Convergence

On the Coast

SGTSG and SGSEG 2019 abstracts

Biennial meeting of the Specialist Group for Tectonics and Structural Geology and the Specialist Group in Solid Earth Geophysics
18–22 November 2019, Port Lincoln, South Australia

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Compiled by Stijn Glorie, Tom Wise and Rian Dutch

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Rian Dutch, compiler

FOREWORD

Welcome to Convergence on the Coast, the 2019 biennial meeting of the Geological Society of Australia's SGTSG and SGSEG, running from the 18th to the 22nd of November 2019 in the stunning seaside town of Port Lincoln, South Australia.

This year the Specialist Group in Tectonics and Structural Geology has joined forces with the Specialist Group in Solid Earth Geophysics to bring you 'Convergence on the Coast'. Our aim is to bring together the research community in structural geology, tectonics and solid earth geophysics within Australia and internationally to discuss the latest research and developments in these fields. The primary focus of this technical conference is to enable collaboration and exchange of ideas between the geoscience research, government and industry communities.

The conference this year is built around eight interdisciplinary themes, headlined by an invited keynote speaker. The themes reflect a broad range of geoscience topics across the structure, tectonics, geodynamics, geophysics, mineral systems and modelling disciplines. The themes include:

- Observational geophysics
- Geodynamics and thermodynamics
- Domes, basins and dynamic topography
- The Australia-Antarctic connection
- Experimental studies of rocks and structure
- Tectonic controls on mineral systems
- Multi-scale structures and fluid-rock interaction
- Plate margin and intra-plate orogenesis.

The Convergence committee would like to thank our Diamond Sponsor Geoscience Australia and our Gold Sponsor Equinor for their support of the conference. The committee would also like to acknowledge the support of the South Australian Department for Energy and Mining.

We sincerely hope you enjoy your time in Port Lincoln and the conference.

Rian Dutch, Chair – SGTSG and Stephan Thiel, Chair – SGSEG
On behalf of the SGTSG and SGSEG organising committees.

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KEYNOTE SPEAKERS

IOCG and affiliated deposits in tectonically active regions: Impact on deposit types and structural attributes of ore systems

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Ore systems with polymetallic iron oxide copper-gold (IOCG), iron oxide-apatite (IOA), albitite-hosted uranium and affiliated deposits, including those of Canada and Australia, are characterized by a regular sequence of iron oxide and alkali-calcic alteration (IOAA) facies and breccia that defines the prograde metasomatic path of the systems. At the root of and across these systems, sodic metasomatism (facies 1) is regionally developed along tectonic and stratigraphic discontinuities, including fault zones, in the apical parts of and along intrusions, and in favourably reactive units. In areas of intense fluid circulation, the Na facies forms corridors of albitite that can extend several kilometres in strike. The preferential siting of albitite in discontinuities along which deformation tends to be partitioned, the residual porosity left in albitite by dissolution-reprecipitation, and their isotropic nature favour the formation of extensive breccia zones, fracture and fault networks, and damage zones. The enhanced permeability facilitates subsequent fluid flow and can serve as ground preparation for ore deposition. Facies 1 Na transitions into skarn (clinopyroxene/garnet), Na-Ca (albite-scapolite) and high-temperature Na-Ca-Fe (albite, amphibole, magnetite) alteration (facies 1-2) to zones of high-temperature Ca-Fe (amphibole, magnetite, apatite) alteration (facies 2). In carbonate-rich units, skarn forms early, and is replaced by the high-temperature Ca-Fe facies, hence the need to distinguish these two facies systematically. Facies 1 and 2 are the earliest and commonly deepest facies. They demarcate areas of interest at the regional scale and form the immediate host of iron oxide-apatite (IOA) deposits and some magnetite skarn bodies. Systems that evolve to high temperature K-Fe (magnetite-K-feldspar/biotite) alteration (facies 3), to K-skarn (clinopyroxene, garnet and K-feldspar) and K-felsite breccia (K-feldspar) (facies 4), and lower temperature K-Fe and Ca-Fe-Mg (sericite, K-feldspar, hematite, chlorite, carbonate) alteration (facies 5) can form polymetallic IOCG deposits that can include critical metal and uranium ores. IOA deposits hosted within systems that evolved to these latter facies commonly host REE that can be remobilized into REE ore-shoots during renewed magmatic or orogenic activity. Increasing intensity of facies 3, 4 and 5 is intimately associated with brecciation even outside of discrete fault zones. This contrasts with the systematic and structurally controlled brecciation of albitite that postdates sodic alteration. Copper sulphide precipitation is so systematic during facies 3 and 5 alteration that a genetic link is empirically clear even though sulphides precipitate in veins and as breccia infill. Low-temperature K±Al, Si, Ba or Fe assemblages (facies 6) form vein systems within, or epithermal lithocaps above, earlier facies and can lead to five-element vein and epithermal deposits. Synmetasomatic intrusive, tectonic and/or volcanic activity favours fluid mixing, cyclical build-up and telescoping of alteration facies. The tectonic or thermal telescoping of albitite within the field of facies 3 and 5 can lead to albitite-hosted U and Au-Co±U deposits. The prograde, retrograde, repeated or telescoped sequence of metasomatic reactions serve to map the metal pathways to ore and control metal precipitation, metal associations and the types of deposits formed in IOAA systems. The albitite corridors provide first order information on the geometry of the structures and discontinuities that formed the main fluid pathways, while the presence of facies 3 through 5 provides insights for defining and ranking their mineral favourability. Brittle to brittle-ductile deformation prevails across IOAA systems, which is a typical trait of many hydrothermal systems. However, ductile fabrics also form during the high temperature Ca-Fe alteration; their relationship should be carefully investigated and ductile fabrics not mistaken as evidence for orogenic overprints. The resulting paragenetic ore deposit model provides effective, predictive and globally applicable mapping and exploration tools for, and vectors to, IOCG and affiliated mineralization. In turn, the presence or absence of certain alteration facies at regional scale helps prognosticate the zonation of the system and possible fault zones that can offset certain components to a different crustal level.

Quantifying volumetric fluid flow rates in fault-controlled hydrothermal systems: insights from contemporary and exhumed seismogenic hydrothermal systems

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Injection-driven swarm (IDS) seismicity is the characteristic response to injection of large volumes of overpressured fluids into fault zones within low permeability host rocks. Such swarm sequences typically have durations of days to several months and involve up to thousands of predominantly microseismic slip events with moment magnitudes M_w in the range $-2 < M_w < 2.5$. These events correspond to rupture diameters between approximately 1 m and 200 m, and slips between 0.05 mm and several mm. In contrast to mainshock-aftershock sequences, IDS sequences do not have a large rupture near the start of the sequence and do not exhibit Omori Law decay of seismicity rate with time. However, they do exhibit Gutenberg-Richter frequency-magnitude relationships with b-values ranging between 0.85 and 3.5. The largest IDS ruptures typically have $M_w < 4.5$, corresponding to a rupture diameter of 1000 m and a slip of several cm. Both natural and engineered IDS sequences characteristically exhibit diffusion-like migration of a seismicity front with time as the fluid pressure front migrates away from the injection source. Contemporary IDS sequences have recurrence intervals of years to many decades.

Deep fluid injection experiments in low permeability rocks demonstrate that seismicity rates correlate with injection pressure and flow rate. Additionally, injected fluid volumes ΔV and cumulative seismic moment release ΣM_0 have a relationship of the form

$$\Sigma M_0 = \alpha G \Delta V$$

where G is the shear modulus and α is a geometric factor. The cumulative moment release during repeated, natural, injection-driven swarms is used to quantify injected fluid volumes, flow rates and flow histories associated with fluid release from a deep, intraplate fluid reservoir (Nový Kostel, Czechia, 2000 – 2011) and an upper crustal magmatic-hydrothermal system (Hakone caldera, Japan, 2001 - 2015). Individual IDS sequences typically are associated with injection of $10^4 – 10^5$ m^3 of fluid over periods of days to many weeks at rates between 20 Ls^{-1} and 400 Ls^{-1}. Flow histories on decadal timescales constrain fluid production rates in these systems and provide new insights about the architecture and dynamics of flow during fault-valve behaviour in the seismogenic mid- to upper crust.

The insights provided by the seismicity style and fluid flow in engineered and natural contemporary high fluid flux fault systems have application to understanding flow regimes in some fault-related hydrothermal ore systems, such as many fault-related orogenic Au deposits that are interpreted to form by injection-driven failure in overpressured, high fluid flux regimes. The typical dimensions of these deposits indicate cumulative rupture areas between 1 km^2 and 3 km^2 and require ΣM_0 of 10^{14} - 10^{15} Nm, cumulative slips less than several cm, and injection of $10^4 – 10^5$ m^3 of fluid during each swarm. The net slip in lode-hosting faults indicates slip accumulation via more than 10^3 swarms. Accordingly, net injected fluid volumes as high as 10^8 m^3 are required to produce a 50 t Au deposit. This corresponds to deposition of several 10s of kg of Au per swarm, or extraction of 0.6 ppm Au from the advecting Au-bearing fluid. Swarm recurrence intervals indicate that such deposits can form in $10^4 – 10^5$ years; however, flow is active during only a small fraction of that time.

Using experiments to understand dynamic earthquake processes

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Fault zones and associated slip (ranging from aseismic creep to earthquakes with slip velocities >1 m/s) play a key role in the development of the Earth's crust. Fault activity localises, directs and facilitates crustal-scale fluid flow and fault movement is crucial in the accommodation of strain in the brittle upper-crust. From an economic perspective, fault processes contribute significant prosperity: they control the migration and accumulation of hydrocarbon reserves in fault-bounded sedimentary basins, and fault activity influences the architecture of fluid flow associated with formation of many types of hydrothermal ore deposits. However, seismic activity also comes at significant cost. Globally, approximately 2.7 billion people live in areas of seismic hazard, and in the past 10 years alone, earthquakes and related hazards have cost in excess of A$130 billion. Despite their significance there is much that we don't understand about the dynamic process of fault slip and what causes a fault rupture to grow into a large, damaging earthquake.

In recent years experimental studies in rocks physics have attempted to answer fundamental questions about dynamic slip processes, such as, 1) how stress and fluid states evolve in the lead-up to failure, 2) how a seismic rupture begins, propagates and arrests, 3) how the presence and properties of a fluid influences the dynamics of fault slip , and 4) what the links are between fault dynamics, energy release and friction, and seismologically-derived source parameters. Technological advances in laboratory equipment have provided new understandings of dynamic processes, mechanics, and the behaviour of fault zones during slip. In this presentation I will outline some of the key developments, including research that we have undertaken at ANU. Our research uses custom built laser interferometry and strain gauges to simultaneously acquire high fidelity, high resolution displacement/velocity and stress data at conditions comparable to the seismogenic regime in the Earth's crust.

Our laboratory experiments are comparable to a small-scale version of a highly-stressed fault rupture nucleation zone. The small displacements that we achieve are ideal for studying the initiation of slip and the critical first stages of dynamic weakening, where fault strength transiently decreases with increasing slip velocity. Much of my research has concentrated on using the technological developments described above to explore the rapid evolution of the material properties of contact points between the fault surfaces, referred to as 'asperities'. I will show that over time scales of less than one millisecond, displacements < 50 μm and slip velocities of $>$ 0.1 m/s, enough heat is generated to melt minerals such as quartz (melting temp. ~1700 °C). However, melting alone does not drive additional fault weakening; the melt layer must reach temperatures sufficient to cross the kinematic threshold referred to as the 'glass transition' so that strain can be accommodated through viscous shearing. When melted regions quench at the end of slip, they can weld the fault surfaces together, instantaneously increasing the cohesive strength and changing conditions necessary to reactivate the fault. I will also discuss how the addition of other fluids into a fault system (e.g. water, argon) can dramatically change the strength of the fault, how asperities interact and the formation of off-fault damage.

These results highlight how technological advances are giving us new understandings into the link between mechanical and microstructural processes. Into the future, these developments will allow us to explore the fundamental physics of fault slip, which in turn, can be applied to macroscopic understanding of the earthquake cycle and the evolution of fault rupture. Additionally, these new techniques provide the opportunity to resolve, on the lab scale, the relative components of the earthquake energy budget, which will improve the scalability of results and provide a better understanding of seismic source parameters.

Source to Sink: The impacts of mantle convection on sediment routing systems

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Earth's mantle undergoes vigorous convection on million-year timescales as heat is transferred from depth to the surface. Whilst this flow has long been linked to the large-scale horizontal forces that drive plate tectonics and supercontinent cycles, geologists have increasingly recognised the signature of this convection in transient vertical motions in the rock record. This “dynamic” topography mostly arises from buoyancy associated with thermal isostasy within the lithospheric mantle. However, flow within the convecting mantle gives rise to an additional component that has lengthscales varying from 10,000 km down to 500 km and typical amplitudes of ±1 km. Transient uplift and subsidence events can evolve at rates as fast as 500 m/Myr over cycles as short as ~3 Myr, leading to periodic overwriting of the geological record that results in complex interpretational challenges. Despite these difficulties, a growing number of observational and computational studies have highlighted the important role of dynamic topography in fields as diverse as intraplate magmatism, sedimentary stratigraphy, landscape evolution, paleo-shorelines, oceanic circulation patterns, and the stability of ice sheets. In this talk, several case studies will be used to illustrate how these events can be reconstructed from records of erosion, transport and deposition of clastic sediments from continental interiors to passive margins.

The role of inheritance in forming and reactivating rifted margins and building collisional orogens

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A long-standing problem in Earth Sciences and in particular in modelling is to evaluate the role of inheritance in a Wilson cycle. Inheritance can be defined as the difference between an "ideal" layer-cake and a "real" lithosphere containing inherited heterogeneities of structural, compositional or thermal origin. The reactivation of rifted margins during onset of collision, or alternatively of orogenic structures during rifting, reflect the interplay between inheritance (innate/"genetic code") and physical processes at play (acquired/external factors). Physical processes are generally applicable and easy to test in models, while assessing the role of inheritance asks to understand the history of a geological system as well as to define inherited features and their potential in controlling subsequent deformation phases.

The aim of the presentation is to provide a conceptual framework about how to integrate inheritance in the description of tectonic systems and how to explore its control on the deformation, rheology, strain distribution and magmatic budget. Two examples are discussed: 1) orogenic inheritance and its control on the evolution of rift systems, and 2) rift inheritance and its control on the initiation of subduction and subsequent collision. The presentation will focus on two well-studied examples, which are the North Atlantic and the Iberian-Biscay-Pyrenean-Alpine Tethys systems. While the former shows a complex polyphase rift evolution with variable magmatic budgets along strike, the latter shows rifts that range from hyperextended, to exhumed to successful margins that have been reactivated to variable degrees during the successive convergence.

For the two examples the state of the lithosphere and its rheological evolution across the Wilson cycle will be presented. In the case of the North Atlantic a particular focus will be on depletion processes of the mantle during late orogenic stages and their control on strain partitioning and magmatic budget during subsequent rifting. In the case of the Iberian-Biscay-Pyrenean-Alpine Tethys system the focus will be on the rift architecture and rheology, which is characterized, in the distal parts, by the formation of weak hydrated minerals (e.g. clay, serpentine) due to fluid and reaction assisted extension. The occurrence of these weak, hydrated lithologies at the most distal parts of the margins has a strong influence on the rheology of these domains and may control the strain distribution during subduction initiation.

The two examples enable to discuss how inheritance can be integrate and used in tectonic and magmatic systems. In both the North Atlantic and the Alpine Tethys-Pyrenean systems it appears that the role of inheritance is most important during the transitional stages, i.e. during the formation and early reactivation of a rift system. In contrast, during steady state subduction or seafloor spreading, deformation and magma may be controlled mainly by physical processes. Thus, the “genetic code” of a geological system (e.g. inheritance), may become less important and physical processes may start to control when strain and magma are localized. Future research will be necessary to test these ideas/concepts in order to have a more realistic understanding of how tectonic systems evolve through a Wilson cycle.

Seismic imaging of the upper mantle structure beneath the western Mediterranean: influence of mantle flow on continental deformation

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The complexity of the tectonic history and orogenesis in the westernmost Mediterranean are primarily due to the convergence of Africa with Eurasia during the Cenozoic. The Gibraltar system, which includes the Rif Mountains of Morocco and the Betics in Spain, forms a tight arc around the Alboran Basin. Further to the south the Atlas Mountains, an example of an intracontinental fold and thrust belt, display only modest tectonic shortening, yet have unusually high topography (~4100 m). To the south of the Atlas, the Anti-Atlas is the oldest mountain range in the region, has the lowest relief, and extends toward the northern extent of the West African Craton. To help unravel the regional tectonics, we collected broadband seismic data from 105 stations across the Gibraltar arc and into southern Morocco. We use shear wave splitting analysis for a deep (617 km) local S event and over 230 SK(K)S events to infer azimuthal seismic anisotropy and we image the lithospheric structure with receiver functions and waveform analysis techniques. One of the most striking discoveries from these imaging methods has been evidence for localized, near vertical-offset deformation of both crust-mantle and lithosphere-asthenosphere interfaces at the flanks of the High Atlas. These offsets coincide with the locations of Jurassic-aged normal faults that have been reactivated during the Cenozoic. This suggests that these lithospheric-scale discontinuities were involved in the formation of the Atlas. Shear wave splitting results show that the inferred stretching axes are aligned with the highest topography in the Atlas, suggesting asthenospheric shearing in mantle flow guided by lithospheric topography. Geodynamic modeling suggests that the inferred seismic anisotropy may be produced by the interaction of mantle flow with the subducted slab beneath the Alboran, the West African cratonic keel, and the thinned lithosphere beneath the Atlas. Isostatic modeling based on these improved lithospheric structure estimates indicates that lithospheric thinning alone does not explain the anomalous Atlas topography. Instead, an upwelling component induced by a mantle anomaly is also required to support of the Atlas, suggesting that the timing of uplift of the Atlas is contemporaneous with the recent volcanism in the Middle Atlas.

What can we learn from numerical experiments about continental collision during the Phanerozoic and Precambrian Eons?

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The theory of plate tectonic and the development of numerical modelling methods have allowed us to investigate the dynamic evolution of different types of orogens and to compare styles of orogenesis from the Phanerozoic with those in the Precambrian when the mantle was warmer than today. We can now characterize the variability of tectonic processes during deep subduction of crustal rocks and their exhumation to the surface, to understand tectonic juxtaposition of crust from different depths, relationships to magmatic complexes and other important parameters. Different styles of continental collisional have been proposed and investigated using numerical modeling. One of the most intriguing features is the appearance of blueschists and ultrahigh pressure (UHP) metamorphic rocks in the geological record since the late Neoproterozoic. Based on several series of experiments using a 2D coupled petrological–thermomechanical tectono-magmatic numerical model, we characterize distinct burial–exhumation scenarios for UHP metamorphic rocks. Points of interest include the variability of exhumation mechanisms and the possible geodynamic effects of melting at UHP conditions or during later heating after the exhumation. Differences in the tectonic evolution of metamorphic rocks might be recorded by distinct P–T–t paths. We can evaluate this possibility by comparing P–T–t paths of rocks with those derived from numerical experiments for which the geodynamic regime is known. Moreover, experimental P–T–t paths fully reflect the complexity of the evolution seen in rocks. A series of experiments with higher mantle temperatures and radiogenic heat production has been performed to evaluate possible differences between Phanerozoic and Precambrian collisional orogens. At an upper-mantle temperature of 80–100 K above the present-day value we detect a change to distinct modes of collision which are associated with shallow slab breakoff that precludes the formation of UHP metamorphic rocks. Possible styles of collision between the first continental (micro)plates in the Archean were studied with another series of experiments with initial conditions appropriate to the Eoarchean–Mesoarchean. Microplates that form over delaminating–upwelling mantle in the experiments collide with each other during horizontal shortening forming strongly deformed reworked accreted crust showing several episodes of metamorphic overprinting. Thus, using numerical modelling and available geological data from a collisional orogen we might be able to determine both a tectonic regime responsible for the formation of particular rock types and explain the possible complexities in the predicted P–T–t paths.

Australian crust under ice: what the Bunger Hills tell us about the Proterozoic assembly of Australia

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The majority of the global geological record relates to events along convergent margins as they are zones of focussed metamorphism, magmatism and deformation. The spatial and temporal reconstruction of paleocontinents thus relies on a robust understanding of craton margin tectonics. Mesoproterozoic Australia comprises three Archean-Paleoproterozoic cratonic nuclei and their formerly joined Antarctic equivalents, separated by a series of juvenile and reworked belts. Together, these marginal terranes are united by a high-temperature metamorphic and magmatic record that challenges a simplistic view of continental amalgamation. Despite this, our understanding of the Mesoproterozoic assembly of parts of Australia and East Antarctica has arisen in a piecemeal fashion, and an orogen-wide (>2000 km) thermal framework, until now, has been largely non-existent.

Recent geophysical, isotopic and metamorphic data from the Bunger Hills and Windmill Islands, East Antarctica, reinforce a Mesoproterozoic Australian-Antarctic connection, and allow for a holistic re-evaluation of secular changes in the thermal character of the orogen, the likely thermal drivers for thermally extreme crustal behaviour, and a reappraisal of the Mesoproterozoic amalgamation of Australia.

Mantle-heating is concluded as the overarching thermal driver of Mesoproterozoic orogenesis (two events: ca. 1340–1260 Ma and ca. 1220–1120 Ma). The first event was magmatically juvenile and spatially confined to central parts of the orogen, being ultimately controlled by the pre-metamorphic crustal geometry. The second event was pervasive (continental-scale), involved sustained (high-T >80 Myr) and remarkably consistent high-ultrahigh thermal gradients (~150 °C/kbar), voluminous mantle and crustal melting, and little metamorphic evidence for crustal thickening. Many of these features appear congruent with the thermal expression of mantle lithosphere removal. Final craton amalgamation occurred prior to ca. 1220 Ma, and was central to the longevity of such thermally anomalous conditions.

ORAL PRESENTATIONS

The lithospheric architecture of Australia from multi-observable probabilistic inversion

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The recently developed multi-observable probabilistic inversion[1,2] is providing new insights into the physicochemical structure of the continental lithosphere and its complex interaction with the sublithospheric upper mantle. Some key aspects of this method are: (a) it combines multiple geophysical observables with different sensitivities to deep/shallow, thermal/compositional anomalies, (b) it is thermodynamically consistent, (c) it uses a general probabilistic (Bayesian) formulation to appraise the data; (d) no initial model is needed; (e) a priori compositional information relies on robust statistical analyses of a large database of natural mantle samples; (f) it provides a natural platform to estimate uncertainties and (g) it handles multiscale parameterizations and complex physical models. Here we present preliminary results from the first application of this method in the Australian continent. Specifically, we jointly inverted multiple seismic, geothermal and potential field datasets to image the complex lithospheric architecture and mantle domains beneath Australia. We also discuss some recent technological advances in the implementation of 3D MT into the joint inversion and the potential for mapping compositional anomalies (e.g. metasomatised regions) within the lithospheric mantle.

References

[1] Afonso, J.C. et al., (2013), J. Geophys. Res., 118, doi:10.1002/jgrb.50123

[2] Afonso, J.C. et al., (2016), J. Geophys. Res., 121, doi:10.1002/2016JB013049

Loop: an open source 3D probabilistic geological and geophysical modelling platform

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Current, commercial, 3D geological modelling platforms do not cater to modellers of hard rock, poly-deformed metamorphic terranes. We propose and present a new open source platform which, although still under development, will enable geophysically constrained AND structural geology-rule based geological modelling and domaining.

The Loop project is a OneGeology initiative, initiated by Geoscience Australia and funded by Territory, State and Federal Geological surveys (Australia and in-kind from Canada, UK and France), the Australian Research Council and the MinEx CRC.

We will develop a new open source “3D implicit geo-structural simulator and modelling platform” that will address the entire 3D geological modelling workflow from guiding efficient observations sampling in the field to the production of a series of consistent 3D geological models with uncertainty assessment and characterisation. More importantly, structural geological rules are being implemented allowing the integration of all field based observations and the modelling of poly-deformed terranes.

Building 3D models, even with the advent of implicit techniques is still a highly specialised and costly task (both in time and computing resources) and often only adapted to “simpler” basin geometries. The Loop project aims to develop technologies to mitigate 3D geological risk in resources management. The project is expected to create new knowledge and methods in the field of 3D geological modelling through the innovative application of mathematical methods, structural geology concepts and cutting-edge probabilistic programming. The expected outcomes are an enhanced capability to model the subsurface, characterise model uncertainty and test multiple geological scenarii.

Loop is a new platform that will enable field geologists, researchers from academia and government organisations, explorers, resources modellers and managers to better define their 3D geological environment as well as assessing the requirement for optimised additional data/knowledge acquisition. The platform will be Open Source, scalable and applicable to problems from the mine scale to the plate scale, in data rich and poor environment. It will serve to solve problems related to urban geology, basins resources exploration and exploitation as well as minerals and scientific exploration in poly-deformed metamorphosed terranes.

We present the overall philosophy behind the project and current advancement in the field of forward and reverse structural modelling.

Structural controls of the Ernest Henry IOCG deposit: insights from integrated structural, geophysical and mineralogical analyses

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Iron Oxide Copper-Gold deposits (IOCGs) are structurally controlled, and typically display zonation of iron oxides and sulphides, which is potentially related to redox zonation. There are three main factors that determine the location and architecture of an IOCG: 1. fluid pathway(s); 2. trap/host, and; 3. plumbing system. Generally, these are loosely referred to as structural controls, but they exercise very different functions within the system. In this study we integrate the results of petrophysical property analyses, structural fabric analyses and TIMA scans that provide information on both mineralogy and texture.

220 samples were sampled from 6 separate drill holes which form an approximately N-S transect across the Ernest Henry Mine, near Cloncurry, NW Queensland, Australia. Anisotropy of Magnetic Susceptibility (AMS) were collected for each sample, and information on each samples texture and mineralogy were obtained using a Tescan Integrated Mineral Analyser (TIMA). The results when placed in an ore-proximal-distal-background framework, allow us to understand the footprint of the system.

The results demonstrate that the albite-magnetite lithologies present within the hanging wall shear zone have a strong NE-trending, SE-dipping fabric with a south plunging lineation. The orientation of the lineation suggests the thrust zones formed a jog across two N-S faults during sinistral transpression, as opposed to reverse shearing associated with NW-SE shortening. The fabric in the footwall is consistent with pure strain, indicating that the footwall acted as a relatively rigid block during deformation. The nature of the magnetite grains within these lithologies suggest that the magnetite post-dates the formation of the shear zone. Therefore, the shear zone is an early fluid trap. The NNW-trending upright faults, either side of the deposit, likely control the precipitation of magnetite-albite within the thrust system, thereby controlling the medial footprint/ reduced zone of the Ernest Henry mineral system.

Between the highly magnetised shear zones there is breccia, which is mineralised, and constitutes the bulk of the ore system. This breccia has a randomised AMS fabric, which is consistent with brecciation of the pre-mineralisation tectonic fabrics. The brecciation is coincident with, or pre-dates pervasive to semi-pervasive potassic alteration which is dominated by K-feldspar in the breccia, but may also be present as biotite alteration. The brecciated, potassicly altered zones are still relatively reduced (i.e., contain magnetite) but there is some magnetite destruction to hematite, pyrite and chalcopyrite, which in this case indicates more oxidised conditions in the proximal zone. Alteration was likely focused here due to increased permeability, possibly as a result of over-pressuring and subsequent brecciation. One model for metallogenesis is that reduced fluids (present in the system) mixed with oxidised fluids (carrying the metals).What we deduce to be the last gasp of the system is only represented in a few samples, but preserves a sub-horizontal, N-S lineation that overprints the breccia, indicating strike-slip movement within a N-S fault zone. The rock contains quartz, calcite, chlorite and iron oxide, which in this case is almost entirely hematite, as determined from the susceptibility: density ratio. This style of alteration, although not adequately represented in the sampling contains the highest proportion of chalcopyrite from the samples assessed thus far, and it is the most oxidised assemblage.

The results to date suggest that the metasomatic alteration products present at Ernest Henry (i.e., sodic, potassic and calcic alteration) are coincident with redox zonation. However, the zonation of the system is controlled by the pre-existing architecture, a compressive jog within a north-south trending strike-slip fault. Mineralisation occurs during the transition from ductile-brittle to brittle conditions when the D4 transpressional jog transitions to a D5 brittle transtensional strike-slip system.

Late Jurassic subduction initiation and tectono-magmatic evolution of southern Karakoram, NE Pakistan: a new concept of Neo-Tethys subduction

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Two subduction systems are responsible for controlling the tectonic setting of Karakoram and Himalaya, one under Kohistan and other under Asia. The timing of the Indo-Asia collision remains a controversial topic since last three decades. Earlier it was believed that the oldest subduction related magmatism, both along Karakoram and Kohistan were of mid-Cretaceous age. Detailed field investigation, geochemical analysis combined with high-precision U-Pb dating has been addressed to constrain the timing of magmatism within Karakoram Metamorphic Complex (KMC), Hunza valley NE Pakistan. The exposed rock units record pre-, syn-and post-collisional history of Indo–Asia convergence. Pre-collision intermediate magmas, which have since been metamorphosed to upper-sillimanite zone conditions (Qtz + Bt + Pl + Kfs ± Ms) at Dilbar, north of Karimabad yielded a U–Pb zircon age of 150.1 ± 0.8 Ma, which represents the oldest recorded subduction-driven magmatism associated with closure of the Neo-Tethys Ocean. Two plutonic units from southern sillimanite zone (Chikas monzodiorite and Hasanabad garnet two-mica leucogranite) yielded a U–Pb age of 107.5±1.5 and 105.7±0.7 Ma respectively which shows close similarity with Hunza Plutonic Unit (~105 Ma) which is the central part of huge EW trending Karakoram batholith. The deformed leucogranite (Qtz + Bt + Kfs + Pl ± Grt ± Aln) and a garnet-bearing pegmatite (Qtz + Grt + Pl + Kfs + Bt ± Ms ± Aln) yielded U–Pb zircon ages of 82.6±0.5 Ma and 65.5±0.6 Ma, respectively, which documents post-collisional arc magmatism. The deformed leucogranite contains high Th, U, K content which supports the concept of Kohistan arc collided first with Asia and then with India. A hornblende-rich amphibolite (Hbl + Bt + Pl + Qtz + Ttn ± Cpx) exposed near Barbar-ill yielded a U–Pb zircon age of 50.9 ± 0.8 Ma, interpreted to have resulted from early burial and loading of the Asian plate margin coincident with the onset of final Indo–Asia convergence at ca. 50–52 Ma and closure of the Main Mantle Thrust (MMT). Combined with all available data, it is believed that magmatism prevailed within Karakoram for ~140 Ma (~150 to ~9.3 Ma) and in Kohistan Island Arc for nearly ~128 Ma (~154 to ~26 Ma). The geochemical characteristics indicate a “continental arc signature” i.e., Enrichment in LILE (Ba, K, Sr, and Pb) and LREE (La, Ce, Pr, Nd, Sm), depletion in HFSE (Nb, Ta, Zr,P, Ti and Hf) and HREE (Gd, Tb, Ho, Yb, Lu) with pronounced negative Nb, P and Ti anomalies which suggest subduction-related origin of the magmas. The oldest meta-granodiorite rock display adakitic geochemical characteristics, such as high SiO_2 and Al_2O_3 contents, low Y and Yb contents, positive Sr anomalies, and high Sr/Y and La/Yb ratios, in combination with high Mg# (50–61) which reflect the slab breakoff process during the initial Neo-Tethys oceanic crust subduction.

Keywords
Indo-Asian collision, Late-Jurassic subduction, Tectono-magmatic evolution, Karakoram Metamorphic Complex (KMC), U-Pb zircon geochronology

Reactivation of high-angle inherited structures

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Pre-existing structures in the crust have been shown to influence continental rift propagation and basin structure (Molnar et al. in press), as well as accretionary orogenic architecture (Dufréchou et al 2014). These structures include shear zones, steps or changes in the crustal architecture, sutures and orogenic belts. The significance of these inherited structures has been highlighted because they are increasingly implicated in conceptual models of mineral systems (McCuaig and Hronsky 2017). Here we explore how high-angle inherited structures influence tectonic reactivation in accretionary orogens and continental rifts. High angle faults (transverse structures) in accretionary orogenic systems are often interpreted to form in response to heterogeneous behaviour of a subduction zones, which manifests as different modes of deformation in the overriding plate (Abdullah and Rosenbaum 2018). We have identified cryptic high-angle structures in the central Lachlan Orogen that are characterised by a significant steps in the Moho. These steps are oriented at ~90° to the orogenic grain and has influenced: (1) the pattern of igneous intrusion, including the highly mineralised Macquarie arc; (2) the radiogenic isotopic responses of several generations of plutons; (3) dyke emplacement; (4) the scale and distribution of basin systems and; (5) a major kink in the structural grain of the orogen. Significantly these cryptic inherited structures have a first-order control on the distribution of porphyry Cu-Au mineral systems. The steps in the Moho are interpreted to have formed during extension of the Australian lithosphere during the Neoproterozoic or Cambrian and was active until at least the Carboniferous, illustrating a protracted and repetitious influence on the orogenic system. Analogue experiments show that orientation of the inherited heterogeneities with respect to the extension direction strongly influences how rifts propagate and reactivate. Inherited structures parallel with, or at low angles with a rift result in rapid rift propagation and strong strike-slip reactivation of the pre-existing structures (Molnar et al in press). High-angle heterogeneities cause propagating rift branches to laterally offset, which is characterised by the complex rhombic fault patterns (Molnar et al. in press). When the inherited structure is oriented perpendicular to the rift, they influence the basin evolution by stalling basin propagation and focusing basin subsidence (Molnar et al. in press). These behaviours have significant implications for the patterns of superimposed Palaeoproterozoic to Mesoproterozoic basins of the North Australian Craton, which have been built on a complex basement substrate. These basins formed during different regional extension directions to create different basin geometries, which in may have been influenced by variation in the behaviour of inherited basement structures.

References

Abdullah, R., and Rosenbaum, G., 2018, Devonian Crustal Stretching in the Northern Tasmanides (Australia) and Implications for Oroclinal Bending: Journal of Geophysical Research: Solid Earth 123, 7108-7125.

Dufréchou, G., Harris, L.B and Corriveau, L. 2014. Tectonic reactivation of transverse basement structures in the Grenville orogen of SW Quebec, Canada: Insights from gravity and aeromagnetic data. Precambrian Research 241, 61-84. https://doi.org/10.1016/j.precamres.2013.11.014.

McCuaig, T.C. and Hronsky, J., 2017. The mineral systems concept: the key to exploration targeting, Applied Earth Science,126:2, 77-78. DOI: 10.1080/03717453.2017.1306274.

Molnar, N., Cruden, A. and Betts, P.G. in press. Interactions between propagating rifts and linear weaknesses in the lower crust. Geosphere.

Geophysical interpretation and tectonic synthesis of the Palaeoproterozoic southern McArthur Basin

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The southern McArthur Basin is located in the northeast of the Northern Territory and forms part of a larger basin system that spanned the North Australian Craton during the Proterozoic. The basin preserves sedimentary sequences from at least four, vertically stacked and unconformity bound superbasin sequences, which are lateral equivalents to the Leichhardt, Calvert and Mount Isa superbasins in northwest Queensland. In the southern McArthur Basin, these sequences are comprised of the Tawallah, McArthur, Nathan and Roper Groups. They were deposited, and deformed in response to several different extension and crustal shortening events that affected the North Australian Craton.

High-resolution geophysical data was used to inform on the structural architecture of the southern McArthur Basin, and in particular the Batten Fault Zone which is known for its sediment hosted base metal deposits, such as McArthur River and Teena. Gravity and magnetic data were interpreted to determine the fault architecture and overprinting relationships, and geological cross-sections were forward modelled to constrain the architecture in 2D. Multiple cross-cutting 2D models were used to inform on the 3D structural architecture. Results of the interpretation and modelling highlight the nature and overprinting relationships of major fault systems, regional scale folding, broad scale variations in the preserved thickness of stratigraphy, sub-basin controlling structures and potential source rocks of base metals. Modelling and interpretation results were used to develop a new synthesis for the structural and tectonic evolution of the southern McArthur Basin, which was linked with the broader geodynamic framework of northern Australia.

Results indicate the 1790–1710 Ma Tawallah Group (Leichhardt and Calvert superbasins) evolved during at least two extensional and one mild inversion event. At ca. 1760–1740 Ma, the region experienced north–south-directed extension, causing reactivation and development of northwest normal and northeast to north-northeast strike-slip faults. At ca. 1740 Ma the basin experienced minor inversion which caused reverse movement along north-northeast faults, and widespread erosion. Renewed northwest–southeast-directed extension from 1730–1690 Ma saw deposition controlled by north-northeast to northeast normal faults, strike-slip movement along northwest faults and the extensive emplacement of volcanics. The ca. 1670–1600 Ma McArthur Group and the 1600–1575 Ma Nathan Group (Isa Superbasin) were deposited largely within a sag basin which was periodically interrupted by short-lived extension and inversion events, driven by deformation occurring along the margins of the continent. Broadly north–south-directed, intermittent extension occurred during deposition of the middle McArthur Group and resulted in significant sub-basin deepening in some areas, and uplift and erosion in others. Sub-basins developed in the central Batten Fault Zone in north-south trending transtensional segments of the north-northwest-trending Emu Fault Zone, and adjacent to east–west-trending cross-faults between the Hot Spring Fault and Emu Fault Zone. A weak inversion event at ca. 1640 Ma is thought to have caused syn-depositional uplift along extensional faults, folding in proximity to the Emu Fault Zone, and an influx of breccias into previously developed sub-basins. Following this, sedimentation continued until the onset of the second phase of the Isan Orogeny which caused reverse movement along north-northwest to north-northeast faults resulting in significant uplift and erosion across the southern McArthur Basin. Renewed basin development during the Mesoproterozoic saw deposition of the Roper Group across the region, prior to further deformation associated with post-1313 Ma northeast–southwest-directed crustal shortening which caused reverse and thrust faulting and folding in the Batten Fault Zone.

Are the Peake and Denison Ranges the missing link between the Gawler Craton and the Mt Isa Province? Correlations in the timing and style of alteration with implications for continental reconstructions and IOCG exploration

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Proterozoic continental reconstructions seek to understand the arrangement of the continents, and are commonly argued to be valuable for the purposes of exploration targeting at the terrane-scale. However, reconstruction models are almost always based on correlating lithologies or similar-aged magmatic or tectonic events and rarely draw upon hydrothermal or mineralising events as piercing points. We argue that the correlation of hydrothermal/alteration/mineralising systems of similar ages and styles are paramount when using continental reconstructions for exploration targeting, as they indicate that all of the ingredients necessary to create a particular style of mineralisation are present.

We present correlations between alteration in the Peake and Denison Ranges in the northeastern Gawler Craton and alteration systems associated with extensive mineralisation in the Eastern Fold Belt of the Mount Isa Province. Titanite U–Pb geochronology obtained via Laser Ablation–Inductively Coupled Plasma–Mass Spectrometry (LA–ICP–MS) from calc-silicate alteration in the Peake and Denison Ranges reveal multiple ages between c. 1515–1470 Ma. These ages are younger than known ages of alteration or mineralisation associated with the c. 1595–1575 Ma Hiltaba–Gawler Range Volcanics (GRV) event in the Gawler Craton, but do coincide with the timing and style of alteration and mineralisation associated with the c. 1530–1490 Ma Williams and Naraku batholiths in the Eastern Fold Belt.

Previous reconstruction models have argued for lithospheric continuity between the eastern Gawler Craton and the Mount Isa Province, and the timing of hydrothermal alteration in the Peake and Denison Ranges lends support to those models. Whether the hydrothermal system in the Peake and Denison region represents a linked, but temporal shift in the locus of potential mineralising processes in the eastern Gawler Craton, or is a separate system is unclear. However, timing and style of Peake and Denison alteration are coeval with, and identical to phases of (Iron-oxide–Copper–Gold) IOCG mineralisation in the Isan Eastern Fold Belt, making the Peake and Denison Ranges region highly prospective for further mineralisation.

Shear induced dynamic tilting of the Australian plate

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Continent-scale dynamic vertical motions of the earth's surface have long been attributed to sinking or raising density anomalies in the mantle. In that regard, the unique flatness of the Australian continent has inspired many geologists to track the signature of those epeirogenic surface motions induced by the mantle flow. For example, it has been proposed that the large-scale tilting of the Australian continent since the Late Cretaceous was mainly driven by a subducted slab promoting vertical normal stress at the base of the lithosphere. However, this model fails to explain some of the long-wavelength dynamic uplift and subsidence events across the Australian continent. Of particular interest is the episode of tilting during the mid-Eocene. This episode was contemporaneous with the Australian plate accelerating to the north to speeds reaching up to ~7 cm/yr relative to the east Antarctica. This correlation between plate acceleration and tilting suggests a dynamic link between these two processes, and therefore a possibly different mechanism for epeirogenic surface motions. As a working hypothesis, we propose that the large-scale mantle flow field associated to the relative motion of plates with respect to the underlying asthenosphere can exert shear stress at the base of the lithosphere and induce a form of dynamic topography. Our analytical calculations for an isoviscous lithosphere perturbed by a sinusoidal variation in shear stress at the base of the plate indicates that the shear traction can induce up to a few hundreds of meters of dynamic tilting, of which the magnitude and rate depends on the perturbation wavelength as well as the viscosity of the plate. Two-dimensional thermo-mechanical numerical experiments using non-Newtonian viscosities for both the lithosphere and asthenosphere show that plate motion can result in the tilting of the entire plate by more than -/+1 km. This tilting occurs rapidly within a few hundreds of thousands of years. Our findings can explain the coeval mid-Eocene anomalous subsidence in the Great Australian Basin and uplift in the NW margin of the continent, which have been lacking a dynamic explanation. This tilting of the Australian plate has major impacts on the basin development around its margins, especially on the inversion of the pre-existing structures in the Otway Basin of the southeast Australia. Our numerical models also explain the prolonged compressive stresses acting on that margin and the resulting basin reactivation events.

Imaging shear zones (?) and mafic underplates: examples of 3D forward and inverse gravity modelling from the East Albany–Fraser Orogen and Yilgarn Craton margin

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The Proterozoic East Albany–Fraser Orogen is an underexplored but prospective region exposed along the southeast margin of the Archean Yilgarn Craton, in southwest Western Australia. To the north and east, the orogen is largely covered by the Eucla and Bight Basins. To assist exploration, the Geological Survey of Western Australia has acquired high resolution gravity data (approx. 2–4 km station spacing) across the orogen. This dataset reveals in exquisite detail several Bouguer gravity anomalies that are among the most distinct on the Australian continent. These include the Rason Regional Gravity Low, a very low amplitude gravity anomaly that extends approx. 500 km along the most southeast margin of the Yilgarn Craton, parallel to the northeast trending Albany–Fraser Orogen. The other is the high amplitude gravity anomaly produced by the Mesoproterozoic, metagabbro-dominated Fraser Zone, of the East Albany–Fraser Orogen. Gravity inverse and forward modelling methods have been used to determine the possible sources of these anomalies.

Our geological understanding of the East Albany–Fraser Orogen and Yilgarn Craton margin has advanced with recent geological mapping campaigns and geophysical data acquisition. An interpreted bedrock geology map covers the orogen at 1:250 000 scale resolution and higher. The structure of the orogen at depth has been imaged in three deep crustal seismic reflection profiles, and a Moho model, from passive seismic p-wave receiver function analysis, images the crustal thickness of the southern Yilgarn Craton and East Albany– Fraser Orogen. These datasets provide important constraints on our understanding of the structure of the orogen and on 3D Bouguer gravity modelling and interpretation.

Gravity inversion, performed in Geosoft's VOXI Earth Modeller, clearly images the possible 3D geometry of the Mesoproterozoic metagabbro-dominated Fraser Zone. In particular, this method images the margins of the Fraser Zone, which is bound by major shear zones that are located on steep gravity gradients. The northwest margin of the Fraser Zone, bound by the Fraser Shear Zone, is imaged consistently in density models as a moderately southwest dipping (approx. 75°) density contrast. The southwest margin of the Fraser Zone, bound by the Newman and Boonderoo Shear Zones, has a more complex geometry but is generally subvertical to steeply northwest or southeast dipping. The geometry of the Fraser Zone imaged in density models is broadly consistent with deep crustal reflection seismic interpretations and sparse structural measurements.

Comparison of the Bouguer gravity image with the Moho model shows that the northeast trending minima of the Rason Regional Gravity Low is located to the northwest of the zone of thickened crust that extends along the Albany–Fraser Orogen and Yilgarn Craton margin. Crustal scale 3D gravity forward modelling, performed in 3D modelling software Geomodeller (Intrepid Geophysics), demonstrates that the gravity low produced by the thickened crust can be shifted to the northwest by the addition of a voluminous dense unit coincident with a large non-reflective zone imaged in the thickest part of the crust, in reflection seismic profiles. This dense non-reflective zone in the Yilgarn Craton lower crust is interpreted as a mafic underplate that could have formed during Proterozoic extension along the margin or as a mafic underplate to the Gnowangerup-Fraser Dyke Swarm (c. 1210 Ma) and possibly a remanent of the Marnda Moorn Large Igneous Province.

Cambrian eclogite-facies metamorphism in the central Transantarctic Mountains, East Antarctica: extending the record of early Palaeozoic high-pressure metamorphism along the eastern Gondwanan margin

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Elucidating the timing and thermal character of high-pressure metamorphic events requires detailed petrological and geochemical investigation of eclogite-facies mineral assemblages in addition to geochronological interrogation. In the Miller Range Nimrod Complex, central Transantarctic Mountains, boudinaged mafic domains are hosted within upper-amphibolite- to granulite-facies rocks which were deformed during the Ross Orogeny. Although partially retrogressed along their margins, the mafic rocks preserve evidence of a precursor eclogite-facies assemblage containing garnet, omphacite, pargasite, quartz, rutile and either H_2O or melt. Phase equilibria forward modelling and Zr-in-rutile thermometry indicates that the eclogite assemblage reached peak pressure-temperature (*P*–*T*) conditions of 15.5–17 kbar and 690–750 °C. Clinopyroxene-sodic-plagioclase symplectite, and sodic-plagioclase coronae rimming garnet, hornblende, ilmenite and orthopyroxene overprint the high-pressure assemblage. Compositions and modal proportions of garnet, retrograde orthopyroxene and hornblende suggest a post-peak pressure evolution that evolved through *P*–*T* conditions of 8–10 kbar and 660–840 °C, documenting termination of their near-isothermal exhumation from high-pressure conditions. Moreover, the near-complete compositional homogenization of mafic garnet suggests that the mid-crustal residence time for the retrogressed eclogites was c. 50 Myr. In-situ LA–ICP–MS U–Pb dating of zircon and rutile preserved in the mafic rocks yields concordant ages of 535.9 ± 14 Ma and 536 ± 20 Ma, respectively. The Cambrian-aged zircons show an absent to weakly negative Eu anomaly signature and flat heavy-rare earth element (HREE) distributions, typical of zircons crystallised in the absence of plagioclase and presence of garnet, and therefore diagnostic of the eclogite-facies conditions the rock experienced. The Cambrian zircon population contrasts with older — likely Palaeoproterozoic — discordant zircons that have evident negative Eu anomalies and are HREE enriched. These zircons are interpreted to be protolithic, consistent with existing geochronology from the region. The Cambrian mineral ages are inferred to represent the timing of eclogite-facies metamorphism associated with Ross Orogenesis. The early Palaeozoic eastern Gondwanan margin contains a diverse array of eclogite remnants, each documenting contrasting geodynamic styles. The northern Victoria Land and central Tasmanian eclogites record high-thermal gradient metamorphism and rapid exhumation within their continental rock hosts, and the oceanic southern New England Fold Belt eclogites record refrigerated, long-lived metamorphism. Thus, the Miller Range eclogite-facies rocks expand the spatial footprint of high-pressure metamorphism during the Ross Orogeny along the early Palaeozoic eastern Gondwanan margin.

Scissor detachments and oroclinal warps in the Grampians Ranges, western Victoria - a case study of semi-ductile cover sequence deformation driven by brittle trans-tensional bedrock deformation

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One of the enduring mysteries of the ?Late Ordovician - Late Silurian Grampians Ranges in western Victoria has been the origin of obvious, large-scale, late-stage open warp structures that wend their way through the geology twisting and truncating an already tilted, folded and imbricated succession, through strike-swings of more than 90° in places. Synchronous granite intrusion constrains warping to the Early Devonian. Maintenance of near-constant dip-magnitudes in strata across the warps shows warp-axes plunge subvertically, implicating strike-slip tectonics. However, the clearest spatial and temporal association of the warps is with widespread sub-horizontal detachment faults (Marathon Fault system splays) within, and especially at the base of, the Grampians Group succession. Grampians Group was deposited unconformably on Cambrian bedrock that includes deformed Stavely Arc rocks. A basal Grampians Group unconformity is preserved in places, but is mostly faulted out by Marathon Fault splays. Interpreting movement history and context of basal detachment faults is tricky since hangingwall and footwall successions are different, but down-dip truncation of tilted Grampians Group strata implies extension. This is corroborated by drillhole STAVELY02, which intersects a gently east-dipping basal Marathon Fault zone with striations and steps that indicate top-to-east (i.e. extensional) displacement. Interpreting movement history of Marathon Fault splays within Grampians Group is easier; stratigraphic/structural markers are offset across such faults. Matching of markers show these Marathon Fault splays to be scissor-like, with clockwise hangingwall strike rotations relative to footwall rocks. Hangingwall strata show oroclinal strike curvatures, which result in marked differences to footwall strike where scissor fault displacements are large. Strike differences typically converge to fault tip-lines, indicating that strike curvatures - the warps - resulted from scissor fault growth, as fault footwalls were 'pulled' and/or 'rotated' out from beneath overlying strata. Scissored fault displacements and warping reflect progressive lateral rotational fault propagations. In Cambrian bedrock, magnetic Stavely Arc rocks occur in discrete steeply-dipping linear Cambrian fault slices. Geophysics and outcrop constraints show these are disrupted by regional-scale strike-slip faults and tens-of-km-scale Z-shaped megakinks. These are traced, using potential field data, towards and beneath the Grampians Ranges, where they directly underlie Grampians Group-hosted scissor faults and the large warps. This coincidence demonstrates age-equivalence and soft-linkage between Cambrian bedrock-hosted dextral transtensional faults, rifts and megakinks, and derivative Grampians Group-hosted transtensional scissor faults and subvertical oroclinal warps. An area-balanced retrodeformation scenario for Early Devonian structures utilises scissored Marathon Fault displacements to reconcile the strikingly different sub-vertically plunging smoothly-curved oroclinal warp fold morphology typical of the Grampians Group against the angular, fault-truncated, Z-shaped megakink morphology typical of the underlying Cambrian bedrock. Deformation was bedrock-driven, differences in structural style attributed to age and degree of lithification at the time of transtensional wrenching – Cambrian bedrock was ~100 million years old and well lithified when it was wrenched and rifted in the Early Devonian, and so deformed in a brittle mode. The Grampians Group cover was young, poorly lithified, and deformed in a semi-ductile mode. Space-differences resulting from the different deformation modes were locally accommodated by scissored movements across distributed subhorizontal Marathon Fault splays. These eventually linked up to become a detachment. Despite the apparent complexity, most structures in the Grampians Group can be related back to a simple theoretical block diagram that involves bedrock-driven brittle dextral transtensional faulting and dextral (Z-shaped) rotational mega-kinking beneath a ductile Grampians Group cover succession.

The North Cycladic Detachment System: insights from the Upper Cycladic Unit of Tinos MCC, Cyclades, Greece

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Tinos metamorphic core complex (MCC) is one of the well-studied objects in the Cyclades. It was exhumed below the North Cycladic Detachment (NCDS) During the Oligocene and Miocene times. Tinos Island consists of the Cycladic Blueschist Unit, below the detachment, that records an Eocene HP-LT metamorphism. The hanging wall is represented by the Upper Cycladic Unit showing only a Late Cretaceous greenschist-facies event. The exhumation of Tinos MCC was achieved in the back-arc region of the retreating Hellenic subduction coeval with the orogenic collapse of the Hellenides.

Tinos MCC corresponds to a crustal boudin, where shear zones have formed in its neck. The shear zones have evolved to form the top-NE North Cycladic Detachment System, which exhumed the core-complex. At about 14 Ma, the MCC and the NCDS were intruded by a granitoid pluton that locally uplifted the detachment.

In this work, we discuss the deformation of the Upper Cycladic Unit and to study the 3D geometry of the NCDS. To do so, we have carried out the production of a new geological map, accompanied by NE-SW and NW-SE cross-sections, based on field work and interpretation of high-resolution satellite images.

We found that the Upper Unit is intensely folded following the top-to-the-NE regional direction of shearing. Such folding has not been described before in the literature and suggests that the upper unit was deformed by an upper detachment similar to that observed in Mykonos.

Our observations indicate the existence of constrictional folds in the NCDS. These folds show axes parallel to the shearing direction, with a larger wavelength than the one observed in the upper and lower units, which implies continuous relocalization of the detachment plane during exhumation.

Microstructural and stress variations in the mantle section of an oceanic transform zone: records of the seismic cycle

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Mantle earthquakes that occur deeper than the 600 °C isotherm in oceanic transform faults indicate seismic rupturing at conditions where viscous deformation (bulk ductile behavior) is dominant. However, direct geological evidence of earthquake-related deformation at ambient upper mantle conditions is rare, impeding our understanding of earthquake dynamics in plate-boundary fault systems. The Bogota Peninsula Shear Zone, New Caledonia, is an ancient oceanic transform fault exhumed from upper mantle depths. Ductile structures in the Bogota Peninsula Shear Zone formed at temperatures > 800 °C and microstructures indicate that differential stress varies spatially and temporally. Spatial variation is observed as an increase in differential stress with strain toward localized zones of high strain; stress increases from 6–14 MPa in coarse grained tectonites to 11–22 MPa within 1–2 km wide mylonite zones. Temporal stress variation is observed by the formation of micro-deformation zones that seem to have brittle precursors, are filled with fine-grained recrystallized olivine grains and crosscut the background fabrics in the harzburgites that host them. The micro-deformation zones record stresses of 22–65 MPa that are 2–5 times higher than the background, steady-state stresses in the surrounding mantle rocks. We interpret the observed spatial and temporal variations in microstructures and stresses in the upper mantle to demonstrate the influence of seismic events in the upper part of the oceanic transform fault system. We attribute the increase in stress with strain to be the result of imposed localization induced by downward propagation of the seismic rupture into the underlying mantle. The micro-deformation zones could result from brittle fractures caused by earthquake-related deformation in the mantle section of the transform fault, which are in turn overprinted by ductile deformation.

Synthesizing the spatial and temporal variations in stresses and microstructures in the Bogota Peninsula Shear Zone we propose a conceptual model where brittle fracturing and shearing take place during coseismic rupture at increased stress, ductile flow at decaying stress is concentrated in the micro-deformation zones during postseismic relaxation, and uniformly distributed creep at low stress occurs in the host-rocks of the micro-deformation zones during interseismic deformation. The results from the Bogota Peninsula shear zone allow us to build a picture of earthquake-related deformation in the upper mantle section of oceanic transform faults during the seismic cycle.

Geochronology and multi-scale geophysics reveal lithospheric architecture of the North Australia Craton between Tennant Creek and Murphy inlier

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Although mid-Paleoproterozoic basement inliers of the North Australian Craton are mostly well characterised, widespread basin cover has hindered investigations of the Craton's broader tectonic architecture, especially in the Northern Territory. Resolving the first order tectonic features of the Craton will increase our understanding of the craton's tectonic evolution, help identify buried structural corridors that are prospective for mineral systems, and inform debate regarding enigmatic high-temperature, low-pressure tectonometamorphism during the so-called Barramundi Orogeny. We approach this challenge by combining geochronology with multi-scale geophysical data.

New SHRIMP U-Pb ages from monazite in pelitic schists and gneiss reveal that rocks from Tennant Creek, the Murphy inlier and beneath the Barkly Tablelands were locally deformed at amphibolite facies conditions at ca. 1850 Ma. Elevated metamorphic grades are spatially associated with a series of large structures that can be traced in potential field imagery between Tennant Creek and the Murphy Inlier. This near-surface expression of a 400 kilometre long tectonometamorphic corridor coincides with elevated conductivity at depth in long period magnetotelluric data. Also, preliminary passive seismic receiver function data image a 5–10 kilometre offset in moho depth across this corridor, and models of the Lithosphere-Asthenosphere boundary indicate that the corridor is associated with a change in Lithospheric thickness of ca. 40 kilometres. These results are interpreted as a lithospheric-scale plumbing system that may have significant implications for the region's mineralisation potential. We also interpret this ca. 1850 Ma structural corridor to have formed due to tectonic processes similar to those operating today, as opposed to the 'ensialic' models originally proposed for the Barramundi Orogeny.

The approach implemented here demonstrates the effectiveness of combining multi-scale imaging of the lithosphere together with robust geological observations, and provides a template for identifying other structures of major significance which may represent the primary architecture controlling the distribution of mineral systems.

The necessity of a Neoproterozoic full plate reconstruction to quantify the global earth system and understand deep time plate tectonics

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A full-plate topological reconstruction of the ancient earth is a requirement to understand the kinematic evolution of various plates on the planet and integrate preserved geology with the tectonic geography of deep-time. For example, the relics of the complex arc-arc, arc-continent and continent-continent collisions that forms much of north-east and east Africa, all of Arabia, north-west India, Madagascar, southern India, and into Sri Lanka and East Antarctica can be reconstructed to indicate a major plate kinematic reconfiguration at ca. 750 Ma, which is broadly coeval with the start of Neoproterozoic India's southern progress from Tonian polar regions to the tropical margin of western Australia and eventually to collide with Africa to form the largest mountain range known prior to the Himalaya (the East African Orogen).

These GPlates-based reconstructions then form a platform to investigate deep-earth process controls on the wider earth system. The scenario discussed above involves the closure of an equatorial ocean seaway (the Mozambique Ocean), at the same time that the nascent Pacific Ocean opened. The evolution of these oceanic gateways affects climate and nutrient dispersal through changing ocean current patterns. In addition, the creation and destruction of topography can be investigated by integrating thermo-barometric information from the preserved orogens and from detrital phases in successor basins. Together, this creates a work-program to address an earth science grand-challenge—creating evolving bathymetric-topographic models for deep time and modelling these plate-ocean-continent configurations to examine nutrient supply and dispersal, climate-controlling chemical fluxes/sinks and their effects on developing the habitable earth.

The c. 1515 Ma Spilsby Event: syn-tectonic A-type magmatism and lithospheric controls on the localisation of late-stage deformation in the Gawler Craton, South Australia

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The Gawler Craton, in South Australia, is composed predominantly of Archaean lithosphere which underwent a number of major reworking events in the Proterozoic, contradicting the paradigm of Archaean lithosphere forming rigid cratonic blocks resistant to deformation. It is uncertain why the Gawler Craton preserves this record of reworking, and what mechanisms led to its final cratonisation in the Mesoproterozoic. This study focusses on the Mesoproterozoic Spilsby Event, one of the final events recorded in the Gawler Craton, with the objective of understanding the tectonic drivers and lithospheric-scale controls on this magmatism and deformation, integrating structural geology, whole rock geochemistry, Nd isotopes, SHRIMP U-Pb zircon geochronology. The Spilsby Suite comprises a granodiorite pluton intruded by comagmatic granite, granodiorite, aplite and pegmatite dykes. It is deformed by a moderately low temperature solid-state fabric, open to tight folding associated with a weakly developed axial planar foliation and localised shearing, interpreted to have occurred synchronous with emplacement in a NE-SW-directed transpressional regime. The Spilsby Suite has an A-type chemistry, with a trace element and moderately evolved isotopic signature consistent with derivation from refractive local basement crust, rather than requiring a mantle input, and intruded at c. 1515 Ma. Occurrences of magmatism and deformation at c. 1515 Ma within the Gawler Craton are either restricted to the eastern, northern and western margins of the craton, or are associated with pre-existing structures. Evidence of deformation at c. 1515 Ma is notably absent from the central part of the Gawler Craton where the c. 1595–1575 Ma A-type Gawler Silicic Large Igneous Province is located. This suggests that the lithosphere of the central part of the craton had essentially cratonised at c. 1515 Ma following large-scale crustal melting of the Gawler SLIP, and that as a consequence deformation was partitioned to the craton margins or reactivation of existing structures. The c. 1515 Ma Spilsby Event may be related to penecontemporaneous plate margin magmatism recorded in the Coompana Province directly to the west of the Gawler Craton.

Exploring for the future in Australia: characterizing and assessing the lithosphere for resource discovery

Karol Czarnota on behalf of the Exploring for the Future Program team

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Given demand is outstripping the rate of new resource discoveries, improvements in exploration are needed to maintain growth in global living standards. To position Australia to meet this challenge, the Australian Government initiated the $100.5 M Exploring for the Future program (2016–2020), focused on establishing an integrated resource prospectus over northern Australia and parts of South Australia for minerals, energy and groundwater resources. This unprecedented investment into new data collection and analysis is resulting in one of the best-characterized pieces of lithosphere on Earth (between Tennant Creek and Mt Isa) as well as transforming our understanding of Australia's structural architecture and Earth processes, with global implications.

Here I showcase key advances in semi-continental characterization of the lithosphere from the surface down to the lithosphere-asthenosphere boundary, achieved by Geoscience Australia in collaboration with state and territory geological surveys and academia. Highlights include: enhanced surface mineral mapping using 30 years of Landsat data; establishment of spatially variable soil geochemistry baselines and anomaly detection using machine learning with apparent controls by Cenozoic geodynamics; unprecedented imaging of near surface geological structure utilizing the world's largest airborne electromagnetic survey with implications for surface-mantle dynamic coupling; integrated national hydrochemistry coverages; new generation of world-leading continental-scale gravity, magnetics and radiometric coverages; systematic mapping to and of subsurface geology along four mega-sequence unconformities; identification of new crustal boundaries using isotopes (Nd, Hf, Pb, U-Pb, Ar); discovery of new basins and shear zones through newly acquired onshore deep reflection seismic profiles; and mapping metasomatised mantle and structures utilizing ~50 km spaced long-period magnetotellurics (AusLAMP) and passive seismic (AusArray).

All the aforementioned multidisciplinary datasets are integrated within a mineral systems framework to predict mineral potential undercover, often reducing the search space by 70–90%. Regional assessments are supplemented with more focused minerals, energy and groundwater studies benchmarked by drilling programs. In addition, Economic Fairways are modelled to further de-risk mineral exploration undercover by taking into account mining costs given the spatial distribution of cover-thickness, energy and transport infrastructure. All these data and some associated analytics are now available through a new online portal, which makes the datasets and new scientific insights discoverable and accessible to communities, government, industry, and academia, free of charge.

What do rift structures on the North West Shelf tell us about Gondwana break-up?

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The widely held view of the evolution of the North West Shelf of Australia is that the fundamental basin architecture was established by NW-SE oriented extension in the Carboniferous and Permian associated with rifting of the Lhasa terrane, by a further phase of NW-SE oriented extension in the Lower and Middle Jurassic associated with the separation of the Argoland terrane and by E-W oriented Upper Jurassic to Lower Cretaceous extension that culminated in the separation of Greater India and Australia.

The presence of fundamental NE-SW oriented Carboniferous to Permian aged rift structures is well established, and with seismic data that now images deeper structures more effectively, the architecture of that rift system is becoming increasingly apparent. What is less clear is the nature of Triassic deformation, which forms a passive, post-rift sequence in most of the Carnarvon Basin, but shows a continuation of the Permian extension, and a significant episode of volcanism, further to the NE. However, evidence of a failed Permian rift raises questions about the location and timing of separation of the Lhasa Terrane.

A renewed phase of extension began in the latest Triassic in the western part of the Northern Carnarvon Basin, but became progressively younger to the NE. A very clear and consistent pattern of ENE oriented extension, that interacts with the older NE-SW oriented Permian aged structures, is apparent across the whole of the Northern Carnarvon and Roebuck Basins, and in to the Browse Basin. This is at odds with the NW-SE oriented extension predicted by Argoland rifting.

Upper Jurassic and Lower Cretaceous extension is surprisingly localised, being most evident in the SW corner of the Northern Carnarvon Basin (in the Exmouth sub-basin), around the Thouin Graben which marks the boundary between the Northern Carnarvon and Roebuck basins, and in the area of the Vulcan sub-basin. Elsewhere this event has surprisingly little expression, but the fact that it is evident in locations so far removed from the site of Australia-Greater India separation is puzzling, and perhaps requires a re-appraisal of existing models of Gondwana break-up.

Relationships between the configuration of continents and of basal mantle structures

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The evolution of the structure of Earth's mantle is linked to tectonic motions: oceanic lithosphere recycled at subduction zones sinks into the mantle over ~200 million years, and large-scale upwelling preferentially occurs away from sinking slabs. As a result, the relatively stable locations of subduction zones over the past 230 million years wraps around the present-day geometry of two Large Low Shear Velocity Provinces (LLSVPs) under Africa and the Pacific. Together with the close spatial relationship between LLSVPs and the reconstructed eruption sites of Large Igneous Provinces, this has led to the hypothesis that LLSVPs could have been fixed and rigid for hundreds of million years, controlling the locations of mantle upwelling. However, the location of subduction zones and therefore mantle downwelling is expected to have changed over the past billion years, a time period over which supercontinent Rodinia broke up (between ~800–600 Ma), and supercontinent Pangea assembled (between ~600–350 Ma) and has been dispersing over the last 200 Myr.

Here, we use a recent tectonic reconstruction extending back to 1,000 Ma as boundary condition of a series of global convection models across which parameters including initial age are varied. To evaluate the success of different models, we quantify the fit between the present-day structure of the lower mantle predicted by each mantle flow model and inferred from seismic tomography models. We analyse the evolution of the shape and location of model basal thermo-chemical piles, quantify their distance to reconstructed Large Igneous Provinces (LIPs), and analyse their spatial and temporal relationship with the dispersal and assembly of supercontinents Rodinia and Pangea. We show that model basal thermo-chemical piles have been mobile over the last 1,000 Myr, and we identify a ~200 Myr lag for surface continental configurations to be reflected in the configuration of basal mantle structures. While this lag is expected given average slab sinking rates, it is often overlooked when linking supercontinent cycles to long-wavelength mantle convection.

Magnetic field inversion of Gairdner dyke anomalies from the new GCAS data

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The Gawler Craton Airborne Survey (GCAS) provides an unprecedented magnetic field mapping resource for interpretation of the Gairdner dyke swarm. Individual flight-line dyke intersections supply ideal isolated anomalies for magnetic field inversion: the geological attribution of the magnetization is obvious and the simple, predictable geometry of the dykes is well suited to parametric description. In consequence the geological interpretation of the parametric inversion results is straightforward. Magnetic field images and enhancements enable detailed mapping of the dykes and the depths to their tops are estimated with almost maximal reliability for unconstrained inversions. Nevertheless, there are considerable uncertainties in the various model parameters. We use selected dyke anomalies to investigate confidence in inversion-supplied estimates of magnetization, thickness, dip and depth extent of the dykes. Estimation of the dip of the dykes is in part dependant on magnetization direction for which we have some constraints from remanent magnetization measurements. These model studies highlight the limitations of less simple inversions where problems often arise due to poorly predictable distribution of magnetization.

Towards an Isotopic Atlas of Australia: tracing tectonics through time and space

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Geoscientists have access to increasingly sophisticated tools to image the earth at a range of depths, based on a range of physical properties such as density, magnetic susceptibility, electrical conductivity, seismic velocity etc. Many of these tools have been, and are being, applied systematically across Australia providing unprecedented views of our continent. The variations in physical properties revealed in these images provide a snapshot in an ongoing, dynamic evolution, and are the result of the combined effects of billions of years of geological history.

Appropriate interpretation of such images requires an understanding of relative and absolute timing of processes leading to the current configuration. Measurements of geological time are largely based on measurements of the products of natural radioactive decay, with different methods being applicable to different geological materials, and providing time constraints on differing geological processes. The Australian geoscience community has been a long-term leader in the development and application of many of these isotopic methods.

Several decades of isotope geoscience means Australia is blessed with one of the best isotopic data coverages of any continent. With some exceptions, however, isotopic data are generally not widely available in map view, or at continental-scale. These data are, by their nature, collected at the individual sample level and the results are dispersed amongst decades of academic literature, theses and geological survey reports. Most of these individual reports focus on local- to regional-scale features, and the isotopic data appear in disparate formats with widely varying levels of detail.

Here we present the results of recent efforts to consistently compile and categorise age and isotopic data at the continental-scale. This work is ongoing, as additional legacy data is added, and ever greater volumes of new data are produced. Thematic maps based on a range of isotopic methods will be presented, specifically Sm-Nd, Lu-Hf, U-Pb, K-Ar and Pb-Pb. The patterns expressed in these maps provide a spatial and temporal record of (i) continental growth, (ii) crustal re-organisation via magmatic, metamorphic and structural processes, (iii) exhumation and cooling of the mid- to upper-crust, and (iv) the chemical character of mineralising fluids.

The isotopic maps alone provide a sharper and more complete view of the evolution of the continent, and yet there is likely much more information that can be derived from these data. Continental-scale patterns in geological ages and isotopic signatures provide a powerful overlay on similar scale geophysical images, offering the potential to derive additional meaning from each dataset. The systematic compilation of the isotopic data, and their visualisation in map form, allows for a more quantitative exploration of correlation and causation between geochemical, structural and geophysical features. In this respect, we have barely scratched the surface of "paleogeophysics".

Constraining upland erodibility and marine deposition: Late Quaternary source-to-sink sediment transfer in the Gulf of Papua

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At the Earth's surface, coupled tectonic, climatic and surface processes drive sediment transfer from continent interiors to their margins. Understanding this transfer and its feedback of the driving mechanisms is one of the main challenges in modern geosciences. To be able to simulate this process and access new knowledge regarding landscape evolution, sedimentary basins, nutrient fluxes to the ocean, or greenhouse gas capture via the weathering of rocks, we need to be able to parameterise on an appropriate time scale the erodibility of rocks, the parameter that controls the process turning solid rocks into mobile sediments. In this study we seize the opportunity offered by the Papua New Guinea landscape, a natural laboratory to investigate coupled tectonic, climatic and surface processes in source-to-sink context. This rugged landscape, including its drainage system, is young. It is tectonically very active with high-uplift rates and it experiences precipitation rates exceeding 10 m/yr, driving high-erosion rates and a terrigenous sediment flux of ~384 Mt/yr into the active foreland basin of the Gulf of Papua. This part of the world is therefore an ideal location to constrain the erodibility of equatorial mountainous catchments, which will give us the capacity to numerically simulate the Late Quaternary landscape evolution of southern PNG.

Constraining the uplift, precipitation and erosion rates within the Gulf's watershed is necessary in order to simulate source-to-sink sedimentary processes. Uplift rates along the south-western flank of the Papuan Peninsula were constrained using the present-day elevation of remnants of late Miocene volcanics that were deposited near sea level during the Miocene and have subsequently been uplifted to their present elevation. Present-day Tropical Rainfall Measuring Mission (TRMM) rainfall estimates were used to represent spatially varying Late Quaternary precipitation rates. To constrain terrestrial erodibilities, simulations were run using Badlands, an open-source landscape evolution model developed at the University of Sydney. Source-to-sink sediment transport over the past 35 Kyr was simulated with a range of different erodibility coefficients and the results compared to the present-day natural sediment loads of the Fly and Purari Rivers to constrain a range of erodibility coefficients that best account for the documented recent sediment flux into the Gulf of Papua. Comparing simulation results to observed sediment accumulation rates in the deep-sea Gulf assisted in constraining the distribution of sediment in the marine environment in Badlands.

Results show an increase in the Plio-Quaternary uplift rate from negligible at sea level along the southwestern coast of the Papuan Peninsula to > 470 m/Myr in the peaks of the Owen-Stanley Range, with a less dramatic increase from the southeast of the Peninsula (~270 m/Myr) towards the northwest (~720 m/Myr). Comparisons with present-day fluvial sediment loads constrain erodibility coefficients for the Gulf of Papua in Badlands to within the range 5.53–7.41 x 10^{-6} s^{-1}, with an estimated uniform erodibility coefficient of ~7.0 x 10^{-6} s^{-1}. Subsequently, the marine accommodation variable was constrained to within the range 0.005–0.009, so that the largest depocentres in the Gulf are on the continental slope. A sensitivity analysis reveals that erosion and deposition in the Badlands model for this study is more sensitive to changes in precipitation rate than to changes in the uplift rate. These findings permit the simulation of sediment transfer processes for the Gulf of Papua during the Late Quaternary, informing our understanding of the catchment's surface evolution and the stratigraphy of the deep-sea basin. With the majority of sediment entering the Gulf sourced from the Papuan Orogen (~74%), the locus of sediment deposition migrates from the deep sea to the continental shelf with marine transgression.

Geology and geophysics-based lithological classification for structural interpretation in the Yerrida basin (Western Australia)

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We propose and test a lithological classification methodology allowing the recovery of lithologies a posteriori from geophysical inversion results constrained by prior geological information. Our technique relies on the self-organizing maps algorithm to classify the inverted model in terms of lithologies. It utilises prior geological information in the form of geological uncertainty, the expected spatial distribution of petrophysical properties, and geophysical inversion results. To ensure local geological consistency of recovered lithological models, the proposed technique relies on a process called post-regularization scheme. It enforces elementary geological principles in the recovered lithological model while maintaining geophysical validity. The application of the proposed methodology to the Yerrida basin (Western Australia) allowed us to confirm previous results. It also suggests that the structural model needs to be updated in some areas. In particular, the greenstone belts present in the north east of the Yerrida basin, which are of particular interest for their economic mineral potential, might not follow the same geometry as previously expected.

Thermochronological and geochemical footprints of post-orogenic fluid alteration recorded in apatite: implications for mineralisation in the Uzbek Tian Shan

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The Uzbek Tian Shan is a prominent metal-rich belt, hosting world-class orogenic Au deposits such as Muruntau. However, its post-collisional history in relation to fluid alteration and mineralisation remains elusive. We present apatite U–Pb dates and rare earth element geochemistry for 44 granitoids, revealing a prolonged history of low-grade metamorphism and associated fluid alteration between ~285 and ~240 Ma. A resulting apatite U–Pb age interpolation map reveals two young anomalies that are interpreted as post-orogenic fluid circulation cells. In addition, the extent of Meso-Cenozoic denudation is presented using apatite fission track (FT) age data. In areas of good data coverage, the combined Apatite U–Pb and FT anomalies reveal a correlation with the locations of orogenic Au mineralisation. Although more data is required to further evaluate such correlation, our study illustrates that integrated multi-method apatite thermochronology and geochemistry may have the potential to become a novel viable tool for mineral exploration.

Towards updatable, national high-resolution seismic velocity models of the lithosphere

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Since the 1990s multiple passive seismic experiments have been successfully carried out by academia to image the Australia lithosphere. Over this time new seismological imaging methods have evolved resulting in numerous models of the Australian lithosphere using body-wave tomography, surface wave data, ambient noise analysis, and full waveform inversions. Despite this advance benchmarking of these different models is hard to achieve as they are often based on different underlying datasets. To overcome this problem, the Australian government and academia have united around the Australian passive seismic Array project (AusArray) which aims to obtain a national half degree data coverage and an updateable 3D national velocity model which grows in resolution as data became available.

AusArray unites data collected from the Australian National Seismological Network, multiple academic transportable arrays and seismometers in schools. Geoscience Australia’s Exploring for the Future program has doubled the rate of national data collection. Extensive quality-control checks have been applied across this combined dataset to improve the robustness of subsequent modeling and will be made publicly available. This data and inversion code framework allows robust national-scale inversions to be rapidly undertaken as new data is available.

Here we present the first national P and S body-wave tomography model of the Australian Lithosphere. A new earthquake catalogue of ~26,000 events, dating from 1993, was used to estimate first-arrival times. Parametric data was used in non-linear tomographic inversion using a realistic wave propagation scheme and an adaptable irregular grid-mesh. This approach allows the sensitivity of the data to be adequately treated. The velocity architecture shows strong correlation with known major crustal and lithospheric mantle boundaries which will be briefly outlined along with preliminary results of receiver functions studies between Tennant Creek and Mt Isa.

Rudall Province- witness to assembly of Western and Northern Australia Cratons, but how did it happen?

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Majority of the western Australia is underlain by Precambrian rocks that are divisible into two Archean to Paleoproterozoic cratons, the West Australian and North Australian cratons, separated by Proterozoic orogens and basins which were covered by phanerozoic Canning basin. The Archean Yilgarn and Pilbara cratons were assembled into the West Australian Craton along the Capricorn Orogen during the late Paleoproterozoic (2000 Ma) - Glenburgh Orogeny, which then combined with the North Australian Yapungku Orogeny to form proto-Australia. The understanding of the timing and style of Yapungku is still debated. Main know facts are:

- The 1804–1762Ma Kalkan Supersuite generated within locally extensional setting, caused either by slab roll back or extension unrelated to collisional event.
- The 1589–1549 Ma Krackatinny Supersuite are interpreted to be derived from the melting of mafic crust; the geochemical signature of high Sr/Y are consistent within-plate in an extensional setting.
- The c. 1300 Ma Camel Suite has geochemical signature similar to Kalkan, may also have been emplaced in an extensional setting.
- The majority of analysed igneous rocks from the Rudall have evolved Hf isotopic signature; imply that magmatism derived from the reworking of continental crust with limited input of juvenile material.
- All the Rudall domains seem to be allochthonous to the Pilbara and Western Australia Craton in general.

Equipped with this knowledge and we have tested existing conceptual models presented by for assembly of western and northern craton using numerical techniques. The results show that so far none of the existing models fits 100% the geology, but exhibit only part of know geological sequence, with some very interesting resemblances to geological record. What does it tell us? Are the concepts incorrect? Is modelling not realisitc enough? How do they sit in relations to adjacent Australian blocks? All this is currently under investigation.

We have used 2D and 3D fully coupled thermomechanical -petrological modelling approach, along with possible reconstructions of the plates movements using GPlateas.

Incorporating fault kinematics into implicit 3D geological modelling

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One challenge of creating 3D structural geological models is incorporating and honouring geological observations and knowledge. Faults are particularly challenging to model because they introduce discontinuities in the surfaces being modelled that are difficult to include in the surface description. There are two approaches used for incorporating the fault displacement into surface descriptions: the first approach adds a displacement function (step function) into the mathematical description of the surface. The step function does not capture fault kinematics and is only correct for faults where the fault is orthogonal to the layers being faulted. The second approach deforms an existing continuous surface using a fault operator to account for the fault displacement. This approach is capable of using fault kinematics but requires the geometry of the surface prior to faulting to be known. Neither approach is capable of modelling the interaction between faults within complicated fault networks e.g. duplex systems, flower structures and listric fault systems. In this study we adapt the fault operator and apply it in reverse to the model area and geological observations. The model area is restored to pre-fault locations and the older geological surfaces can be interpolated within this space. The model area is then reprojected back into the faulted locations. This approach directly uses the kinematics of the faults it is also possible to model interactions between co-eval faults where the resulting geometry is the result of combining the fault displacements. This requires a new description of faults where faults are represented by a graph containing individual segments that represent individual slip events. We demonstrate these approaches applied using the new open source probabilistic 3D geological modelling package Loop3D on two synthetic examples: a normal fault system and a duplex system.

Lithospheric architecture of the North Australia Craton: insights from passive seismic imaging and integration with other techniques

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Imaging the structure and composition of the lithosphere has been increasingly recognised as an important prerequisite for understanding the relationship between mineral deposits and the systems that generate them. To this end, high-resolution 3D seismic velocity characterization of the Australian plate has been identified by the UNCOVER initiative as a priority to improve mineral exploration success. Government and academia have therefore united under the auspices of the Australian passive seismic Array project (AusArray). AusArray aims to obtain a national half-degree data coverage and an updated 3D national velocity models with improved resolution as further data become available.

Underpinning AusArray is a computational framework for seismic-data processing and tomographic inversion. This framework has been developed within Geoscience Australia’s Exploring for the Future program and is outlined in a separate presentation. The first stage of Geoscience Australia's passive seismic imaging project has been the development of P and S body-wave tomography models. Currently, the highest resolution data coverage is available for a region in the North Australia Craton, approximately covering Tennant Creek and Mt Isa.

Here we examine the lithospheric architecture of the North Australian Craton imaged in the Tennant Creek - Mt Isa region. At a broad level, P- and S-wave tomographic images show strong correlation with major crustal boundaries. However, velocity variation patterns between the phases are not always positively correlated. Contrasting Vp and Vs trends provide insights into which features are likely to be reflective of thermal structure and those that are more likely due to alteration. These features are further examined through integration with reflection profiles, magnetotelluric resistivity models, isotope geochemistry, and xenocryst data. Finally, we briefly comment on the implications for mineral systems in the region.

The influence of metamorphic reactions on localisation of deformation

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The conditions for localisation of deformation in a viscoplastic material always involve some form of softening of the material as it deforms. The softening is defined by a softening modulus, $h=\left(\frac{\partial\sigma}{\partial\varepsilon}\right)_{T,\dot{\varepsilon}}$, which measures the way in which the stress, σ, changes with increasing strain, ε, at constant temperature, T, and strain rate, $\dot{\varepsilon}$. However softening, although necessary for localisation is not a sufficient condition. In order to localise, the softening must exceed the intrinsic strain rate hardening, measured by the strain rate sensitivity, $m=\left(\frac{\partial(\log\sigma)}{\partial(\log\dot{\varepsilon})}\right)_T > 1$, which is a feature of all power law materials with stress exponent, $N > 1$. The critical condition for localisation is $\lambda=\frac{m(\sigma-h)}{\sigma}\geq 0$ where λ is a measure of the growth rate of the shear band; at this critical condition the amplification of any incipient shear zone becomes positive and the shear zone grows in amplitude. Below this condition any incipient shear zone decreases in amplitude. In this paper we explore various modes of softening and strain rate hardening but concentrate on two examples: (1) softening induced by recrystallisation of alkali-feldspars + quartz + mica during deformation and (2) softening during recrystallisation and serpentinisation of olivine. We show that a change in the standard deviation of a grain size distribution influences m and hence influences the conditions for localisation.

In order to proceed, we invoke a thermodynamically based logarithmic mixing law that describes the bulk constitutive behaviour of mixtures of deformation mechanisms and of mineralogies with a range in grain sizes. This enables the stress strain curve for the bulk material to be followed during recrystallisation and/or mineral reactions and hence for the evolution of σ, h and m to be tracked along with identification of the critical conditions for localisation.

We discuss the conditions for localisation in a granitic lower crust and for the initiation of subduction zones in the oceanic lithosphere. In particular, one can define a critical (cool) lithospheric geothermal gradient for deforming/reacting lithosphere that enables a through-going shear zone to develop.

The Papuan Orogen: a misplaced Mesozoic belt of the Tasman Orogenic Zone?

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The tectonic framework for the Tasman Orogenic Zone of eastern Australia is well established as an overall convergent plate margin from the Cambrian to the Middle Triassic. From the middle Cretaceous to the present, an extensional tectonic regime developed, leading to breakup of the eastern continental margin. Although the nature and duration of these two tectonic regimes are well established, the intervening Late Triassic to Cretaceous period is largely missing from the geological record of mainland eastern Australia. The leading explanations for this gap in the geological record often appeal to crustal extension and subsidence to transport these rocks to the east and offshore, where they are now submerged and of unknown character. New findings from an evaluation of regional zircon provenance in Papua New Guinea and West Papua may offer a new solution to this problem. A compilation of detrital and inherited zircon age populations in Papua New Guinea and West Papua demonstrate that the Papuan Peninsula of Papua New Guinea, together with the northern terranes of mainland New Guinea, are allochthonous to the northern margin of the Australia continent, and were instead derived from eastern Australia. These findings imply that much of the New Guinea landmass first developed adjacent to the eastern margin of the New England Orogen, and as part of the Tasman Orogenic Zone. Significantly, these basement inliers preserve a semi-continuous record of magmatism from the Late Triassic to the Cretaceous. Not only do these results provide a solution to the missing Mesozoic record of eastern Australia, they also provide the first direct evidence for a long-lived convergent margin to the east of Australia during this time, herein termed the Papuan Orogen. If correct, these findings mark a significant advance in our understanding of the Mesozoic evolution of the eastern Australia Tasman Orogenic Zone and necessitate a major revision of southwest Pacific plate tectonics.

Magnetotellurics – imaging lithospheric architecture and linking to mineral potential in northern Australia

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The Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) is a collaborative national survey that acquires long-period magnetotelluric (MT) data on a half-degree grid spacing (approximately 55 km) across the Australian continent. This project aims to map the electrical conductivity/resistivity structure in the crust and mantle beneath the Australian continent. Geoscience Australia has a significant investment in AusLAMP and is a key contributor to the delivery of this national program.

Geoscience Australia, in partnership with State and Northern Territory Geological Surveys, has also undertaken regional-scale MT surveys, along onshore deep reflection seismic transects and in potential mineral and energy provinces across the country. The targeted signal range is audio and broadband MT, which provide an investigation depth from tens of metres to tens of kilometres. These data provide new insights into basement architecture, crustal architecture and resource potential in these regions.

We will present some new models and results from AusLAMP data and regional survey data from the Northern Territory and Queensland, which show a remarkable correlation between conductive anomalies, crustal-scale boundaries and the distribution of giant mineral deposits. For example, the Carpentaria Conductivity Anomaly at the eastern margin of the Mount Isa Province characterises the position and geometry of the ancient Gidyea Suture Zone. The distribution of known gold and copper deposits shows a close spatial correlation with the suture zone, indicating that this structure is potentially a fundamental control on iron oxide–copper–gold (IOCG) deposits in its vicinity. The implication is that crustal-penetrating structures act as potential pathways for transporting metalliferous fluids from the lower crust/upper mantle to form mineral deposits in the upper crust.

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Multiscale 3D geological model of the Yalgoo Dome through subsampling of vector maps based on stratigraphic hierarchy

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Three-dimensional (3D) geologic models have become important in geological studies as they have been proven to be effective in visualizing geology in 3D space, communicating geological information and predicting geological properties and behavior. In the mineral sector, it is more common to produce singular static models created with geologic data upscaled and/or downscaled to a predetermined scale appropriate for a specific purpose. This limits the meaningful geologic information provided and increases the inherent risk involved in relying on the model to make informed geological assessments, since:
a) Upscaling data loses information to fit a model,
b) Downscaling data depends on interpolators to fill in missing data,
c) Scaling methods are driven by assumptions that are not necessarily consistent with the geological understanding.

To optimize the existing static models, geological modelling is going towards integrating multiscale datasets into one model wherein data could be subsampled and dynamically visualized in a particular scale optimal to the desired purpose.

In this paper, we present the initial findings of generating a multiscale model for the Yalgoo Dome through subsampling geological 2D vector maps, particularly from the 500K data-rich geologic mapping of the Murchison Domain by the Geological Survey of Western Australia (GSWA). The Yalgoo Dome is a mineralized and lithologically diverse elliptical dome, located in the western Youanmi Terrane, Yilgarn Craton. It is made of concentric distribution of a magmatic core, multiple granitoid intrusions, bordering greenstone sequences and transpressive shear zones to the east that host syntectonic metagranitic suites. Both greenstones and syn-granitoid intrusions are intruded by posttectonic granites.

The multiscale model is built through systematically subsampling the vector maps (ESRI shapefile .shp format), ensuring 3D sample representativity and preserving heterogeneity. These vectors contain the stratigraphic hierarchal information, such as for each polygonal feature, the corresponding unit name, formation, group/suite, supergroup/supersuite, and so on. The upscaling workflow includes simplifying the geometry of these vectors and considering crucial vertices critical to keeping the topology. The workflow is tested using varying simplification and aggregation algorithms and tolerance limits built-in to ArcGIS. The bedding plane measurements collected by the GSWA in the Western Australia Rocks database (WAROX) are also subsampled depending on the scale of interest. Using the resulting simplified polygons and the associated bedding orientations as inputs into the GeoModeller software, the resulting 3D geological models are created. These resulting models are used to describe the implications and constraints of the subsampled input to the output. In addition, the uncertainty associated with the models is also quantified using the CURE Engine.

Multiscale subsampling using hierarchal filters demonstrates direct effects on how we visualize the geology. It also provides a new approach to refine geological understanding of the region by modelling the stratigraphy, relative ages of emplacement, and showing how these relate to the crustal architecture of the Youanmi Terrane. Moreover, this same workflow can be extended and applied to implement other categorical and numerical filters.

Keywords
multiscale analysis, geological modelling, stratigraphic hierarchy, Yalgoo Dome

Tectonic and isotopic evolution of the Dharwar craton, south India: insights from archean magmatic and meta-igneous zircon U-Pb, REE and Hf isotopes

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The initiation of modern style plate tectonics on earth is debated to have occurred during the Archean era. The Dharwar craton in south India is an archean terrane about which, various tectonic models have been proposed to explain the continental growth and tectonic history involving the western and eastern domains within the craton (WDC and EDC). U-Pb and Hf isotopic studies from zircons sourced predominantly from detrital sequences and limited coverage of magmatic basement gneisses and other granitic suites have been used to explain the contrasting crustal processes within the WDC and EDC. Recent studies show the presence of a new crustal domain within the Dharwar craton termed as the central Dharwar (CDC). In this study, we have obtained U-Pb, Rare earth element (REE) and Hf isotopic data from zircons collected from magmatic and meta-igneous suites all across the Dharwar craton to create a more robust archean crustal evolution model integrating previous data. The U-Pb data captures various stages of Tonalite-throndhjemite-granodiorite (TTG) gneissic accretion in the WDC at 3.4 Ga and 3.2 Ga, the CDC at 3.3 Ga and 3.0 Ga and following transitional type TTGs in the EDC from 2.7 – 2.6 Ga. The granitic bodies within the WDC were dated at 3.0 Ga, 2.6 Ga and CDC at 2.6 Ga, 2.55 Ga. The REE compositions from the same zircons were used to infer depth of crystallisation compared to the plagioclase stability field. The $(La/Yb)_N$, $(Gd/Yb)_N$ ratios in zircons were cumulatively used to reveal the timing of crustal thickening associated with deeper partial melting of the source to produce the TTG domains around 3.2 Ga and 2.6 Ga. The combined εHf plot from all the terranes reveal that crustal growth and recycling was continuous and coeval within the WDC and CDC until 3.0 Ga. Crustal recycling continued in CDC till 2.55 Ga with continental crustal input. The 2.6 Ga potassic granites arise from a juvenile source with a T_{DM}^C = 3.0 Ga. The εHf values from the transitional TTG gneisses on the north of Dharwar craton show that crustal growth in EDC originated from a juvenile source with T_{DM}^C = 2.9 Ga and accreted coexisting WDC and CDC as a separate crustal domain on the east of Ramagiri greenstone belt which is proposed to be the boundary between the CDC and EDC in the northern side of Dharwar craton.

The Old Wrench: a 300 my history of strike-slip and oblique-slip reactivation, and inversion along the northern Australian margin from the Permian to the present

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Australia's northern margin hosts a series of Phanerozoic sedimentary basins collectively known as the North West Shelf. Their polyphase history, dominantly extensional, and closely associated with the breakup of Eastern Gondwana, includes the early formation of intracratonic basins (from the mid-Devonian), overprinted by Permo-Carboniferous multi-mode rifting that generated the dominant NE-trending structural trends that persist to the present-day. Subsequent Mesozoic extension, associated with the formation of abyssal plains, further refined the margin. Phases of rifting and resultant basin type appear strongly controlled by Precambrian (possibly Palaeoproterozoic) structural trends, which link to the Moho.

During this polyphase rift history, at least 12 periods of inversion have punctuated the margin, from the Carboniferous to the Neogene, with structural inheritance a key factor in controlling inversion locations. These various events, recorded across most of the North West Shelf, caused inversion, folding, uplift and erosion, often resulting from right-lateral oblique inversion. Structural restorations and palaeostress determinations indicate that strike- or oblique slip would be the dominant reactivation mechanisms during reactivation and inversion, given the orientation of the dominant faults.

At present the North West Shelf hosts both active and passive segments and is also strongly controlled by right-lateral oblique reactivation mechanisms. Present day strike-slip geomorphology and strike-slip focal mechanism solutions from earthquakes since 2000 also support a strongly strike-slip margin at the present time.

So the NWS has experienced repeated shortening events from the Permian to the Present, during an overall extensional history, punctuated by numerous inversion episodes. Most inversion episodes since the Permian have involved strike- or highly oblique-slip, a situation that persists to the present. The present-day strike-slip focal mechanisms may be indicative of a second-order stress system controlling the NWS.

Dynamic uplift – mantle flow, asthenospheric temperature anomalies or lithospheric thickness?

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Dynamic topography is increasingly recognised as a significant contributor to global surface elevations. Depending on the geological setting, surface topography could be generated either isostatically through crustal thickening, thinning of the lithospheric mantle or ponding of hot, buoyant asthenospheric mantle beneath the plate, or by active mantle upwelling. Here, we investigate the formation mechanisms of dome-shaped topographic features, which are observed globally in both continental and oceanic settings. Such domes are typically up to 2000 km in diameter and 2 km in elevation. Many have approximately circular planforms and semi-radial drainage patterns where sub-aerially exposed. Other common features include positive long-wavelength free-air gravity anomalies, regular to mildly thinned crust, coincident slow shear-wave velocities in the underlying mantle, and evidence of significant uplift in the recent geological record. Some domes also exhibit volcanic activity at their centre, which is often of basaltic affinity. In this study, we focus on three of these domes, located in North America, southwest Africa and northeast Brazil. We collate disparate observations from river profile analysis, sedimentary architecture and uplifted marine terraces to place quantitative constraints on the history of uplift. We estimate the excess temperature and depth range of melting using the geochemistry of volcanic rocks. We derive present-day upper mantle temperatures from seismic tomography models and construct palaeo-geotherms using mantle xenoliths from kimberlite pipes. By integrating these independent and diverse observational constraints, we can investigate the relative importance of different mechanisms of topographic support, with implications for the origin of other prominent anorogenic topographic domes on Earth.

Integrating isotopic signatures and geodynamic numerical models to fingerprint geodynamic settings

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In this study, we introduce a new approach to predict the Hf-isotopic evolutionary pattern for rifting and collisional settings based on the integration of numerical models and 176Hf/177Hf isotopes. Two critical factors are considered to estimate the Hf isotopic evolution trends for specific tectonic settings: (1) the source components of magmatism; that is the ratios between juvenile melts and recycled continental crust estimated by geodynamic numerical modeling; (2) the source isotopic compositions; that is the 176Hf/177Hf ratio of depleted mantle and continental crust through time which is estimated from a global compilation and radiogenic production calculations. The geodynamic numerical models allow us to estimate the proportion of juvenile mantle-derived material added to the crust through time. On the basis of this proportion, we calculate changing 176Hf/177Hf ratios using mixing models. We use this modeling approach in the case study region of the Halls Creek Orogen, Western Australia to elucidate its tectonic setting through time.

Predicted Hf isotopic patterns generated through this numerical approach imply that juvenile signals are observed during back-arc extension, whereas evolved signatures dominate collisional settings. The links between predicted Hf isotopic evolution, geodynamic numerical models and measured Hf isotopic evolution trend resolve three discrete stages in the tectonomagmatic development of the Halls Creek Orogen: (1) oceanic crust subduction; (2) back-arc basin formation with additions of juvenile mantle input; and (3) docking of the North Australian and Kimberley cratons resulting in the development of mixed-source magmatism formed in a collisional setting and basin closure. This approach can validate geodynamic models by isotopic datasets, which should lead to a more rigorous understanding of crustal evolution.

A multiscale investigation of a gold mineral system in the eastern Yilgarn

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The eastern Yilgarn Craton and its margins are host to the Yamarna Terrane and Albany-Fraser Orogen. This region is an area of significant mineral interest due to the presence of the recent Gruyere gold discovery and the world-class Tropicana gold deposit. Our multiscale study determines crustal structure in the region containing the Gruyere gold deposit and identifies key components of the associated mineral system (deep-penetrating fault structures, fertile zones, depositional sites) using a data integrated interpretation approach supported by machine learning on drillcore. Multiple relevant geological, petrophysical and geophysical data are used to map the lithospheric architecture between the Gruyere and Tropicana deposits in three dimensions. Machine learning provides support for geophysical interpretation by neural network clustering of geological characterisation obtained from drillcore around particular petrophysical attributes such as conductivity, density and magnetism. Machine learning results show that conductive anomalies may be linked to remanent fluid conduits and shearing observed in drill core. Density anomalies can be attributed to basaltic rocks and specific types of alteration. Magnetotelluric data identifies discrete south-plunging conductive anomalies that appear related to a deep crustal conductive zone which together are interpreted to represent conduits that facilitated transport of metalliferous fluids from a remanent fluid reservoir to depositional sites in the upper crust. This interpretation is supported by reprocessed seismic imaging which better resolves the nearer surface reflections and steeper structures and reveals lithospheric architecture permissive for fluid transport. Inversion of potential field data is integrated with the lithospheric interpretation to image the extent of greenstone belts and shear zones under Phanerozoic cover, but also reveals a potential fertile zone east of the Dorothy Hills Shear Zone. West-dipping structures, interpreted as backthrusts propogating from a mid-crustal ramp, intersect the surface to bound an as-yet unnamed greenstone belt near Yeo Lake and potential gold camp.

The state-of-play of geochronology and provenance in the Neoproterozoic Adelaide Rift Complex

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The Adelaide Rift Complex is a rift basin in South Australia that formed resultant of Rodinia's breakup and subsequent evolution of the Australian passive margin of the Pacific basin. It holds a globally significant and exceptionally well persevered Neoproterozoic–early Cambrian succession. Much work has been done over the last century delineating the lithostratigraphy and sedimentology of this vast basin. The rift complex contains evidence for Tonian syn-rift deposition, salt tecto-stratigraphy, the climate catastrophe of the Cryogenian, the Cryogenian ecosystem eukaryote take-over, microbe/algal reef development, the Neoproterozoic Oxygenation Event, the Ediacaran Acraman Impact and the Ediacaran development of large multicellular animals. Yet, the rocks are poorly dated, and the sediment provenance, and link with tectonic evolution, is remarkably poorly known.

We have created a centralised database of the currently available and previously unpublished detrital zircon geochronology for the Neoproterozoic of the Adelaide Rift Complex, highlighting where the available data is from, and where there are stratigraphic and spatial gaps in our knowledge. By treating the U–Pb detrital zircon data with data analytical techniques, we provide a first look overview of the change in provenance, and subsequently (generalised) palaeo-tectonogeography that this suggests during the Neoproterozoic. These data show a change from dominantly local sources in the middle Tonian, to dominantly far-field sources as a focussed, channelled rift-basin develops over time. This is very apparent in the NW of the basin, where Musgrave-derived sources dominate the siliciclastic supply in the later Tonian. The Cryogenian icesheets punctuate this with an ephemeral return to more local sources from nearby rift shoulders. This effect is particularly apparent during the Sturtian Glaciation than in the younger Marinoan Glaciation. In the Ediacaran, we see an increasingly stronger influence of younger (<700 Ma) detrital zircons from an enigmatic source that we interpret to be from southern (i.e. Antarctic) sources. We also note that we see a slight shift in the late Mesoproterozoic age peaks, from ca. 1170 Ma to ca. 1090 Ma, with a corresponding decrease in older ca. 1600 Ma detritus.

This work forms the basis of continuing work to improve our understanding of the geochronology, provenance and palaeo-tectonogeography of the Adelaide Rift Complex.

Shear heating during exhumation: an example from the Nordfjord-Sogn Detachment, Hyllestad, Norway

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The Nordfjord-Sogn detachment zone in South-Western Norway is a large scale (>100 km in length) brittle–ductile extensional structure of Caledonian age, which juxtaposes two distinct lithologies in the Sognefjorden area, the allochthonous Hyllestad Complex (hanging wall) against the (para)autochthonous Western Gneiss Complex (footwall). Based on phase equilibrium modelling, the aluminous garnet–kyanite–staurolite–muscovite–paragonite–ilmenite–rutile–quartz schists of the Hyllestad Complex are interpreted to record peak P–T conditions of 12–14 kbar and 620–650˚C, equating to depths of 40–50 km. Peak temperatures for the Hyllestad Complex are some 50 to 100˚C hotter than previously calculated based on conventional, and reflect a geothermal gradient that is significantly warmer than recorded by the bulk of analysed samples from the boundary of the Western Gneiss Complex and Nordfjord-Sogn detachment zone. Microshear bands, defined by fine-grained biotite and sillimanite, interpreted to be formed through top west movement of the Nordfjord-Sogn detachment zone and marginal replacement of kyanite porphyroblasts by sillimanite suggests that the rocks were exhumed along the detachment to depths of less than 20 km at high temperatures. Shear heating during exhumation is proposed to account for this thermal perturbation, in which the heat supplied was sufficient to maintain (near)isothermal conditions. U–Pb LASS geochronology of monazite grains aligned within an extensional fabric defined by quartz–muscovite–paragonite constrain the age of exhumation of the aluminous schists along the Nordfjord-Sogn detachment zone to c. 400–403 Ma. These ages provide constraints on the termination of the Scandian Orogeny within the wider Caledonian Orogeny, with termination of the high-pressure event occurring no later than c. 403 Ma to account for the advent of extension; required to create the Nordfjord-Sogn detachment zone. By c. 379 Ma the Hyllestad Complex would have been exhumed to at least 20 km to account for cooling through rutile closure temperatures at 575–600˚C with greenschist to amphibolite facies overprinting by this time. The Nordfjord-Sogn detachment zone thus has allowed for rapid exhumation through a very large (20–30 km) section of crust, allowing the preservation of high temperatures at shallow depths.

New insights into the subglacial geology of interior of Wilkes Land, East Antarctica: implications for supercontinent evolution

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Revealing ice-covered geology in the remote interior of East Antarctica remains one of Earth's last exploration frontiers. The East Antarctic rock record spans billions of years, forming one of the largest Precambrian continental shields which holds clues to understanding the assembly and breakup of supercontinents in deep time. This bedrock also provides the substrate to the ice cap, influencing the thermal state and mechanical stability of East Antarctica's largest and most vulnerable glacial drainage basins. However, less than 1% of the Precambrian shield of East Antarctica is exposed and the tectonic architecture of vast areas of the interior of the continent remains virtually unknown and only inferred largely from the projection of former conjugate geological counterparts within Gondwana.

Here we present recent advances in uncovering subglacial bedrock in East Antarctica: we focus on the Wilkes region of East Antarctica, which represent part of the Australian conjugate margin, where we used multiple datasets including, aero-geophysical data, potential field modelling and rock- and sediment-based geological analysis to provide new insights into the tectonic evolution and geological architecture of this sector of the East Antarctic Shield. Our improved knowledge of subglacial geology in western Wilkes Land will greatly inform future studies seeking to better resolve the tectonic processes that controlled the evolution of the supercontinents Columbia and Rodinia and Gondwana.

Stagnant slabs at the transition zone linked to widespread volcanism in eastern Australia and Zealandia

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The eastern margin of Australia and Zealandia has experienced extensive mafic volcanism since Australia broke away from Antarctica approximately 80 million years ago. A plume origin has been proposed for age-progressive volcanism observed in leucitite suites on the continent and the Lord Howe rise offshore. Aside from these exceptions, the majority of eruptions in the region exhibit no clear age progression. From our plate reconstruction of the Australia-Zealandia region over the last 80 million years that has most likely accumulated at the transition zone. Compilations of P and S-wave tomography add support for an anomalous transition zone in the region. The relationship between $^{143}Nd/^{144}Nd$ and $^{206}Pb/^{204}Pb$ isotopic ratios in volcanic samples suggest a high degree of lithospheric interaction that is increasingly more pronounced at high latitudes. We propose that widespread, non-age progressive volcanism results from sporadic upwellings triggered by changes in plate kinematics which entrains stagnant subducted material at the transition zone. The most pronounced pulse of volcanism occurs at ~23 Ma and coincides with an abrupt increase in plate velocity and subduction flux. This provides a framework through which to explain non-age progressive volcanism in a region of anomalous mantle composition.

Structural geology of the Horn Island gold deposit and implications for the structure and tectonics of the Torres Strait Islands

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Although the discovery of gold on Horn Island in the Torres Strait dates back to 1894, the island's fascinating history as one of Australia's key naval and air bases during both the first and second World Wars interrupted further exploration until the last few decades.

Kauraru Gold Pty Ltd was formed in 2014 to commence the most-recent exploration of Horn Island, since the collapse of the first open-pit mining operation in 1989 lead to a 20 year government-imposed Mining Restriction. Drilling to 2019 has so far established a gold resource of approximately 500,000 oz, occurring as arrays of quartz and sulphide bearing (pyrite, galena, sphalerite) tension veins and breccias. These are hosted in a ~340 Ma porphyritic intrusion (Horn Island Granite) related to the more extensive Badu Suite granites of the Torres Strait.

While mineralisation is clearly linked to these Carboniferous magmatic processes, two distinct hydrothermal stages can be defined: early (possibly syn-magmatic) and pervasive K-feldspar-hematite alteration associated with Sn, W and Mo, was followed by a later sericite-chlorite-epidote pulse synchronous with economic gold (+Pb-Zn and As-Sb). These two hydrothermal events are separated by development of an extensive shallow-dipping brittle to ductile shear zone network within the host granites.

These shear zones and weakly-developed foliation, acted as local fluid conduits for the second stage of alteration, setting up a deposit architecture where low-strain lenses of nearly undeformed granite are enveloped by anastomosing high-strain structures.

The early history of this shear zone network is still poorly defined but significant displacement and dissection of the granite intrusions likely occurred, possibly contributing to partial exhumation of the host rocks during the Late Carboniferous. In the final stages of movement on the Horn Island shear zones, rotation and slip with roughly northeast over southwest kinematics led to dilation of the enveloped granite, forming arrays of predominantly Southwest-dipping quartz-sulphide tension veins that define economic mineralisation in the main Horn Island pit.

Cessation of movement on the shear zone network is followed by a series of steep Northwest-striking brittle faults that transect Horn Island, crosscutting and locally deforming (dragging) the earlier structures. These faults are associated with the last stages of fluid alteration (silica, clay) and gold mineralisation (+As, Sb) typified by the deposit known as South Silicified Ridge.

The brittle-ductile shearing identified on Horn Island has implications for the structural geology and tectonic evolution of the wider Torres Strait Islands: Carboniferous to Permian volcanic and intrusive rocks that represent the northern-most exposure of the extensive Kennedy Igneous Province. Some initial large-scale observations and interpretations based on geophysics and bathymetric datasets are proposed.

Thermal controls on rifting regimes in earth history – insights from 2-D geodynamic modelling

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The numerical results from geodynamic modelling studies indicate that the efficiency of Earth surface subsidence is most likely to be controlled by the potential temperature of the mantle (Tp). Based on the rheology, the deformation of the rifting basin can be integrated, but not limited to, differences in: (1) the evolution of the initial magma temperature through geological time, (2) the depth to the lithosphere-asthenosphere boundary (LAB), (3) the extension rate, (4) the heterogeneous distribution of the physical and chemical proprieties of crust and mantle lithosphere. Here we present a parameter study for continental rifting, using the numerical modelling platform i2VIS. We investigate the influence of mantle potential temperature and thickness of mantle lithosphere on rift development and melting patterns in the asthenosphere as well as in the crust. We demonstrate that the existence of initial partial melt in the asthenosphere due to higher Tp has a profound influence on geometry of the rift as well as on patterns of melting. On the other hand, the partial melting level significantly reduced with the increased depth of LAB and this leads to a much lower surface subsidence rate under equivalent temperatures. The decline in mantle temperatures during the Archean to Proterozoic is inferred to result in a transition from predominantly vertical to horizontal tectonic processes. Based on our simulation results, we suggest that changes in magma temperature provide the main driving force to control the occurrence and deformation efficiency of the rifting regime (horizontal tectonics), and also prove that the vertical tectonics is likely to have happened under a higher subsidence rate in early hot earth.

Keywords
Geodynamic modelling, Basin Rifting, Archean tectonics, Visco-elasto-plastic rheology

Syn-rift basin inversions and the interplay between tectonic extension, surface processes, and gravitational stress

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Continental rifting is the result of divergent forces acting on tectonic plates and driving extension, normal faulting and subsidence. This process leads to the formation of rift basins and conjugated continental margins where terrigenous and marine sediments accumulate. In this divergent tectonic context, it is surprising to frequently observe short transient episodes of basin inversion in the form of basin depth uplift, contractional re-activation of normal faults, broad low-amplitude folds and long-wavelength shallow-angle unconformities. Often, these transient episodes of basin inversion cannot be related to far field compressional stresses or changes in plate motion. The gravitational body force caused by the buoyant asthenosphere upwelling beneath the rift has often been proposed to explain short-term, spatially localised episodes of compression. Understanding the cause, timing and spatial pattern of inversions along passive margins is critical for hydrocarbon exploration, given their important roles in the formation of structural traps. Using high-resolution 2D numerical experiments of the full rifting process including surface processes allows we have quantified the dynamic interplay between far-field tectonic forces and internal gravitational body forces. We observe that during continental rifting compressive stresses reach a magnitude of 10 to 30 MPa. Interestingly, our experiments show that deep sedimentary basins tend to localize transient episodes of compression, and experience a sharp switch in basement vertical motion from subsidence to uplift up to 2 km. The rift region and the forming continental margins are under the influence of the sediment accumulation, which drive and localize locally derived horizontal gravitational compressional stresses, and horizontal gravitational stresses due to the doming of the asthenosphere. The reduction in sediment supply due to the increasing distance of the continents allows for the acceleration of the doming of the asthenosphere, which promotes both a switch from subsidence to uplift (i.e. the break-up unconformity) as well as a change from extensional to compressional stress at the time of break-up.

Assessing structural variability from geological and geophysical data in the western Wabigoon subprovince, Ontario, Canada

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In the early stages of mineral exploration, ground selection tools are applied to narrow search regions to prospective areas. Traditionally, exploration has relied heavily on manual, time-expensive, human interpretation and the success or failure of a project depends on the experience of current geoscientist. Therefore, applying methods that are efficient in identifying geologic features while minimizing human bias from interpretation can increase the success of an exploration program. For orogenic gold deposits, integrating geological observations and geophysical datasets highlights structurally complex zones that may have acted as fluid pathways or traps and provides insight into regional-scale structural features. This study investigates the use of combined structural variability analysis in an Archean greenstone belt of the Superior Province, near Dryden, Ontario. Spatial variability of lithologies, strike and dip of bedding, and the trend of automatically detected linear magnetic anomalies were calculated. The resulting grids show regions of structural complexity where fluids may have been trapped, identify major deformation zones, and define regional fold traces. These results can be used to improve geological maps, characterize structural domains, and indicate favourable targets for base and/or precious metal exploration. Future work will include defining optimal grid resolution and search radius for variance calculations to identify targets and characterize regional structures accurately.

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Subduction dynamics, continental collision and the formation of cratons

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In the modern Earth, processes such as accretion and continental collision are driven by the combined buoyancy forces along the length of subduction zone acting to overcome the resistance in the congested section [Moresi et al, 2014; Betts et al, 2015]. This is a way that we can amplify the typical stresses available to drive accretion and orogeny if we only consider a vertical cross section of the subduction zone and this can be helpful in understanding the dynamics interaction of plate tectonics, mantle flow and continental deformation.

It is interesting to consider whether this amplification would be similar in the early Earth and consider if it would be a way to supply sufficient stress to construct a long-lived craton. Tectonic origins for the cratonic lithosphere have been favoured in recent discussions but there are reasons to suspect accretion and crustal thickening would have been more difficult under Archean conditions. We expect convective stresses to be lower for the early Earth which had internal temperatures that were higher and viscosities that were lower. Furthermore, the viability of subduction itself in the Archean Earth is still a subject of debate due to the need for thinner cold-boundary layers to “outweigh” a thicker oceanic crust formed at high temperatures. Numerical models suggest subduction would have been thermally and mechanically viable in the Archean but slabs would have been weaker and more prone to break-off [van Hunen and Moyen, 2012].

Very early in Earth’s evolution, a heat-pipe mode of convection might have been favorable — this is a form of stagnant lid convection in which the internal heat is lost by magmatic pipes by-passing the lithosphere and depositing magma at or near the surface. A stagnant lid with the right combination of intrusive and extrusive heat-pipe magmatism, is potentially capable of satisfying the thermal and petrological constraints for the early Archean Earth. [e.g. Moore and Webb (2013), Rozel et al, (2017)]. These models naturally become unstable with respect to mobile-lid convection models as the level of internal heat production decreases.

We conjecture that the transition phase between stagnant lid and a mobile-lid or plate-tectonic style of convection is capable of building or assembling the cratonic lithosphere and not just destroying the stagnant lithosphere. The stresses during the collapse of the thick, stagnant lid can be significantly higher than the convective stresses in either the steady, stagnant lid or the mobile-lid convective regimes (figure 2 B). We discuss these models and compare the deep lithospheric structure with that which occurs when growth is driven by lateral accretion. This builds upon previous studies by Beall at al (2017).

References

Beall, A. P. J. (2017) Gravitational Instabilities Beneath Continents, PhD, University of Melbourne.

Betts, P. G., L. N. Moresi, M. S. Miller, and D. Willis (2015), Geodynamics of oceanic plateau and plume head accretion and their role in Phanerozoic orogenic systems of China, Geoscience Frontiers, 6(1), 49–59, doi:10.1016/j.gsf.2014.07.002.

van Hunen, J., and J.-F. Moyen (2012), Archean Subduction: Fact or Fiction? Annu. Rev. Earth Planet. Sci., 40(1), 195–219, doi:10.1146/annurev-earth-042711-105255.

Moore, W. B., Moore, W. B., and A. A. G. Webb (2013), Heat-pipe Earth, Nature, 501(7468), 501–505, doi:10.1038/nature12473.

L. Moresi, P. G. Betts, M. S. Miller, and R. A. Cayley (2014), Dynamics of continental accretion, Nature, 508(7495), 245–248, doi:10.1038/nature13033.

A. B. Rozel , Golabek, G. J., C. Jain, P. J. Tackley, and T. V. Gerya (2017), Continental crust formation on early Earth controlled by intrusive magmatism, Nature, 1–12, doi:10.1038/nature22042.

Crustal architecture of the inter-plate region between the Pilbara and Kimberley cratons and implications for its geodynamic evolution

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The Paterson Orogen is a Paleo- to Neoproterozoic northwest trending orogenic belt that is interpreted to record the effects of plate margin tectonism between the West Australian Craton (WAC) and North Australian Craton (NAC). However, the boundary between these cratons, the nature of the intervening crust, and the age of amalgamation remain contentious scientific issues. Here we apply a seismically-constrained gravity inversion method focusing on imaging the deep crust between the WAC and NAC, with the aim to characterise the Proterozoic crustal evolution of the Paterson Orogen and related regional components. We present an initial 3D 11-layered model, discretised into close-packed vertical rectangular prisms with a variable vertical cell size. Multiple surfaces were used to build the model: sea surface, topography, the Phanerozoic and Proterozoic sedimentary basins depth, 5 crustal density iso-surfaces, the Mohorovičić Discontinuity, and two mantle surfaces at 50 and 75 km depth.

The results show distinct crustal domains defined by density signatures, basement thickness, and Moho depths. The first domain is characterized by a thin crust (~30 km depth) with an average density of 2.70 g/cc, associated with the Archaean Pilbara Craton. The second domain relates to the Kimberley Craton, with a 44 km depth for the Moho and an average density of 2.92 g/cc for the meta-igneous rocks of the Central Zone in the Lamboo Province and associated high-grade metamorphic rocks, and a lower density response for the other units of the Craton (~2.82 g/cc). The high density anomaly and associated high-grade metamorphism in the Central Zone of the Lamboo Province could be linked to the mafic-ultramafic magmatism during marginal basin development. The crust underneath the Canning Basin exhibits three distinct domains:

a) The Kidson Sub-basin region carries a medium to high density crustal signature of approximately 2.85 g/cc and a 37 km depth for the Moho. The basin is relatively deep (5–8 km) and the crust is thinner (32–35 km thick). The density signature suggests a different composition from the rest of the covered basement in the region, perhaps suggesting the presence of widespread intermediate to mafic intrusive rocks. The low-density signature to the northeast of this basin suggests felsic magmas emplaced into the basement, possibly during the 1080–1040 Ma Giles Event.
b) The domain underneath the Fitzroy Trough/Gregory Sub-Basin is characterized by a 900 km NW-SE trend with a vertically averaged density of 2.98 g/cc and relatively thin crust (~30 km depth). The high density crust in this portion has been interpreted to reflect the remnants of an accretionary complex composed of various high-grade lithotypes, including metasedimentary rocks, mafic to ultramafic volcanic rocks, and possibly an ophiolite belt resulting from the collision between these two terranes.
c) The domain corresponding to the Broome Platform and Willara Sub-basin region is characterized by average low to intermediate density crust of 2.78 g/cc interpreted to result from intrusion of felsic magmas into the crust in this region. The northeast side of the Broome Platform, however, represents a thickened crust possibly in response to the collision. The Paterson area shows a density high gradient zone separating the Talbot/Connaughton terranes from the Tabletop Terrane, coincident with the Camel-Tabletop Fault. This terrane has an average density of 2.85–2.91 g/cc, higher than the other two, and consistent with the presence of extensive unexposed mafic rocks within its limits. This behaviour is repeated through Yeneena Basin to the northwest. The Talbot and Connaughton terranes show an intermediate to low average density of 2.74–2.84 g/cc, similar to that of the Archaean Pilbara Craton. Overall, results reveal a block with a distinct density signature and thickness in the region underneath the Kidson Sub-basin that may be key to the development of new geodynamic models for the region.

Metamorphic architecture of the Mount Woods domain, northeastern Gawler Craton

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The Mount Woods region, in the northern Gawler Craton, is located proximal to the large IOCG deposit Prominent Hill and is therefore a prospective region for mineral exploration. Prominent Hill formed at c. 1580 Ma, coeval with voluminous magmatism and the formation of a large, craton-wide mineral system. Samples from localised regions of outcrop in the southern Mount Woods Domain suggest that the region was at depths of >12 km during this mineralising event, meaning there is little preservation potential for any mineral deposits that formed coevally in the upper crust. However, the Mount Woods Domain contains a series of fault-bound domains that are not exposed and so have not been the subject of geochronology or metamorphic analysis. If these domains remained at upper crustal levels during the c. 1580 Ma event, they may be prospective for mineralisation.

New LA-ICP-MS U–Pb monazite and zircon geochronology collected from a number of shear-bounded blocks throughout the Mount Woods Domain identifies the presence of widespread c. 1730–1690 Ma (Kimban Orogeny-aged) metamorphism in the central Mount Woods region. This event defines the metamorphic character of the central Mount Woods Domain. Calculated phase diagrams suggest that Kimban-aged metamorphism reached conditions of 4–5.5 kbar and 800–850 °C. These samples contain no convincing petrographic or geochronologic evidence for high-grade reworking at c. 1580 Ma. The Kimban-aged domain is bound to the north and south by rocks that record younger (c. 1560–1470 Ma) metamorphic ages. Metamorphic P–T constraints from these samples suggest peak conditions of 4–5 kbar and 750–780 °C.

The new data from the Mount Woods Domain can be interpreted in two ways. One alternative is that the older ages may reflect older domains that remained in the upper crust and were juxtaposed against high grade c. 1580 Ma rocks after peak metamorphism. Alternatively, the older ages may reflect domains that experienced the c. 1580 Ma event but were unresponsive. Distinguishing between these alternatives has significant implications for prospectivity. Terrane-scale in situ Rb–Sr geochronology from biotite is a new technique that can be used to rapidly map out the cooling and exhumation history of the terrane away from the large-scale shear zones. Samples from across the Mount Woods Domain yield a range of Rb–Sr isochron ages from c. 1700–1520 Ma. The preservation of older biotite Rb–Sr ages suggests that some regions of the Mount Woods Domain may not have experienced high temperatures during the c. 1580 Ma event, and therefore these regions may be the most prospective for mineral exploration.

An Integrated study on Cleavage development in the contractional zone of a Paleo- Mesoproterozoic sedimentary cover deformed by gravity gliding: an example from Kaladgi Basin, south western India

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The Paleo-Mesoproterozoic sedimentary cover of the intra-cratonic Kaladgi basin in south-western India exhibits a deformation style that is due to southward gravity gliding of the cover along a detached unconfomity. This resulted in the development of an up-dip extensional deformation zone and a down-dip contractional deformation zone within the cover. The development of rock cleavage in the contractional zone of the cover has been investigated in terms of, mode of occurrence, distribution, geometry, morphology, microstructure, grain scale deformation mechanisms, strain, timing of development in relation to associated mesoscale folds, thermobarometry, crustal depth of development and origin of cleavage.

Cleavage occurs in the study area both as continuous and spaced type. Continuous cleavage is developed in the argillites and is defined by the preferred orientation of phyllosilicates that are distributed evenly throughout the rock and define a slaty cleavage. Relatively coarse cleavage occurs in limestones where the cleavage is defined by the dimensional preferred orientation of calcite grains in the cleavage domains that anastomose around microlithon domains. Spaced cleavage occurs in quartzites, limestones, and dolomites. Spaced cleavage in quartzites is anastomosing, rough, and fairly continuous along the strike whereas in limestones and dolomites, such cleavage is parallel, relatively smooth, and continuous along length. Spaced disjunctive cleavage in limestones and dolomites is frequently associated with profuse pressure-solution seams against which compositional laminations are offset when the bedding and cleavage intersect at acute angles. The spaced cleavage in quartzites is characterized by a domainal fabric with cleavage domains defined by dark seams that display concentrated opaques and fine grains of muscovite. The microlithon is composed of quartz grains that show a moderate to strong dimensional preferred orientation. Cleavages in the study area are axial planar to the associated folds and generally strike ESE–WNW to E–W with dips ranging 35°−85° due SSW to S or NNE to N. Detailed analysis of cleavage-fold relationships in the Mesoproterozoic cover sediments of Kaladgi basin, south western India, revealed three types of timing relationships between cleavage and folds: (1) cleavage developed earlier than folds. (2) Cleavage developed later at some stage of folding and (3) non-development of cleavages in folds. The final geometry of cleavage in relation to folds at any location is a combined effect of relative timing of cleavage development and mechanism of folding that involves layer parallel shortening, flexural slip, tangential longitudinal strain, syn- to post- fold flattening and hinge migration.

Flattening type strain is associated with cleavage development and shortening orthogonal to the cleavage range ~10–40%. Cleavage microstructures indicate a combination of three deformation mechanisms — crystal plastic deformation, pressure solution and dynamic recrystallization are related to cleavage development. Illite crystallinity index study from cleavage bearing argillites from various stratigraphic levels range between $0.54°\Delta2\theta$ and $0.24°\Delta2\theta$ (in a set of thirty seven samples) and indicate a deep diagenetic to high anchizone metamorphic grade reflecting a temperature range of ~180–300 °C. Using the recrystallized quartz grain-size palaeopiezometer from the folded and foliated quartzites of the sedimentary cover of the basin, it is deduced that the deformation of the cover had occurred under layer-parallel compressive differential stresses that range ~35–96 MPa. Using practical values of strain rate, temperature, water fugacity, geothermal gradients and differential stresses that are appropriate for Kaladgi basin and using the flow laws applicable to naturally deformed quartzites, the representative crustal depth of cleavage forming deformation of the sedimentary cover of the basin at the sample point is estimated to be in the range of 5.61–7.55 km.

State of the arc: long-wavelength geophysics and Macquarie Arc basement

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Ordovician to early Silurian calc-alkaline volcanic, associated intrusive, and shallow-marine sedimentary rocks comprise the Macquarie Arc in the Lachlan Orogen. Although Pb-isotope ratios and positive εNd indicate an intraoceanic setting, there is no consensus regarding its tectonic setting. The range of proposed tectonic models include:

1. Simple intraoceanic models, in which subduction initiated in the Ordovician over a west-dipping subduction zone, an east-dipping zone which later reversed polarity, or a south-dipping zone within a back-arc which later rotated anticlockwise. According to these models the Macquarie Arc should have a basement dominated by ocean-floor MORB;
2. Two-stage intraoceanic models, in which the Ordovician arc developed on an earlier east-dipping Cambrian arc that arose in the palaeo-Pacific and reversed polarity after collision with Gondwana. In these models the Macquarie Arc should have a basement of intermediate composition;
3. The Lachlan Orocline model, which suggests the Macquarie Arc arose close to the Cambrian convergent margin of Gondwana, and so is likely to include portions of Cambrian arc (or even slivers of cratonic Gondwana) in its basement;
4. Or in a very different viewpoint, the Macquarie 'Arc' may have been an extensional system in a back-arc, far behind the frontal arc located outboard of the New England Orogen. These models should have a relatively thin suite of calc-alkaline rocks over MORB basement.

Seismic reflection and refraction surveys across the arc, with corresponding potential-field models, have previously been interpreted to indicate a MORB-like basement, consistent with models of type 1 and (arguably) 4. However, the petrophysical parameters used in the models are inconsistent with this interpretation. Long-wavelength, deeply sourced signals from a variety of geophysical techniques can clarify the composition of the basement, and these differing datasets show remarkable agreement. Long-wavelength aeromagnetic features qualitatively indicate a basement of comparatively low magnetic susceptibility, and quantitative modelling limits this to values typical of intermediate intrusive rocks characteristic of either mature arc or continental basement. Seismic velocity from the AuSREM model maps out a belt of low Vp in the mid- to lower crust, again consistent with an intermediate chemistry, which corresponds closely to the areas of magnetic susceptibility lows. Both datasets indicate along-strike variation in basement character, with 'mafic' properties characterising the southern part of the arc. The boundary between intermediate and mafic basement roughly coincides with the Lachlan Transverse Zone (LTZ), a WNW–ESE-trending belt distinguished by a change in the structural trend of the arc and a concentration of Cu–Au mineral deposits. The LTZ itself appears to be marked (within resolution limits) by a local Vp minimum. Long-wavelength, long period MT signals recorded by the AusLAMP array map out conductivity highs that continue from mid (10 km) to lower (20–30 km) crustal depth and broadly correspond to the Macquarie Arc, and again the LTZ represents the strongest development of this feature.

Petrophysical properties with an intermediate composition in the middle and lower crust below the Macquarie Arc are incompatible with a MORB-like composition, and require the basement of the Macquarie Arc to be either a pre-existing arc, a continental fragment, or a very thick arc in which little of any original seafloor remains in situ. Models of types 1 and 4 are therefore ruled out. The recently reported finding of Cambrian zircons from Macquarie Arc rocks is consistent with either models 2 or 3, but Pb isotope links between the Macquarie Arc and the forearc of the Cambrian Mt Wright Arc on the Gondwana margin suggest support for a version of model type 3, the Lachlan Orocline model.

Kinematic plate reconstruction of New South Wales using Leapfrog and GPlates

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Plate reconstructions are considered key in understanding past tectonic activities, mantle morphology, hotspot drifting, true polar wondering (Gurnis et al, 2011), formation and evolution of basins, mineralogical studies and orogeny's. Having a visualisation of past activity is necessary for the construction of a worldwide geological history and how movement along plate boundaries have governed past processes, thus increasing our understanding of future geological phenomena (Holm et al, 2016). Research has been done regarding plate reconstructions worldwide (see Jingbin et al, 2000, Bugge et al, 2018, Duran et al, 2013) but minimal work has been done in producing a detailed model for New South Wales, Australia. This project aims to bridge this gap by creating a kinematic, 3D plate tectonic model of NSW geology from the Devonian until present time, utilising Leapfrog and GPlates software. Data was acquired from the Geological Survey of NSW and involved fault attribute, state-wide depth to basements, gravity and magnetic resonance data. The fault attribute data was pre-placed in a hierarchical fashion with first order faults representing large deformation, contraction and extension events. Only first order faults were extracted for the basis of this model in the interest of time. The fault, gravity and magnetic (grav/mag) data were imported into Leapfrog to create a static 3D model representing major fault systems. From this model, a series of cross sections were generated in Leapfrog which showed state-wide basins and how faults have influenced them in present time. A backstripping formula was then applied to each cross section to visualise how basins have formed over time given the fault constraints, before loading into GPlates. Upon loading into GPlates, the reconstruction was created using a series of time slices generated from both the cross-sections and backstripping from the Devonian till present. By creating this visualisation, we can place Eastern Australia into the global context of movement and how the geological processes here have affected global movement.

Distal footprints of the Alice Springs Orogeny – Thermochronology of the Pine Creek Orogen, Northern Territory

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The Pine Creek Orogen, Northern Territory, is one of the few remaining basement terranes in Australia for which there is no available apatite fission track (AFT) data. High- to medium-temperature constraints for pre-orogenic sedimentation, peak orogenisis and metamorphism in the Paleoproterozoic are reasonably well established, however, subsequent evolution of the orogen remains poorly understood. This study presents the first AFT data for the Pine Creek Orogen, using samples from the Cullen Supersuite granite and Plum Tree Volcanics in the Central Domain of the orogen, focussed around the NW striking Pine Creek Shear-Zone. Three samples were also analysed for apatite (U-Th-Sm)/He (AHe) data to supplement modelling. Thermal modelling was conducted using QTQt, and produced consistent thermal histories across the study area. Samples display a significant cooling event through APAZ temperatures (60–120 °C) at ~350 Ma, coinciding with the Alice Springs Orogeny in central Australia. It is therefore proposed that observed Carboniferous cooling in the Pine Creek Orogen was a response to significant exhumation in the region as a response to uplift in the orogen driven by the distal Alice Springs Orogeny. Overburden was removed from above rocks previously buried deeper in the crust as uplift facilitated increased rates of erosion, allowing cooling of exhumed units. In this study we therefore propose that deformation during the Alice Springs Orogeny had a much broader influence on the Northern Territory than previously reported, and was responsible for significant uplift more than 1000km from the locus of deformation in the Arunta Region and Amadeus Basin. Following uplift induced cooling in the Pine Creek Orogen in the Devonian – Carboniferous, sample locations are interpreted to have reached the surface (or near surface) following the termination of the Alice Springs Orogeny. Unconformable sediments of the early Jurassic Plover Formation preserved as remnant islands across the orogen indicate the presence of an erosional surface in the Central Domain. Thermal history modelling suggests that after the basement exhumed to the surface, subsequent shallow deposition in the Pine Creek Orogen induced minor burial and reheating. This reheating phase terminated when the sedimentary overburden was removed during the late Cretaceous.

A nonlinear theory of structures in layered intrusions

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Layering is common in many intrusions, for example Stillwater, Skaergärd and the Bushveld. The explanations for layering are many and diverse but most depend on hypotheses centred around (episodic) crystal settling to form a crystal mush at the base of an intrusion and/or multiple intrusive events. The precise form and distribution of layering developed by such mechanisms are not explained by these hypotheses. We explore a nonlinear process for layering formation in which strong coupling exists between magma flow, mineral reactions and diffusion processes during cooling of the Bushveld complex. The process we explore is shear banding which is well documented in polymer melts and a range of other fluid/solid mixtures. Shear banding takes two forms, namely, gradient banding where layering develops parallel to the shearing plane during simple shearing, and vorticity banding where layering develops normal to the shearing plane and parallel to the shearing direction. Superimposed on this classification in some systems is a concentration dependence on strain rate. The Bushveld layering appears to be a form of gradient banding with concentration dependence. Shear banding of the type discussed here is a phase transition whereby an initially homogeneous suspension spontaneously separates into layers once a critical shear strain is reached. The phase transition is driven by a compositionally dependent viscosity. Microstructures, geometry and organisation of layering and associated structures in the Bushveld are consistent with the layering originating as shear band instabilities in a shearing crystal mush. This includes the multifractal geometry, splitting and coalescence of layers, “pot-holes” and viscous fingering. Any further progress relies on establishing the detailed geometry, and hence the dynamics, of the layers.

Multi-scale structural analysis of the Fraser Shear Zone

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The northeast-trending, approximately 350 km long Fraser–Harris Lake Shear Zone separates the Ni–Cu mineralised, metagabbro-dominated Fraser Zone from the felsic orthogneiss-dominated Biranup Zone in the east Albany–Fraser Orogen, Western Australia. The interpretations of deep crustal seismic reflection line 12GA-AF3, combined with gravity modelling have revealed the crustal-scale geometry of the Fraser Shear Zone to be a moderately southeast-dipping structure that soles onto the Harris Lake Shear Zone at approximately 20 km depth. The combined Fraser–Harris Lake Shear Zone forms the crustal-scale structure that juxtaposed the Fraser and eastern Nornalup Zones against the eastern Biranup Zone, above a region of thickened crust.

Outcrops along the Fraser Shear Zone consist of migmatitic, isoclinally folded, strongly boudinaged and sheared metasedimentary rocks of the 1332–1304 Ma Snowys Dam Formation that were intruded by c. 1300 Ma dominantly mafic magmas of the Fraser Zone. Strong transposition and attenuation resulted in layer thickness ranging from 10s of meters to the millimetre-scale. Mapping and structural analysis of 3D photogrammetry outcrop models (5–100 m long x 5–30 m wide; pixel size 1–10 mm), derived from drone imagery, combined with field observations, allow for a comprehensive outcrop study between the bird and the human eye perspective revealing a complex history of dominantly reverse and dextral kinematics. The main foliation is moderately to steeply east- or southeast-dipping and contains variably plunging stretching and mineral lineations. Shear-sense indicators include S–C–C' fabrics, asymmetric boudins, asymmetric strain shadows around porphyroclasts, foliation deflection against second order high-strain zones, and asymmetric folding. The new perspective and scale of observation provided by drone technology reduces the upscaling from field observations to aeromagnetic data by one order of magnitude. However, extrapolating our interpretations to the scale of aeromagnetic data still requires at least one order of magnitude of upscaling and the dimensions of the photogrammetry models cannot resolve with confidence the relationship between lithologies and magnetic intensities. Previous studies showed that the Snowys Dam Formation and the mafic rocks are the most and least magnetic units, respectively. In high-resolution aeromagnetic datasets (40–100 m line spacing, i.e. pixel size 10–25 m), the Fraser Shear Zone is represented by thin (50–250 m), closely spaced (100–700 m apart), highly magnetic horizons that appear locally strongly attenuated, isoclinally folded and boudinaged and affected by variously oriented splay faults. The Fraser Shear Zone ranges from one to eight km in width, and in aeromagnetic data the wider areas of the shear zone display structures such as rootless isoclinal folds and boudins, and the overprinting splay faults are dominantly east-trending. These areas occur within releasing bends and thus correspond to the relatively lower strain zones; the east-trending splay faults are here interpreted as oblique faults with normal and dextral components (R-shears). The narrower parts of the shear zone contain linear, closely spaced magnetic horizons which do not commonly show any visible structures. We interpret these as areas of strong transposition and attenuation corresponding to the relatively higher strain zones. The splay faults affecting these areas are dominantly southeast-trending and interpreted as reverse faults with antithetic sinistral component (R'-shears).

At the thin section scale, microstructures, akin to their larger-scale counterparts, are key to defining the metamorphic history of the Fraser Shear Zone. The peak metamorphic assemblage of garnet–clinopyroxene–orthopyroxene–hornblende (brown)–plagioclase–quartz is only preserved in small-scale (1–5 cm) mafic boudins and indicates high-pressure granulite conditions. The S-, C- and C'-planes, associated with foliation boudinage, indicate localised fluid movements and contain variously hydrated and retrogressed assemblages consisting of garnet–clinopyroxene–hornblende (green)–plagioclase–quartz–ilmenite–melt. Further retrogression results in a clinopyroxene-free assemblage, a younger generation of green hornblende, and the retrogression of ilmenite to magnetite.

How far does it go? Investigating the extent of the Mawson Craton beneath the interior of East Antarctica using 'agrid' and multiple geophysical datasets

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The Mawson Craton, which encompasses the Gawler Craton of South Australia and the geological basement of Terre Adélie in East Antarctica, is proposed to extend a considerable distance into the interior of East Antarctica. It is likely, however, that the spatial scale of the Mawson Craton is no larger than major cratonic units of Australia. This raises the possibility of enigmatic tectonic blocks within the interior of East Antarctic that have no exposure along the coast or the conjugate plate margin of Australia. To investigate the inland extend of the Mawson Craton and the likely character of related enigmatic terranes beneath the cover of ice, we draw upon a combination of two new approaches: a probabilistic segmentation of the deep lithosphere of Antarctica, and exploratory analysis of further 3D geophysical datasets in a robust, performant computational environment.

The probabilistic segmentation is based on a newly available set of likelihood maps for boundaries within the deep lithosphere of East Antarctica, and matching maps for the segmentation of the deep lithosphere beneath Australia. These maps have been calculated by combining analyst-dependent picks of boundaries defined by multiple datasets (seismic wavespeed, gravity anomaly and large-scale sub-ice topography) in a series of qualitative operations which incorporate uncertainty. The set of six likelihood maps show lithospheric boundaries across a range of detail and confidence. The maps of East Antarctica and Australia at intermediate detail, which we use in the discussion that follows, are therefore informed by the ability to compare lithospheric boundary likelihoods in less detail (with strong constraints) or greater detail (with more limited constraints) for both continents.

Geophysical datasets constraining the interior of East Antarctica have improved as a result of the major international field campaigns of the International Polar Year (2007/08) and through the results of analyses based on satellite data. The majority of studies of the continental interior, however, are based on the analysis of a single dataset which has given rise the situation where many alternate interpretations need to be compared and/or considered together. We make use of an open source research environment, 'agrid', which provides a computing framework for data import, visualisation, processing and export. This environment enables dynamic updating to improved datasets, and the incorporation of metadata, which assists in creating probabilistic output maps. It can be computationally challenging to work with multiple datasets, especially in 3D and carrying related metadata, so the 'agrid' environment draws on technologies such as dask scaling to enable components of the python coding ecosystem to perform well together.

We combine the two newly available approaches, likelihood maps of the segmentation of the deep lithosphere and a variety of datasets handled using the 'agrid' computational environment, to investigate the extent of tectonic blocks with likely Australian affinities beneath the ice cover of East Antarctica. We find a consistent set of geophysical indications that provide evidence for the location of the interior boundary of the Mawson Craton. We also identify the extent of an enigmatic block wholly under the cover of ice. This block is distinct from the Mawson Craton exposed in South Australia and in coastal East Antarctica and has a deep lithosphere defined by faster seismic wavespeeds. We present some alternative tectonic interpretations for this enigmatic block in the light of published global plate tectonic reconstructions for the Neoproterozoic.

Deciphering the Barcode of Earthquakes

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Faults accommodate plate tectonics, control the strength of Earth's crust, contribute significantly to crustal fluid and heat flow and thus resource formation, and generate one of the most devastating natural hazards: earthquakes. Currently, earthquakes are considered as chaotic non-linear events. However, they imprint distinct "barcode- like" deformation patterns called "damage zones" around a slipping fault. The damage zone occupies the largest part of a fault, plays an essential role during fault growth and has a significant impact on fluid flow and rock mechanical properties. We propose here that damage zones encode the signature of the multi-physics processes of faulting and earthquakes.

We present first analytical, experimental and numerical results that decipher this barcode through newly discovered *dissipative pressure waves*, here called $^{d}(P)$ *–waves*, which form, in addition to their elastic counterpart, the $^{e}(P)$ *–waves* known from seismology, under certain critical conditions. In contrast to elastic waves, they appear as characteristically spaced, sharp pressure peaks that manifest themselves as localized tabular zones of volumetric damage in the host rock. We interpret the deformation bands of the damage zone around a fault as the expression of $^{d}(P)$ *–waves*.

Here, we present first tests in the laboratory and in the field that show that the fault damage zone is indeed the consequence of a $^{d}(P)$ *–wave*. The method allows, for the first time, to extract quantitative information directly from natural fault damage zones on the size of the underlying earthquakes, the flow and mechanical properties of the host rock, and the spatiotemporal evolution of fluid and mechanical pressure associated with faulting.

Our project constitutes an important step towards the elusive goal of earthquake forecasting with the caveat that the theoretical Multiphysics and Multiscale solution clearly shows that the process underlies an uncertainty principle known from quantum mechanics. In future work we wish to help to establish innovative quantitative methods for the exploration of fault-bound resources and the prediction of rock material properties under geological conditions. The experimental investigation of the fundamental instability has broader applications in the fields of industrial processing of multiphase materials, civil, mechanical, and reservoir engineering and solid mechanics.

Collisional processes from subduction to collision and collapse: what could field geologists possibly learn from computer models?

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Most of the highest mountain belts and orogenic plateaux are located along collisional suture zones where plates collide. They are one of the most fundamental outcomes of plate tectonics processes, one with far reaching consequences for economic geology, global and local climate and biodiversity. During the 1970's and 1980's, tectonicists were occupied with understanding the geology of present-day orogenic systems within the kinematic framework of plate tectonics. In the 1980's and 90's, the first generation of computer models documented how subducting lithospheric mantle could drive collisional processes. In these models, the colliding crusts are accreted on both side of a suture zone owing to a major décollement at the base of the weaker lower crust above the stronger lithospheric mantle. As collision proceeds, the mountain growths in height until its gravitational potential and viscous resistance balance tectonic-driving forces. At that point, the mountain growths laterally forming an orogenic plateau as ongoing convergence is accommodated by accretion of foreland crusts into the plateau, as well as lateral escape of strong lithospheric blocks along trans-lithospheric strike-slip faults. This model has been successful in accounting for a large number of observations, and it is still the dominant model to explain the formation of orogenic plateaux. Interestingly, in the 1990's and 2000's this model also served to stimulate research into processes not fitting well into the collision-accretion paradigm. These include the presence in orogenic crust of high- to ultrahigh-pressure crustal rocks and mantle massifs. High-pressure crustal rocks pose the problem of continental subduction and the fate of the deeply subducted crustal slab, whereas mantle massifs pose the problem of the involvement of the mantle in collisional processes. Over the past decade, thermo-mechanical computer codes and high-performance computers have grown in power and availability. They can handle mechanical properties with complex elasto-visco-plastic rheologies that mimic rocks' natural response to deviatoric stresses and their dependence with temperature, accumulated strain, partial melting and other important metamorphic reactions. Two-dimensional coupled thermo-mechanical numerical experiments are used to simulate proctracted orogenic histories extending over 100 myr. These experiments document a broad range of interrelated processes including subduction, obduction, continental subduction, continental collision, thin-skin tectonics in the form of upper-crust imbrication, intra-continental thick-skin tectonics, slab detachment, contractional domes, solid-state diapiric re-accretion of deeply subducted crust and trapping of mantle massifs, continental slab partial melting and slab-focused channel flow, and rapid exhumation of ultra-high pressure (UHP) crustal rocks into extensional gneiss domes. They illustrate complex dynamics with adjacent regions recording coeval contractional and extensional deformation despite steady-state boundary conditions.

Our synthetic orogenic system records a four-phase history from subduction, collision, orogenic mass transfer, and collapse. These can be further reduced into two broader periods. The first period corresponds to the syn-convergence advective build-up of gravitational and thermal anomalies in relation to the advective burial or uplift of density interfaces and isotherms. The second period starts when a combination of convergence slowdown and/or thermal relaxation changes the balance between the external driving force and viscous force (i.e. the strength of the lithosphere). At that stage, the diffusive decay of thermal anomalies controls the tempo of the warming of the orogenic system and its thermal weakening. During this second period, gravitational stresses act on an orogenic system growing weaker through time as thermal relaxation proceeds.

AusLAMP across the Delamerian Orogen and Curnamona Province

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AusLAMP is a collaborative national project to cover Australia with long period magnetotelluric (MT) data in an approximately 55 km spaced array. With South Australia, Victoria and Tasmania now complete and NSW, NT, QLD and WA well underway, we are now armed with a tool to understand the architecture of the entire lithosphere across large areas. Signatures from past tectonothermal events can be retained in the lithosphere for hundreds of millions of years when these events deposit conductive mineralogy that is imaged by MT as electrically conductive pathways. MT also images regions of different bulk conductivity and can help to understand the continuation of crustal domains down into the mantle, and address questions on the tectonic evolution of Australia.

The AusLAMP data presented here were collected as part of three separate collaborative projects involving several organisations. Geoscience Australia (GA), the Geological Survey of South Australia, the Geological Survey of New South Wales, the Geological Survey of Victoria, and the University of Adelaide all contributed staff and/or funding to collection of AusLAMP data; GA and AuScope contributed instrumentation. The data covers the Paleo-Mesoproterozoic Curnamona Province, the Neoproterozoic Flinders Ranges, and the Cambrian Delamerian Orogen, encompassing eastern South Australia and western New South Wales and western Victoria.

The Cambrian Delamerian Orogen marks the transition along the eastern margin of Proterozoic Australia from a passive to an active continental margin, and has potential for a range of mineral systems. The Delamerian Orogen, the Curnamona Province, the Neoproterozoic Adelaide Rift Complex and Cambrian volcanic and sedimentary rocks deposited in a volcanic arc and back arc setting, all inverted during the c. 514–490 Ma Delamerian Orogeny. The Curnamona Province is also prospective, with strong similarities between the Benagerie Ridge volcanics of the Curnamona Province and the Gawler Range Volcanics of the Gawler Craton, and a mantle conductivity anomaly joining the two provinces.

This project represents the first model of electrical resistivity that images the entire Curnamona Province and most of the onshore extent of the Delamerian Orogen. Preliminary resistivity models indicate a highly conductive crust in the Curnamona Province. Within the Delamerian Orogen, the lithosphere is mostly resistive, with isolated conductive anomalies spanning different depths from around 10 km down to the lower lithosphere. The expansive Murray Basin cover of the southern parts of the Delamerian Orogen is imaged as a widespread shallow conductor.

Xenolith and seismic studies of eastern South Australia and particularly western Victoria have revealed a highly enriched and fertile lithosphere, with slow seismic wavespeeds. Subduction-related enrichment during the Delamerian Orogen has, in part, been overprinted by the signature of recent volcanism in the form of the Newer Volcanic Province (NVP). The NVP, previously only imaged by MT in Victoria is now revealed in its full onshore extent. The resistivity models, together with these other types of data will enable us to identify lithospheric scale structures and test proposed tectonic models on the evolution of the Delamerian Orogen.

A trapdoor mechanism for slab tearing and melt generation in the northern Andes

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Segments of flat subduction are commonly recognised in subduction zones, but little is known about the behaviour of slabs along the edges of flat slab segments. Well constrained earthquake data from the northern edge of the Peru flat slab segment reveal that the subducting Nazca slab is more contorted than previously assumed, with a prominent tear developing along a lateral ramp that bounds the Peruvian flat slab beneath southern Ecuador. The slab geometry and associated tear are spatially linked to Sumaco Volcano in the Amazonian Basin, ~100 km east of the Andean Belt. Sumaco mafic lavas are ultrapotassic, enriched in incompatible elements, and show little evidence for crustal assimilation. These geochemical signatures are consistent with low degree (≤3%) melting of an upper mantle source comprising depleted MORB mantle (DMM) within the spinel stability field, and metasomatism of the source by melts derived from the basaltic portion of the slab within the garnet stability field (>80 km depth). This focused melting is explained by heating and decompression due to a trapdoor-style sinking of the torn slab edge, generating a poloidal flow that necessarily advects mantle from beneath.

In-situ U-Pb calcite geochronology of tectonic veins: a case study on the brittle deformation history of Thailand

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The timing of low-temperature crustal deformation is usually established by indirect methods such as apatite fission track (AFT) thermochronology. U-Pb dating of calcite in tectonic veins has recently been developed as a method that can potentially directly date brittle deformation events. Using in-situ calcite U-Pb dating, this study sheds new light on the upper crustal deformation history of Thailand. We present in-situ U-Pb dates from calcite veins associated with hydraulic fracturing during fault movement that demonstrate multiple fluid events. These fluid events are distinguished based on the trace element geochemistry (e.g. Mn and LREE concentrations) in the calcite veins. U-Pb calcite ages demonstrate tectonic activity at ~216–209 Ma in the Khao Kwang Fold and Thrust Belt associated with the Indosinian stage 2 collision between the Sibumasu Block and the Indochina Block. Brittle deformation along the Three Pagodas Fault Zone was dated at ~45 Ma and ~24 Ma. These calcite U-Pb dates are in agreement with the timing of cooling obtained from regional AFT data, as well as with zircon and monazite U-Pb dates for gneiss complexes along the Mae Ping Shear zone, that trends parallel to the Three Pagodas Fault zone. Hence, our study illustrates the applicability of calcite U-Pb dating to constrain the timing of regional as well as localised deformation in Thailand.

Statewide 3D fault model of NSW

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The pre-Devonian geological architecture and associated mineral resources of New South Wales are largely obscured by younger sedimentary cover. This poses significant challenges in understanding the state's geology as well as exploring for new resources. Prospective rocks lie, for the most part, untested beneath this cover, creating a tremendous opportunity for new mineral discoveries using new geological concepts and technologies.

The Geological Survey of New South Wales (GSNSW) has developed a statewide 3D fault model of NSW.

The model integrates all available geological and geophysical data to determine the geometry of faults and structures that define the architecture of the state's orogens. Constraining datasets for this model include surface mapping; geological cross-sections; well data; digital elevation models; seismic, gravity and magnetic data; and 2D forward models.

The NSW statewide 3D fault model follows the completion of the GSNSW Seamless Geology Dataset, which provides a statewide compilation of the best-available mapping data in an internally consistent format.
The 3D fault model aims to match the seamless dataset as closely as possible within the software-processing and interpretation limitations.

The NSW statewide 3D fault model comprises four components:

- Curnamona Province and Delamerian Orogen model
- Western Lachlan Orogen and southern Thomson Orogen model
- Eastern Lachlan Orogen model
- New England Orogen model.

The models are available as Geoscience ANALYST projects, GOCAD® and DXF compressed files. The models include the topography of the pre-Devonian basement and fault surfaces, incorporating fault attribution which is consistent with the seamless geology dataset.

All fault surfaces have the following properties:

- dip direction
- dip angle
- fault depth
- fault kinematic
- fault order
- fault name.

The NSW statewide 3D fault model provides a geological framework for future detailed modelling of geological terranes. The model will advance the understanding of the crust, tectonic setting and Phanerozoic geodynamic evolution of eastern Australia, as well as guiding greenfields mineral exploration in NSW.

The probable geology of the Aurora Basin, East Antarctica

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Little is known about the vast subglacial geology of the East Antarctic interior. The rocks are inaccessible under kilometres of ice, but are nevertheless likely to be of global importance because of the role they play in modulating the behaviour of this overlying ice. Ice sheets are affected by heat coming through the underlying crust. This heat is spatially variable largely a function of variations in crustal structure controlled by tectonic evolution over hundreds of millions of years. The heat produces subglacial lakes and changes the friction for the slow-moving ice. The solid Earth response to changes in ice mass also depends on the spatially heterogenous rigidity of the lithosphere. However, the tectonic evolution and crustal nature of East Antarctica are poorly constrained, especially in the deep interior. Due to the lack of data and constraints, ice sheet models, and models of glacial isostatic adjustments are forced to apply crude assumptions of heat flow, lithospheric strength etc. Better understanding of the crustal structure and tectonic development of Antarctica are needed to produce reliable estimates of the Antarctic contribution to global sea level change. A key area is Aurora Subglacial Basin. The bed topography is located below sea level and the ice sheet feeds some of the East Antarctica's most vulnerable outlet glaciers. We aim to produce a subglacial geological map of the Antarctic interior in the Aurora basin. By using probabilistic and Bayesian methods in a spatial framework, we can advance our understanding of what to expect and also present the range of possible interpretations.

We start from a coastal geology with constraints aided by considering the conjugate Australian margin and work our way southwards under the ice sheet. We use published geological observations, geochronology and geochemistry from Sabrina Coast and Knox Coast. We include plate reconstructions of Gondwana, that links Antarctica with Australia to help us extrapolate affiliated terranes. The further away we get from geological observations, the more the uncertainty increases, but we can guide the interpretation using geophysical data sets. The uncertainties are quantified and provide us with spatial distributions of potential interpretations. High resolution airborne datasets from e.g. the ICECAP campaigns provide detailed but sparse constraints, and satellite potential fields are used to interpolate areas with sparse observations. Deeper crustal structure and the mantle lithosphere is incorporated directly from geophysical data. The outcome is compared against other continents. We use the Australian continent as a prior reference model but also consider global averages. All modelling and computation are performed in the open source agrid package.

We produce a new type of geological map over the Aurora Subglacial Basin. The geology is attributed with probabilistic dimensions. Absolute values can be extracted from the model to provide ice sheet and geodetic models with the most probable interpretation of the subglacial geology, or extreme end-members, e.g. the highest potential heat production or smallest possible Archean cratons. The probabilistic framework will also be useful in stochastic plate reconstructions. The resulting maps provide a new tool for geological mapping in a number of settings, where direct observations are sparse. We hope that our approach will be useful for the interdisciplinary research community to provide better heat maps and better constraints for the lithospheric properties. As additional data becomes available, the model can be adapted and improved in our Bayesian framework.

Evidence for resubduction of lawsonite-eclogite during return flow, Southern New England Orogen, Australia

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Translating burial and exhumation histories from the petrological and geochronological evolution of high-pressure mineral assemblages in subduction channels is key to understanding subduction channel processes. Convective return flow, either serpentinite or sediment hosted, has been suggested as a potential mechanism to retrieve deeply buried rocks and exhume them to the surface. Numerical modelling predicts that during this convective flow, fragments of oceanic crust can be cycled within a serpentinite-filled subduction channel, experiencing multiple burial cycles. Geochronological and petrological evidence for such cycling during subduction is preserved in a lawsonite-eclogite from serpentinite mélange in the Southern New England Orogen, in eastern Australia. Lu–Hf garnet and lawsonite, U–Pb zircon, U–Pb titanite and Ar–Ar and Rb–Sr phengite geochronology, supported by phase equilibria modelling and garnet zonation, suggests two cycles of burial that accompanied more than 1000 km of trench migration. Lu–Hf garnet and lawsonite and U–Pb zircon ages constrain the first burial event to ca. 500–490 Ma. This initial subduction of the eclogite formed Lu- and Mn-rich garnet cores, porphyroblastic lawsonite and micro zircons at P–T conditions of at least 2.3 GPa and 550 °C. Partial exhumation to ca. 1.9 GPa and 500 degrees is recorded by approximately 11 vol% garnet dissolution. Reburial of the eclogite resulted in renewed growth of new garnet, and prograde-zoned phengite and recrystallization of titanite at P–T conditions of 2.7 kbar and 590 °C. U–Pb titanite, phengite Rb-Sr and Ar-Ar ages record the recrystallization of these minerals during this second event at ca. 460 Ma. This was then followed by a second exhumation event, where chlorite and glaucophane partially replaced garnet and omphacite respectively, and garnet rims were again reabsorbed, at approximately 2.0 GPa and 500 °C. These conditions fall along a cold approximate geotherm of 7 °C/km, supported by the presence of pristine lawsonite. Partial exhumation and reburial occurred over ca. 30 Ma over an approximate pressure and temperature fluctuation of 1.2 GPa and 140 °C, providing some estimation on the rates of subduction channel material cycling.

Significance of primary lithospheric architecture in magmatic and hydrothermal copper, gold and nickel deposits: common threads across multiple deposit types

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Iron-oxide copper gold (IOCG) deposits form in part by hydrothermal fluids exsolved from magmatic sources and in this respect share some similarities to porphyry Cu -Au deposits, which likewise derive from fertile magmatic rock systems. In contrast, Ni-Cu and associated PGE deposits form through crystallisation of sulphur-rich mafic magmas. The common theme through these deposit types are the presence of syn-mineralisation magmatic intrusions. As the mantle is the ultimate source for the melting that forms the mineralisation-related intrusions, whether as a result of fractionation of felsic or intermediate magmas from a primary mafic source, or by direct crystallisation of a mantle-derived magma. Therefore, at the broadest scale, the magmatic pathways related to these deposit types is one that extends from the mantle into the crust. The subsequent magmatic-derived fluid systems exsolved from the causative intrusions in the formation of IOCG and porphyry-related deposits are, in a sense, an extension of this primary magmatic process.

We investigate the mantle to crust connections of three terranes with a view to understanding the similarities and differences between the three deposit styles of interest. We do this utilising lithospheric-scale electrical resistivity models based on magnetotelluric (MT) data. We first review the AusLAMP -derived resistivity models from the IOCG terrane of the Gawler Craton. We then review resistivity models across porphyry Cu from active subduction settings and also investigate the AusLAMP models across the Musgrave Province, which is known for layered mafic intrusion-related Ni-Cu sulphide systems.

We look to active subduction systems of the Pacific oceanic plates into the American continent and New Zealand. Mantle conductors form atop the subducting slab as a result of dewatering of the down going oceanic plate and metamorphism in the overlying continental mantle. Magma pathways are sub-vertical to the surface beneath the back arc with control for the location of porphyry deposits. The South Australia IOCG mineral system appears largely controlled by a metasomatised mantle signature. In this case, connection of fossil magmatic pathways into the crust is primarily controlled by the rheology of the cratonic Gawler Craton lithosphere: pathways preferably used weaker lithosphere to percolate upwards along the craton margin. Ni-Cu deposits in the Musgrave Province appear to show an upwelling conductive mantle signature, which may also explain slightly elevated lower crustal density (Alghamdi et al., 2018). However, the Musgraves show later stage intraplate overprinting in the crust from the Petermann Orogeny, resulting in strong east-west oriented quasi-linear gravity highs and associated high crustal conductivity.

The results show the importance of scale. Similarities exists in the crustal geometries likely reflecting the influence of rheological boundaries controlling residence of magma and fluid ascent, as well as saturation processes of melt with a volatile phase. However, the insights gained from the large (>100's km) aperture of the AusLAMP program allows an informed view of the mantle connection to these systems and highlights the nature of subduction modified mantle for IOCG systems. In case of the Gawler Craton and the Musgrave Province, an upwelling of higher conductivity mineralogy is seen below regions of known mineralization.

Crustal hot spot metamorphism powered by anomalous high heat producing Th–U concentrations

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High geothermal gradient metamorphism characterised by cordierite-bearing prograde amphibolite facies mineral assemblages requires thermally energetic environments which represent significant excursions from normal continental thermal conditions. For this reason, heat advected from magmas generated at depth are typically considered necessary to create a high geothermal gradient environment, and therefore, metamorphism should be spatially and temporally associated with magmatism with elevated thermal conditions being transient. While this will likely remain the governing paradigm, we present evidence from the Arkaroola region of the northern Flinders Ranges, South Australia, where high geothermal gradient mineral assemblages are not obviously spatially or temporally associated with magmatism. Our study focusses on cordierite-bearing schists from within the lower Adelaidean stratigraphy of the Adelaide Rift Complex. These strata directly overlie the Mount Painter Inlier, a basement inlier comprised of Mesoproterozoic metasediments and granitic rocks which display some of the world's most anomalous enrichments in heat producing elements (Th, U and K). We present results from in-situ U–Pb monazite geochronology combined with phase equilibria modelling to argue that the rocks of the lower Adelaidean began undergoing prograde metamorphism at c. 580 Ma, much earlier than previously thought, significantly pre-dating the onset of the regional Delamerian Orogeny at c. 520 Ma. Phase equilibria modelling indicates that metamorphism took place under highly perturbed geothermal gradient conditions in excess of 180 °C/kbar (> 48 °C/km) and was highly sensitive to burial depth within the basin. From our results we interpret the Arkaroola region to be an example of a basin-hosted metamorphic system thermally driven by endogenous heat production.

Experimental alteration of monazite in granitic melt: Pb mobility during melt-mediated coupled dissolution-reprecipitation

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Monazite U-Pb dating of high-temperature metamorphic rocks (upper-amphibolite–granulite-facies) commonly produces complex linear age arrays ('smears') along Concordia. These datasets are widely interpreted by textural criteria linked to U–Pb analysis to infer either variable Pb-loss between two discrete events or protracted metamorphism (lasting >50–100 Myr). Experimental studies of the isotopic systematics of monazite have been previously restricted to studies that react monazite with aqueous fluid or 'sol-gel' compounds. Our experimental approach reacts monazite with granitic melt (7 kbar and 750 °C) to produce a range of complex monazite textures found in natural rocks, including: (i) development of core (relict mnz1) and rim (newly grown mnz2) textures separated by an interface annulus of fine and densely distributed porosity (interpreted as involving coupled dissolution-precipitation); (ii) broadly pitted and porous domains transecting entire grains without change in chemistry of mnz1 (interpreted as involving dissolution); and (iii) texturally and chemically homogenous euhedral crystals of mnz2 (involving nucleation and precipitation). Three key geochronological patterns are identified: (1) preservation and inheritance of precursor monazite (mnz1) ages within pristine (unreacted) core domains; (2) disturbance of partially dissolved mnz1 domains (i.e. mnz1 with melt-filled porosity) with ages showing minor discordance; (3) newly precipitated mnz2 lacking porosity yielding two age patterns: (a) ages that spread along Concordia for tens of Myr from the age of the starting material toward younger ages and (b) ages close to 0 Ma. These observations show that within a short duration (<24 hours experiment time) variable expulsion of radiogenic Pb from precursor monazite can produce age data trends comparable to those obtained from natural high-grade rock samples. This study informs on variable REE, Y, Th, U and Pb mobility during coupled dissolution-precipitation at amphibolite–granulite-facies melt-bearing conditions. It demonstrates that ultra-local melt at a coupled dissolution-precipitation interface may be saturated in dissolved components including the U-Pb isotopic character of the precursor monazite, such that newly precipitated monazite may copy or partly inherit the age of a precursor grain. A highlight of this study is that monazite newly grown during coupled dissolution-precipitation may not always faithfully record the age or duration of metamorphism within melt-bearing rocks typical of a variety of geodynamic settings.

The importance of the Uno Fault for the southern Gawler Ranges: regional controls on volcanism, magmatism, fluid flow and alteration

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The Gawler Ranges are formed by the c. 1595–1575 Ma Gawler Range Volcanics (GRV) and comagmatic Hiltaba Suite (HS) granitoids. The GRV have been subdivided into a lower older (>1588 Ma) and an upper younger sequence (<1588 Ma). The southern margin of the Gawler Ranges represents a major W-E oriented, about 200 km long geological boundary between outcrops of the Mesoproterozoic GRV in the north and Neoarchean to Paleoproterozoic basement rocks to the south. Field studies and geophysical interpretations, undertaken in association with the Mineral Systems Drilling Program (MSDP), showed that this margin is not simply an erosional feature but was also significantly shaped by tectonism contemporaneous with GRV-HS magmatism.

The principle structure defining the southern Gawler Ranges margin is the Uno Fault, which consistently shows a down-to-north movement along its course. The approximate trace of this fault system is known from a number of well-studied segments, however, large tracts are mainly inferred from airborne magnetic data. The Uno Fault was first mapped north of Lake Gilles, about 80 km west of Port Augusta, as an E-trending normal fault extending laterally for about 40 km. Recent geochronological studies in the Myall Creek area have revealed that parts of the exposed volcanics, which were previously interpreted as upper GRV, are in fact lower GRV. Re-examination of the outcrop geology and aeromagnetic data indicated that the upper and lower GRV are juxtaposed against each other in this area by a major NE-trending fault, which can be connected to the southwest with the Uno Fault. To the northeast, the trace of the Uno Fault gradually fades in aeromagnetic images due to increasing thickness of overlying cover rocks.

Mapping the Uno Fault along the southern Gawler Ranges margin indicates that this structure has a fundamental influence on the distribution of the upper GRV. This fault appears to restrict the felsic lavas of the Eucarro Rhyolite and the Yardea Dacite to its northern, downthrown side with no erosional remnants or outliers of upper GRV known to the south of the Uno Fault. In contrast, the lower GRV occur mainly to the south of the Uno Fault but are locally also exposed north of this fault. Therefore, movements along the Uno Fault likely controlled emplacement and deposition of the upper GRV lavas by forming a topographic barrier. This raises the question if the Uno Fault may represent the southern margin of a gigantic caldera structure.

The northeastern part of the Uno Fault is intruded by a late-stage Hiltaba Suite pluton as indicated by a circular magnetic anomaly truncating the fault. Nearby epithermal quartz veining and alteration with associated Au-Ag-Pb-Zn mineralisation at Parkinson Dam is most probably related to fluid flow along the Uno Fault during the GRV-HS tectono-thermal event. In the southwestern part of the Gawler Ranges, the Uno Fault has been targeted near Paney for potential mineralisation. Drilling at Black Eagle Rock intersected zones of intensively brecciated and altered GRV containing epithermal quartz veins with variable amounts of fluorite, pyrite, galena and sphalerite. Farther to the northwest, towards Hiltaba, the orientation of the Uno Fault appears to swing to the northwest but becomes increasingly difficult to follow as its magnetic signature is overprinted by a number of voluminous Hiltaba Suite granite plutons that intruded along this structure. In this area, the NW-trending intra-GRV Eurilla-Progress Fault Zone shows features similar to those of the Uno Fault. It offsets upper GRV units with down-to-north movement and is intruded and truncated by the NW-elongate Hiltaba Pluton, documenting its syn-magmatic activity. Drilling into this fault zone intersected epithermal quartz-pyrite veins anomalous in Au-Ag-Pb-Mo-As-Sb-Bi. This shows that fault systems along the southern Gawler Ranges not only facilitated magma ascent and emplacement but also provided pathways for hydrothermal fluids leading to alteration and mineralisation.

Role of regional stress change in evolution of orogenic gold deposits in central Victoria

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From the start of the Delamerian Orogeny at ca. 515 Ma to the end of the Tabberabberan Orogeny at ca. 370 Ma, the eastern continental margin of Gondwanan Australia experienced both accretionary growth and the development of the Lachlan Orocline. Central Victoria lies within this Orocline, and is partly underlain by a Proterozoic continental fragment, the Selwyn Block. All of the million-ounce orogenic gold deposits in the region lie either on or in the western hangingwall of the Selwyn Block. Most mineralized zones in the orocline are associated with faulting and fracturing controlled by a slowly rotating regional stress field. Dilatant structures generated or reactivated during the stress field rotation aided the transport and precipitation of mineralized fluids within the brittle and brittle-ductile crust. The largest gold deposits formed where fluid pathways either remained open or reopened in this rotating stress field, allowing multiple pulses of gold-rich fluids.

In the Stawell Zone, the maximum compressive stress in the Cambrian rocks was associated with NE-SW shortening in the Delamerian Orogeny (ca. 515 to 490 Ma). When the stress field rotated to E-W during the Benambran Orogeny (ca. 445–435 Ma), gold-bearing faults were localized on the flanks of inherited structures like the Magdala Basalt dome. By ca. 425 Ma these structures were reactivated and further mineralized due to a reoriented regional stress field. In the Bindian (ca. 420–410 Ma) and Tabberabberan orogenies (385–370 Ma), the Stawell Zone was further deformed as the stress field continued to rotate clockwise through NNW-SSE to NE-SW.

In the Ordovician rocks of the Bendigo Zone, the first gold mineralization event (corresponding to D4 event in the Stawell Zone) is associated with E-W shortening in the Benambran Orogeny (445–435 Ma). Here, the 3D geometries suggest much of the gold mineralization post-dates the Benambran E-W-compression. In particular, Pabst (1919) first identified a later mineralization event, stating that there was “a very close association between the major strike-faulting and the occurrences of economic gold shoots”. Both field and drill core data show that ore shoots do not always follow the first order, gently N-S-plunging folds. Instead, the ore shoots were primarily related to dilation that post-dated the initial E-W-compression. We consider that strike-slip movements that produced the dilation seen locally are related in space and time to larger scale changes in the regional stress field. In the Bindian (~420 Ma) and Tabberabberan (~390 Ma) orogenies, the stress field progressively rotated clockwise to ca. N-S and large volumes of mineralized fluids deposited gold in structures that were formed in alignment with the new stress state.

The Silurian rocks of the Melbourne Zone host the Tabberabberan Costerfield gold-antimony deposits. Here the orebodies were controlled by a transpressional fault and fracture system that was initiated when the local maximum compressive stress was oriented N-S.

In each of the deposits examined, the regional stress field in which brittle deformation took place has controlled dilation sites and subsequent fluid pathways and thereby the locations, timings, orientations and sizes of the resulting ore-shoots.

Reference

Pabst, V., 1919. Geology of the Bendigo Goldfield, Vic.-Relationship between major strike-faults and deposition of the most productive reefs and systems of spurs: Chem. Engin. Mining Rev. 11, p. 279-287.

The influence of mantle flow on the evolution of the Canning, Southern Carnarvon and Cooper basins since Paleozoic times

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During Paleozoic times the Canning, Southern Carnarvon and Cooper Basins developed within the continental interior of the Gondwana supercontinent, thousands of kilometres away from active plate boundaries. These basins were largely unaffected by the tectonic forces focused at these margins and the relative tectonic quiescence of their histories makes them attractive places to search for indicators of past dynamic topography; the topography due to mantle flow.

We investigate the influence of mantle flow on the subsidence histories of intercontinental basins by comparing one-dimensional backstripped tectonic subsidence histories from the Canning, Southern Carnarvon and Cooper basins to estimates of dynamic topography computed from the first geodynamic models of mantle flow spanning the entire Phanerozoic Eon.

We identify episodes of anomalous vertical motion by comparing the tectonic subsidence history inferred from well data to that obtained from forward models of basin stretching. We then investigate the influence of dynamic topography on episodes of anomalous vertical motion in basin by quantitatively establishing the contemporaneity of trends in tectonic subsidence and dynamic topography histories.

We find that throughout the Carboniferous–Triassic Australia was positioned over a mantle upwelling above a hot structure at the base of the mantle. Tectonic uplift of the Canning and Southern Carnarvon basins in the Triassic–Jurassic was augmented by dynamic uplift produced by the upwelling, and possibly amplified by an active mantle plume during Permo-Triassic times. During the Late Jurassic–Cretaceous, Gondwana broke-up and Australia drifted east away from the mantle upwelling towards a downwelling produced by Permian subduction along the east Australian margin, which resulted in a period of accelerated subsidence in the Canning and Southern Carnarvon basins. The models predict a slab associated with convergence between India and East Africa stagnated near the top of the lower mantle for 250 Myr, before sinking in the lower mantle during mid-Permian times, which resulted in a minor phase of dynamic uplift of the Cooper Basin. During Cretaceous times the Cooper Basin moved over a downwelling resulting in a period of accelerated subsidence, consistent with previous results.

P-T and age constraints on metamorphism in Mabel Creek Ridge, Northern Gawler Craton, Australia

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The Gawler Craton is one of the major cratonic elements of the Precambrian Australian continent, and has complex geological history from Archean. It consists of Archean to earliest Paleoproterozoic nucleus that is surrounded by Proterozoic orogenic belts. The Mabel Creek Ridge is located on the north of Coober Pedy Ridge and stands southmost part of the Nawa Domain. Previous metamorphic zircon and monazite ages from granulite-facies gneisses suggested this region was widely affected by the Kimban Orogeny at ca. 1730–1690 Ma and underwent high-temperature reworking during the Kararan Orogeny at ca.1590–1560 Ma. The later metamorphism is consistent with the emplacement of Gawler Range Volcanics-Hiltaba Suite as well as the extensive iron-oxide copper gold (IOCG) in the eastern Gawler Craton. In situ U-Pb monazite geochronology, calculated metamorphic phase diagrams, and trace elements pattern of monazite and garnet provide evidence for post-peak metamorphism in Mabel Creek Ridge. Metapelitic granulite (R1686100B) from drillhole AM/PB 2 in central part of the high TMI response area defining the Mabel Creek Ridge contains garnet + plagioclase + K-feldspar + biotite + sillimanite + quartz assemblage with late-stage cordierite that formed at around 800 °C and 6 kbar at ca. 1575 Ma followed by decompression. In the east part Mabel Creek Ridge, garnet + cordierite + sillimanite-biotite bearing metapelite (R1689844) from drillhole G3 DDH 1 records similar P-T evolution conditions of around 800 °C and 6 kbar at ca. 1575 Ma. Garnet from AM/PB 2 R1689100Bshow Y (+HREE)-rich cores and core-to-rim decreasing in Y (+HREE) abundances that are compatible with Rayleigh-type fraction of Y (+HREE) during garnet growth. However the Y pattern for garnet from G3 DDH 1 R1689844 is more complicated and shows an overall rim-ward increase, which could be caused by the later resorption or breakdown of other HREE-Y bearing minerals during the garnet growth. Monazite from G3 DDH 1, shows a broad trend of increasing Y content with decreasing apparent age except for the cores with high Y content, which probably records from the decomposition of Y-rich garnet5 rim. The absence ofcorrelations between Y content and age for monazite from AM/PB 2 is consistent with the Y-poor rim of garnet where decomposition would not have supplied much Y during post-peak decompression.

The apparent absence of c. 1575 Ma metamorphism in the seismically-defined hanging wall to the Mabel Creek Ridge penetrated by GOMA DDH4, suggestd the Mabel Creek Ridge records a different evolution history to north Nawa Domain. Moreover, the seismic data shows predominantly north-dipping structures but divergent structures (Horse Camp Fault and Box Hole Creek Fault) flanking the Mabel Creek Ridge, which resemble a metamorphic core complex, and thus further work is needed to explore this notion.

POSTER ABSTRACTS

Post-orogenic extension and exhumation of the Stong - Taku magmatic and metamorphic core complexes, Peninsular Malaysia

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The Stong and Taku magmatic and metamorphic core complexes of northern Peninsular Malaysia form two dome shaped bodies that are interpreted to have formed along a pre-existing suture zone during Cretaceous post-orogenic extension. The formation of a single large extensional detachment exhumes two spatially offset domes associated with crustal melting, the emplacement of syn-kinematic plutons and widespread migmatisation. From these observations we infer that an initial Cretaceous thermal anomaly was responsible for the formation of extensional gneiss domes associated with simple shear and rotation of normal faults. Arrays of simultaneously formed structures documents that deformation occurred over a wide temperature range by NW-SE extension. Fission track ages indicate that the formation of the detachment and a first phase of Late Cretaceous cooling was followed by renewed Eocene - Oligocene exhumation, associated with the formation of the adjacent transtensional Malay Basin in the offshore Peninsular Malaysia. Similar strike-slip deformation has been quantified in onshore and offshore Thailand where local transpressional basin formation overlapped with exhumation of metamorphic core complexes, as observed in the Western gneiss belt. This mechanism involved ductile deformation of large-scale, sub-horizontal detachments at mid-crustal levels, which may have developed synchronously with major strike-slip faults associated with the India-Asia collision and subsequent extrusion of the Indochina peninsula. Further studies analysing the formation and evolution of Southeast Asian basins driven by extensional detachments, or systems of low-angle normal faults that created significant footwall crustal exhumation, should contribute to the resolution of the many competing geodynamic scenarios for the tectonic development of Southeast Asia.

Structural interpretation of newly acquired aeromagnetic data over the Tanami Region

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The Tanami Region is located approximately 600 km to the northwest of Alice Springs in the Northern Territory and straddles the border with Western Australia. The region lies within the North Australian Craton and comprises Paleoproterozoic metasedimentary and volcanic rocks that overly an Archean basement and have been extensively intruded by granites. The Tanami region is highly prospective for gold, and preserves several world-class deposits including Callie, Tanami, Granites and Groundrush.

The Northern Territory Geology Survey (NTGS) acquired a high-resolution aeromagnetic and radiometric survey across the Tanami Region in 2018. The survey is one of the largest surveys ever completed in the Northern Territory, and was acquired at 200 m resolution, with industry partners funding 100 m infill in some areas. This work presents preliminary interpretations of the newly acquired aeromagnetic and radiometric data. Interpretations aim to define major structural features and their overprinting relationships, and map the extent of different lithological packages, including units known to be prospective for gold. The new aeromagnetic interpretation will provide constraint for potential field modelling along existing deep crustal seismic surveys, and will provide a framework for reassessing the structural architecture and tectonic evolution of the Tanami Region.

Permo-Triassic geodynamics of eastern Gondwana: insights from zircon petrochronology in Zealandia

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Paleozoic-Mesozoic supra-subduction units, which originally formed along the paleo-Pacific margin of eastern Gondwana, are now preserved in eastern Australia, Antarctica, and Zealandia. Previous studies have characterized the temporal and geochemical history of magmatism within this broad accretionary orogenic system, but much less is known about Zealandia because (1) 94% of the continent is submerged beneath the southwest Pacific Ocean, and (2) the continent was fragmented by multiple phases of deformation. In order to circumvent this shortfall, we investigated a large number of detrital zircon U-Pb ages (n = 5536), zircon trace element data (n = 4713), and zircon Hf isotope data (n = 599) from the Paleozoic to Mesozoic fore-arc basin units in New Zealand (Brook Street, Murihiku, Dun Mountain-Maitai terranes, and Kaka Point Structural Belt) and New Caledonia (Teremba and Koh-Central terranes). The combined petrochronological data allow us to reconstruct the history of arc magmatism and the relative roles of crustal growth and recycling along the Zealandian margin of eastern Gondwana. A comparison of the new Hf isotope dataset with existing data from eastern Australia (Tasmanides) and Antarctica (central Transantarctic Mountains, Marie Byrd Land), allows us to determine (1) the nature of along-strike spatio-temporal variations in arc magmatism, and (2) the variations in the inferred subduction dynamics (e.g. contractional/advancing or extensional/retreating arc systems) along the Gondwana margin.

The value of structural data

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During mapping, structural geology interpretations are continuously evolving through the integration of new outcrop observations and the continuous building of conceptual hypotheses. These hypotheses provide predictions that are then tested through further mapping and observations. In other words, structural geology should guide our mapping path, and consequently structural sampling, over given structures. However, different mapping schools will proceed either (i) by form surface mapping, i.e. following a reference foliation or (ii) by producing a structural cross section, physically mapping across structures rather than following a foliation. Both methods are valid but may produce slightly different results especially in the 3rd dimension.

We present preliminary results on the assessment of the value of structural data and how different sampling methods will affect 3D structural geological uncertainty during mapping and 3D model building. We will use a newly developed open source 3D structural probabilistic modelling platform (Loop - loop3d.org) to produce 3D structural geological models. The aim is to establish a structurally controlled structural data sampling workflow in order to best reproduce complex geometries. We will optimise the spatial distribution of structural data and assess whether data should be collected preferentially in varying part of the structures (e.g. we may need more data around the fold hinge area). The questions we are trying to address are: 1) what is the minimum amount of data, their type (axial surface, axis, folded foliation) and location within the structure, 2) how to capture both small- and large-scale structures, 3) how does purely random sampling compared with structurally controlled sampling?

We use the Eldee structure in the Broken Hill block as our laboratory. The Eldee structure consists of a polydeformed structure including multiple folding and shearing events. The structure was re-mapped using a combination of form surface mapping, cross-sectioning and structural sampling on a regular grid.

This study will help develop new workflows for machine-assisted structural mapping and 3D modelling in complex polydeformed terranes.

Tectonic evolution of the forearc mantle reconstructed by dikes in the peridotites of the New Caledonia ophiolite

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Subduction zones are one of the most dynamic and important parts of the Earth system, however, the mechanisms of subduction initiation are not well established. Studies of subduction initiation have predominantly focused on the basal contact (metamorphic sole) between the subducting plate and the overlying mantle, the forearc crust, and the tectonic contact between the forearc crust and mantle. The best-preserved geological record of subduction initiation is likely to be within the forearc mantle, which forms above the descending plate during the incipient stages of subduction, and is subsequently obducted onto continental margins as ophiolites.

The New Caledonia ophiolite is one of the largest exposures of forearc mantle on Earth. It represents the oceanic lithosphere of the Loyalty Basin, which was emplaced onto the basement rocks of New Caledonia during the Late Eocene. Geochemical studies show the occurrence of both ridge- associated melting and forearc hydrous melting in the highly depleted harzburgites of the Massif du Sud, suggesting that the oceanic lithosphere formed in a supra-subduction zone setting established in the vicinity of an active spreading centre. Dikes (e.g. granitoid, boninitic, microgabbro, tholeiitic, diabase, pyroxenite) that intrude the peridotites of the New Caledonia ophiolite are ubiquitous and can shed light on the pre-obduction tectonic evolution of the forearc mantle. We have analysed the distribution, orientation, composition, and overprinting relationships of dikes, as well as their relationships with structural features such as the mantle fabric. U-Pb geochronology is used to put absolute time constraints on melt transport and intrusion of the different groups of dikes in the forearc mantle. The age of melting and possible perturbation of the geochemical system at the whole rock scale is assessed by whole rock Re-Os composition.

Drainage and sedimentary responses to dynamic topography: insights from source-to-sink landscape evolution modelling

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Dynamic topography induced by mantle flow interacts with surface processes and can affect all segments (from fluvial to deep marine) of the sediment routing systems at long-wavelength (≳1,000 km) and over long-time scales (≳1 Myr). Field observations and numerical investigations suggest that interactions between dynamic topography and surface processes can be preserved in the geological record. However, it remains challenging to isolate the fingerprints of dynamic topography in the geological record that primarily reflects tectonic processes. Landscape Evolution Modelling (LEM) is useful to evaluate the landscape responses to dynamic topography. Previous numerical studies did not fully capture the surface evolution because they focused either only on erosional or depositional responses. Here, we design generic source-to-sink models using the landscape evolution model pyBadlands to investigate the influence of dynamic topography on landscape evolution and stratigraphic formations. pyBadlands models sediment transport from source to sink, which makes it possible to represent both erosional and depositional responses to external forcing. We consider a wave of dynamic topography propagating under a tectonically stable continent, forcing the surface to undergo dynamic uplift and dynamic subsidence. Our modelling results show that inland incision, spatial sediment accumulation and depocenter migration strongly depend on the direction of sediment transport relative to the direction of dynamic topography propagation. The migrating dynamic topography induces an asymmetric erosion of the hinterland, leading to a characteristic rerouting of the river network following the migration direction of dynamic topography. The drainage reorganizations, which can persist for ~10 million years after transient dynamic topography, lead to variations in sediment supply to offshore regions. The propagation of dynamic topography induces contrasting stratigraphic record along the margin, and along-strike stratigraphic variations in terms of stacking patterns, stratal geometries and formation of stratigraphic surfaces. We suggest that source-to-sink modelling approaches are powerful to explore the interplay between dynamic topography and surface processes, and can provide insights into recognizing the geomorphic and stratigraphic signals of dynamic topography in the geological record.

A revised structural elements map of the North West Shelf

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The widely used scheme of naming basins and their regional subdivisions on the North West Shelf of Australia emerged from relatively sparse data collected during the early stages of exploration. Such data allow the recognition of large-scale structures and depocentres with broadly distinct tectono-stratigraphic signatures. While that scheme has endured, the availability of extensive, high quality seismic data and stratigraphic information from numerous exploration wells means that we can define much more precisely the structural elements that comprise the margin and the stratigraphic signatures of the basin fill. This has highlighted some inconsistencies in the existing nomenclature, the presence of structural elements of different ages and the presence of boundaries between basins that in instances can appear somewhat arbitrary.

We present a revised map of the North West Shelf that shows the structural elements with distinct tectono-stratigraphic signatures that comprise the margin, and applies a consistent nomenclature to them. The aim is to provide a framework that will allow for the better demarcation of distinct hydrocarbon provinces and improved targeting of exploration programmes. This is a work in progress, and can only be improved by broad community input. We invite you to visit our poster, to use the pens available to add details that we have missed, correct errors that we have made, and rectify any omissions. Alternatively, you can add comments to our blog (https://wordpress.com/view/nwshelfstrucelements.home.blog) where you will also be able to see that latest version of the map, share your thoughts and contribute to a stimulating discussion.

Treasure maps and the billion-year stability of cratonic lithosphere

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Sustainable development and transition to a clean-energy economy is placing ever-increasing demand on global supplies of base metals (copper, lead, zinc and nickel). Consumption over the next ~25 years is set to exceed the total produced in human history to date. A growing concern is that the rate of exploitation of existing reserves is outstripping discovery of new deposits. Therefore, improvements in the effectiveness of exploration are required to reverse this worrying trend and maintain growth in global living standards.

Approximately 70% of known lead, 55% of zinc and 20% of copper has been deposited between 2 Ga and recent by low temperature hydrothermal circulation in shallow sedimentary basins. Despite 150 years of research, the relationship between these deposit locations and local geological structure is enigmatic and there remains no accurate technique for predicting their distribution at continental scales.

Here, we show that modern surface wave tomography and recent parameterisations for anelasticity at seismic frequencies can be used to map lithospheric structure, and that sediment-hosted base metal deposits occur exclusively along the edges of thick lithosphere. Approximately 90% of the world's sediment-hosted copper, lead and zinc resources lie within 200 km of these boundaries, including all giant deposits (>10 megatonnes of metal). Incorporation of higher resolution regional seismic studies into global lithospheric thickness models further enhances the robustness of this relationship. This remarkable observation implies long-term lithospheric edge stability and a genetic link between deep Earth processes and near-surface hydrothermal mineral systems, providing an unprecedented global means to identify fertile regions for targeted mineral exploration. Moreover, this new finding provides clear economic justification for funding targeted seismic arrays, theoretical advances in imaging techniques, and laboratory experiments on the mechanical properties of mantle rocks.

Neotectonics and submarine landslides: a newly identified mass transport province off the Exmouth Plateau and Cape Range, WA

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A newly identified offshore landslide province situated along the western side of the Exmouth Plateau, extending down to the Cape Range, hosts dozens of mass transport deposits identified from 2D seismic data. This province, which currently extends from the Investigator Sub-basin through the Ningaloo Arch and into the Southern Carnarvon Basin, lies to the west of previously described, larger landslides, including the Glencoe and Salsa landslides, and south of the Thebe/Bonaventure slide (all previously documented using 3D seismic surveys).

Identified on the basis of seismic facies and distinct morphologies, we identify more than 60 mass transport deposits, most occurring within the top 2 seconds of two-way travel-time (roughly within the top 2.5 km of depth, within the Neogene). Individual slides vary in volume from 600 km^3 to over 700 km^3, and often occur as “complexes” comprising multiple stacked deposits that can be in excess of 21 km long and up to 200m thick. Transport directions vary locally from southwards to northwestwards. The MTDs with the largest volumes (>680 km^3) occurr in close proximity (less than 1 km) from major (>20 m displacement), often surface-breaching faults that acted as headscarps. This indicates potential for a causal relationship between faults (neotectonics) and mass transport.

Many of the bounding faults, include those that breach the surface (indicative of relatively young age), show evidence of reactivation, inversion and/or wrench motions, consistent with present-day stress orientations and focal mechanism solutions. This suggests that neotectonic fault movements may have caused the mass transport deposits adjacent to them. Age determinations for the MTDs require cores from the bases of the slides to be recovered. Whilst not possible within the current analysis, the nearby Gorgon slide was found to have an age of ~1 my at its base, with younger periods of movement (~0.5 my).

Results from this study compare favourably to known neotectonic features (faults, folds, inversion anticlines) both onshore and offshore in the region, and to other known MTDs. It is likely that the extent of the MTD province may be considerably larger than previously known. Additional work is required to document the full extent of the province, and links to neotectonic deformation and present-day seismicity.

Variable inversion of multi-mode, polyphase rift basins, North West Shelf, Australia

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Interpretation of deep seismic lines from the NWS shows that two principal modes of rifting developed during multiple phases of extension and continental breakup on Australia's North West Shelf:

1. Early phase rifting (Late Proterozoic and Early Palaeozoic), characterised by low-angle detachment faults (soling out at the Moho), crustal necking and hyper-extension. These thin-skinned fault systems were reactivated during subsequent rift events in the Late Paleozoic and Mesozoic;
2. Outboard narrow rift basins, bound by high-angle normal faults that cut into the upper mantle, and progressively localised extensional deformation. In some cases the narrow rifts matured into seafloor spreading centres during breakup, typically outboard of the thin-skinned systems.

Rifting events were punctuated by periods of thermal sag, often in conjunction with pulses of shortening. For major inversion, including during the Mid- to Late Triassic, there is a marked difference in the manner in which the two different types of rift basin responded to inversion events. The low-angle detachment fault systems, relatively well-oriented for reverse movement during reactivation, developed large inversion anticlines towards the inboard basin margin. 2D restorations show that uplift and erosion associated with these shortening events resulted in forced regression of clastic deltas, driven by a reduction in accommodation and increased sediment supply, linked to a series of 2nd and 3rd order sequence boundaries.

In contrast, the high-angle fault systems associated with the narrow rift basins are poorly oriented for reactivation during compression and tend to be characterised by wrench/flower structures, generally with relatively limited uplift and erosion. In addition, the sub-basins tend to be associated with well-developed synclinal geometries. This is interpreted to be the result of lithospheric down-warping due to a combination of loading at the base of the lithosphere (due to thermal decay) and in-plane compressional stress. The increased accommodation in these rapidly subsiding synclinal basins often coincides with a marked change (deepening) in depositional setting and development of aggrading shelf margins.

Tectonic controls on nickel and gold mineral systems; Halls Creek Orogen, Western Australia

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Geodynamic models, geological-geophysical interpretations, and isotope analysis illustrate that there are links between the nickel and gold mineral systems in the Halls Creek Orogen, Western Australia. Whole-rock Nd and Ar-Ar analysis of rocks throughout the region, when compared with the geodynamic models suggest that nickel and gold mineralization in the Halls Creek Orogen can be related to basin development and subsequent basin closure during the convergence of North Australian Craton and Kimberley Craton, respectively.

The results of geophysical interpretation revealed that the controlling structures of gold mineralisation are attributed to late deformation in the region appear to be related to plate collision during the 1835–1805 Ma Halls Creek Orogeny or during subsequent strike-slip movement of the c.1000–800 Ma Yampi Orogeny. 40Ar/39Ar geochronology on single muscovite crystals from the alteration zone in the Nicholsons Find Mine and Mount Bradley gold deposit illustrate that the gold deposit formation occurred at 1838 Ma in Mount Bradley Mine in the Eastern Zone and at 1826 Ma in Nicholsons Find Mine in the Central Zone. Therefore, suggesting that gold mineralisation occurred during the early stage of 1835–1805 Ma Halls Creek Orogeny, corresponding to the tectonic switch from an extensional to compressional regimes, and related to basin closure.

The Nd isotopic signature of magmatic rocks records varying proportions of crustal melting versus juvenile mantle magma input in the Halls Creek Orogen. The magmatic rocks that were deposited in the c.1865–1835 Ma Central Zone are dominantly crustally contaminated mantle-derived magmas resulting from lithospheric extension and upwelling of decompression melts. Whereas, the rocks in the Western and Eastern zones recording the melting of the pre-existing Neoarchean basement. Whole-rock Nd analysis confirmed the input of juvenile melts in the centre of the orogen before the 1835–1805 Ma Halls Creek Orogeny, supporting the upwelling of decompression mantle melts during the basin development. These analyses also revealed the spatial links between nickel and gold mineralization and lithological units with positive εNd values.

The results present that the isotopes may record the favourable tectonic settings for this mineralization in extensional zones which characterized by fluxes of juvenile magmas. While considering the role of mantle-derived magmatism in gold and nickel mineralization and the close spatial correlation between the gold and nickel mineralized region in the Halls Creek Orogen with regional positive εNd signatures, we choose rocks with more juvenile signature (i.e. more radiogenic) as the more fertile rocks in mineral systems prospectivity analysis.

The results of geodynamic models, geophysical interpretation, and isotopic analysis are used to understand the critical processes in the gold and nickel mineralization, which are presented by predictor maps. The GIS-based knowledge-driven fuzzy method used to integrate the predictor maps and create the prospectivity maps. Herein we show that mafic-ultramafic units prospective for nickel mineralization formed by upwelling of decompression mantle melt during crustal thinning and extension during basin development, and typically consist of the most juvenile magmas in the region. Whereas, gold deposits formed during the compressional regime and basin closure, and are located along a major shear zone separating two terranes. Another critical element that appears to be related to gold prospectivity is the presence of lithologies with a juvenile signature. In contrast to nickel analyses which are closely related to mafic-ultramafic units, the source component seems less influential when attempting to target orogenic gold deposits.

Structural and metamorphic characterisation of the subduction-accretion rocks near Walcha, NSW

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The southern New England Orogen from west to east, consists of a buried volcanic arc, concave to the east forearc basin (Tamworth Belt) and a subduction–accretion complex (Tablelands Complex) associated with a west-dipping subduction zone. Many authors propose that these three belts were deformed into a megafold in the north (Texas-Coffs Harbour Orocline) and two smaller scale, megafolds (Manning-Hastings/Nambucca Orocline) in the south. In this study, structural, petrographic and x-ray diffraction studies have been undertaken on deformed, HTLP rocks associated with the Tia Complex and LTHP subduction-accretion rocks of the Tablelands Complex with the aim to test whether (1) the Manning Orocline existed and (2) the structure in the accretion-subduction complex is as simple as some authors have suggested.

Mapping of the subduction-accretion rocks west of Walcha reveals dominantly S2 fabrics which have been crenulated and folded during D3. Bedding is tightly folded into mesoscopic folds (F2) which plunge gently southsouthwest axial plane to which is a steeply dipping axial surface cleavage S2. The sharp changes in structural vergence of F2 folds suggest fault-bounded packages of rock consistent with their origin in a subduction-accretion complex. Petrographic analyses shows that the western most exposures were subjected to HTLP overprinting associated with the Tia Granodiorite in contrast to those closer to Walcha which lack this overprint.

The rocks up to 10 kilometers north of Walcha, assigned to the Sandon Beds are considered by Li et al. (2013) to contain only one fabric (S1). Our studies indicate that they record a structurally more complex history resulting in a variety of cleavages developing including pencil cleavage, penetrative cleavage and spaced crenulation cleavage. The variability in the orientation of the spaced crenulation cleavage in adjacent outcrops suggest it has been re-folded. Thin section examination reveals limited evidence for the HTLP event suggesting that the effects of this event is patchy.

The rocks east of Walcha consist of two packages separated along the north-south trending Tia Falls Line (Tia River-Oxley Hwy junction). Petrogaphic and x-ray diffraction analyses of K-white mica, limit the HTLP event to sequences W of Yarrowitch. E of Yarrowitch, the meta-chert-slate dominated sequences are multiply deformed, show fabrics produced during the 3 deformation events that have been formed under lower greenschist facies conditions. In addition, b cell parameter determined from K-white micas (9.040–9.045) reflect the HPLT event.

Thus the structural-metamorphic history recorded is far more complex than previously suggested resulting in multiple tectonic fabrics and a variety of mineral assemblages produced during the two major events. The assumption that the Manning Orocline exists based on the variation in orientation of one tectonic fabric is therefore not tenable.

Mid-crustal extensional structures of an accretionary orogeny, geophysical evidence from the Macquarie Arc, the Tasmanides

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Extensional accretionary orogens form often during lithospheric extension, basin formation and associated sedimentation due to prolonged subduction trench retreat. These extensional tectonic systems are often overprinted by transient and episodic shortening events during trench advance causing basin inversion and extensional fault reactivation. Our research is focussed on understanding the geometry of the Macquarie Arc and bounding Devonian basins, the deformation events and styles that controlled the crustal architecture of the Tasmanides accretionary orogen. In doing so, we propose a crustal scale tectonic model that explains the geometry of the Ordovician to Silurian Macquarie arc. The Macquarie Arc is unusual because it is made up of three separate belts, it is not understood whether they originated as a continuous belt or separate belts.

We constructed crustal-scale, joint 2.5D gravity and magnetic data forward models constrained by reflection and refraction seismic results, petrophysical data (bulk density and magnetic susceptibility) and structural data to unravel the architecture of the arc. The Bouguer anomaly gravity profiles data were collected at 1km station spacing during the October 2017 Field work (512 km). The results highlight: (1) the relationship between the geometry of faults bounding Macquarie arc structural belts and Devonian rift basins; (2) the folded Devonian and Silurian stratigraphy is truncated by faults that were reactivated during the Devonian; (3) Inversion of Early Silurian normal faults into thrust or reverse faults; (4) that imbricated blocks of the Macquarie Arc partially underlie Devonian Basins. (5) that the mid-crust is imbricated with faults extending to the Moho. The crustal-scale models suggest a geometry that is consistent with a hyper extended arc characterised by a series of imbricate faults that slice the mid crust and sole into the Moho. This extensional regime for the eastern Macquarie arc is interpreted to a result of late Silurian slab roll back.

Toward a digital seamless chronostratigraphic solid geology dataset of Australia

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Much of Australia is covered by a thin veneer of sediments or weathered materials. To unravel the geological history and mineral resource potential of Australia, and to address the challenge of exploring through cover, Geoscience Australia (GA) has been undertaking a new approach to solid geology mapping of Australia since 2017 to produce several continental scale seamless solid geology maps of major geological eras in Australia, i.e. Mesozoic, Paleozoic, Neoproterozoic, and pre-Neoproterozoic. Through the Exploring for the Future on-going program, GA will be delivering the first series of publicly available seamless solid geology maps covering the entire North Australia Craton.

This work is based on a multidisciplinary approach, where the GA's 1:1,000,000 scale Surface Geology of Australia, state surveys' recent solid geology mapping, drill hole data, seismic profiles and interpretation of potential field data are integrated to characterize the geology from the surface down to the crystalline basement. These solid geology layers depict mapped geological units that are defined in GA's Australian Stratigraphic Units Database (ASUD) and major structures. Through ASUD, the solid geology maps can be linked to other geoscience databases including geochemistry and geochronology.

In addition to be the first series of maps of its kind produced at an unprecedented continental scale, these results support the development of key prospecting tools, including cover thickness mapping, mineral potential mapping and basement geology mapping. For example, these results provided new insights into the geological province boundaries beneath a number of sedimentary basins and the South Nicholson Basin was redefined to be three times larger and more prospective than previously interpreted. This work also shed light on the pre-Neoproterozoic basement geology under the Canning Basin, where the geology has been mapped in far more details than ever before, including the interpretation of a number of basement terranes.

In the longer term, GA aims to extend these solid geology maps to cover the entire Australian continent. This work will become the first ever produced seamless solid geology of this scale available in the public domain. Additional layers, such as an Archean layer and a Cenozoic surface geology layer from the 1:1,000,000 scale surface geology of Australia will also be made available.

Numerical modeling of drainage evolution in southeast Tibet influenced by tectonics coupled with surface processes

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The three river region (Salween, Mekong, and Yangtze Rivers) in southeast Tibet provides an example of drainage evolution in active orogenic system. Over decades of investigations based on geomorphic evidence analysis, or landscape evolution modeling, the main factor resulting in the unusual drainage patterns in this area remains controversial. Some studies argued that the horizontal tectonic deformation has brought the previous rivers to be nearly parallel in extraordinary close space. In contrast, others suggested that can be explained by drainage reorganization, and the capture and reversal events merely appeal to the surface uplift. Tectonics and surface processes integrate to shape the topography of fluvially conditioned mountain ranges, and important two-way feedbacks exist between them. The direct feedback through isostatic response is related to the vertical aspect of exhumation and surface uplift. Surface processes also alter the thermal and stress field in the lithosphere by redistributing significant volumes of materials, which further affect both horizontal and vertical components of tectonic displacement. We study the drainage evolution in the three river region using a fully coupled 3-D model built by the UWGeodynamics module, which coupled the geodynamics code Underworld 2 with landscape evolution model code Badlands. The fully coupled models have the advantages of taking complex interactions into consideration. Results demonstrate that tectonics and surface processes both influence the drainage, and the large-magnitude tectonic shear is the primary control on the drainage patterns.

Seismic expression of Cretaceous-Cenozoic magmatic plumbing systems in the Bass and Gippsland Basins

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Magmatic activity in hydrocarbon-bearing basins has both detrimental and beneficial impacts on prospectivity. In order to mitigate risks associated with increased exploration along magma-poor continental margins such as the southern Australian margin, a good understanding of magma transport within sedimentary basins is imperative. The use of three-dimensional (3D) seismic data delivers the necessary insight in magma transport through sedimentary basins. This study uses a combination of 3D and 2D seismic data to describe the differing magma plumbing styles of the syn- and post-rift magmatic activity hosted in the Bass and Gippsland Basin.

Although the Bass and Gippsland Basins are adjacent to each other, separated by the Bassian Rise, they only partly share their geological history and therefore the distribution and chronology of igneous events differs significantly. The Bass Basin was more influenced by the separation of Antarctica and Australia and the Gippsland Basin more affected by the opening of the Tasman Sea to the east. Within the Gippsland Basin, magmatism mainly occurred in several phases ranging from the Late Cretaceous (Campanian) to Middle Eocene, with the most abundant activity occurring during the Late Cretaceous. Detailed mapping of available 3D seismic reflection datasets illustrates that, in the upper crust, magma travelled from the centre of the Gippsland Basin (Central Deep) towards the basin-bounding major faults in the north (Rosedale Fault System) and south (Darriman Fault System). This magma travelled through an extensive interconnected network of sills, spanning over 40 km laterally and several kilometres vertically, to finally extrude onto the paleo-surface as lava flows near the basin edges. This network has been established over several magmatic pulses starting from the Campanian to the Middle Eocene, with extrusive activity and fractionation progressing from east to west along the northern Rosedale fault. Subsequent magmatism is represented by a Middle Eocene volcanic cone complex, located in the Central Deep near the Bream Field. In contrast to the Late Cretaceous magmatism, these volcanic cones are fed by underlying intrusions and vertical to near-vertical faults or dykes. A small area in the south-east of the basin, near the Sailfish-1 well, hosts several pyroclastic cones of Miocene age. Based on the age and location of this magmatic activity, it is more likely to be related to the Tasmanian Cenozoic magmatism. The Bass Basin on the other hand hosts a large number of igneous rocks with ages ranging from the Cretaceous to the Miocene, with the magmatic activity mainly occurring during the Miocene. Cretaceous to Eocene magmatic activity is mainly focussed at major faults near the basin edges. In contrast to the Gippsland Basin, no lateral network of sills has been observed and magma transport through the upper crust inhibits a more vertical nature through vertical to near-vertical dykes and faults. Miocene magmatic activity is constrained to the centre of the Cape Wickham Sub-basin and is expressed as volcanic cones and few sills. This phase of magmatic activity shows a remarkable age trend, with younger, Miocene, magmatic activity towards the south. This trend is in concordance to magmatic activity observed on the Australian mainland and seamount chains offshore eastern Australia.

Magmatism in rift basins is often perceived negatively with regards to hydrocarbon plays, however several examples exist within the Bass and Gippsland basins proving otherwise (e.g. lava flow sealing the Kipper Field, volcanics overlying reservoirs of the Yolla Field). A better understanding of magmatic plumbing systems in rift basins will aid in exploration and mitigation of associated risks in these petroliferous areas.

The thick or thin of the Arthur Complex, western Tasmania

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In western Tasmania, the Arthur Complex separates the western Mesoproterozoic Rocky Cape and Neoproterozoic Smithton Basin sequences from the eastern Oonah Formation and overlying rocks. Previous models of the region (e.g. Berry 2014) suggested that the Complex lies in a thin-skinned, west-directed thrust system that was driven over the nearshore Rocky Cape Group and its offshore correlate, the Oonah Formation. However, recent work by Mulder et al. (2018) showed that the Oonah Formation is Neoproterozoic, suggesting that correlation with the Rocky Cape Group is invalid and throwing doubt on the nature of the contact between the eastern and western packages.

By integrating the mapped geology with the potential field data, we present a thick-skinned model where the Arthur Complex structures initially formed as deep, rift-related faults dipping at perhaps 20 to 50° that separated the shallow-water western Smithton Basin from the deeper water eastern Oonah Formation and the coeval Cooee Dolerite. This rifting is related to the Rodinian breakup. Subsequently, the eastern side filled with sediments before a second rifting event in the Ediacaran and early Cambrian deepened the water depths in the east and generated further mafic magmas (Spinks Creek, Crimson Creek and Luina basalts). The second rifting marked the breakup of VanDieland from the Mawson Continent (East Antarctica). Some mafic magmas may have ponded at depth below the rift as a dense, variably magnetic body is present below 10 to 15 km.

These rift-related packages were inverted during the Tyennan Orogeny, which affected all of the VanDieland microcontinent. Syn-rift faults were steepened to their present attitudes, between 50 and 80°, and the blueschist facies rocks of the Arthur Complex were exhumed. This thick-skinned model is similar to those seen elsewhere in this part of Gondwana, (e.g. central Victoria (Cayley et al. 2011), or East Antarctica (Godard and Palmeri 2013).

References

Berry R. F. 2014. Cambrian tectonics-the Tyennan Orogeny. In: Corbett K. D., Quilty P. G. and Calver C. R. eds., Geological evolution of Tasmania, pp 95-110, Geological Society of Australia (Tasmania Division), Hobart, Tasmania.

Cayley R. A., Korsch R. J., Moore D. H., Costelloe R. D., Nakamura A., Willman C. E., Rawling T. J., Morand V. J., Skladzien P. B. and O'Shea P. J. 2011. Crustal architecture of Central Victoria: results from the 2006 deep crustal reflection seismic survey. Australian Journal of Earth Sciences 58, 113-156, doi: 10.1080/08120099.2011.543151.

Godard G. and Palmeri R. 2013. High-pressure metamorphism in Antarctica from the Proterozoic to the Cenozoic: a review and geodynamic implications. Gondwana Research 23, 844-864, doi: 10.1016/j.gr.2012.07.012.

Mulder J. A., Berry R. F., Halpin J. A., Meffre S. and Everard J. L. 2018. Depositional age and correlation of the Oonah Formation: refining the timing of Neoproterozoic basin formation in Tasmania. Australian Journal of Earth Sciences, 1-17, doi: 10.1080/08120099.2018.1426629.

Underworld: expanding the use of geodynamics research codes

Louis Moresi and Romain Beucher — pp the underworld development team

https://github.com/underworldcode (University of Melbourne, Australian National University, Monash University and the open source community)

Underworld (www.underworldcode.org), the parallel, particle-in-cell, finite element, research code, has been a staple for the geodynamics modelling community with a number of applications areas including:

1. Dynamic models of subduction systems and convergent margins
2. Extensional basin systems with evolving upper surfaces coupled to erosion / deposition models
3. Mantle convection simulations with complex rheology
4. Solid mechanics with localisation, visco-elastic behaviour and history dependent "damage"

In the past, Underworld was executed by painstaking editing of xml files that completely defined the computational problem. User-level parameter variations always had to have been anticipated by the development team and there was limited capacity for users to debug problems with their xml files or isolate the underlying implementation.

Underworld2 introduced a python front end that permitted users to combine underworld components in novel (and often unexpected) ways, and introduced an Underworld python "style" that helps users to write code that is safe in parallel and efficient for the kinds of geodynamics problems the code is intended to solve. Adopting this style frees the user from the need to understand the detailed implementation of the underlying parallel finite element engine or the equation solvers.

Underworld remains a complex software product with many dependencies that can be difficult to install, particularly if you want to use the same machine to do anything else. We have therefore developed a number of alternative practices to help make Underworld more accessible:

1. Ubiquitous use of Jupyter notebooks with their built-in help system
2. Installation via docker containers that isolate the complexity and bundle all dependencies
3. Cloud deployments of all training materials, examples, and sample published results
4. A simplified interface aimed at beginner-to-intermediate users (UWGeodynamics)
5. A supported github-based Underworld user community for users to exchange ideas and examples

We will demonstrate the cloud-deployed Underworld code and show how it has become a tool that scales from the classroom to top-tier supercomputing facilities. We will discuss our philosophy that allows recent research results to propagate quickly to other researchers and to students.

References

Beucher, R., L. Moresi, J. Giordani, J. Mansour, D. Sandiford, R. Farrington, L. Mondy, C. Mallard, P. Rey, G. Duclaux, O. Kaluza, A. Laik and S. Morón. UWGeodynamics: A teaching and research tool for numerical geodynamic modelling. Journal of Open Source Software 4(36), 2019

L. Moresi, S. Quenette, V. Lemiale, C. Mériaux, W. Appelbe, and Mühlhaus. Computational approaches to studying non-linear dynamics of the crust and mantle. Phys. Earth Planet. Inter, 163:69–82, 2007.

Neoproterozoic tectonostratigraphy of Tasmania: a record of multi-stage rifting during the initiation of the Pacific Ocean

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The Tonian to Ediacaran geology of Tasmania, southeast Australia preserves an extensive record of continental rifting related to the Neoproterozoic development of the Pacific Ocean. We develop a tectonostratigraphic framework for Neoproterozoic sedimentary and magmatic rocks in Tasmania with the aim of better understanding the number and duration of Neoproterozoic rift events and their relationship to rifting elsewhere along the paleo-margins of the Pacific Ocean. New and previously published structural, stratigraphic, sedimentary provenance, age, and geochemical data establishes four tectonostratigraphic stages in Tasmania that formed during three episodes of Neoproterozoic rifting.

Rift Event 1 in Tasmania initiated with Tonian (ca. 780–750 Ma) intraplate magmatism on King Island and deposition of clastic sedimentary and rift-related igneous rocks comprising the protoliths of that were metamorphosed in the Cambrian in western Tasmania. The latter stages of Rift Event 1 are recorded by an eastward thickening and deepening succession of late Tonian (< 780 Ma–730 Ma) siliciclastic and carbonate strata (tectonostratigraphic stage 1). The detrital zircon provenance of Tonian clastic strata in Tasmania is dominated by large age populations at 1800–1600 Ma, 1450 Ma, and 1300–1100 Ma and small populations at 780–760 Ma. These detrital zircons were likely recycled from underlying late and middle Mesoproterozoic strata, which were progressively unroofed during Rift Event 1, and from Tonian granites on King Island. Cryogenian glaciogenic strata and thick successions of mafic volcaniclastic turbidites were deposited during tectonostratigraphic stage 2. These strata contain unimodal 670–640 Ma detrital zircon age populations and record a second rift event (Rift Event 2). The final Neoproterozoic rift event in Tasmania (Rift Event 3) involved voluminous ca. 580 Ma basaltic volcanism and active extensional faulting (tectonostratigraphic stage 3) and was followed by latest Ediacaran—early Cambrian sag-phase sedimentation (tectonostratigraphic stage 4).

The three Neoproterozoic rift events in Tasmania are broadly contemporaneous with punctuated Tonian–Ediacaran rifting along the paleo-margins of the Pacific Ocean in southeast Australia, East Antarctica, and western Laurentia (Proterozoic North America). Rift Event 1 in Tasmania is interpreted to mark the initial breakup of Australia-Antarctica and western Laurentia to form the nascent Pacific Ocean. Geological correlations permit Tasmania to have remained attached to either the eastern margin of Australia-Antarctica or the western margin of Laurentia during the late Tonian and Cryogenian before being isolated as a late Ediacaran microcontinent in the Pacific Ocean during Rift Event 3.

Can deformation and melt migration influence crustal behaviour? An example from the Coompana Province of South Australia

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New work from the eastern Coompana Province of South Australia provides insights into how the distribution of melt can influence strain partitioning and affect the behaviour of the crust. Structural observations, and geochemical and geochronological constraints from drill core of migmatitic host rocks and granitic intrusions from the Coompana Province basement reveal that the period between 1200 and 1141 Ma was dominated by extension. However, these constraints, in conjunction with the geophysical datasets reveal a change in the partitioning of strain within the crust.

A three stage sequence of structural events was observed within this period:

1. Initial extension was widespread with pervasive development of flat-lying foliations and recumbent isoclinal folds that are defined by leucosomes, dated between c. 1200 and 1160 Ma. The leucosomes are parallel to, and contemporaneous with shoshonite sheets dated at 1174 Ma. These observations suggest widespread EW-directed crustal thinning prior to c. 1160 Ma.
2. This was followed by local development of cm-scale, melt-filled reverse faults in drill core, and local upright folding that is observed in the seismic images and suggested by the stereonets of the leucosomes.
3. Later extension was focused into a NE-trending shear-bounded corridor that projects from the NW margin of the Gawler Craton. This corridor is characterised by thinner crust on seismic profiles and abundant, overlapping plutons of A-type, high KFe granite, dated at c. 1150 Ma. No evidence for anatexis is observed at this time.

The change in extension style represents a switch from “ductile” pervasive deformation, to more “brittle” focussed crustal behaviour, with the switch coinciding with the development of reverse faulting and upright folding. We propose that this switch in behaviour can be attributed to the distribution of melt in the region. Initial extension occurred in the presence of significant melt, which allowed the crust to behave in a relatively ductile manner. We suggest that the reverse faults and upright folding record a brief change in stress, likely related to plate margin processes to the east. The shortening event led to the redistribution of melt, which migrated through vertical structures to higher crustal levels, essentially strengthening the lower and middle crust. Shortening also resulted in minor strike-slip shear reactivation of the arcuate northwest-margin of the Gawler Craton. When the region returned to extension, the change in melt distribution throughout the crustal profile caused the crust to behave in a more “brittle” manner. Extension was focussed along the sheared NW margin of the Gawler, which reactivated and propagated to the SW leading to the focussed tearing along the transtensional corridor. The thinner crust within this corridor focussed the ascent of the A-type, high KFe magmas, further weakening the crust in this corridor and promoting strain partitioning into a narrow zone, rather than throughout the province.

Crustal architecture and volcanic distribution in the central North West Shelf of Australia: insight from potential field modelling

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The Roebuck Basin is considered a new and relatively untested hydrocarbon province in the central North West Shelf of Australia. Inconsistent results from drilling for hydrocarbons highlights the need to better understand the deep structures along this rifted margin that initially formed as an intra-continental, failed rift during Late Permian. Recent wells penetrated the previously unknown Lower-Middle Triassic fluvio-deltaic sedimentary package in the Bedout Sub-basin (inboard part of the Roebuck Basin), including intervals with major oil and gas discoveries. Another two wells, Anhalt 1 and Hannover South 1, only penetrated the top of this succession and they encountered volcanics in the Rowley Sub-basin (outboard part of the Roebuck Basin). Steeply dipping clinoforms observed in the seismic data in the Rowley Sub-basin have been interpreted either as a lava delta complex associated with a failed triple junction; or as a series of back-stepping, Late Permian carbonate ramps and banks, interpreted to have developed on a thermally subsiding rift flank. The implication for prospectivity between the two scenarios is significant. Geoscience Australia undertook a Triassic regional basin analyses, including potential field modelling to validate whether the two proposed models are a plausible solution. A combination of magnetic and gravity 2.5D modelling along nine key regional seismic lines, considered the distribution of potential intrabasinal volcanic rocks and the crustal structure, including Moho depth and depth to top crystalline basement.

New seismic interpretation correlated to recent wells, including 2D and 3D seismic reflection surveys was integrated with deep seismic reflection and refraction data resulting in an improved geometry and lithology model that was input into the potential field analyses. The results show that the combined Jurassic and Triassic successions reach up to 16 km deep in the central North West Shelf.

The Lower-Middle Triassic sediment package in the Rowley Sub-basin correlates with up to 10 km of dense material (about 2.7 g/cm^3 density) and contains magnetic features partially sourced from basalts at the top of the section, as intersected in Anhalt 1 and Hannover South 1. Combined with other causative sources within basement, the basalts correlate with a spatially large positive magnetic anomaly that extends north onto the Scott Plateau and into the Barcoo Sub-basin; in the offshore southwest part of the Browse Basin, where Warrabkook 1 intersected Late Jurassic volcanoclastics at its total depth. The presence of high density and high positive magnetic anomalies in the Lower-Middle Triassic and basement supports the presence of a large igneous province in this area. This interpretation in the outer Rowley Sub-basin downgrades the petroleum prospectivity in this area for this Lower-Middle Triassic interval. Petroleum prospectivity remains in the area due to the overlying sediments containing good source rocks which have been identified to have good to excellent generative potential.

The Lower-Middle Triassic sediment package in the adjacent northern Carnarvon Basin has been intersected only on the Lambert Shelf; encountering fluvio-deltaic sediments. In the offshore part of the northern Carnarvon Basin, the nature of this sediment package still remains enigmatic. It correlates with low density sediments (about 2.5 g/cm^3 density) that include magnetic bodies on the outboard Exmouth Plateau. The basement and crust show crustal thinning with the presence of a thick layer of interpreted hyper-extended continental crust or exhumed lithospheric mantle. This crustal domain is overlain by thick onlapping Lower-Middle Triassic sediments which form a triangular shape depocentre in the inboard northern Carnarvon Basin, wrapping around the edge of the Pilbara Craton. The location of this initial thick sediment package suggests that it was controlled by the inherited thermal structure of the Late Permian-early Triassic rift architecture that is associated with some volcanics related to a large igneous province extending across the central North West Shelf. As described in the Rowley Sub-basin, the petroleum prospectivity of the northern Carnarvon Basin remains in the overlying sediments showing similar characteristics and indicating good to excellent hydrocarbon generative potential.

There and back: recording metamorphism in the Western Gneiss Complex

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The Western Gneiss Complex (WGC) in Norway records subduction of continental lithosphere up to >125 km during the Silurian-Devonian Caledonian Orogeny. The earlier Gothian (1750–150 Ma) and Sveconorwegian (ca. 900 Ma) Orogenies created a sparsely reactive rock system that experienced later kinetic inhibition. ~95% of the WGC is comprised of felsic gneiss that hosts mafic eclogite facies and minor metapelitic volumes. The mafic and metapelitic rocks predominantly record Caledonian subduction while the volumetrically dominant felsic rocks record little to no evidence of deep burial. The southern ultrahigh-P domain in the Sognefjord region contains mafic eclogite facies assemblages which record pressures ~2–2.2 GPa and temperatures of 650–700 °C. As the thermobarometric intensity of Caledonian reworking is comparatively mild in the Sognefjord region, it presents the opportunity to explore the evolving pattern of metamorphic reactivity in mafic and felsic rocks during Caledonian subduction and exhumation. Detailed structural mapping reveals a complex pattern of evolving rock reactivity linked to chemical and mechanical catalysis. Mafic rocks only meters apart show dramatically contrasting responses to Caledonian reworking.

Essentially unmodified mafic rocks contain pristine orthopyroxene or hornblende-bearing leucosomes. Caledonian reworking in reactive mafic rocks is expressed in three different ways. Early (D1/S1 Caledonian) deformation is recorded by a low-intensity biotite foliation overgrown by eclogite-facies garnet- clinopyroxene-phengite coronas. D1/S1 Caledonian is overprinted by meter-scale D2/S2 Caledonian eclogite facies (garnet-clinopyroxene-phengite-rutile-quartz-phengite-rich veins) shear zones that continued to metamorphically update, leaving behind kinetically stalled strain-abandoned D1/S1 Caledonian domains. Thus, reactive mafic rocks captured prograde Caledonian burial while unreactive companion mafic rocks captured nothing. Caledonian D2/S2 eclogite is overprinted by initially diatexitic shear zones (D3/S3) that evolve into solid-state deformation zones (D4/S4) at 100 m+ scales. The metamorphic effect on mafic eclogites is to convert them to biotite-hornblende-plagioclase amphibolite schists. The lack of garnet in these retrogressed rocks suggests that pressures were less than 1.0 GPa by this time. The hydrous mineral assemblages define intensely developed D4/S4 structural fabrics. In contrast to reactive mafic rocks, felsic rocks show no evidence for high-pressure metamorphism, only recording Caledonian D4/S4 overprinting. Where this happens, sparse (<0.1% of outcrop at 100m scale) garnet is formed as coronas on pre-Caledonian biotite, or as small matrix grains. Where the felsic rocks do record metamorphic change, they are already ~50% exhumed. They were completely unreactive during prograde or near peak retrograde conditions. We speculate the evolving pattern of rock reactivity was controlled by chemical catalysis linked to hydration. Conceivably during the latter stages of the high-grade Sveconorwegian Orogeny, retrogression established localised hydrous rock volumes within generally H_2O-low content crust. In high-grade crust, it is well recognised that retrogression is commonly localised into mafic rocks, creating a lithologically controlled petrological reactive preconditioning. During the Caledonian, mafic rocks that escaped this pre-conditioning remained unreactive, while spatially adjacent rocks that were pre-conditioned became reactive, resulting in a coupling of metamorphic mineral growth, fluid generation and strain localisation. In comparatively fluid-poor rocks, prograde mineral development stalled and strain shifted to more fluid-rich domains. This evolution is recorded by the transition from low-strain biotite-bearing mafic assemblages to high-strain eclogites that contain abundant muscovite-garnet-clinopyroxene veins, attesting to the presence of fluids. In contrast, the immediately enclosing felsic rocks (at meter-scale) were completely unreactive at this time, implying that significant barriers to fluid-migration must have existed. During post-peak Caledonian conditions, 50m-scale diatexitic domains (D3/S3) developed that resulted in complete replacement of the eclogite facies assemblages by amphibolite facies assemblages. The origins of these diatexitic structures are obscure because subsequent strain localisation (D4/S4) has destroyed the evidence for their origins. Within these diatexitic zones and the overprinting D4/S4 domains is the first time felsic rocks become reactive. Thus the metamorphic record of the Caledonian Orogeny in the Sognefjord region was essentially completely modulated by spatial patterns of fluid availability during the prograde and retrograde history.

Compositionally-based thermal conductivity of igneous and metamorphic rocks

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Thermal conductivity (*k*) is essential for determining the heat flow of the Earth, which allows for geothermal investigations, understanding tectonic and volcanic processes, mining and drilling, exploration, and petroleum maturation. The aim of this paper is to develop a predictive compositional method for estimating *k*, of igneous rocks, and comparing these values with the direct measurement of *k*. To measure the *k*, an optical scanner, designed by Professor Yuri Popov in 1983, is used as this is the quickest and most efficient way. 340 new *k* measurements were made, along with 77 measurements from literature. All the samples have their major element geochemistry and modal mineralogy, which is used to show empirical relationships between composition and *k*. The arithmetic, geometric, square-root, and harmonic mean mixing models are tested to determine *k* indirectly. Results show the geometric model produces a consistent best fit and that the primary control on *k* is SiO_2. Due to this successful method, further study into metamorphic rocks is now being developed. The focus of the next paper is to focus on how anisotropy (α) and *k* are related by using metamorphic rocks. For metamorphic rocks, *k* parallel ($k_{||}$) to the foliation is higher than the *k* perpendicular ($k_{\perp}$), and these values are used to determine anisotropy, $\alpha = \frac{k_{||}}{k_{\perp}}$.

The 200 metamorphic samples selected are from various countries, do not have any fractures, are crystalline (i.e. non-porous), have no weathering and range between 2x2x2 cm and 15x15x15 cm. For each sample, *k*, density and mineralogy is analysed. The arithmetic, harmonic, Voight-Reuss-Hill average, effective medium and Hashin-Shtrikman mean mixing models are used to determine *k* as an indirect method. The geometric mean is not used as it does not consider any textures within a rock, and therefore, cannot be used here due to anisotropy. From the following mixing models, root-mean-square (RMS) is used to analyse each mixing model to see which model produces the most effective *k* value.

Constrained 2D inversions of magnetotelluric data using 1D probabilistic inversions results

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Exploration under cover and identification of mineral systems are of great interest to the Australian geoscience community. Significant effort has been made to acquire continent wide magnetotelluric (MT) data to image mineral systems architecture at the lithospheric scale. Infield MT surveys have been carried out to characterize covered mineralized targets at the deposit scale. Mineral deposits and the fluid pathways associated to them are generally conductive anomalies located in the resistive basement or upper crust. Their precise and reliable detection in terms of depth and extent can be complicated by the presence of a thick conductive cover. In these situations, deterministic magnetotelluric inversion requires significant constraints and regularisation to overcome high non-uniqueness.

We propose an MT data driven workflow for deriving those constraints. This in turn can lead to better resolution of the bodies of interest. We first perform probabilistic inversions using 1D trans-dimensional Markov chain Monte Carlo samplers for estimating subsurface conductivity and its associated uncertainty for each site along a 2D line. These inversions are designed to be robust to non-1D effects present in the data. Next, using a lateral prior, the 1D probabilistic models are fused to form a low resolution 2D posterior ensemble. This is used to derive constraints on identified interface locations and layer resistivities. Finally, model roughness penalties are formulated to constrain the 2D deterministic inversion.

This workflow is assessed using synthetic data computed from a realistic 3D Earth. Results are compared to unconstrained 2D and 3D inversions to quantify the improvement in reliability and resolution.

Geological mapping under Antarctic ice: a new approach to information synthesis and uncertainty representation

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Geologists have developed a consistent and detailed methodology and symbology for geological maps over the past two centuries. Geological maps imply underlying formation processes by their nature, but the reality is that geological data are associated with a range of uncertainties and alternative interpretations that are lost when boundaries are inked, and polygons colorized. We wish to build on the mapping tradition, but also provide new layers of useful information. Such new methods are especially appropriate in working with the unknown subglacial geology in Antarctica.

Geophysical and statistical methods have the potential to improve our knowledge of large-scale geological phenomena under shallow cover sequences or ice. Depending on the techniques and datasets used, interpretations of geology guided by geophysics can be contradictory. New data can reduce uncertainty and increase resolution, but also yield new interpretations that need to be considered alongside existing alternatives.

To enable the generation of valid inferences from multiple, evolving datasets, we introduce a probabilistic mapping technique. The theoretical framework for our approach is well established, but rarely applied to spatial data sets. Geological attributes such as age and rock type are associated with statistical distributions based on probability densities or likelihood and represented as spatial data in a projected grid. To achieve this, we add new methods with additional stochastic tools to the open source computing environment 'agrid', which is well suited to multivariate and multidimensional probabilistic analysis and visualisation. Communication of multidimensional and probabilistic models provides new challenges. We explore alternative solutions for disclosing uncertainty in geophysical data and geological interpretations.

The resulting maps provide an estimate of geophysical and geological properties with robust associated probability and uncertainty. Our approach is particularly useful in an Antarctic setting, where geological observations are sparse. Forward computation of derived properties, e.g. crustal heat generation, may be assigned uncertainty to form a stochastic multidimensional grid. Our workflow can easily be updated as new data become available. Well-founded synthesis of information and quantification of uncertainty has high value to interdisciplinary research use of geological constraints such as ice sheet modellers.

An insight to the tectonic geography of Mesoproterozoic northern Australia through detrital zircon geochronology and provenance study of the greater McArthur Basin

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The greater McArthur Basin is a Proterozoic subsurface basin system, extending from north-east Western Australia to north-west Queensland over a significant portion of the Northern Territory. The region hosts large and proven hydrocarbon reserves, high grade mineralisation as well as an unperturbed sedimentary record of its geological era.

The 'super-basin' consists of five distinct packages from the McArthur Basin, the Birrindudu Basin and the Tomkinson Province. These packages categorise basin-wide rocks of similar age, lithology and stratigraphic position. This study focuses on the Favenc and Wilton packages, which are interpreted to reflect a transition from freshwater, anoxic, lacustrine conditions into a restricted, shallow-water, dominantly marine environment.

LA-ICP-MS detrital zircon U–Pb age data presented in this study provides new age constraints on both the Favenc and Wilton packages and illuminates the spatial and temporal variations in provenance. The maximum depositional age of the Dook Creek Formation of the Mount Rigg Group (Favenc Package) is 1614 ± 78 Ma. Further up stratigraphy into the lower Roper Group (Wilton Package), zircon grains from the Hodgson Sandstone and the Jalboi Formation constrained the maximum depositional ages of these units to 1591 ± 90 Ma and 1633 ± 89 Ma respectively. At the top of the Roper Group, the Kyalla Formation was deposited after 1313 ± 47 Ma, but before the ca. 1313 Ma Derim Derim dolerites that intrude them.

REE and Lu-Hf isotopic data were also obtained and analysed in order to establish intra-basin correlations and the nature of magma in which the zircons originated from. When integrating all detrital zircon data sets, results indicated that the formations within the Favenc and lower section of the Wilton packages were sourcing from similar regions south of the basin system; in particular the Arunta Province and the Tennant Orogeny. Stratigraphically younger sediments then introduced detritus from easterly sources within the Mount Isa Province.

A tectonic model is then proposed to illustrate the sequence of events that led to the uplift and erosion of these igneous provinces. Rifting between the combined South Australian Craton and the North Australian Craton from Laurentia (ca. 1.5 Ga), followed by the subduction of the Mirning Ocean and collision with the West Australian Craton (post 1.45 Ga) exhumed distinct provenance sources at different stages, controlling the changes in detrital origin. Development in palaeogeography would also have consequences for basin restriction, as connectivity to the open sea would be limited by multiple sources surrounding the depositional system. Ultimately, this study provides insight into how tectonic activity can influence the evolution of a basin’s sedimentary input and palaeoenvironment.

Multiscale structural analysis of Boulder Lefroy Shear Zone in eastern goldfields of Western Australia

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Large-scale crustal shear zones are commonly associated with the formation of various epigenetic deposits like IOCG, copper-porphyry and orogenic gold deposits. In Archean orogenic gold terranes of Yilgarn, most Au mineralisation occurs within linear greenstone belts, whose structures are spatially controlled by regional crustal-scale shear zones. Such crustal-scale shear zones provide the required permeability for mid-crustal fluid flow leading to mineralisation. The study of such plumbing system is therefore often seen as essential to better understand the distribution of deposits.

The Boulder Lefroy Shear Zone (BLSZ) in the Eastern Goldfields province of Western Australia is an example of such crustal-scale shear zone. The BLSZ is a N-NW trending major crustal-scale shear zone which formed during the Late Archean Kalgoorlie Orogen at c. 2655 to 2625 Ma. The shear zone extends over a strike length of 200 km and is a part of the greenstone sequence of Kalgoorlie Terrane in the Eastern Goldfields Superterrane. Historical research done on the BLSZ emphasise its role in controlling the distribution of gold in four world-class gold camps including Golden Mile, present in its proximity. Using aerial imagery and aeromagnetic anomalies previous authors have suggested that the BLSZ recorded sinistral kinematic. However, the inferred sinistral nature of the shear zone and the associated structural record remains poorly documented. A better understanding of the structural history of the shear zone is essential to further define its role in controlling mineralisation and distribution of deposits.

Our research approach relies on a multiscale structural analysis of the Boulder Lefroy Shear Zone combining camp-scale geophysical structural interpretation with field-based structural mapping of an outcrop exposure of the BLSZ near Kambalda. 1:1000 scale detailed geological mapping along with drone-based photogrammetry was done in selected outcrops of BLSZ to focus on detailed structural analysis and identifying the orientation of the deformed kinematic indicators. Georeferenced, overlapping photos of each outcrop were captured by the drone during automated flights and were fed into the photogrammetry software Agisoft Metashape to produce textured 3D models, Digital Elevation Models (DEM) and orthorectified mosaics for each outcrop. The produced models are used to complement field mapping and further assist in evaluating the finite strain of the study area. At a camp-scale, interpretation of structures from aero-magnetic geophysical datasets was carried out using ArcGIS and correlated with field-based and photogrammetry interpretations. Preliminary results from this multi-scale structural analysis show little evidence for strike slip movement along the BLSZ with strain record pointing towards dominant pure flattening strain record.

Dating of fault gouge along the central segment of Xianshuihe-Anninghe-Xiaojiang fault system, in the Daliangshan area, southeastern Tibetan Plateau margin

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The Xianshuihe-Anninghe-Xiaojiang fault system (XXF), located at the southeastern margin of Tibetan Plateau, severs as a large-scale left strike-slip lithospheric fault to accommodate easternward movement and clockwise rotation of Tibet crustal mass around the eastern Himalayan syntaxis. Hence, the deformation history of XXF can provide crucial information to improve understanding of the tectonic dynamic mechanism of easternward growth of Tibetan plateau. Regionally, detailed structural analysis revealed two main deformation episodes (first stage of NE-SW oriented compression and then NW-SE directed contraction) happened during the Cenozoic time. However, the absolute age of deformation events at work still remain uncertain because of the large absence of Cenozoic deformation records. In this study, six fault gouges were sampled along the central segment of XXF, in the Daliangshan area in order to quantificationally yield the timing of brittle faulting through illite age analysis method. The fault rocks are mainly made up with cataclasite and fault gouge which indicate brittle deformation feature. Fault gouge were separated to four different size fractions ranging from 2–0.5 μm, 0.5–0.2 μm, 0.2–0.1 μm and <0.1 μm by gravitational and centrifugal settling using the Stokes' Low. X-ray diffraction (XRD) analyses were performed to determine mineral assemblages, calibrated 001 illite Full-Width-at-Half-Maximum (FWHM) value and illite polytype compositions for different size fractions. XDR analysis for air-died glass slides shows a wide range of FWHM from 0.26–1.23 °2θ and reflects the range of epizonal to diagenetic grades with decreasing of size fraction. The XRD results for ethylene glycol glass slide indicate none of smectite present in all size fractions. XRD study for random powder specimens of each size fraction reveal that the illite polytype compositions mainly consist of authigenic 1M+1Md and detrital 2M1 illite polytypes and the proportion of 2M1 illite in the clay component typically decreases with the reduction of size fraction. XRD results prove that these fault gouge samples are suitable for illite age analysis and the following K-Ar dating for different size fractions will absolutely establish timing of brittle faulting along the central segment of XXF, which are significant to understand the Cenozoic tectonic evolution of southeastern Tibetan plateau.

Slab-edge upwellings trigger intraplate volcanism in East Asia

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East Asia contains many Holocene volcanic centres, several of which are located far (up to ~1500 km) from the Japan trench. Examples of these intraplate Holocene volcanoes include Jeju and Ulleungdo (South Korea), Tianchi/Changbaishan (North Korea), and Long-gang, Jingbohu, Erkeshan and Wudalianchi (China). Seismic data have previously been used to link magmatism at Changbaishan with the return flow generated by the subducting Pacific plate, but the influence of 'subduction-induced upwelling' on other East Asian intraplate volcanoes remains unclear. Here we integrate geophysical observations with a compilation of available geochemical data, and we show that the spatial distribution and geochemical affinities of East Asian Holocene intraplate volcanoes are linked to discontinuities in the subducting Pacific and Philippine Sea plates.

The lack of a low-velocity seismic anomaly in the lower mantle and a small volume of erupted basalt preclude the existence of a deep mantle plume beneath East Asia. In fact, tomography data reveal that the Pacific plate transitions from shallow subduction (which begins at the Japan trench) to 'slab stagnation' at a depth of ~600 km under East Asia. Although the Philippine Sea plate dips more steeply and appears to be torn in several locations, it also becomes horizontal at a depth of ~500 km under the East China Sea.

When placed in the context of these slab models, the locations of Wudalianchi and Erkeshan link to the edge of the stagnant Pacific plate. Tianchi, Long-gang and Jingbohu align with the Pacific plate shallow subduction-slab stagnation transition. Prominent low-velocity seismic anomalies suggest that Ulleungdo melts correspond to poloidal flow along the southwestern margin of the Pacific plate. Low-velocity seismic anomalies also imply that Jeju volcanism is related to tearing of the Philippine Sea plate.

Contribution of an enriched source to the East Asian intraplate volcanoes is indicated by consistently high total alkalis (3.1–15.3 wt.%) at a variety of SiO_2 concentrations (42.8–71.6 wt.%). High La/Yb ratios (up to 85) signal low degrees of partial melting of deep (garnet-bearing) mantle. Low Ba/La (13.27 ± 6.07; mean ± standard deviation) and Th/Ce (0.08 ± 0.04) are consistent with negligible inputs of slab fluids and slab melt, respectively. Overall, these data are most compatible with a model in which the East Asian Holocene intraplate volcanoes formed via subduction-induced upwelling caused by the interaction of the subducting slabs with the upper part of the lower mantle.

Strain localization in Palaeoproterozoic shear zones exposed on Williams Island, Eyre Peninsula, South Australia

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In the southern Eyre Peninsula, shear zones contemporaneous with the Kalinjala Shear Zone extend eastward to Cape Catastrophe and south to Williams Island. These shear zones are of equivalent age to the Kimban Orogenic events (1850–1700 Ma) recognized in the Kalinjala Shear Zone and York Peninsula (Zang and Fanning, 2001). The basement for Williams Island is composed of an Archean complex intruded by the Palaeoproterozoic Lincoln Batholith and transected by two major shear zones. Deformation contemporaneous to that identified in the Kalinjala Shear Zone and recognised on Williams Island provides another key region for studying the configuration of Gondwana and for appreciating the role of tectonic reconstructions in the Gawler Craton.

There are two major shear zones on Williams Island accommodating dextral strike-slip transport and the transfer of strain into oblique south-up thrusts that are localized by a swarm of narrow (<10 m) NW-trending mafic dykes (Tournefort dyke swarm) within the Palaeoproterozoic granitoids and orthogneisses of the Lincoln Batholith. Large strains have been localized within mafic dykes, whilst comparatively little strain has been accommodated within the granite orthogneiss host rocks. There are three significant deformations, D_1 is localized to the Archean and regions of the earlier Jussieu dykes, D_2 fabrics are predominantly defined by a granulite two-pyroxene assemblage and D_3 is more localized to the shear zones and associated with amphibole grade mineral assemblages.

The metamorphosed granitoids of Williams Island preserve a complete spectrum from primary igneous textures to banded mylonites with finite strains (X/Y ~5 and Y/Z ~2.0) that lie in the constructional field. There is an easterly skewed asymmetry of strain distribution from the immediate host gneiss to sheared mafic dykes. This is attributed to the rotation of planar, initially vertical dykes into west-dipping orientations associated with west-over-east dextral transport and a D_3 exhumation. Average pressure estimates of ~7 kbar and 12 kbar for D_2 and D_3 respectively suggest exhumation of Williams Island to shallow crustal levels occurred sometime after peak D_3 conditions. The dominant dextral strike-slip west-block up movement identified on Williams Island is part of a fan-like conjugate response to the east-block-up exhumation accommodated by the Kalinjala Shear Zone.

Reference

Zang, W. and Fanning C.M, 2001. Age of the Kimban Orogeny revealed. MESA Journal 23, 28-33

The influence of pre-existing structures on the development of the Marlborough Fault System, South Island, New Zealand

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The presence of pre-existing weaknesses in older rocks can lead to structural inheritance that will influence how deformation is accommodated at modern plate boundaries. Inherited tectonic structures can be reactivated even when they are not perfectly oriented relative to the current strain conditions. This highlights the importance of characterising pre-existing structures when investigating the development of modern-day plate boundaries, and for prediction of earthquake rupture propagation pathways. The 2016 Mw 7.8 Kaikoura earthquake, South Island, New Zealand, is recognised as the most structurally complex earthquake recorded in modern history. However, so far there has been no explanation for this complexity. The earthquake initiated in the North Canterbury Tectonic Domain (NCD) and propagated northeastward into the Marlborough Fault System (MFS). These tectonic domains are located in a transpressive setting, which occurs within a transition zone between the westward directed Hikurangi subduction zone, beneath the east coast of North Island, and the dextral, oblique strike slip Alpine Fault, South Island, associated with continental collision. Faults within the MFS have been migrating south over time and the next fault is predicted to form within the NCD, the location of the first ruptures of the Kaikoura earthquake. Pre-existing structures in the Cretaceous basement rocks of the MFS may have contributed to the southward migration of faults and thus the complexity of earthquakes in the region. The bedding within the basement is consistently vertical to sub-vertical and strikes at 030°. Faults within the basement are consistently parallel to bedding. The MFS faults strike at 060°. The northernmost fault in the MFS developed at around 4 Ma, and since this time, northeast South Island has rotated 20° clockwise due to southward propagation of the Hikurangi subduction zone. Our hypothesis is that the southward migration of the MFS faults could be caused by a strain hardening process due to rotational lock up of the basement structures. Understanding the development of the MFS could provide a framework for the prediction of earthquake rupture propagation patterns in the region, and thus assist with hazard mapping and future risk mitigation. In order to test a number of different hypothesis on the geodynamic framework of the region, we will carry out series of laboratory experiments with transpressional boundary conditions, and internal basement structure variations analogous to northeast South Island. This contribution will present findings from recent fieldwork on the structural architecture of basement rocks in the MFS, and preliminary results of analogue modelling of transpression.

Proterozoic magmatic and deformation styles reflect a strengthening lithosphere

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Proterozoic magmatism in central southern Australia reflects a temporal and isotopic switch from inter-cratonic recycling of Palaeoproterozoic lithosphere during a significant mantle depletion event, to craton-margin magmatism focused between cratonic roots and a newly formed Proterozoic tract. Geochronological and isotopic data constrain the timing and duration of the evolution from a thin, enriched lithosphere (c. 1200–1120 Ma), to a thick, strong craton-like root <100 Ma later at c. 1074 Ma. Whilst structural controls on magmatism throughout the lithospheric column indicate increasingly brittle behaviour. We suggest that the scale of a mantle depletion event at c. 1200–1120 Ma was sufficient to strengthen the lithospheric mantle enough to act as a buffer to subsequent asthenospheric upwelling.