork, we determined the Mary Kathleen shear zone contains higher and lower strain regions and preliminary trace element analysis indicates that high strain regions contain more REE than low strain regions suggesting a relationship between deformation and migration of a REE-bearing fluid. This presentation will outline our results to date and discuss the role of ductile shear zones in hydrothermal ore deposits.

Keywords: Rare Earth Elements (REE) · Shear Zone · Ductile Deformation · Hydrothermal · Ore deposit

Bending and segmentation of magmatic arcs

Gideon Rosenbaum[1], John T. Caulfield[2], Teresa Ubide[1], Jack F. Ward[1], Dan Sandiford[3], Mike Sandiford[4]

[1]*School of Earth and Environmental Sciences, The University of Queensland, Brisbane, Queensland*
[2]*Central Analytical Research Facility, Queensland University of Technology, Brisbane, Queensland*
[3]*School of Earth Atmosphere and Environment, Monash University, Clayton, Victoria*
[3]*School of Geography, Earth and Atmospheric Sciences, The University of Melbourne, Melbourne, Victoria*

Many modern and ancient arc systems are segmented along strike, showing bends, kinks, and gaps that separate two coeval arc segments. Such patterns in magmatic arcs may reflect structural heterogeneities in the overriding plate and subducting slab, and/or processes that affected the magmatic arc after its formation (e.g., oroclinal bending). Importantly, along-strike disruption in magmatic arcs commonly coincides with clusters of ore deposits, suggesting that processes responsible for arc segmentation may play a crucial role in the origin of large mineral deposits. To better understand the mechanisms that control arc segmentation and bending, we investigated spatio-geochemical patterns in the Andean volcanic arc and possible links to the three-dimensional structure of subducting Nazca plate. We used a series of geochemical indices to determine whether spatial variations in Holocene volcanoes along the Andes are also geochemically anomalous. These indices, which provide insights into the depth and degree of melting and the role of metasomatic subduction inputs in melt generation, allow us to identify ‘anomalous’ arc magmatism. Typical arc magmatism is defined as melts generated in the sub-arc mantle wedge through slab-derived fluid metasomatism, with or without contributions from subducted sediments. In contrast, we show that anomalous volcanism in South America appears to relate to geometric anomalies in the subducting Nazca plate (e.g., beneath Sumaco, Laguna Blanca and Payun Matru), or to areas affected by variations in mantle flow due to proximity to the slab edge (Crater Basalt Volcanic Field). By establishing relationships between anomalous magmatism and slab structure, we propose that similar geochemical fingerprints could be used to explore the magmatic response to slab deformation and/or tearing in older arc systems, particularly in cases where the three-dimensional slab structure is no longer detectable.

Wide or narrow rifting in Proterozoic northeastern Australia – ¿Porque no los dos?

Anindita Samsu[1], Peter G Betts[1], Fatemeh Amirpoorsaeed[1], Alexander R Cruden[1]

[1]*School of Earth, Atmosphere and Environment, Monash University*

Wide and narrow rifts are two end-member models of continental lithospheric stretching. Proterozoic back-arc extension in the present-day North Australian Craton is related to plate margin processes to the south and east of the proto-Australian continent. This extension is linked to the formation of multiple intracratonic basins, spread over >1000 km, comparable to wide rifts. However, some areas appear to have localised greater extensional strain and sedimentation than others, similar to basins in narrow rift settings. Here we present the results of a series of analogue experiments of extension followed by shortening, which show that both wide and narrow modes of rifting apply to the North Australian Craton and impact subsequent basin inversion.

Our experiments simulate wide rifting by extending a multi-layer, brittle-ductile model lithosphere that is analogous to a hot, thickened lithosphere immediately following orogenesis. We demonstrate that a narrow pre-existing weakness in the lithospheric mantle causes strain to localise mainly above the weakness. This results in the formation of several major basins above the lithospheric weakness and minor basins across the rest of the model. Extension is immediately followed by shortening of the model, where we observe that inversion structures are localised along pre-existing basins. Shortening is accommodated by several mechanisms including reverse reactivation of normal faults and buckling and/or inversion within pre-existing basins, consistent with field observations and geophysics. Our results show that pre-existing, rift-related structures can remain active during subsequent deformation, exerting first-order control on the formation and preservation of fluid transport pathways across different levels of the crust.

The 1800-1700 Ma tectonism in Mt Isa Inlier - implication for the tectonic evolution of the North Australian Craton and supercontinent reconstructions

Ioan Sanislav[1], Joshua Spence[1], Paul Dirks[1],Truong Le[1], Helen McCoy West[1]

[1]*James Cook University*

The Mount Isa Inlier is considered to have formed the eastern margin of the North Australia Craton prior to amalgamation to Laurentia and assembly of the Nuna supercontinent. The timing and nature of the collision between the North Australia Craton and Laurentia remain poorly constrained and attributed either to the ~1850 Ma Barramundi Orogeny or to the ~1600 Ma Isan orogeny. The intervening period, ~1800 Ma to ~1600 Ma is in general attributed to a protracted history of successive extensional events that resulted in a series of three stacked sedimentary basins commonly referred to as Superbasins.

Recent field mapping combined with geochronology, structural interpretations and metamorphic PT conditions indicate that between 1800 Ma and 1700 Ma the Mount Isa Inlier experienced two periods of synchronous folding, metamorphism and plutonism. The first period occurred between ~1800 Ma and 1770 Ma and is best recorded south of the Plum Mountain Fault in the Tick Hill area but evidence of this event can be found as far north as Kajabbi. This event is marked by the syn to late tectonic intrusion of the Saint Mungo, Tick Hill, Monument Syenite, Bowler Hole and Marindi Creek plutons. The maximum PT conditions recorded during this event are recorded by garnet amphibolites from the Tick Hill area at ~7 kbars and 700°C. The second period occurred between ~1750 Ma and 1710 Ma and is best represented within the Mary Kathleen Domain although sequences further west such as the Eastern Creek Volcanics have also been deformed during this period. This event is constrained by the intrusion of the pre- to syn– to post tectonic Wonga and Burstall plutons between ~1740 Ma and ~1710 Ma. The maximum PT conditions recorded during this event are recorded by kyanite and sillimanite bearing schists indicating ~5 kbars and up to 650°C. Both of these periods of tectonism have correlatives not only in the North Australia Craton but also in other similar age Proterozoic terranes from Australia and from Laurentia suggesting that they are part of a series of global tectonic events and have to be taken into account when performing tectonic reconstructions. Moreover, it suggests that most likely the amalgamation of the North Australia Craton to Laurentia did not occur during a single discrete tectonic event but rather as a series of tectonic events spread over a prolonged period of time.

Bye-bye Benambran? Reappraising the evidence for early Silurian deformation in Tasmania/lutruwita

Robert J Scott[1], Michael J Roach[1], Zachary Corbett[1], Issi Port[1], Austin Reeve[1], Daniel B Fisher[1], Kyry Keo[1], James Waldron[1]

[1]*Discipline of Earth Sciences, University of Tasmania, Hobart*

Structural analysis of the Stony Head Sandstone (SHS) at Beechford overturns decades old misconceptions about the structure and deformation history of the lower Mathinna Supergroup (MSG) in NE lutruwita. Exposures of the SHS and overlying Turquoise Bluff Slate (TBS), which together comprise the Early – Middle Ordovician lower MSG, have long been interpreted to occupy the hinge, lower limb and, locally, the overturned upper limb, of a kilometre-scale, east-facing, recumbent F_1 syncline [1]. Powell and Baillie [1] argue the recumbent domain was formed by back-rotation of originally steeply inclined, NE-verging F_1 folds, during later displacement across a NE-dipping D_2 thrust ramp. Both phases of deformation were attributed to the mid-Devonian Tabberabberan Orogeny. In contrast, Reed [2] interprets recumbent folds as Benambran (Early Silurian) structures, which predate the latest Early Silurian (?) to Early Devonian upper MSG. If the latter is correct, lower MSG strata (exposed over <300 km^2) are both (i) the only rocks in lutruwita deformed by the Benambran Orogeny, and (ii) the only MSG strata in which folds related to the main phase of Tabberabberan deformation have not been (definitively) recognised (cf. [2]; [3]).

Our new work shows that the original style, scale, geometry, orientation, and character of F_1 folds in the SHS is almost identical to steeply inclined, NE-verging, Devonian F_1 folds in the Silurian Retreat Formation (upper MSG) at Bellingham, 20 km to the east, with which they are here correlated. Originally recumbent folds in the SHS are D_2 structures with amplitudes and wavelengths of metres to tens of metres, compared to hundreds of metres for the larger F_1 folds in NE lutruwita. F_1 and F_2 folds at Beechford are overprinted by small-scale, typically kink-like, upright to steeply inclined, NW-trending F_3 (Devonian F_2 of most previous workers) and NE-trending F_4 folds. However, scale and deformation intensity differences between F_1 and the later folding events mean the original geometry of the larger F_1 folds at Beechford is substantially preserved. The 0.01- to 1 mm-spaced, disjunctive S_1 cleavage is the strongest, most pervasive fabric in the SHS. In contrast, S_2 is largely restricted to mudstone interbeds, in which it is locally the most obvious fabric (in outcrop). In the mostly <1 m thick mudstones of the SHS, S_2 is a gently dipping, 0.05- to 1 mm-spaced, crenulation cleavage. However, in the more intensely deformed, mudstone-dominated TBS, S_2 (or a composite S_1/S_2 fabric) is likely the continuous fabric described by earlier workers. Previously noted differences in the number and intensity of cleavages developed in the lower and upper MSG likely reflect lateral and vertical strain gradients (for multiple deformation events), and the strong influence of lithology on cleavage morphology and orientation. We necessarily reject two published pre-Devonian ages for cleavage in the lower MSG ([4]; [5]), noting neither coincides with recognised depositional hiatuses in the MSG nor the Benambran Orogeny in mainland Australia. We conclude all folding in the MSG is Devonian or younger, and that there is no evidence for the Benambran Orogeny in lutruwita.

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Detrital garnet Lu-Hf geochronology: a novel tool to probe into Antarctic geological history from Australian shorelines

Sharmaine Verhaert[1], Stijn Glorie[1], Martin Hand[1], Jacqueline A Halpin[2,3], Anthony R Milnes[1]

[1]Department of Earth Sciences, School of Physical Sciences, The University of Adelaide, Adelaide, SA 5005, Australia
[2]*Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, TAS 7001, Australia*
[3]*The Australian Centre for Excellence in Antarctic Science, University of Tasmania, Hobart, TAS 7001, Australia*

East Antarctica remains one of the least understood geological regions on Earth, due to its extensive ice sheet cover and remote location. The East Antarctic Craton recorded the assembly and breakup of previous supercontinent configurations and contains important information on their tectonic evolution. However, bedrock outcrops are scarce and mostly limited to coastal areas along Antarctica's continental margin. As an alternative, detrital studies on eroded outflow sediments and glacial deposits could aid in understanding the tectono-metamorphic history of East Antarctica.

The Fleurieu and Yorke Peninsula coasts (South Australia) host a number of garnet-bearing heavy mineral placer sands which were winnowed from glacial sediments in the Permian Troubridge Basin and concentrated by wave action. The source of the garnets is enigmatic, but it's been hypothesized that they might have an Antarctic origin and were transported by Permian glaciers, together with a variety of rock clasts (erratics), to what is now the South Australian margin of the formerly contiguous Australian-Antarctic system within the Nuna-Rodinia-Gondwana supercontinent configuration. We test this hypothesis by constraining the age of the garnets using a novel analytical method. Traditional Sm-Nd or Lu-Hf dating methods are unrealistic for dating detrital garnets, given the laborious and time-consuming sample preparation requirements that would need to be applied to individual grains. We have developed laser-based in-situ garnet Lu-Hf geochronology (Simpson et al., 2021) which allows several hundreds of garnets to be dated in a single day. Applied to the placer garnets, our Lu-Hf age results reveal a dominant ~630-590 Ma and minor ~1700 Ma provenance that cannot be linked to local Australian continent tectonic events. Instead, the garnets are considered to have been derived from East Antarctica, where Grenvillian- and Pan-African-aged metamorphic events have been extensively described and similar ages have been recorded (e.g. Hagen-Peter et al., 2016; Jacobs et al., 2003; Lamarque et al., 2018). Hence, our novel analytical capability provides the opportunity to probe into East Antarctic tectonic history from Australian shorelines to reveal key information from study areas that are presently entirely ice-covered or were entirely eroded away during the last 250 million years of Earth history.

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Slab segmentation generates anomalous volcanism and giant porphyry ore deposits in Indonesia

Jack F. Ward[1], Gideon Rosenbaum[1], Teresa Ubide[1], Mike Sandiford[2], Dan Sandiford[3]

[1]School of Earth and Environmental Sciences, The University of Queensland, Brisbane, Queensland 4072, Australia
[2]School of Earth Sciences, University of Melbourne, Carlton, Victoria 3053, Australia
[3]School of Earth, Atmosphere and Environment, Monash University, Melbourne, VIC 3800, Australia

Subduction-driven mantle wedge metasomatism generates magmatic rocks that are typically calc-alkaline in composition and positioned above subducted slabs that are 90–150 km deep. Some Holocene arc volcanoes in Indonesia, however, are alkaline in composition and/or positioned above sections of slab that are much deeper than 150 km. Here, we statistically evaluate a variety of geophysical and geochemical datasets to shed light on the geodynamic processes responsible for the formation of these anomalous volcanoes. Seismic tomography data and slab models show that there is a spatial association between anomalous volcanoes and discontinuities in slab geometry, which we interpret to represent slab tears. The compositions of mafic rocks from the anomalous volcanoes are consistent with deep (i.e., in the garnet stability field), low degree partial melting of previously metasomatized mantle mostly unaffected by contributions from the subducted slab. The distribution of Pliocene–Holocene porphyry deposits is also correlated with slab discontinuities, and the geochemical compositions of these deposits show asthenospheric affinities. Based on the geophysical and geochemical data, we ascribe the origin of the anomalous volcanoes and porphyry ore deposits to asthenospheric melting driven by convective flow at slab edges. Our results are potentially applicable to other volcanic arcs and could facilitate the identification of anomalous magmatism and areas of elevated metal fertility.