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Pitfalls of classifying ancient magmatic suites with tectonic discrimination diagrams: An example from the Paleoproterozoic Tunkillia Suite, southern Australia

Justin L. Payne[a,*], Gary Ferris[b], Karin M. Barovich[a], Martin Hand[a]

[a] *Continental Evolution Research Group, Centre for Tectonics, Resources and Exploration (TRAX), Mawson Building DP313, University of Adelaide, SA 5005 Australia*
[b] *Monax Mining Limited, PO Box 247, Export Park, SA 5950 Australia*

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ABSTRACT

The 1690–1670 Ma felsic Tunkillia Suite was generated through the central Gawler Craton, southern Australia, during or after the waning stages of the 1730–1690 Ma Kimban Orogeny. Previous models for the generation of the Tunkillia Suite used trace element tectonic discrimination diagrams to suggest a subduction-related petrogenesis. Subsequently, Tunkillia Suite magmatism was used to infer an active plate margin in paleotectonic reconstruction models. In part, this led to the suggestion of a long-lived active margin on the southern edge of paleo-Australia that was correlated with the long-lived active margin of south-western Laurentia. The more detailed geochemical and isotopic analyses used in this study highlight the shortcomings of analysis based upon simple application of trace-element tectonic discrimination diagrams.

The combination of detailed geochemical assessment and new geochronology demonstrates that some intrusions previously used to characterise the tectonic setting of the Tunkillia Suite are in fact unrelated. Tunkillia Suite intrusions are typically high-K, alkali-calcic and magnesian and are dominantly felsic (>70 wt% SiO_2), moderately peraluminous granitoids. Trace and rare earth element abundances display large variations. Sr and Y concentrations range from 40 to 550 ppm and from 4.7 to 41 ppm, respectively. Eu/Eu^* values range from 0.2 to 1.6 and combined with REE patterns demonstrate the varying composition of restite associated with melt generation of the Tunkillia Suite. The majority of the Tunkillia Suite display chemical characteristics typical of a plagioclase- or hornblende-dominated restite with only three samples demonstrating garnet-rich restite composition. Nd-isotope characteristics of Tunkillia Suite intrusions suggest a crustal column of variable age exists in the Gawler Craton, as variation in $\varepsilon_{\mathrm{Nd}}(T)$ values (−6.3 to +2.6) cannot be accounted for simply through assimilation and fractional crystallisation processes.

The limited SiO_2 compositional range of the Tunkillia Suite inhibits unequivocal tectonic classification due to the inability to determine mantle melt composition and infer mantle melting conditions leading to the generation of the Tunkillia Suite. Geochemical, isotopic and mineralogical characteristics of the Tunkillia Suite are most consistent with a 'late- to post-tectonic' setting for petrogenesis. The term 'late- to post-tectonic' is used in this instance as a genetic descriptor based upon the comparison with Phanerozoic granitoid suites formed in such a setting after collisional orogenesis. Contrary to the suggestion of previous studies, a subduction-related arc setting is not readily reconcilable with the chemical and mineralogical characteristics of the Tunkillia Suite.

1. Introduction

The study of Archaean and Proterozoic felsic magmatic suites is typically undertaken to establish mechanisms of petrogenesis and, from this, constrain the tectonic regime active at the time of their generation (e.g. Bonin et al., 1998; Eklund et al., 1998; Griffin et al., 2000; Peterson et al., 2002; Sheppard et al., 2003, 2004; Clemens et al., 2006; Lopez et al., 2006). The tectonic setting of Precambrian magmatic suites is often largely inferred from comparisons with Phanerozoic magmatic rocks and the timing of generation with respect to other tectonic events (Foden et al., 1988; De et al., 2000; Griffin et al., 2000; Sheppard et al., 2004; Whalen et al., 2004; Wade et al., 2006). One end member of such comparison is the use of trace-element tectonic discrimination diagrams to infer the tectonic setting of magmatic suite petrogenesis.

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* Corresponding author. Fax: +61 8 8303 4347.
E-mail address: justin.payne@adelaide.edu.au (J.L. Payne).

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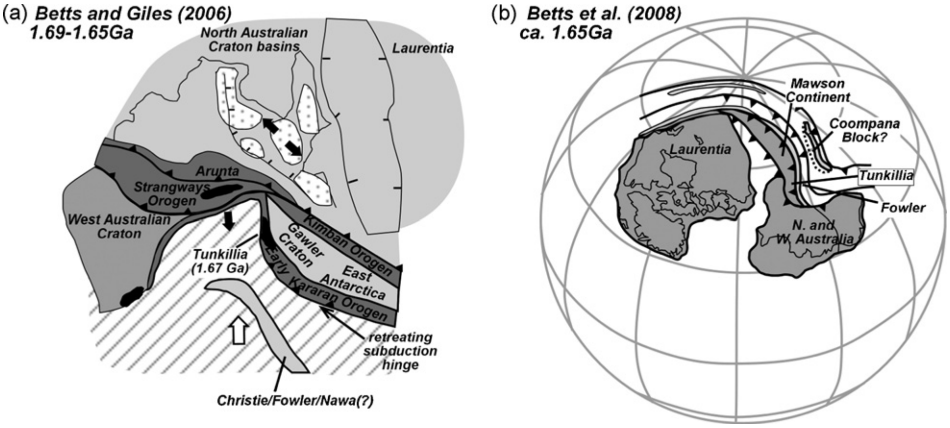

Fig. 1. Examples of reconstruction models for Paleoproterozoic Australia that utilise a subduction-related petrogenesis for the Tunkillia Suite (inferred location on figures marked) to infer a long-lived active margin on the southern margin of Australia. (a) Modified from Betts and Giles (2006) with their interpreted position of Tunkillia Suite on Gawler Craton. (Note that this interpretation is also erroneous as the Tunkillia Suite outcrops in the terrane inferred to be the crust of the Fowler/Christie/Nawa domains.) (b) Modified from Betts et al. (2008) displaying their interpreted continuing accretion of terranes via north-dipping (current co-ordinate frame) subduction to the southern margin of the Australian continent and the extension of this plate margin to Laurentia.

The basic thermodynamics of mineral reactions responsible for the generation of melt are unlikely to have changed over time, and ancient and modern-day magmatism must therefore occur under the same intensive physical parameters (i.e. *P*–*T* conditions). This provides a basis for the classification of ancient magmatism through comparison with modern felsic magmatic suites. However, the Earth's chemical reservoirs (i.e. upper and lower crust, lithospheric mantle and aesthenosphere) have evolved and undergone compositional changes throughout Earth history (e.g. Taylor and McLennan, 1985; McDonough and Sun, 1995; Collerson and Kamber, 1999; Hawkesworth and Kemp, 2006). The changes in bulk chemical composition and potential variation in tectonic regimes (e.g. Brown, 2007) mean that tectonic discrimination methods using element abundances constructed from modern, well-characterised igneous suites need to be applied with caution to ancient magma systems.

The Tunkillia Suite (Gawler Craton, South Australia) is a felsic magmatic suite that was emplaced between 1690 and 1670 Ma (Hand et al., 2007). It is a good example of an ancient magmatic suite whose tectonic setting has been classified using trace element tectonic discrimination diagrams derived from modern magmatic suites. Limited geochemical data were used to suggest a subduction-related petrogenesis (Teasdale, 1997; Betts and Giles, 2006). A subduction-related classification of the Tunkillia Suite has important implications for reconstruction models of Proterozoic Australia and is used by Karlstrom et al. (2001), Betts et al. (2002), Giles et al. (2004) and Betts and Giles (2006) to infer a long-lived active margin on the southern edge of proto-Australia during the Paleoproterozoic (Fig. 1). Despite the importance of the Tunkillia Suite in underpinning reconstruction models of the Australian Proterozoic, virtually no work has been done on the geochemical and isotopic nature of the Tunkillia Suite. By combining new geochemical, isotopic and geochronological data with mineralogical information we demonstrate that the previous 'subduction-related' classification of the Tunkillia Suite is incorrect. This revised classification has significant implications for reconstruction models of the Proterozoic which are discussed.

2. Geological setting

The Gawler Craton (Fig. 2) is composed of a central late Archaean-early Paleoproterozoic nucleus surrounded, overlain and intruded by Palaeo- (1850–1610 Ma) and Mesoproterozoic (1590–1510 Ma) rocks (Daly et al., 1998; Ferris et al., 2002; Hand et al., 2007). Neoproterozoic and Phanerozoic sedimentary rocks and sediments overlie much of the craton. These cover sequences have greatly restricted the understanding of the crustal composition and tectonothermal evolution of the craton (Ferris et al., 2002). Tectonic domains have been interpreted using a combination of Total Magnetic Intensity (TMI) and gravity modelling (Fig. 2, after Fairclough et al., 2004).

The late Archaean nucleus of the Gawler Craton consists of *c.* 2560–2480 Ma metasedimentary, volcanic and granite-greenstone lithologies which have been extensively deformed during the *c.* 2460–2430 Ma Sleafordian Orogeny (Daly et al., 1998; Tomkins et al., 2004; Swain et al., 2005a; McFarlane, 2006; Fanning et al., 2007). This Archaean nucleus is bordered to the east by mid- to late-Paleoproterozoic metasedimentary lithologies, the *c.* 1850 Ma Donington Granitoid suite (Daly et al., 1998; Reid et al., 2008), Engenina Adamellite (~1690 Ma, Daly et al., 1998) and younger Mesoproterozoic Gawler Range Volcanics and Hiltaba Suite intrusions (1595–1575 Ma, Creaser and White, 1991; Creaser, 1995; Johnson and Cross, 1995; Allen and McPhie, 2002).

The Nuyts Domain, situated to the south and west of the Archaean nucleus of the Gawler Craton (Fig. 2), is interpreted to consist of the Tunkillia, St Peter and Munjeela Suite intrusions (Fairclough et al., 2004). The St Peter Suite (1620–1608 Ma) is a mafic-felsic suite interpreted as forming in a subduction-related arc (Swain et al., 2008). The Munjeela Suite consists of a small number of muscovite-garnet-bearing plutons that are constrained to *c.* 1590–1580 Ma (Payne, 2008).

The Fowler Domain along the western Gawler Craton margin has little outcrop but is interpreted from geophysical data and sparse drill-holes to consist of Paleoproterozoic igneous and metamorphic rocks (Teasdale, 1997; Daly et al., 1998; Hand et al., 2007). A mildly deformed gabbro yields an emplacement age of 1730 ± 10 Ma (Daly et al., 1998). Younger intrusive and metamorphic ages span the interval 1570–1450 Ma but have little tectonic context (Teasdale, 1997; Swain et al., 2005b; Fraser and Lyons, 2006). No constraints have yet been placed upon the maximum depositional age of metasedimentary protoliths but they have been demonstrated to have undergone metamorphism at *c.* 1720 (Teasdale, 1997).

The orogenic events that have shaped the evolution of the Gawler Craton are comparatively poorly understood. The *c.* 2460–2430 Ma Sleafordian Orogeny produced greenschist to granulite facies metamorphism and syn-tectonic magmatism (Daly and Fanning, 1993; Tomkins, 2002; Tomkins et al., 2004; Swain et al., 2005a; McFarlane, 2006). The structural and geochronological evidence of the Sleafordian Orogeny is largely overprinted by later