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Proterozoic granulite formation driven by mafic magmatism: An example from the Fraser Range Metamorphics, Western Australia

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ABSTRACT

Elevated heat flow and mafic magmatism during lithospheric extension have often been invoked as a mechanism to drive high-temperature low-pressure metamorphism that produces granulite facies mineral assemblages. Typically, however, evidence of the contemporaneous heat source, such as coeval mafic magmatism, is absent. In this study, we present pressure–temperature (*P*–*T*) pseudosection analysis combined with U–Pb isotopic data from zircon and monazite that constrain both the conditions and timing of granulite facies metamorphism in the Fraser Range Metamorphics of the Albany-Fraser Orogen in southern Western Australia. These results also elucidate the extremely rapid timing of, sequentially, deposition of sedimentary protoliths, mafic magmatism, partial melting, and metamorphism within the Fraser Zone during the Mesoproterozoic. The youngest detrital zircons, together with the magmatic ages of intrusive rocks, constrain the depositional age of the protoliths to the Fraser Range Metamorphics to between 1334 and 1293 Ma. Peak metamorphic conditions at *c.* 1290 Ma were *c.* 850 °C at pressures of 7–9 kbar. Peak metamorphism was followed by a period of isobaric cooling at pressures of *c.* 9 kbar. U–Pb zircon ages from leucosomes and metamorphic overgrowths in the metapelitic rocks indicate crystallization of partial melts at 1290 Ma, essentially coincident with the emplacement of mafic rocks at 1292 Ma. In situ analyses of both matrix hosted monazite and monazite inclusions in garnet yield ages between 1285 and 1268 Ma, with no significant age difference between monazite in the two textural positions. Cooling of the Fraser Zone below the Rb-Sr biotite closure temperature (~400 °C) occurred at 1260 Ma. Cooling and strengthening of the Fraser Zone rendered it less susceptible to subsequent tectonic events that affected rocks to the north and south of this resistant lozenge. Only rare geochronological evidence of later events can be resolved in recrystallised monazite rims dated at 1234 ± 17 Ma.

1. Introduction

The source of heat that drives high-temperature, low-pressure metamorphism at a regional scale in Precambrian terranes has long been a source of contention (Bohlen, 1987, 1991; Brown, 2006, 2007; Ellis, 1987; Harley, 1989, 1990, 1992; Jamieson et al., 1998; Sandiford and Powell, 1986, 1991). In part this is due to difficulties in linking the age of metamorphic assemblages to the magmatic and tectonic history of the terrains. Recent studies have suggested that backarc regions undergoing extension are locations where surface heat flow is elevated (Hyndman and Currie, 2011; Hyndman et al., 2005). Mafic magmatism in these regions may be a significant source of heat (Brown, 2006, 2007; Clark et al., 2009, 2011; Collins, 2002a,b; Hyndman et al., 2005). In younger orogens, where the boundary conditions of the metamorphic system are better understood, studies have linked magmatism in backarc settings to the formation of granulites (e.g. Kemp et al., 2007). However, in older, deeply exhumed Proterozoic orogenic systems, the link between granulite formation and magmatism has been more challenging to demonstrate. The difficulties may arise from the greater degree of post-metamorphic overprinting, the effects of prolonged lower-temperature alteration and in establishing the durations of metamorphic events in these systems.

The Fraser Zone forms part of the Paleo-Mesoproterozoic Albany Fraser Orogen (Fig. 1; Kirkland et al., 2011b; Spaggiari et al., 2009, 2011) and is a tilted block of lower-middle to lower crust. The zone contains the Fraser Range Metamorphics (Spaggiari et al., 2009), dominated by metagabbros, sheets of metagranite, and layers of pelitic, semipelitic to calcic, and occasionally iron-rich metasedimentary rocks (Clark et al., 1999; Spaggiari et al., 2011). Metamorphism is generally regarded as having occurred during the amalgamation of the West Australian and Mawson Cratons during

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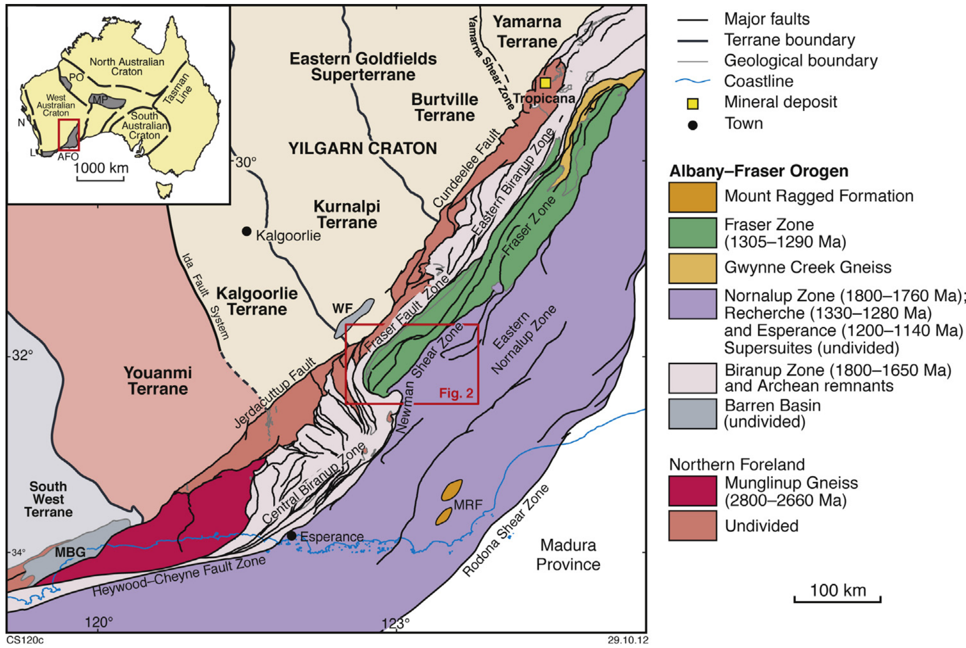

Fig. 1. Simplified, pre-Mesozoic interpreted bedrock geology of the eastern Albany-Fraser Orogen and tectonic subdivisions of the Yilgarn Craton (modified after Cassidy et al., 2006; Spaggiari et al., 2009, 2011). Abbreviations used: AFO = Albany-Fraser Orogen; L = Leeuwin Province; MBG = Mout Barren Group; MP = Musgrave Province; MRF = Mount Ragged Formation; N = Northampton Province; PO = Paterson Orogen; WF = Woodline Formation.

the Mesoproterozoic (Bodorkos and Clark, 2004a,b; Kirkland et al., 2011a; Spaggiari et al., 2009). The abundance of geochronologically useful accessory phases (zircon and monazite) and the development of thermobarometrically informative mineral assemblages allow robust pressure–temperature–time (*P–T–t*) constraints to be placed on the evolution of this zone of the orogen. Zircon geochronology allows the resolution of temporal relationships between crystallization of mafic magmas and the metamorphism recorded by the metasedimentary units. The ability to link directly the timing of granulite facies metamorphism with the crystallization of large volumes of mafic rocks, and thereby provide a solid link between *P–T* evolution and heat source, has proved difficult in many other Proterozoic terranes.

2. Geological setting

The Albany–Fraser Orogen, on the southern and southeastern margin of the Archaean Yilgarn Craton, is part of the Proterozoic West Australian Craton (Fig. 1). The orogen consists of Paleoproterozoic and Mesoproterozoic (1800–1140 Ma) rocks and modified marginal rocks of the Archaean Yilgarn Craton (Kirkland et al., 2011a,b; Spaggiari et al., 2011). A major component of the orogen is the Kepa Kurl Booya Province (Spaggiari et al., 2009), comprising Proterozoic crust probably amalgamated by 1345–1260 Ma (Albany-Fraser Stage I) tectonism (Spaggiari et al., 2009). It includes three geographical and structural, fault-bounded zones defined as the Biranup, Fraser, and Nornalup Zones (Fig. 1; Spaggiari et al., 2009). The Biranup and Nornalup Zones are dominated by older crustal units reflecting the reworking and rifting of the Yilgarn Craton margin (Kirkland et al., 2011a,b), whereas the Fraser Zone is a Mesoproterozoic component which has been interpreted to represent the suture between the West Australian and Mawson Cratons (Bodorkos and Clark, 2004a,b; Spaggiari et al., 2009). However, more recent studies have demonstrated that rocks equivalent to the Biranup zone are exposed to the east of the Fraser Zone, suggesting that the suture must lie further to the east, possibly now concealed beneath the Eucla Basin (Kirkland et al., 2011b; Spaggiari et al., 2011). This study focuses on the rocks of the Fraser Zone, specifically the Fraser Range Metamorphics.

2.1. Geological setting of the Fraser Range Metamorphics

The Fraser Range Metamorphics is a northeast-trending suite of granulite-facies mafic rocks interlayered with metagranites and metasediments (Fig. 2). Myers (1985) interpreted the Fraser Zone to represent a large layered mafic intrusion, whereas Condie and Myers (1999) suggested that the rocks were remnants of multiple oceanic magmatic arcs with trace element chemistry suggesting a subduction-related source. Myers (1985) identified five structurally interlayered mafic units, separated by faults, interleaved with slivers of quartzofeldspathic gneiss, metasedimentary gneiss, quartzite, metagranite, and pegmatite (Fig. 2). The structural geometry of these units is dominated by a northeast-trending, steeply dipping foliation that contains a moderately well-defined lineation. The boundaries between units are believed to represent major thrust faults, with the Fraser Fault as the leading northwest-verging fault. The dextral and thrust kinematics observed within the Fraser Fault suggest that the Fraser Zone was thrust northward over the Biranup Zone (Kirkland et al., 2011a; Spaggiari et al., 2011).

Ages from a metagabbro of 1291 ± 21 Ma (whole-rock Sm-Nd isochron; Fletcher et al., 1991) and a SHRIMP U–Pb zircon age of 1291 ± 8 Ma (De Waele and Pisarevsky, 2008) are interpreted as the igneous crystallization ages of the mafic protoliths in the Fraser Zone. An additional age constraint of 1301 ± 6 Ma for the age of mafic magmatism is provided by an intrusive charnockite from Mt Malcolm (Clark et al., 1999). Orthopyroxene-bearing orthogneiss north of Mt Malcolm yielded a U–Pb SHRIMP zircon age of 1293 ± 9 Ma which Clark et al. (1999) interpreted as the igneous crystallization age of a post-D_1 and pre-D_2 intrusion. De Waele and Pisarevsky (2008) found evidence for younger granitic gneiss at 1280 ± 10 Ma and 1256 ± 23 Ma. These younger rocks are similar in age to a 1288 ± 12 Ma aplite dyke (Clark et al., 1999), believed to have intruded following a discrete second metamorphic event (M_2).