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P–T–t evolution of a large, long-lived, ultrahigh-temperature Grenvillian belt in central Australia

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ABSTRACT

The ~120,000 km^2 Musgrave Province forms part of a continuous Musgrave–Albany–Fraser mid-late Mesoproterozoic orogenic system that transects central and southern Australia, and continues into formerly contiguous Antarctica. Voluminous felsic magmatic rocks that intruded over the interval 1330–1150 Ma, corresponding globally to the Grenvillian timeline, dominate the Musgrave Province. However, rare but widely distributed metapelitic granulites contain peak metamorphic mineral assemblages comprising garnet + sillimanite ± quartz ± spinel. These are variably overprinted by coronae and/or symplectites of cordierite-bearing assemblages such as cordierite + spinel + magnetite ± plagioclase ± garnet. Petrologic forward modelling and Zr-in-rutile thermometry indicates these peak mineral assemblages developed at thermally extreme conditions of approximately 1000 °C and ca. 7–8 kbar. These ultra-high temperature (UHT) conditions appear to have prevailed throughout the Musgrave Province, across an approximate 600 km strike distance. The retrograde P–T evolution was characterised by modest decreases in pressure during the initial high temperature segment of the cooling path, suggesting that the crust was not significantly thickened as a result of tectonism. Combined SIMS (SHRIMP) and LA–ICP–MS U–Pb geochronology constrains the total range of metamorphic monazite growth/recrystallisation ages span 1263–1111 Ma with most individual samples spanning an age range of ≥80 Myr. The total age span implies approximately 150 Myr of perturbed thermal conditions during the Musgrave Orogeny. Our data requires that monazite is extremely resistive to isotopic resetting, even when exposed to extreme thermal conditions for long (≥80 Myr) periods. The thermal conditions, large regional footprint and long timescale of metamorphism and magmatism classify the Musgrave Province as a large, hot orogen.

1. Introduction

The Musgrave–Albany–Fraser Orogen represents the Australian component of the global Grenvillian-aged orogenic system (Fig. 1). The Musgrave–Albany–Fraser system has been widely used as a ‘piercing point’ for Proterozoic reconstructions linking Laurentia and Antarctica to Australia (Moores, 1991; Karlstrom et al., 2001; Duebendorfer, 2002; Wingate et al., 2002). The Grenville belt in Laurentia is well documented as reflecting predominantly collisional tectonics (e.g. Hoffman, 1991; Davidson, 1995; Cawood and Pisarevsky, 2006). However, for the Australian Grenvillian-aged belts it is much less clear what the prevailing tectonic regime was (Myers et al., 1996; Wingate et al., 2002; Wade et al., 2008; Aitken and Betts, 2009a; Morrissey et al., 2011). In older continental reconstructions of Proterozoic Australia there was a tacit assumption that the Grenvillian-aged tectonism in the Musgrave Province (Fig. 1) reflected amalgamation (Maboko et al., 1991). However, subsequent work demonstrated that the high-pressure rocks upon which this assertion was made are not Grenvillian-aged, but rather the product of late Neoproterozoic (Ediacaran) to Cambrian intracontinental compressional reworking (Maboko et al., 1992; Camacho and Fanning, 1995; Scrimgeour and Close, 1999; Gregory et al., 2009; Raimondo et al., 2009; Raimondo et al., 2010; Walsh et al., 2013). More recent work on the Western Australian portion of the Musgrave Province (Fig. 2) has demonstrated that voluminous and comparatively juvenile felsic magmatism during the middle of three Grenvillian-aged events to have formed and shaped the Musgrave Province, the 1220–1150 Ma Musgrave Orogeny, has geochemical characteristics more akin to ‘within-plate’ magmatism rather than arc-related affinities (Smithies et al., 2011). Ultimately, the prevailing tectonic setting during the Musgrave Orogeny remains poorly understood.

This study focuses on the Musgrave Orogeny as it is the most pervasive Grenvillian-aged events to have formed and shaped the Musgrave Province. One approach to investigating the possible tectonic setting of the 1220–1150 Ma Musgrave Orogeny is to study the time-integrated thermal structure of the crust, as metamorphic rocks provide a primary

Abbreviations: bi, biotite; cd, cordierite; g, garnet; ilm, ilmenite; ksp, K-feldspar; ky, kyanite; liq, silicate melt; mt, magnetite; opx, orthopyroxene; pl, plagioclase; q, quartz; ru, rutile; sill, sillimanite; sp, spinel.

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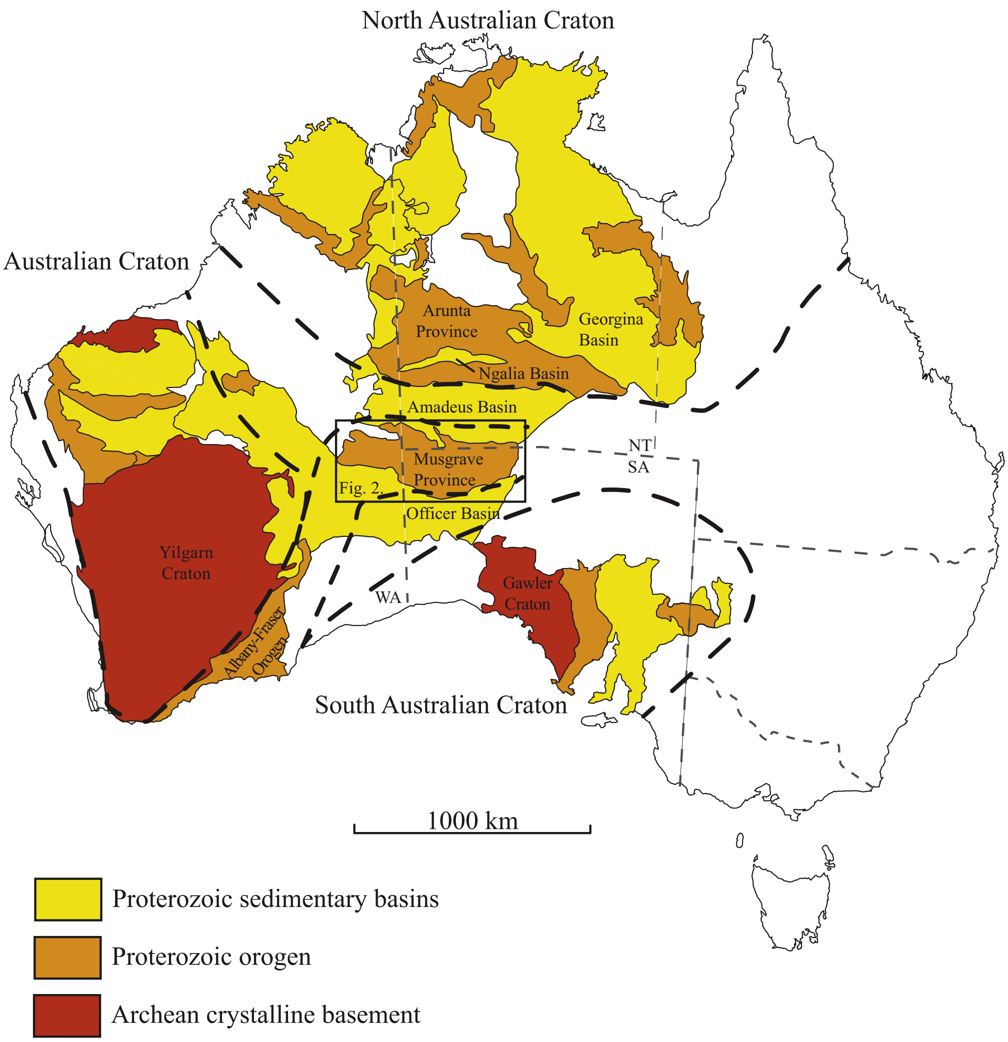

Fig. 1. Map of Australia showing the location of the Musgrave Province with respect to the major cratonic basement and basin regions.

record of the temporal thermal state of the Earth (Brown, 2007), which in turn can be characteristic of different tectonic settings. As the number of studies investigating the metamorphic evolution of rocks in the Musgrave Province is small (Maboko, 1988; Clarke and Powell, 1991; Maboko et al., 1991; Camacho and Fanning, 1995; Clarke et al., 1995; Glikson et al., 1996; White and Clarke, 1997; Scrimgeour and Close, 1999; White et al., 2002; Kelly et al., 2006; Gregory et al., 2009; Smithies et al., 2011) relative to the size of the province, there is considerable scope to provide new and useful constraints on the thermo-physical conditions of the Musgrave Orogeny. The purpose of this study is to present a broad regional foundation for the thermal structure of the crust at the time of the Musgrave Orogeny by investigating samples from widely separated locations in the province. UHT metamorphism in the Musgrave Province has been suggested by recent workers (e.g. Smithies et al., 2011; Smithies et al., 2014), however, these studies utilise magmatic crystallisation temperatures in addition to limited constraints from phase equilibria. This paper combines quantitative metamorphic phase equilibria (calculated pseudosections) and Zr-in-rutile thermometry with accessory mineral U–Pb geochronology, to demonstrate that the Musgrave Orogeny was regionally characterised by elevated thermal gradients (≥40 °C km^{-1}) and ultrahigh-temperature (UHT) conditions over a timescale potentially as long as 150 Myr. The regionally extreme thermal conditions identify the Musgrave Province as an ancient large, hot and long-lived terrain. In conjunction with the existing and extensive dataset on magmatic rocks produced during the Musgrave Orogeny (Smithies et al., 2010; Smithies et al., 2011), we infer that protracted metamorphism and magmatism occurred in hot, probably thin crust, and possibly occurred within an extensional setting. Our findings have implications for: 1) the ability of Earth's crust to generate and sustain extreme thermal conditions for long periods of time; 2) the interpretation of U–Pb monazite geochronology in high-grade gneiss terrains; 3) the ability of monazite to resist isotopic resetting during prolonged exposure to high temperatures; 4) the ability of high-Fe–Al metapelitic rocks to reliably record evidence of UHT metamorphic conditions; 5) the tectonic setting of the Musgrave Province during the Musgrave Orogeny; and 6) the 'spatial footprint' of regional UHT metamorphism.

2. Regional geology

The Musgrave Province is an east–west trending Mesoproterozoic basement province that outcrops over ~120,000 km^2, straddling the Northern Territory, South Australian and Western Australian borders (Camacho and McDougall, 2000; Aitken and Betts, 2008; Wade et al., 2008) (Figs. 1, 2). The external east–west orientation of the outcropping Musgrave Province is a strong function of the overprinting intraplate Ediacaran- to Cambrian-aged Petermann Orogeny (Camacho et al., 1997; Wade et al., 2008). The Petermann-aged structures have dissected the older rocks such that granulite facies gneisses are exposed to the south (hangingwall) and amphibolite facies and lower-grade mid- to upper-crustal basement and cover rocks are exposed to the north (including north of the Woodroffe Thrust) (Fig. 2). The trends of structural fabrics related to older events such as the Grenvillian-aged Musgrave