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Collision-related granitic magmatism in the Granites–Tanami Orogen, Western Australia

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ABSTRACT

The Palaeoproterozoic Granites–Tanami Orogen (GTO) is a significant auriferous province located in the poorly exposed southwestern part of the North Australian Craton (NAC). U-Pb data from Sensitive High Mass Resolution Ion Microprobe (SHRIMP) studies, Sm–Nd isotopic data, geochemistry and petrological studies all suggest that granitic rocks in the Western Australian portion of the GTO were emplaced around ca. 1795 Ma broadly synchronous with gold mineralization. These are variably fractionated, peraluminous, and derived from, or interacted with, ca. 2600 Ma upper crustal material.

Deformation, metamorphism and magmatism around 1795 Ma in the GTO were synchronous with the Stafford Orogeny in the Arunta Orogen of central Australia. This deformation was the product of north- to northeast-directed compression within the GTO, and is associated with greenschist facies regional metamorphism. Amphibolite facies metamorphism is restricted to the immediate aureole of certain granitic rocks. This process is clearly a thermal overprint of the regional greenschist facies metamorphism, and indicates that the granitic rocks were emplaced during peak regional metamorphism or soon after.

The granitic rocks are inferred to have formed in response to convergence and amalgamation of the GTO and the northern part of the Arunta Orogen along an accretionary margin delineated by the Willowra Lineament, which extends for thousands of kilometres in central and western Australia. Synchronous ca. 1795 Ma orogenic gold mineralization and syn-collisional granitic rocks have been identified across extensive regions throughout the NAC (e.g. the Pine Creek and Halls Creek orogens) suggesting that the Palaeoproterozoic assembly of Australia was marked by a widespread, significant metallogenic event at that time.

1. Introduction

Granitic rocks are extensively studied in the literature because of their abundance in the upper part of the crust, and because they present petrogenetic ‘windows’ into the evolution of deeper crustal sources. In particular, plutonic rocks have distinctive geochemical characteristics that can provide clues to their tectonic setting during emplacement (e.g. Pitcher, 1983; Pearce et al., 1984).

Numerous studies have related temporally and spatially associated Phanerozoic magmatism to convergent margins that include subduction, and syn- to post-collision extensional settings (e.g. Chappell and White, 1974, 1992, 2001; White and Chappell, 1983, 1988; Harris et al., 1986; Sylvester, 1989; Brown, 1994; Barbarin, 1999; Young, 2003; Bonin and Bébien, 2005; Bonin, 2007). There are also numerous investigations that have shown that granite classification and discrimination techniques based on Phanerozoic systems can be applied to Proterozoic analogues (e.g. Condie, 1982; Patchett and Arndt, 1986; Torsvik et al., 1996; Vassallo and Vernon, 2000; Patchett and Chase, 2002; Steltenpohl et al., 2003; Haapala et al., 2005).

A collisional tectonic setting associated with convergence has been proposed recently for the Palaeoproterozoic evolution of the GTO (Bagas et al., 2008, 2009). Such tectonic settings commonly entail the convergence of terranes, plate locking and spasmodic reactivation, as has been the case during the Cenozoic along the present northern edge of the Australia Plate (e.g. Pubellie et al., 2003). These large-scale plate interactions can involve horizontal crustal-shortening, uplift, medium- to high-temperature metamorphism, and the generation of collisional-related granitic rocks (e.g. Singh et al., 2004).

Granitic rocks generated in specific settings in the context of plate tectonics are commonly thought to relate to pera-

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luminous, metaluminous, and peralkaline magmatism that can be distinguished using the concept of alumina saturation. This distinction is calculated according to the ratios of molecular $Al_2O_3/(CaO + Na_2O + K_2O)$ (A/CNK), which is known as Shand's Index (Shand, 1947; Maniar and Piccoli, 1989; Clarke, 1992). Based upon this classification factor, peraluminous granites have A/CNK ratios of > 1, metaluminous granites have A/CNK ratios of <1, and peralkaline granites have A < NK. Even though this is a simple geochemical classification, it has been found that: (1) many peralkaline granites are associated with post-tectonic extension within plates, (e.g. Bonin, 2007); (2) subduction-related granites tend to be metaluminous, although some metaluminous granites are collision-related (e.g. Martin, 1987; Wedepohl, 1991); and (3) granites related to a continent-continent collisional setting tend to be peraluminous, although some are subduction-related (e.g. White and Chappell, 1983; Wedepohl, 1991; Chappell and White, 1992, 2001; Maas et al., 1997; Chappell, 1999).

The GTO has emerged as a major Proterozoic orogenic gold province within the NAC (Wygralak et al., 2005; Huston et al., 2007), having produced in excess of 300 tonnes of gold so far. In comparison with other north-Australian Proterozoic provinces, however, a good understanding of the geological evolution of the GTO, and its relationships to adjacent orogens (Arunta, Halls Creek) is only just emerging (Crispe et al., 2007; Bagas et al., 2008, 2009). To date, almost all descriptions of granitic rocks in the GTO have been from occurrences in the Northern Territory. In this contribution, the Palaeoproterozoic granitic rocks from the Western Australian part of the GTO will be examined in an effort to characterize and petrogenetically fingerprint the plutonic suites, and place these into a regional tectonic framework that can aid in improving our understanding of this and adjacent Proterozoic terranes in northern Australia, their metallogenic importance, and palaeo-tectonic evolution.

Whole-rock Sm-Nd isotopes, U-Pb SHRIMP data of magmatic and inherited zircons, and trace element geochemistry are used to constrain the sources of the granitic rocks and the likely tectonic setting during their formation in the GTO. The results obtained herein will be compared with existing data from the Northern Territory. In particular, we will examine if peraluminous granites exist in the GTO, as this composition is known to be very rare in the NAC (Wyborn, 1988), or whether the peraluminous signatures reflect either extensive fractionation of primary "I-type" compositions or overprinting alteration.

An improved understanding of the evolution of the GTO also aids exploration for orogenic gold (and other metals) within this fertile yet relatively under-explored region and analogous terrains throughout the NAC.

1.1. Geology of the Granites–Tanami Orogen

The GTO is a poorly known Palaeoproterozoic terrane in northern-central Australia, straddling the state border between Western Australia and the Northern Territory (Figs. 1 and 2). The orogen is part of the NAC (Myers, 1990; Myers et al., 1996), which also includes the Halls Creek, Pine Creek, Mount Isa and Tennant Creek orogens (among others). The NAC is bounded to the south by the Central Australian Craton along the Willowra Lineament (Bagas et al., 2008), and to the east by the Phanerozoic Tasmanides (Scheibner, 1974) of eastern Australia (Fig. 1).

Bagas et al. (2008) defined the GTO as including postulated Neoarchaean and Palaeoproterozoic rocks that predate the late Palaeoproterozoic cover sequences in the Tanami geographic region of Western Australia and the Northern Territory. Crispe et al. (2007) assigned the cover rocks to the ca. 1758–1700 Ma Pargee Sandstone and the ca. 1735–1640 Ma Birrindudu Group.

The GTO in Western Australia comprises tightly folded greenschist-facies ca. 1864–1844 Ma metasedimentary and volcanic rocks and mafic sills, intruded by ca. 1795 Ma granitic rocks and mafic dykes (Bagas et al., 2008). In the Northern Territory, the oldest exposed metasedimentary unit within the orogen is the ca. 1864–1844 Ma Dead Bullock Formation (Crispe et al., 2007), which is a ~1 km-thick, upward-fining sequence of sandstone, siltstone, shale, chert, and rare volcanic rocks (Vandenberg and Meixner, 2003, 2004; Lambeck, 2004; Lambeck et al., 2008). The oldest Palaeoproterozoic unit in the Western Australian portion of the GTO is the ca. 1864 Ma Stubbins Formation (Bagas et al., 2008), which also consists of sandstone, siltstone, shale, chert, and volcanic rocks (Fig. 3). Both the Dead Bullock and Stubbins Formations are overlain by sandstone, siltstone, and shale assigned to the ca. 1864–1844 Ma Killi Killi Formation (Fig. 3; Crispe et al., 2007; Bagas et al., 2008). Due to poor exposure, nowhere are these formations seen in contact, but considering that the Killi Killi Formation appears to conformably overlie both, the Stubbins and Dead Bullock formations are probable correlatives (Fig. 3).

Palaeoproterozoic deformation in the region is characterized in Western Australia by: (1) an early (between 1864 and 1844 Ma), layer parallel fabric (S_{GTO1}) best developed in sericite-rich shale. The cleavage is associated with isoclinal folds trending north-south (F_{GTO1}); and (2) ca. 1795 Ma disharmonic folding with wavelengths of about 1 km (D_{GTO2}-D_{GTO3}) typically associated with greenschist facies regional metamorphism (Bagas et al., 2008).

Metasedimentary rocks in metamorphic aureoles of granites vary from sericite-rich to quartz-rich, with minor amounts of plagioclase (commonly altered to sericite, clinozoisite, and albite), authigenic tourmaline, and muscovite containing rims of chloritized biotite. The biotite has been interpreted to indicate proximal granite and overgrows greenschist-facies mineral assemblages, with biotite formed on the edge of the aureoles. The biotite is commonly altered to chlorite, which is suggestive of either retrograde metamorphism, or multiple periods of greenschist facies regional metamorphism.

2. Granitic rocks

Granitic rocks are a major component of the GTO, spatially representing around 50% of the orogen. These rocks appear to be late syn- to post-orogenic, emplaced during a protracted single, ~30 Ma long period of magmatic activity (1825–1791 Ma; Smith, 2001) that overlaps with the ca. 1795 Ma age of orogenic lode gold (Adams et al., 2007; Crispe et al., 2007; Huston et al., 2007; Williams, 2007; Bagas et al., 2009).

Based on geochemical studies on granites in the Northern Territory portion of the GTO, Dean (2001) and Green (2004) recognized three major, broadly synchronous compositional suites—termed the Birthday, Frederick and Grimwade suites, which are distinguished principally on the basis of their aeromagnetic signatures (Crispe et al., 2007).

In Western Australia, three of the prominent granitic bodies are termed herein the Slatey Creek Granite (south and north of the Coyote gold deposit), Balwina Granite (northwest of Coyote), and Lewis Granite (west of the Kookaburra-Sandpiper gold deposits; Fig. 2). These intrusions form large heterogeneous and zoned granitic complexes consisting of variably foliated monzogranite and granodiorite (Figs. 2 and 4). All of these granites intrude the Stubbins and Killi Killi formations, and preceded deposition of the ca. 1758–1700 Ma Pargee Sandstone (e.g. Crispe et al., 2007).

Although outcrop is sparse in the area, regional mapping, and interpretation of regional magnetic and gravity data obtained by