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Transformation of an Archean craton margin during Proterozoic basin formation and magmatism: The Albany–Fraser Orogen, Western Australia

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ABSTRACT

The Albany–Fraser Orogen is a well-preserved example of Proterozoic modification of an Archean craton margin. The formation of two successive basin systems accompanied by magmatism along the southern and southeastern Yilgarn Craton margin in Western Australia reflect distinct changes in tectonic regimes, resulting in significant transformations of the Archean craton crust. Provenance analysis from detrital zircons indicates that the first basin system – the c. 1815–1600 Ma Barren Basin – was dominantly filled with Neoarchean detritus derived from the Yilgarn Craton, and Paleoproterozoic detritus derived from coeval voluminous, mostly felsic magmatism. The abundance of locally derived sediment deposited onto a reworked Archean Yilgarn Craton substrate, coupled with the progressively more juvenile isotopic signature of magmas, indicates a largely extensional tectonic setting, consistent with either a continental rift basin or a long-lived backarc basin system. This extensional regime led to the formation of a passive margin and oceanic basin along the craton edge – the c. 1600–1305 Ma Arid Basin – and formation of an ocean-continent transition in the most heavily modified, outboard region of the craton margin (the eastern Nornalup Zone). A change in tectonic regime is denoted by the formation of an oceanic-arc – the c. 1410 Ma Loongana Arc, preserved in the adjoining Madura Province. Oceanic subduction led to accretion of the Loongana Arc onto the craton edge, recorded by the presence of exotic detritus derived from this arc deposited into a foreland basin (uppermost Arid Basin). This accretion event triggered crustal thickening and the earliest phase of magmatism of Stage I of the Albany–Fraser Orogeny at c. 1330 Ma. A change to west-dipping subduction beneath the accreted portion of the Loongana Arc placed the orogen into a backarc setting, into which the remainder of the Recherche Supersuite mafic and felsic magmas were intruded. Thus, the Albany–Fraser Orogen is regarded as an Archean craton margin that preserves a long history of Proterozoic transformation dominated by extensional processes that resulted in the formation of orogen-wide, basin systems, accompanied by magmatism. The recognition that the Albany–Fraser Orogen has always been part of the West Australia Craton, and the tectonic regimes that have affected it, provide important constraints on reconstructions of the Nuna and Rodinia supercontinents.

1. Introduction

Archean craton margins have become increasingly recognized as sites of significant tectonic activity and mineralization (Begg et al., 2009). The initial structure, thermal state and crustal compositional range (i.e. crustal inheritance) of the Archean crust has a fundamental influence on the subsequent tectonic evolution of these margins, as indicated by recent studies of Phanerozoic hyperextended magma-poor rift systems and their oceanic basins (Manatschal et al., 2014). In rift systems, for example, crustal inheritance may control processes such as the locus of rifting and rift architecture, zones of lithospheric weakness, thermal structure, and the magma budget (Manatschal et al., 2014). However, understanding the nature and role of crustal inheritance

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during Proterozoic modification of Archean craton margins requires knowledge of the tectonic regimes including stress state, basin type and evolution, and the nature of accompanying magmatism.

It is well known that sedimentary basins preserve information about tectonic history and setting, crustal architecture and paleotopography, and evidence of eroded tectonic elements in their detritus (e.g. Rahl et al., 2003; Martin et al., 2008; Cawood et al., 2012). Analysis of sedimentary basins is particularly beneficial when linked with an understanding of associated magmatic rocks, which in turn can provide independent constraints on tectonic settings.

We have examined the contact between the Archean Yilgarn Craton and the Proterozoic Albany–Fraser Orogen in southern Western Australia using a comprehensive U–Th–Pb and Lu–Hf isotopic database on detrital zircons and inherited and magmatic zircon in granites. The Albany–Fraser Orogen preserves two regionally extensive basin systems, the 1815–1600 Ma Barren Basin and the 1600–1305 Arid Basin (Spaggiari et al., 2011). The Barren Basin contains a detrital zircon age and Hf isotopic fingerprint that can be readily accounted for by proximal Archean and Proterozoic sources shed off the denuding Archean craton and its margin. The Arid Basin shares a similar Proterozoic provenance, but lacks the Archean detritus and also reveals a distinctive, new 1425–1375 Ma exotic source. The identification of this exotic source is important as it reflects a major tectonic change, with the formation of an arc near the craton margin. This 1425–1375 Ma source is juvenile and can be readily tracked to magmatism of the Loongana Arc in the Madura Province to the east. Thus, by linking basin analysis, detrital zircon provenance, and the associated magmatic history, we constrain the tectonic evolution of this Archean craton margin throughout the Proterozoic. This evolution has implications for supercontinent reconstructions (e.g. Aitken et al., 2015) yet its potential connection to Laurentia remains cryptic (e.g. Wade et al., 2008; Cawood and Korsch, 2008; Pisarevsky et al., 2014).

2. Overview of the Albany–Fraser Orogen and Madura Province

Part of the West Australian Craton, the Albany–Fraser Orogen extends over a distance of at least 1200 km along the southern margin of the Archean Yilgarn Craton (Fig. 1). The eastern margin of the Albany–Fraser Orogen and the Madura Province lie under cover of the Cretaceous and Cenozoic Bight and Eucla Basins, and their boundary is defined by the east-dipping Rodona Shear Zone – a broad zone of deformation interpreted as dominated by thrusting, overprinted by sinistral strike-slip shearing (Fig. 2; Spaggiari et al., 2012, 2014a). The Madura Province appears to be dominated by rocks of oceanic affinity, and contains the Loongana Arc (Kirkland et al., 2015; see also Section 5 below).

The Albany–Fraser Orogen is dominated by Paleoproterozoic and Mesoproterozoic rocks that are largely a product of reworking of the southern and southeastern Yilgarn Craton from at least 1815 Ma through to 1140 Ma (Nelson et al., 1995; Kirkland et al., 2011a; Spaggiari et al., 2011). Paleoproterozoic tectonic events include dominantly felsic magmatism during the Salmon Gums Event (1815–1800 Ma), the Ngadju Event (1780–1760 Ma), and the Biranup Orogeny (1710–1650 Ma), which includes the c. 1680 Ma, high-temperature, compressional Zanthus Event (Fig. 3; Kirkland et al., 2011a; Spaggiari et al., 2011, 2014b). Mesoproterozoic tectonism is defined as the Albany–Fraser Orogeny, which is separated into two stages: Stage I (1330–1260 Ma) and Stage II (1225–1140 Ma) (Clark et al., 2000; Bodorkos and Clark, 2004a; Spaggiari et al., 2014b). Stage I was a widespread, coeval felsic and mafic magmatic event accompanied by deformation and high-temperature and moderate- to high-pressure metamorphism and is generally interpreted as marking the collision between the West Australian and Mawson Cratons (Nelson et al., 1995; Clark, 1999; Clark et al., 2000, 2014; Bodorkos and Clark, 2004b). Stage II was dominated by craton-vergent thrusting, high-temperature and moderate-pressure metamorphism, and mainly felsic magmatism after c. 1200 Ma and has generally been interpreted to reflect intracratonic orogenesis (Myers, 1995; Clark et al., 2000; Dawson et al., 2003; Spaggiari et al., 2009, 2011, 2014a). Most metamorphic dates from Archean to Paleoproterozoic rocks in the Albany–Fraser Orogen yield Stage II ages, with the exception of those from the Fraser Zone, which is dominated by Stage I metamorphic ages (Kirkland et al., 2011a, 2014a; Clark et al., 2014).

The Albany–Fraser Orogen is divided into two main tectonic components: the Archean Northern Foreland, and the dominantly younger, Neoarchean to Mesoproterozoic Kepa Kurl Booya Province (Fig. 3; Spaggiari et al., 2009). The Northern Foreland consists of dominantly greenschist facies rocks of the Archean Yilgarn Craton intruded by Paleoproterozoic and Mesoproterozoic magmatic rocks, deformed and metamorphosed during the Albany–Fraser Orogeny (Myers, 1990, 1995; Nelson et al., 1995; Spaggiari et al., 2009, 2011, 2014b). The Munglinup Gneiss is a higher metamorphic grade component of the Northern Foreland contained within thrust sheets exhumed from a deeper crustal level (Nelson et al., 1995; Spaggiari et al., 2009, 2011, 2014a).

The Kepa Kurl Booya Province is defined as the various, dominantly Proterozoic crystalline basement crustal components (Spaggiari et al., 2009). It includes four, geographical and structural, fault-bounded zones defined as the Tropicana, Biranup, Fraser, and Nornalup Zones (Figs. 1 and 3; Spaggiari et al., 2009, 2011, 2014b). In summary, where Yilgarn Craton rocks dominate and are clearly recognizable, even through the effects of reworking, they are defined as belonging to the Northern Foreland. Where pre- to syn-Stage I orogenic Proterozoic rocks are dominant, even though they may include Archean Yilgarn Craton remnants, they are defined as belonging to the Kepa Kurl Booya Province. An exception is the dominantly Archean Tropicana Zone, which is interpreted as part of the Yilgarn Craton, but has a distinctly different geological evolution that cannot be readily correlated with adjacent Yilgarn Craton terranes, such as the Yamarna Terrane, but shares much of the Paleoproterozoic history of the Albany–Fraser Orogen (Kirkland et al., 2014a; Occhipinti et al., 2014).

The Biranup Zone spans the entire length of the Albany–Fraser Orogen and is dominated by strongly deformed orthogneiss, with lesser amounts of metagabbroic and hybrid rocks that range in age from 1815 to 1625 Ma (Fig. 1; Nelson et al., 1995; Spaggiari et al., 2009; Kirkland et al., 2011a). The magmatic rocks intrude metasedimentary rocks of the Barren Basin. The Nornalup Zone is the southern- and easternmost unit of the Albany–Fraser Orogen and also spans its entire length, although much of the original Paleoproterozoic basement appears to be masked by dominantly granitic intrusions of the 1330–1140 Ma Recherche and Esperance Supersuites.

The approximately 450 km long Fraser Zone is defined by a strong, distinct geophysical signature in both aeromagnetic and gravity data – the latter reflecting high density attributed to the dominance of metagabbroic rocks (Smithies et al., 2013; Figs. 1, 2 and 4). It contains the 1305–1290 Ma Fraser Range Metamorphics, which comprise thin to voluminous sheets of metagabbroic rocks interlayered with sheets of granitic gneisses of the Recherche Supersuite, as well as hybrid rocks, all of which intrude sedimentary rocks of the Snowys Dam Formation in the Arid Basin (Spaggiari et al., 2011, 2014c; Smithies et al., 2013, 2014, 2015a). Peak metamorphic temperatures and pressures recorded in the pelitic rocks of the Snowys Dam Formation reached c. 850 °C at pressures of 7–9 kbars at c. 1290 Ma (Clark et al., 2014). The pressure