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Research paper

Ultra-hot Mesoproterozoic evolution of intracontinental central Australia

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ABSTRACT

The Musgrave Province developed at the nexus of the North, West and South Australian cratons and its Mesoproterozoic evolution incorporates a 100 Ma period of ultra-high temperature (UHT) metamorphism from ca. 1220 to ca. 1120 Ma. This was accompanied by high-temperature A-type granitic magmatism over an 80 Ma period, sourced in part from mantle-derived components and emplaced as a series of pulsed events that also coincide with peaks in UHT metamorphism. The tectonic setting for this thermal event (the Musgrave Orogeny) is thought to have been intracontinental and the lithospheric architecture of the region is suggested to have had a major influence on the thermal evolution. We use a series of two dimensional, fully coupled thermo-mechanical-petrological numerical models to investigate the plausibility of initiating and prolonging UHT conditions under model setup conditions appropriate to the inferred tectonic setting and lithospheric architecture of the Musgrave Province. The results support the inferred tectonic framework for the Musgrave Orogeny, predicting periods of UHT metamorphism of up to 70 Ma, accompanied by thin crust and extensive magmatism derived from both crustal and mantle sources. The results also appear to be critically dependent upon the specific location of the Musgrave Province, constrained between thicker cratonic masses.

1. Introduction

Ultrahigh-temperature (UHT) metamorphism is the thermal extreme of crustal metamorphism, reflecting temperatures in the range of 900–1000 °C at crustal depths of ~35–50 km (Harley, 1998; Brown, 2006, 2007; Kelsey, 2008). The tectonic settings in which UHT metamorphism might occur remains unclear, with both accretionary and collisional orogenic settings put forward (see summary in Kelsey, 2008). UHT conditions in orogenic settings have been rigorously tested using numerical methods by Sizova et al. (2010), Gray and Pysklywec (2012) and Ueda et al. (2012). Currie and Hyndman (2006) have shown that similar conditions might be approached in the lower regions of modern back-arc basins, and Brown (2006) suggested that many Pan-African aged UHT belts indeed resemble inverted back-arc basins. It is, nevertheless, likely that conditions which may lead to UHT metamorphism relate to more than one specific setting.

The Musgrave Province, in central Australia (Fig. 1), is an extensive belt of metamorphic and igneous rocks with a protracted Mesoproterozoic tectonothermal history that has recently been recognized as having been dominated by UHT metamorphic conditions (e.g., King, 2008; Kelsey et al., 2009, 2010; Smithies et al., 2011). The scale and duration of UHT conditions was extraordinary, even amongst UHT belts globally. Here, mid-crustal (~7–8 kbar; 25–30 km) temperatures exceeded 900 °C (King, 2008; Kelsey et al., 2009) over much of the >220,000 km^2 region, and throughout the entire duration of the c. 1220 to c. 1120 Ma Musgrave Orogeny (Kelsey et al., 2009, 2010; Smithies et al., 2011). These UHT conditions were accompanied by emplacement of the charnockitic A-type granites of the Pitjantjatjara Supersuite which provides an independent measure of high crustal temperatures (Smithies et al., 2011). This magmatism appears continuous; at least within the analytical uncertainty of U–Pb (zircon) dating, between c. 1220 and c. 1150 Ma, but on a regional basis also shows distinct

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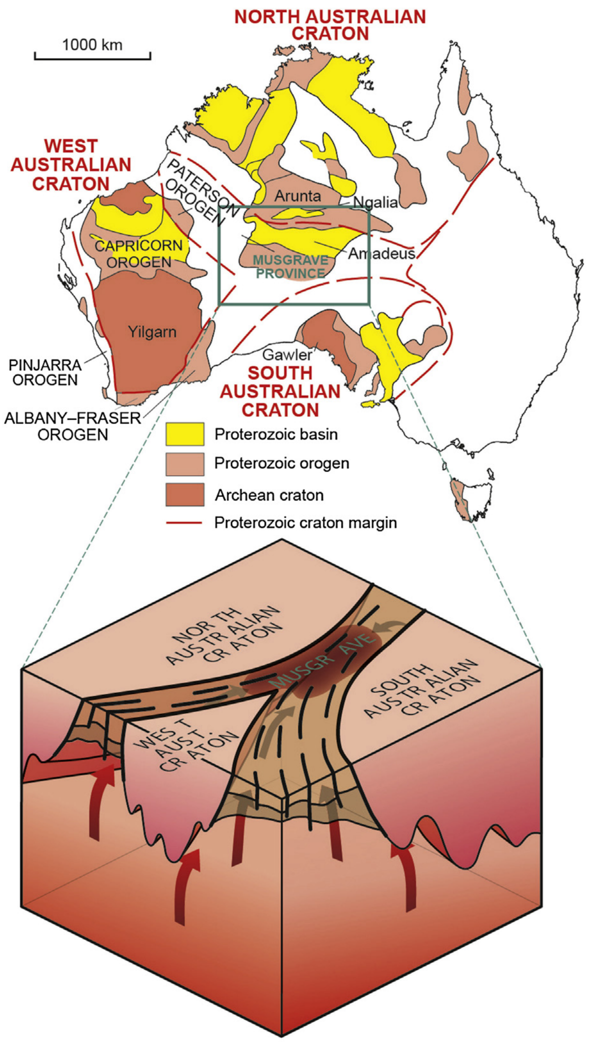

Figure 1. Geographical and geological location of the Musgrave Province.

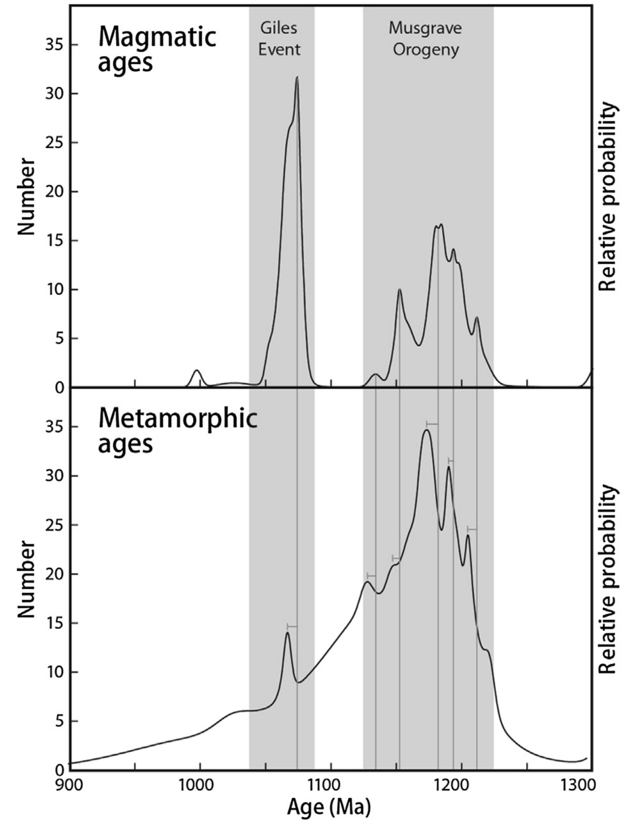

Figure 2. Summary of ion microprobe (SHRIMP) U–Pb zircon geochronology for rocks formed or deformed during the Musgrave Orogeny and the Giles Event in the west Musgrave Province. Data for magmatic ages are weighted means from igneous rocks or orthogneiss and are interpreted to be ages of igneous crystallization. Metamorphic age data represent individual analyses of high U rims interpreted to have grown primarily as a result of crystallization from partial melts in migmatite derived from either ortho- or parageneiss. All geochronological data are available from the Geological Survey of Western Australia's geochronology record series (http://www.dmp.wa.gov.au/geochron/).

peaks in activity (Fig. 2). These peaks broadly coincide with peaks in metamorphic zircon age populations and may suggest that UHT conditions were also punctuated into distinct events with a ~10–20 Ma periodicity (Smithies et al., 2014) or affected difference regions or levels of the crust at different times. These extraordinary thermal conditions relate to what is likely an unusual tectonic setting. However, the UHT event, and the tectonic circumstances that caused it, had a long-lasting influence on the geological evolution of central Australia, including the formation of later (c. 1090–1050 Ma) mafic and felsic large igneous provinces. The prolonged thermal legacy of the Musgrave Orogeny was also in part a result of the concentration of radiogenic heat producing elements into lower to mid-crustal regions (Smithies et al., 2014).

The Musgrave Province has been rigidly fixed at the nexus of three thick cratonic masses (North, West and South Australia cratons – Fig. 1) since at least c. 1290 Ma (e.g., Giles et al., 2004). The Musgrave Orogeny itself has been interpreted as an intracontinental orogeny (Wade et al., 2006, 2008) but initiation of the orogeny in a distal back-arc setting has not been dismissed (e.g., Smithies et al., 2011; Kirkland et al., 2013). It is possible that the unusual thermal conditions throughout the Musgrave Orogeny were strongly influenced by the lithospheric architecture relating to the unusual tectonic position near a ridged cratonic triple point (Fig. 1, at the interconnection of three cratonic masses), which may have played a role in focusing upwelling asthenospheric beneath the province, providing a long-lived supply of both heat and mantle-derived magma (Smithies et al., 2011).

In an attempt to better understand the geological evolution of the Musgrave Orogeny, including the role and range of lithospheric and mantle conditions and process that might contribute to UHT metamorphic conditions, we have conducted a series of fully coupled thermo-mechanical-petrological two dimensional (2D) numerical experiments. The models used in this work simulate the effects of far-field stresses on continental lithosphere with discontinuities on a lithospheric to upper mantle cross-section and is based on the I2VIS code (Gerya and Yuen, 2003; Gerya, 2010). Due to the resolution limitations of three-dimensional modeling, the modeling has been conducted in 2D. 2D not only allows for implementation of visco-plasticity and mineral phase transformation but also related melting/melt extraction processes (Vogt et al., 2012), which require higher resolution than 3D allows for. Nevertheless, we are attempting to model a complex geological history and a lithospheric architecture (including a cratonic triple-junction) that would clearly be affected by 'out of plane' (3D) processes. The models will not exactly replicate the geodynamic 'reality' of the Musgrave Orogeny, but hopefully deliver a range of processes and/or conditions and constraints under which this