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A rift-related origin for regional medium-pressure, high-temperature metamorphism

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ABSTRACT

Crustal-scale exhumation during the Alice Springs Orogeny (*c*. 450–320 Ma) in central Australia has exposed a region of medium-pressure, high-temperature metasedimentary and metabasic rocks that comprise the Harts Range Group (HRG). Similarities in the detrital zircon age spectra between the HRG and surrounding unmetamorphosed, intraplate late Neoproterozoic–Cambrian basin sequences suggest that the HRG is a highly metamorphosed equivalent of these successions. Calculated phase equilibria modelling and thermobarometry constrain peak metamorphic conditions to ∼880 °C and 10.5 kbar, and ∼680 °C and 5.5–8.0 kbar, in the structurally lowest and highest parts of the HRG, respectively. Metamorphic conditions also indicate that burial occurred along a near-linear moderately-high apparent thermal gradient, recorded by the prograde development of andalusite-bearing mineral assemblages at shallower structural levels. Prograde and peak metamorphism was associated with voluminous intrusive and extrusive mafic magmatism, the development of a coarse layer-parallel fabric and north-directed normal shear-sense kinematics. Collectively, these point to an extensional regime. Furthermore, burial and metamorphism at *c*. 480–460 Ma was concurrent with a shallow epicontinental marine environment and ongoing sedimentation in central Australia. Accordingly, the deep burial, metamorphism and deformation of the HRG to mid-lower crustal depths (∼20–35 km) must be justified in the context of the broader intraplate basin evolution at this time. It is difficult to reconcile medium-pressure, high-temperature metamorphism of the HRG with deep burial by tectonic overthickening which is commonly assumed to be the case. In contrast, metamorphism of the HRG seems more compatible with burial within a deep rift-style basin driven by high heat flow and mafic magmatism, suggesting that regional medium-pressure metamorphic terranes are not necessarily reflective of compressional thickening of the crust.

1. Introduction

The deep burial of sedimentary successions to mid-lower crustal depths (∼20–35 km) and subsequent medium-pressure (∼6–10 kbar), high-temperature (MP–HT) metamorphism, is generally regarded as reflecting large-scale tectonic shortening and thickening of the crust (e.g. England and Thompson, 1984; Scrimgeour et al., 2005; Tam et al., 2012; Vance et al., 1998; Vorhies and Ague, 2011; Zhao et al., 2000). However, deep burial of sedimentary successions can also potentially occur within sedimentary basins (e.g. Gac et al., 2012). In particular, deep rift-style basins are a logical setting for the occurrence of regional MP–HT metamorphism as they are commonly associated with high basal heat flows as well as mafic magmatism (De Yoreo et al., 1991; Ruppel, 1995; Thompson and Gibson, 1994). There are a number of examples in which more than 20 km of burial has occurred within well-recognised and preserved crustal-scale rift-style basins including the late Mesoproterozoic Midcontinent Rift System in North America (Allen et al., 1995), the Palaeozoic Dnieper–Donets Basin located in eastern Europe (Starostenko et al., 1999), and the Devonian–Holocene Petrel Sub-basin located offshore northwestern Australia (Baldwin et al., 2003). Super-deep, rift-style basins exhibit a distinctive V-shape morphology in plan view, have evidence for large amounts of localised extension, a prominent structural half-graben asymmetry, and trend at a high angle adjacent to oceanic and orogenic margins (Baldwin et al., 2003). Generally, extension is localised to long (50–100 km) and narrow (40–80 km) depocentres hosted in larger intraplate basins within comparatively thermally stable continental lithosphere (Baldwin et al., 2003; Friedmann and Burbank, 1995).

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A link between high-temperature metamorphism and continental rifting was proposed initially by Wickham and Oxburgh (1985) and Sandiford and Powell (1986). However these, and a majority of subsequent studies ascribing high-temperature metamorphism to an extensional setting (e.g. Gibson et al., 2004), investigate low-pressure, high-temperature metamorphic terranes. Therefore, even in a rift basin setting, it may be assumed that subsequent crustal thickening is required for the burial of rocks to MP–HT conditions (e.g. Tam et al., 2012). Evidently, crustal thickening by contractional deformation remains significantly more prevalent in the geological literature than intrabasinal burial as a driver for regional, lower-crustal, MP–HT metamorphism.

An apparent contradiction to this common interpretation is the suggestion that early Ordovician (*c*. 480–460 Ma) MP–HT metamorphism of the Harts Range Group (HRG) in central Australia occurred within a deep rift basin. Crustal-scale exhumation during the Alice Springs Orogeny (*c*. 450–320 Ma) in central Australia, has exposed the HRG in a tilted mid-lower crustal section, with considerable preservation of the original stratigraphic order. Recent detrital zircon analysis of the HRG (Maidment et al., 2013) indicate that depositional ages and detrital zircon provenance of the protoliths to these high-temperature metasedimentary rocks share strong similarities with the widespread late Neoproterozoic–Cambrian sedimentary successions of the adjacent, unmetamorphosed intraplate Amadeus and Georgina basins. This suggests that the HRG may be a high-grade correlative of the sedimentary sequences that are preserved in the Amadeus and Georgina basins (Buick et al., 2005, 2008; Maidment et al., 2013). If this is the case, then deep burial, metamorphism and deformation of the HRG must be understood in the context of evolution of the broader basin system at this time.

This study uses statistical comparison of detrital zircon age data from the HRG, and the neighbouring, unmetamorphosed Amadeus and Georgina basins, to more fully evaluate whether these sequences are indeed correlatives as previously proposed by Maidment et al. (2013). The results are combined with thermodynamic modelling of metamorphic mineral assemblages to provide the first in-depth internally consistent quantitative constraints on the peak pressure–temperature (P–T) conditions attained by units at different stratigraphic positions within the HRG, and the thermal conditions associated with prograde and retrograde metamorphism. This will enable an investigation of the geodynamic setting of the HRG and thus the viability of syn-rift sedimentation-driven burial leading to regional MP–HT metamorphism. The confirmation that regional MP–HT metamorphism can be attributed to sedimentary burial within a deep rift-style basin has dramatic implications for the interpretation of ancient MP–HT metamorphic terrains that may lack a palaeotectonic context but are otherwise assumed to reflect shortening and thickening of the crust.

2. Geological background

2.1. Regional geology

The Arunta region in central Australia is host to a Palaeoproterozoic–Palaeozoic (*c*. 1900–300 Ma) high-grade metamorphic complex that constitutes the southern margin of the North Australian Craton (Ahmad and Munson, 2013; Morrissey et al., 2011; Scrimgeour et al., 2005). The Harts Range is located in the south-eastern Arunta region, approximately 150 km north-east of Alice Springs, central Australia (Fig. 1). The HRG is a localised supracrustal terrain of amphibolite–granulite-facies metasedimentary and metabasic rocks with protoliths deposited and intruded predominantly during the Cambrian (Buick et al., 2005; Hand et al., 1999; Maidment et al., 2013; Mawby et al., 1999). It structurally overlies and is juxtaposed against the Palaeoproterozoic basement rocks of the Arunta region which extend westward of the Harts Range (Ahmad and Munson, 2013; Maidment et al., 2005). Further afield, the Arunta region is bounded to the south and north by the Neoproterozoic to mid-Palaeozoic (*c*. 900–300 Ma) intracratonic, unmetamorphosed Amadeus and Georgina basins, respectively, which also unconformably overly the Palaeoproterozoic basement. The Amadeus and Georgina basins are structural remnants of the formerly more extensive, continental-scale intraplate Centralian Superbasin that was disrupted by exhumation of the Arunta basement during the Palaeozoic (Fig. 1; Buick et al., 2005; Shaw et al., 1991).

The HRG consists of five main lithostratigraphic units (Maidment et al., 2013). The structurally lowermost unit comprises the metapelitic Irindina Gneiss, including three subdivisions—the Naringa Calcareous Member, Stanovos Gneiss Member and the Harts Range Meta-Igneous Complex (HRMIC; Ahmad and Munson, 2013; Buick et al., 2005; Maidment et al., 2013). The HRMIC consists of variably deformed metagabbro or metadolerite, and laterally voluminous quartz-rich amphibolite. The rocks exhibit a dominant tholeiitic composition, depletion in light rare earth elements, rare earth element patterns characteristic of normal mid-ocean ridge basalts, and a juvenile neodymium isotope signature (Sivell, 1988; Sivell and Foden, 1985). These observations are consistent with shallow lithospheric mantle melting and emplacement of protoliths to the HRMIC in a rift-style setting, with little crustal contamination (Ahmad and Munson, 2013; Sivell, 1988; Sivell and Foden, 1985). One sample of the HRMIC has yielded inherited detrital zircon populations that range down to *c*. 560 Ma (Maidment et al., 2013). The abundance of detrital zircons and the intimate relationship of the mafic rocks, which are interlayered with psammopelitic metasedimentary units, suggests that some of the mafic units in the HRMIC were of volcanic origin (Buick et al., 2001; Maidment et al., 2013).

Coeval mafic and felsic magmatism occurred at *c*. 520 Ma within the Upper Stanovos Gneiss, in the lower HRG (Indiana Suite; Ahmad and Munson, 2013; Maidment, 2005). Similarities in inherited zircon ages and the gradational nature of the contact between megacrystic granite and the surrounding migmatised Upper Stanovos Gneiss suggest that the felsic magmatic rocks formed by partial melting of their metasedimentary host (Maidment, 2005).

The structurally highest unit in the Harts Range area is the Brady Gneiss which is further divided into predominantly lower metapelitic and upper calc-silicate subunits (Buick et al., 2005; Maidment et al., 2013). It is readily distinguished from the underlying units by the comparative scarcity of mafic rocks.

Peak metamorphism occurred during the Ordovician with ages obtained from metamorphic zircon overgrowths from the HRG defining a bimodal distribution with peaks at *c*. 480 Ma and *c*. 460 Ma (Buick et al., 2005, 2001; Maidment et al., 2013), suggested by Maidment et al. (2013) to reflect prograde and retrograde phases of high-grade metamorphism. Granulite-facies metamorphism was associated with partial melting, the development of a pervasive layer-parallel foliation and coarse migmatitic assemblages consisting of garnet–clinopyroxene-bearing leucosomes in metagabbroic rocks of the HRMIC, and coarse garnet-bearing tonalitic leucosomes within metapelite (Hand et al., 1999; Maidment et al., 2013; Mawby et al., 1999; Miller et al., 1997). Peak metamorphic conditions were estimated at 800–850 °C at 9–10 kbar in the structurally lowest parts of the sequence (Buick et al., 2001; Mawby et al., 1999; Miller et al., 1997) implying burial to ∼35 km. Palaeogeographical reconstructions indicate that the HRG was located at least 500 km from the eastern Australian continental margin at this time (Maidment et al., 2013) beneath an E–W trending epicontinental seaway, and the broader shallow marine Centralian Superbasin (Buick et al., 2005; Haines and Wingate, 2007; Webby, 1978).