Precambrian Research 266 (2015) 260–281

Contents lists available at ScienceDirect

Precambrian Research

journal homepage: www.elsevier.com/locate/precamres

The affinity of Archean crust on the Yilgarn—Albany–Fraser Orogen boundary: Implications for gold mineralisation in the Tropicana Zone

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ARTICLE INFO

Article history:
Received 29 January 2015
Received in revised form 22 April 2015
Accepted 19 May 2015
Available online 23 May 2015

Keywords:
Zircon
Pyrite
Granulite
Albany–Fraser Orogen
Yilgarn
Gold

ABSTRACT

Craton margins can be subject to a wide array of gold genesis and redistribution processes, although high-grade terrains on craton margins are frequently viewed as less prospective than lower-grade counterparts. In contrast to this, the high-grade Tropicana Zone, a newly defined Archean crustal component on the eastern margin of the Yilgarn Craton within the Albany–Fraser Orogen (AFO), contains a significant Proterozoic gold deposit. This deposit and zone comprise mid-amphibolite to granulite-facies gneissic rocks with evidence of partial melting and granite injection. The Tropicana Zone contains significant low-Si, LILE-enriched, granites classed as sanukitoids. Along with the distinctive compositions, the rarity of these rocks within any Archean craton suggests that the granitoid protoliths represent a single suite, emplaced during one event.

Due to the intense granulite-facies overprinting of the Tropicana Zone rocks, determination of the magmatic protolith age for these sanukitoids is challenging. Nonetheless, the best age estimate for magmatism is 2692 ± 16 Ma, based on the youngest zircons preserving textural evidence of growth within a viscous silicate melt. This age is older than compositionally similar magmatism found within the Yilgarn Craton, although a sanukitoid in the Northern Foreland of the AFO has a similar age. Furthermore, the granulite-facies metamorphic zircon growth in the Tropicana Zone at 2718–2554 Ma was prolonged compared to that in the Yilgarn Craton. Nonetheless, the Hf isotopic signature of the Tropicana Zone zircon shares strong similarity to that from the Eastern Goldfields Superterrane of the Yilgarn Craton. This implies that the Tropicana Zone reflects a deeper crustal level of the Yilgarn Craton, exhumed and thrust NW an unknown distance over the craton edge. In addition, we observe that the granulite-facies zircons have a less radiogenic Hf-isotope signature than the preserved pre-metamorphic zircon cores. Based on correlations with alpha dose, U and Th content and ^{176}Hf/^{177}Hf we suggest this reflects the preferential destruction and release of unradiogenic Hf from inherited zircon whereas the protolith sanukitoid zircon, with lower U and Th content, was more resistant to mobilisation during high-grade metamorphism. We note this situation may be a more general response of the Hf isotopic system, in which zircon grown in a more mafic melt is less likely to contribute to the metamorphic Hf reservoir than its felsic counterpart.

Juvenile granitic veins dated at c. 1780 Ma intruded into the Tropicana Zone indicate that the Tropicana Zone was structurally emplaced at or before c. 1780 Ma, given similar Proterozoic magmatic events are well documented from (para)autochthonous adjacent units. Re–Os dating of pyrite coeval with one generation of gold in these rocks indicates model ages of c. 2100 Ma, supportive of a Palaeoproterozoic age of mineralisation. This mineralisation event is distinct from major Proterozoic tectonothermal events elsewhere in the AFO. Sanukitoid magmas are well-known for gold fertility and were likely the original

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http://dx.doi.org/10.1016/j.precamres.2015.05.023
0301-9268/

source of gold in the Tropicana Zone, which was subsequently concentrated into brittle structures during several episodes. Gold mineralisation post-dated peak metamorphic conditions and is significantly younger than gold mineralisation within other parts of the adjoining Yilgarn Craton.

1. Introduction

Craton margins are major lithospheric discontinuities that direct fluid, and heat, and in turn, can focus magma from both crustal and mantle sources. Under favourable circumstances these locations can become mineralisation corridors (e.g. Lawley et al., 2013). Craton margins have changed over geological time, reflecting high Archean mantle temperatures with low mantle viscosity compared to relatively low Proterozoic mantle temperatures (Labrosse and Jaupart, 2007). Slower or intermittent Archean subduction-like processes, compared to typically steep Proterozoic subduction, may be expected to result in distinctly different craton margin architectures and processes (Rolf et al., 2012). Understanding the geological history of craton margins is complex because no tectonic setting is unique to them. Craton margins can be sites of lithospheric attenuation, rifting, and subsequent reattachment, and can be adjacent to subduction zones that redistribute material, or they can simply be passive. In addition, where craton margins are accretionary or collisional, exotic terranes may be transferred to them.

The reworked margins of Archean cratons are increasingly recognised as key regions where upgrading of ancient mineral endowments to economically viable levels can occur (Gazley et al., 2011; Hronsky et al., 2012). However, other processes along craton margins, such as terrane transfer, may also play important roles in delivering mineral endowment to the edges of cratons (McMillan et al., 1990). One such example of a dynamic craton margin is the Albany–Fraser Orogen (AFO), which forms the southern and southeastern margins of the Archean Yilgarn Craton in Western Australia (Fig. 1; Spaggiari et al., 2009, 2011, 2014a). This Paleoproterozoic to Mesoproterozoic orogen has extensively modified the Archean Yilgarn Craton margin by events that include episodes of juvenile asthenospheric addition and significant reworking of pre-existing Archean lithologies (Spaggiari et al., 2011; Kirkland et al., 2011a,b). With the discovery of the c. 8 million ounce Tropicana gold deposit in the Tropicana Zone (Doyle et al., 2013) and the 3 Mt Nova-Bollinger Ni deposit in the Fraser Zone (Sirius, 2013), the orogen has recently gained considerable economic importance.

The Tropicana Zone in the northeastern AFO is largely covered by sand-dominated regolith, and in part by Permian sedimentary rocks of the Gunbarrel Basin. Because of this, the geological history of the region has been primarily interpreted from deep seismic reflection, magnetic and gravity datasets, limited surface outcrop investigation, drill cores, and correlations to other regions within the orogen (Occhipinti et al., 2014; Spaggiari et al., 2011, 2014b). Archean rocks of the Tropicana Zone include the Tropicana Gneiss, which hosts the Tropicana gold deposit, and the Hercules Gneiss, which hosts disseminated and vein-related gold associated with the large brittle–ductile Hercules Shear Zone (Watkins, 2012).

Recent structural and geochronological constraints indicate that gold mineralisation at the Tropicana deposit post-dates peak metamorphism and that this deposit is younger than gold mineralisation in the Yilgarn Craton (Doyle et al., 2009, 2013, 2014, 2015). The Tropicana Gneiss was exhumed to greenschist facies conditions by the time of economic gold mineralisation. Major gold-bearing pyrite–biotite–sericite mineralisation is interpreted to have formed in association with shear zones during northeast–southwest compression that post-dated west to northwest vergent thrusting (Doyle et al., 2015). However, the wider tectonic setting and the exotic or indigenous affinity of the Tropicana Zone is unknown. An understanding of the ages and compositions of basement lithologies, along with their relationships to known parts of the Yilgarn Craton and Albany–Fraser Orogen has important implications for constraining gold exploration models.

To improve our understanding of the geological evolution of the Tropicana Zone and its crustal affinity, we studied numerous samples from seven diamond drill cores from two prospects (Hercules and Atlantis) within the Neale Project area (Fig. 2). In this contribution, we report SIMS Secondary Ionization Mass Spectrometry (via SHRIMP – Sensitive High Resolution Ion Microprobe) U–Pb zircon geochronology and LA-ICPMS (Laser Ablation–Inductively Coupled Plasma Mass Spectrometry) Lu–Hf isotopes from zircons in eight samples from five drill cores. We also report Re–Os geochronology on two fractions of a pyrite sample from one drill core and whole-rock geochemistry for the Hercules Gneiss. This dataset places fundamental constraints on the geological affinity of the Hercules Gneiss and helps place mineralisation in the Tropicana Zone within its wider geological context. Additionally, the results serve as a case study on zircon U–Pb geochronology and Hf isotopic systematics of granulite-facies rocks.

2. Regional geological context of the Tropicana Zone

The AFO has been divided into a foreland component (the Northern Foreland) and a basement component, the Kepa Kurl Booya Province (Spaggiari et al., 2009, 2014b). The main tectonic and metamorphic features of the AFO were constructed during several Proterozoic tectonic events (Fig. 3). Paleoproterozoic tectonic events include dominantly granitic magmatism and extensional tectonics at 1815–1800 Ma (the Salmon Gums Event) and 1780–1760 Ma (the Ngadju Event), culminating in the c. 1710–1650 Ma Biranup Orogeny, which includes the c. 1680 Ma compressional Zanthus Event (Kirkland et al., 2011a; Spaggiari et al., 2014b). The orogen-wide, Barren Basin was formed during these events (Spaggiari et al., 2014a).

Mesoproterozoic tectonic events are defined by formation of the Arid Basin (1600–1305 Ma), and Stages I (1330–1260 Ma) and II (1225–1140 Ma) of the Albany–Fraser Orogeny (Clark et al., 2000; Kirkland et al., 2011a; Spaggiari et al., 2014a,b). Stage I of the Albany–Fraser Orogeny was dominated by coeval felsic and mafic magmatism accompanied by deformation and high-temperature and moderate- to high-pressure metamorphism (Nelson et al., 1995; Clark et al., 1999, 2000, 2014; Oorschot, 2011; Smithies et al., 2013, 2015). Stage II involved intense deformation dominated by thrusting, high-temperature and moderate-pressure metamorphism, and primarily felsic magmatism after c. 1200 Ma (Dawson et al., 2003; Spaggiari et al., 2011). The complex thermal history of the AFO has caused significant new mineral growth during these events. However, the extent to which this Proterozoic history has been responsible for gold metallogenesis in the northeastern part of the orogen has until recently been unclear.

Two components of the AFO have specific relevance to the rocks of the Tropicana Zone, namely the Northern Foreland and the Kepa Kurl Booya Province. The Northern Foreland is the part of the Yilgarn Craton which underwent reworking during the Albany–Fraser Orogeny, but did not undergo wholesale Proterozoic magmatic injection. The Northern Foreland comprises mildly reworked greenschist granite-greenstone rocks, and