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Detrital zircon U–Pb–Hf and O isotope character of the Cahill Formation and Nourlangie Schist, Pine Creek Orogen: Implications for the tectonic correlation and evolution of the North Australian Craton

J.A. Hollis[a,*], C.J. Carson[b], L.M. Glass[a,1], N. Kositcin[b], A. Scherstén[c], K.E. Worden[d], R.A. Armstrong[e], G.M. Yaxley[f], A.I.S. Kemp[g], EIMF[h]

[a] Northern Territory Geological Survey, PO Box 3000, Darwin, NT 0801, Australia
[b] Geoscience Australia, PO Box 378, Canberra, ACT 2601, Australia
[c] Department of Geology, Lund University, Sölvegatan 12, S-223 62 Lund, Sweden
[d] BBY Ltd., 17/60 Margaret Street, Sydney, NSW 2000, Australia
[e] PRISE, The Australian National University, Research School of Earth Sciences, Building 61, Mills Road, Acton, ACT 0200, Australia
[f] The Australian National University, Research School of Earth Sciences, Building 61, Mills Road, Acton, ACT 0200, Australia
[g] Centre for Exploration Targeting, School of Earth and Environment, The University of Western Australia M006, 35 Stirling Highway, Crawley, WA 6009, Australia
[h] Edinburgh Ion Microprobe Facility, University of Edinburgh, Edinburgh, UK

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ABSTRACT

Detrital zircon age and Hf isotope patterns for the Cahill Formation and Nourlangie Schist are distinctly different from other Paleoproterozoic successions in the North Australian Craton. The Cahill Formation and Nourlangie Schist comprise the bulk of the Paleoproterozoic strata in the Nimbuwah Domain, the easternmost part of the Pine Creek Orogen on the northern margin of the North Australian Craton. They comprise micaceous and quartzofeldspathic schist, carbonaceous schist, calc-silicate rock, amphibolite and quartzite, deformed and metamorphosed during emplacement of the granitic to dioritic Nimbuwah Complex at 1867–1857 Ma. The Cahill Formation hosts several world-class uranium deposits including Ranger, Jabiluka and Nabarlek. U–Pb SHRIMP and LA-SF-ICPMS detrital zircon spectra for four samples of the Cahill Formation and six samples of the Nourlangie Schist show a similar broad spectrum of ages mainly in the range 3300–1900 Ma. A ubiquitous dominant peak at 2530–2470 Ma matches the age of underlying Neoarchean basement, but is distinct in its dominantly mantle-like Hf and O zircon isotopic character, which shows closer similarity with possible source rocks from the Gawler Craton or alternatively from the Dharwar Craton. Common smaller age peaks occur at 2180 Ma, 2080 Ma and 2020 Ma. The first two have no known magmatic age correlatives in the North Australian Craton. Zircons of the 2020 Ma peak have distinctively unradiogenic Hf and elevated $\delta^{18}O$, at variance with local rocks of this age but similar to detrital zircon of the same age from the Gawler Craton. In contrast to younger Proterozoic sedimentary successions within the Pine Creek Orogen, which contain ubiquitous ca. 1870 Ma detritus, the detrital spectra for the Cahill Formation and Nourlangie Schist contain almost no ca. 1870 Ma detritus. A maximum deposition age of ca. 1866 Ma indicates deposition within error of intrusion of the Nimbuwah Complex. We propose that the Cahill Formation and Nourlangie Schist were deposited at a plate margin immediately prior to convergent tectonism. This resulted in their burial, deformation and amphibolite facies metamorphism during orogenesis associated with the Nimbuwah Event. These findings have implications for understanding the Paleoproterozoic evolution of the Pine Creek Orogen within the context of northern Australia.

* Corresponding author at: Geological Survey of Western Australia, Mineral House, 100 Plain Street, East Perth 6004, Australia. Tel.: +61 892223566; fax: +61 892223633.
E-mail address: Julie.Hollis@dmp.wa.gov.au (J.A. Hollis).
[1] Current address: Territory Iron Pty Ltd, 23 Ventnor Avenue, West Perth, WA 6005, Australia.

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1. Introduction

Detrital zircon age spectra are a powerful tool for interpreting the provenance of sedimentary rocks and, coupled with lithological and tectonostratigraphic constraints, for making correlations between sedimentary successions (e.g. Fedo et al., 2003; Cawood et al., 2012). In addition, the youngest detrital zircon population constrains the maximum age of deposition (e.g. Fedo et al., 2003). Correlation with possible source regions and the change in provenance through time can also provide valuable information on the nature and timing of tectonic processes, such as deposition along active margins, or the arrival of allochthonous terranes at continental margins, or the opening of intracratonic basins (e.g. Barr et al., 2003; Bingen et al., 2001; Goodge et al., 2002; Rojas-Agramonte et al., 2011; Cawood et al., 2012). Combined with other constraints, such as the nature and age of regional magmatism, volcanism, metamorphism, and deformation, together with whole rock and mineral isotopic data, this information can be used to aid paleogeographic reconstructions and tectonic models (e.g. Cawood et al., 2007, 2012).

The O and Lu–Hf isotope composition of detrital zircon provides further information on the nature and evolution of protoliths from which the zircons were sourced. This provides a window into crust and mantle processes important in formation of the original magmatic rocks from which the zircons crystallised, subsequent to their release during erosion and deposition (e.g. Valley, 2003; Kinney and Maas, 2003; Griffin et al., 2004; Kemp et al., 2006; Pietranik et al., 2008). O and Lu–Hf data can also provide further insight on possible source regions or further develop or refine stratigraphic correlations made solely, or largely, on the basis of detrital age data (e.g. Veevers et al., 2005; Howard et al., 2009).

In the North Australian Craton, many Paleo- to Mesoproterozoic sedimentary and metasedimentary rocks have detrital spectra characterised by a dominant ca. 1870 Ma peak with a small ca. 2500 Ma peak (e.g. Neumann et al., 2006; Cross and Crispe, 2007; Claoué-Long et al., 2008a, 2008b; Wade et al., 2008; Worden et al., 2008a; Carson, 2013). Marked exceptions are the 2020 Ma Woodcutters Supergroup, the oldest known succession in the Pine Creek Orogen, and the Ferdies Member of the Dead Bullock Formation in the Tanami region, which have detrital zircon spectra dominated by Neoarchean sources (Cross et al., 2005aCross and Crispe, 2007).

Although the Paleoproterozoic stratigraphy of parts of the Pine Creek Orogen are well characterised (e.g. the Central Domain, Worden et al., 2008b), this is not the case for the amphibolite facies Cahill Formation and Nourlangie Schist that dominate the Paleoproterozoic stratigraphy in the eastern-most part of the Pine Creek Orogen, the Nimbuwah Domain. The relative stratigraphic position and possible correlative units of the Cahill Formation and Nourlangie Schist are not well understood because these units (a) have no known volcanic rocks, tuffs, or dykes that can be used to directly determine ages of deposition, (b) are strongly deformed in tight to isoclinal folds and thrusts, (c) are only locally well exposed and, (d) relative to strata to the west, are more strongly metamorphosed to amphibolite facies conditions. Nonetheless several authors (Needham and Stuart-Smith, 1976, 1985; Needham et al., 1980; Needham, 1988; Ferenczi and Sweet, 2005) have suggested correlations with a number of stratigraphic units of distinct ages in different parts of the orogen. The Cahill Formation and Nourlangie Schist locally host large uranium deposits, including Ranger, Nabarlek and Koongarra, therefore correct stratigraphic correlation has important implications for uranium exploration strategies.

In this contribution we present U–Pb SHRIMP and LA-SF-ICPMS detrital zircon data for four samples of the Cahill Formation and six samples of the Nourlangie Schist from across a wide area of the Nimbuwah Domain in the Pine Creek Orogen. The data show strong consistency between samples and distinct detrital spectra from all other strata for which detrital zircon data are available from the Pine Creek Orogen and from the North Australian Craton in general. We also present zircon O (SIMS) isotope and Hf (LA-MC-ICPMS) isotope zircon data for two, geographically widely spaced, samples of the Cahill Formation and one sample of the Nourlangie Schist. These provide possible constraints on the origins and nature of the Archean to Paleoproterozoic source rocks for the sedimentary precursors to these units. The results have significant implications for stratigraphic correlations across the Pine Creek Orogen, and tectonic and crustal evolution models for the North Australian Craton.

2. Regional geology

The Pine Creek Orogen is exposed over 47,500 km^2 on the northern margin of the North Australian Craton (Fig. 1). It comprises thick successions of Paleoproterozoic clastic and carbonaceous sedimentary rocks and volcanics, unconformably overlying Neoarchaean granitic and gneissic basement (ca. 2670–2500 Ma). The margins of the Pine Creek Orogen are concealed by younger, unmetamorphosed strata, hence the total extent is unknown.

The Pine Creek Orogen is subdivided from west to east into three domains: the Litchfield, Central and Nimbuwah Domains (Fig. 1), based on distinct Paleoproterozoic tectonometamorphic histories and the nature and timing of the main phases of magmatism (e.g. Walpole et al., 1968; Needham et al., 1980, 1988; Ahmad et al., 1993; Worden et al., 2008b). The boundaries between the terranes also broadly correlate with Neoarchean basement highs (Lewis et al., 1995).

Rifting of Neoarchean basement at ca. 2020 Ma (Worden et al., 2008a, 2008b) is thought to have led to the deposition of clastic, carbonate, and carbonaceous sedimentary and volcanic rocks of the Woodcutters Supergroup in a shallow marine basin across the Central and Nimbuwah Domains (e.g. Stuart-Smith et al., 1984). These rocks comprise iron-rich sedimentary rocks, conglomerate, sandstone, quartzite, carbonate, pyritic and dolomitic shale, siltstone, tuff basaltic to andesitic lava and agglomerate.

In the Nimbuwah Domain, the Woodcutters Supergroup and equivalents were overlain by the sedimentary precursors to the Cahill Formation, which now comprises mica schist, carbonaceous schist, calc-silicate rock, para-amphibolite, and quartzite, grading upwards into quartzofeldspathic mica schist of the Nourlangie Schist (Needham, 1988). These were intruded at depth by mainly dioritic to granodioritic magmas of the Nimbuwah Complex at ca. 1867–1857 Ma (Page et al., 1980; Worden et al., 2008b; Carson et al., 20103) during amphibolite-facies metamorphism (ca. 1865–1855 Ma, Ferguson, 1980; Kositcin et al., 2013Hollis and Glass, 2012). Deep crustal Nimbuwah magmatism coincided with sedimentation and volcanism (Cosmo Supergroup and equivalents) in the Central Domain and the Litchfield Domain at ca. 1863 Ma (Fig. 2, Worden et al., 2006a; Worden et al., 2008a; Worden et al., 2008b; Worden et al., 2006a, 2008a,b; Beyer et al., 2013; Kositcin et al., 2013). The Cosmo Supergroup comprises iron-rich sedimentary rocks, tuff, carbonate rocks, shale, greywacke and siltstone of the South Alligator Group deposited in a low-energy environment, overlain by a thick succession of deeper water turbiditic shale and siltstone and interbedded felsic volcanic rocks and tuff of the Finniss River Group (Fig. 2; Needham et al., 1988).

Sedimentation in the Central and Litchfield Domains was followed by extensional high-temperature, low-pressure metamorphism (ca. 1855 Ma, Carson et al., 2008) and associated felsic and back-arc basin mafic magmatism in the Litchfield Domain (ca. 1862–1850 Ma, Glass, 2007, 2011; Worden et al., 2008a). At or after this time, greenschist-facies metamorphism and north-striking upright folding and shearing occurred at upper crustal levels in the Central Domain. Late to post-orogenic, I-type Cullen Supersuite (mainly in the period 1835–1820 Ma, Stuart-Smith et al., 1993;