Unravelling overprinting tectonothermal cycles at the southern margin of the North Australian Craton

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The geological evolution and metallogenic potential of the southern margin of the North Australian Craton (NAC) has been a focus of the Northern Territory Geological Survey's (NTGS) regional mapping program since the early 2000s. Recent detailed geological mapping of HUCKITTA[3], ~150 km northeast of Alice Springs, carried out under the *Resourcing the Territory* initiative, has led to a revised model for the geological evolution of the Aileron and Irindina provinces in that area (eg Weisheit *et al* 2019, Weisheit 2019, Reno *et al* 2022, 2023; **Figure 1a**–**c**). In parallel, detailed studies on copper, tungsten, and polymetallic base metal mineralisation in the Aileron Province have revised the understanding of the nature and timing of mineralisation and its genetic relationship to host stratigraphy, deformation, and metamorphism (eg McGloin *et al* 2019, Reno *et al* 2019, 2021a, b; McGloin and Weisheit 2022, Stuart 2022).

The southern margin of the Archaean–Proterozoic NAC was subjected to multiple phases of tectonism between the Palaeoproterozoic and Carboniferous (eg summarised in Ahmad and Scrimgeour 2013 and Scrimgeour 2013a). The main terrane forming the southern margin of the NAC is the Aileron Province. Its northeastern part experienced a long-lived tectonothermal cycle with multiple phases of magmatism, metamorphism and ductile deformation during the Palaeo- to Mesoproterozoic, as interpreted from integrated petro- and thermochronologic, metamorphic, and structural studies by Reno *et al* (2017, 2020a, b; 2021b, 2022, 2023), Weisheit (2019), Weisheit *et al* (2019), and Reno and Fraser (2021). These studies show that deposition of the sedimentary precursors to the oldest recognised rocks in the northeastern Aileron Province occurred in a basin with active deposition between at least ca 1.86 Ga and ca 1.79 Ga.

Metamorphism began as early as ca 1.79 Ga, contemporaneous with localised intrusions of mafic and felsic bodies in a high thermal gradient, extensional, possibly back-arc environment. Syngenetic base metal mineralisation formed in the Jervois mineral field at this time (**Figure 1c**). The high grade phase of metamorphism lasted until at least ca 1.75 Ga during which time the terrane developed into a series of discrete fault- and shear zone-bounded tectonic domains. Each domain experienced different metamorphic conditions and deformational histories as relative movements along the bounding faults caused deep burial of some domains to granulite facies conditions. Anatectic melts formed during that time in sub-solidus domains and migrated to domains higher in the crust where they crystallised and formed extensive bodies of felsic rocks.

The tectonic regime fundamentally shifted between ca 1.75 Ga and ca 1.73 Ga with the end of the highest temperature phase of metamorphism and a switch to transpression and decreasing pressure. Anatectic melts in the sub-solidus domains began to crystallise around ca 1.73 Ga, indicating final regional cooling. Final vertical juxtaposition of the tectonic domains, final magma emplacement and associated epigenetic copper, tungsten and molybdenum mineralisation, and a switch to isostatic cooling, all occurred between ca 1.73 and ca 1.68 Ga. By that time, regional widespread deformation has ceased and only the higher-grade tectonic domains experienced further progressive and possibly successive ductile deformation proximal to and within the major shear zones (Delny and Entire Point shear zones). Ductile re-activation of parts of the Delny Shear Zone occurred around 1.57 Ga.

Overall, this long-lived tectonothermal cycle could reflect regional events along the southern margin of the NAC, such as opening of a back-arc basin due to subduction further south and closure of that basin due to a collision with an unexposed terrane.

The Palaeozoic Larapinta Event (480–460 Ma) and Alice Springs Orogeny (450–300 Ma) caused deformation and metamorphism in the southern portion of the Aileron Province (eg Collins and Teyssier 1989, Haines *et al* 2001, Scrimgeour 2013a and references therein, Reno *et al* 2020a). The Irindina Province formed during the extensional Larapinta Event in a deep graben that developed over the (currently unexposed) southeastern portion of the Aileron Province; both provinces were deformed and juxtaposed during the compressional Alice Springs Orogeny (eg Mawby *et al* 1999, Hand *et al* 1999a, b; Buick *et al* 2001, 2005, Maidment 2005, Maidment *et al* 2005, Carson 2009, Maidment *et al* 2013, Scrimgeour 2013b and references therein). Previous studies proposed that many of the terrane-scale shear zones in this area, including the south-dipping Delny and Entire Point shear zones at the northern boundary of the Irindina Province, formed during these Palaeozoic events; and that the Alice Springs Orogeny had a strong metamorphic and deformational effect over a geographically large area of the Aileron Province (eg Collins and Teyssier 1989, Scrimgeour and Raith 2001a, b).

New NTGS petro- and thermochronologic data (eg Reno *et al* 2020 a, b; 2023; Reno and Fraser 2021; **Figure 1c**) provide detailed time constraints on the thermal and deformational history of the northeastern Aileron Province and northern Irindina Province that support the Palaeoproterozoic history for the Delny and Entire Point shear zone system as outlined above, and demonstrate that the Alice Springs Orogeny had only minor effects on the thermal and deformational history of the northeastern Aileron Province. These data indicate that the bulk of deformation experienced by the Delny and Entire Point shear zones occurred during the Palaeo- to Mesoproterozoic, and that the Palaeozoic history of this shear zone system in the Aileron Province is dominated by less substantial brittle deformation and episodic fluid

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2 Email: barry.reno@nt.gov.au
3 Names of 1:250 000 and 1:100 000 mapsheets are shown in large and small capital letters respectively, eg HUCKITTA, JINKA

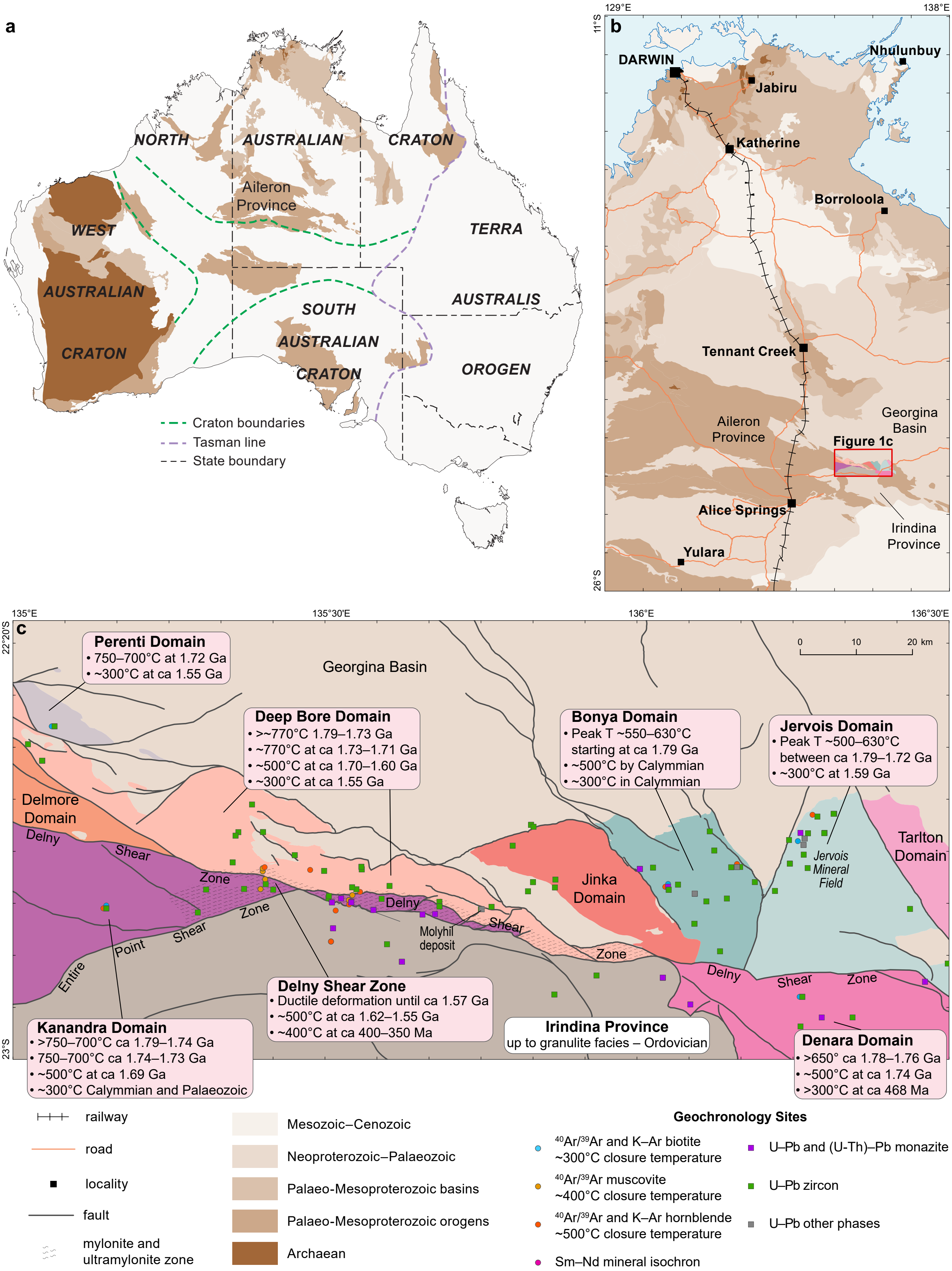

Figure 1. (**a**) Map of Australia showing the location of cratons and major regions of Archaean–Mesoproterozoic rocks. (**b**) Regional geological map of the Northern Territory, including location of **Figure 1c**. (**c**) Map of the tectonic domains in the northeastern Aileron Province summarising thermal and chronologic constraints on metamorphism and isostatic cooling. The Neoproterozoic–Cambrian Georgina Basin is light khaki, the Irindina Province is dark khaki, and the domains of the northeastern Aileron Province are the other coloured polygons. Data and maps are summarised from Zhao and Bennett (1995), Scrimgeour and Raith (2001b), Claoué-Long and Hoatson (2005), Cross *et al* (2005), Maidment (2005), Cross (2009), Kositcin *et al* (2011, 2013, 2014, 2015, 2018a,b; 2021), Reno *et al* (2016, 2017, 2018, 2019, 2020a,b; 2021b, 2022, 2023), McGloin *et al* (2018), Beyer *et al* (2018, 2022), Weisheit *et al* (2019), Kositcin and Reno (2020), Reno and Fraser (2021).

flow. This is in contrast to the part of the shear zone system exposed in Irindina Province rocks, which formed during the Palaeozoic. In the Aileron Province, the interiors of all domains cooled below ~500°C and most domains cooled below ~300°C for the final time by or during the Calymmian Period of the Mesoproterozoic. Two Aileron Province domains adjacent to the northern Irindina Province experienced a thermal overprint during the Palaeozoic: the eastern Kanandra Domain was reheated above ~300°C but below ~500°C during the Palaeozoic, although it was insufficient to completely reset the argon system in biotite or form new biotite; and the western Denara Domain experienced reheating above ~300°C but also at insufficient conditions to form new biotite.

The new data indicate that the Larapinta Event and Alice Springs Orogeny caused a thermal overprint on the northeastern Aileron Province domains in the hanging wall of the pre-existing, crustal-scale Delny and Entire Point shear zones proximal to the Irindina Province, but that this overprint was substantially less thermally and geographically expansive than previously interpreted. Palaeozoic Rb–Sr isochron and argon muscovite ages (Scrimgeour and Raith 2001b) and weakly defined U–Pb discordia arrays in monazite (Reno *et al* 2020a) from samples of the Delny Shear Zone indicate reheating was concentrated within the pre-existing shear zone system and related to fluid flow driven off the adjacent metamorphosing Irindina Province. Reno *et al* (2023) proposed that burial and exhumation of the Irindina Province in this area was predominately accommodated by deformation within and at the margins of the Irindina Province as opposed to the currently exposed Aileron Province portion of the Delny and Entire Point shear zones.

New NTGS petrochronologic, metamorphic, and structural data from the northern portion of the Irindina Province (Reno *et al* 2020 a, 2022), adjacent to the northeastern Aileron Province, support previous regional observations that the Irindina Province was subjected to extensional tectonism and associated amphibolite–granulite facies metamorphism during the period 490–460 Ma, followed by a switch to decompression, exhumation, and associated compressional ductile deformation until at least ca 440 Ma. The peak pressure–temperature phase of the tectonothermal cycle experienced by this portion of the Irindina Province occurred during the 480–460 Ma Larapinta Event; the switch to decompression and exhumation coincides with the beginning of the Alice Springs Orogeny (eg Mawby *et al* 1999, Hand *et al* 1999a, Buick *et al* 2001, Maidment 2005). The Larapinta Event and Alice Springs Orogeny have previously been interpreted as discrete events that affected the Irindina Province; however, Reno *et al* (2022) proposed that in the northern portion of the Irindina Province, the events instead represent two parts of a single 490–450 Ma tectonothermal cycle of extension followed by compression. Younger metamorphic overprint recorded further south in the Irindina Province (eg Hand *et al* 1999, Maidment 2005, Maidment *et al* 2005, Beyer *et al* 2018, Farias *et al* in prep) indicates a progression of deformation and metamorphism southwards as this Palaeozoic cycle developed.

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