Zircon provenance in the basal part of the northwestern Officer Basin, Western Australia

by L. Bagas[1]

Abstract

The Neoproterozoic (c. 900 Ma) Tarcunyah Group forms the base of the Centralian Superbasin in the northwestern Officer Basin, immediately west of the Vines–Southwest–McKay fault system in the central part of Western Australia. The group consists of metasedimentary units that unconformably overlie the southeastern part of the Archaean Pilbara Craton and the eastern part of the Bangemall Supergroup. Sandstone at the base of the group has age populations derived from detrital zircons that are comparable with principal sources from the northern part of the Palaeoproterozoic Gascoyne Complex, Mesoproterozoic Bangemall Supergroup, and Mesoproterozoic to Neoproterozoic Pinjarra Orogen. These units are located about 800 km to the west of the Tarcunyah Group, which is consistent with a predominance of east- to northeast-directed palaeocurrent data from trough cross-bedding in the basal part of the group. This study shows that cumulative-probability plots for zircons can be powerful tools in identifying the source regions for sedimentary rocks.

KEYWORDS: Neoproterozoic, Officer Basin, Tarcunyah Group, zircon dating, statistical analysis.

Introduction

Modern studies of sedimentary provenance rely heavily on U–Pb ages of detrital zircon grains (e.g. Halilovic et al., in press). Zircons are durable in environments of weathering, erosion, and sedimentation, are largely unaffected by low- to moderate-temperature (greenschist to amphibolite facies) metamorphism, and can survive many cycles of erosion and sedimentation during transport over distances of many hundreds of kilometres. Therefore, the age and relative abundance of different populations of detrital zircons in sedimentary rocks should provide maximum age constraints for their deposition and reflect the age and the degree of exposure of the source region.

The Tarcunyah Group lies in the northwestern part of the Paterson Orogen, east of the Pilbara Craton (Figs 1 and 2). Its precise age has been controversial. Blockley and de la Hunty (1975) assigned units in the group to the former Mesoproterozoic ‘Bangemall Group’, which has been elevated by Martin et al. (1999) to supergroup status. Williams et al. (1976) included the Tarcunyah Group in the former ‘Yeneena Group’, and suggested that it was Mesoproterozoic in age and unconformably overlain by rocks assigned to the ‘Bangemall Group’. These unconformably overlying rocks were subsequently found to include Neoproterozoic tillite units and were included in the former ‘Savory Group’ (Williams, 1992) and, subsequently, in the Officer Basin (Bagas et al., 1995, 1999). Chin and de Laeter (1981) reported a Rb–Sr isochron age of 1132 ± 21 Ma for pegmatite veins cutting foliation in the Rudall Complex. They proposed that the pegmatite was emplaced after the waning stages of an early deformation. Consequent recrystallization during deformation of the ‘Yeneena Group’, which then included the Tarcunyah Group, may have been responsible for resetting the Rb–Sr isotopic system, giving the younger age. They alternatively proposed that the pegmatite could have been generated during the early part of this later deformation event at about 1132 ± 21 Ma. Williams (1992, p. 89) suggested an age of between c. 1200 and 1000 Ma for the Tarcunyah Group (then included in the ‘Yeneena Group’), based on assumptions at that time that earlier deformation in the Rudall Complex was at c. 1300 Ma (Clark, 1991) and that the former ‘Savory Group’ was c. 900 Ma, and younger than the Tarcunyah Group.

[1] This contribution forms part of a Masters of Economic Geology thesis project at the Centre for Ore Deposit Research (CODES, Special Research Centre), University of Tasmania, Hobart, Tasmania 7001, Australia.

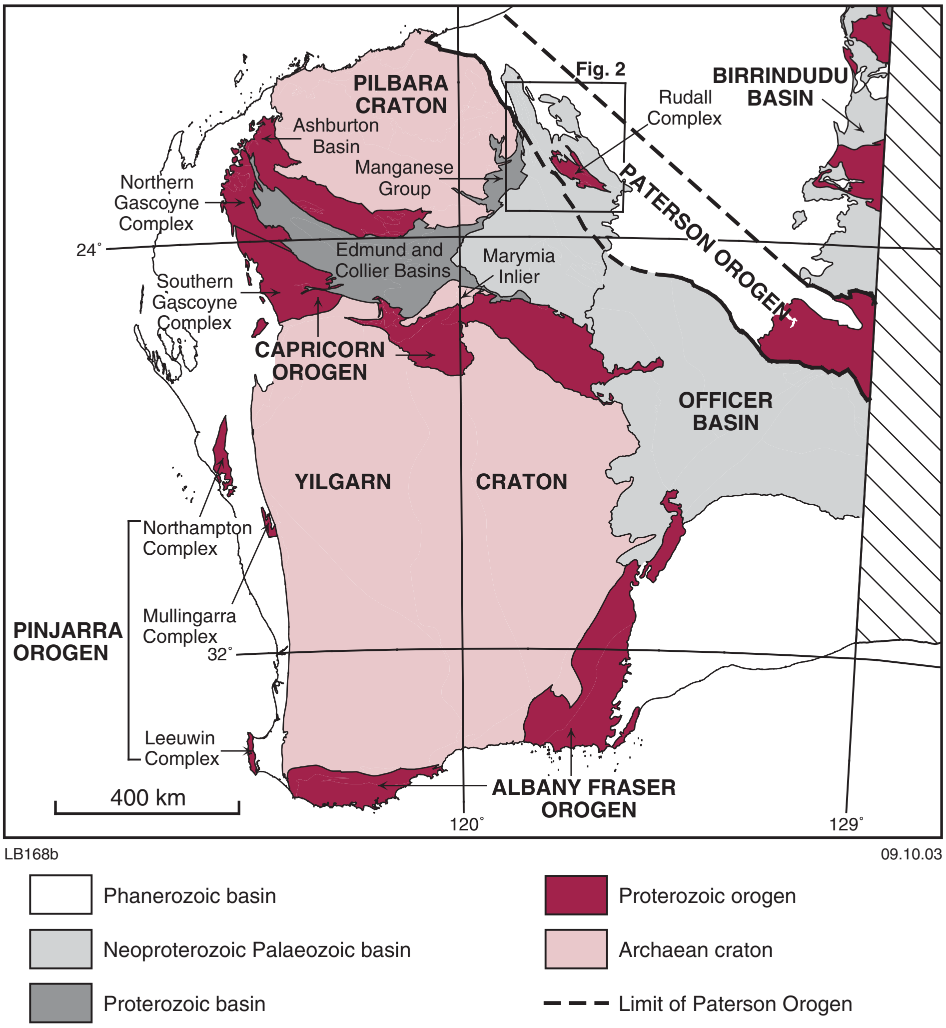

Figure 1. Main tectonic units

Bagas and Smithies (1998) suggested that the earlier deformation affecting the Rudall Complex had a minimum age of c. 1760 Ma based on the ages of cross-cutting granitic rocks, and Bagas et al. (1995, 1999) showed that the basal part of the former 'Savory Group' was a correlative of the Tarcunyah Group.

The wide range of suggested dates and proposed correlations not only reflected uncertainties caused by the lack of adequate dating, but also pointed to more fundamental problems in the understanding of the stratigraphic relationships between units in the Paterson Orogen. The results of recently completed mapping in the region, together with biostratigraphic evidence, have led to a better understanding of the orogen. Bagas et al. (1995) concluded that the Tarcunyah Group is equivalent to Supersequence 1 of the Centralian Superbasin (Walter et al., 1995) and part of the northwestern Officer Basin. They also proposed an age of c. 820 Ma for the group based on correlations with the Adelaide Geosyncline, although the base of the Centralian Superbasin is poorly constrained between 1050 and 800 Ma (Scrimgeour et al., 1999). This correlation was strengthened by detailed seismic interpretation (Perincek, 1996), palynology (Grey and Stevens, 1997), and the presence of the c. 800 Ma *Acaciella australica* and *Baicalia burra* stromatolite assemblages (Stevens and Grey, 1997) in carbonate units in both the Tarcunyah and Sunbeam Groups (Fig. 3).

This study examines new constraints on the age and provenance of the 500 m-thick Neoproterozoic Gunanya Sandstone in the basal part of the Tarcunyah Group using palaeocurrent data and sensitive high-resolution ion microprobe (SHRIMP) U–Pb detrital-zircon ages. In the fluvial to deltaic Gunanya Sandstone (Hickman and Bagas, 1998), palaeocurrent data from trough cross-bedding (Fig. 2) indicate a source region to the west and southwest (Fig. 2), and the SHRIMP U–Pb detrital-zircon age distribution data presented here reveal that the provenance contains Palaeoproterozoic to late Mesoproterozoic rocks. The areas containing rocks of

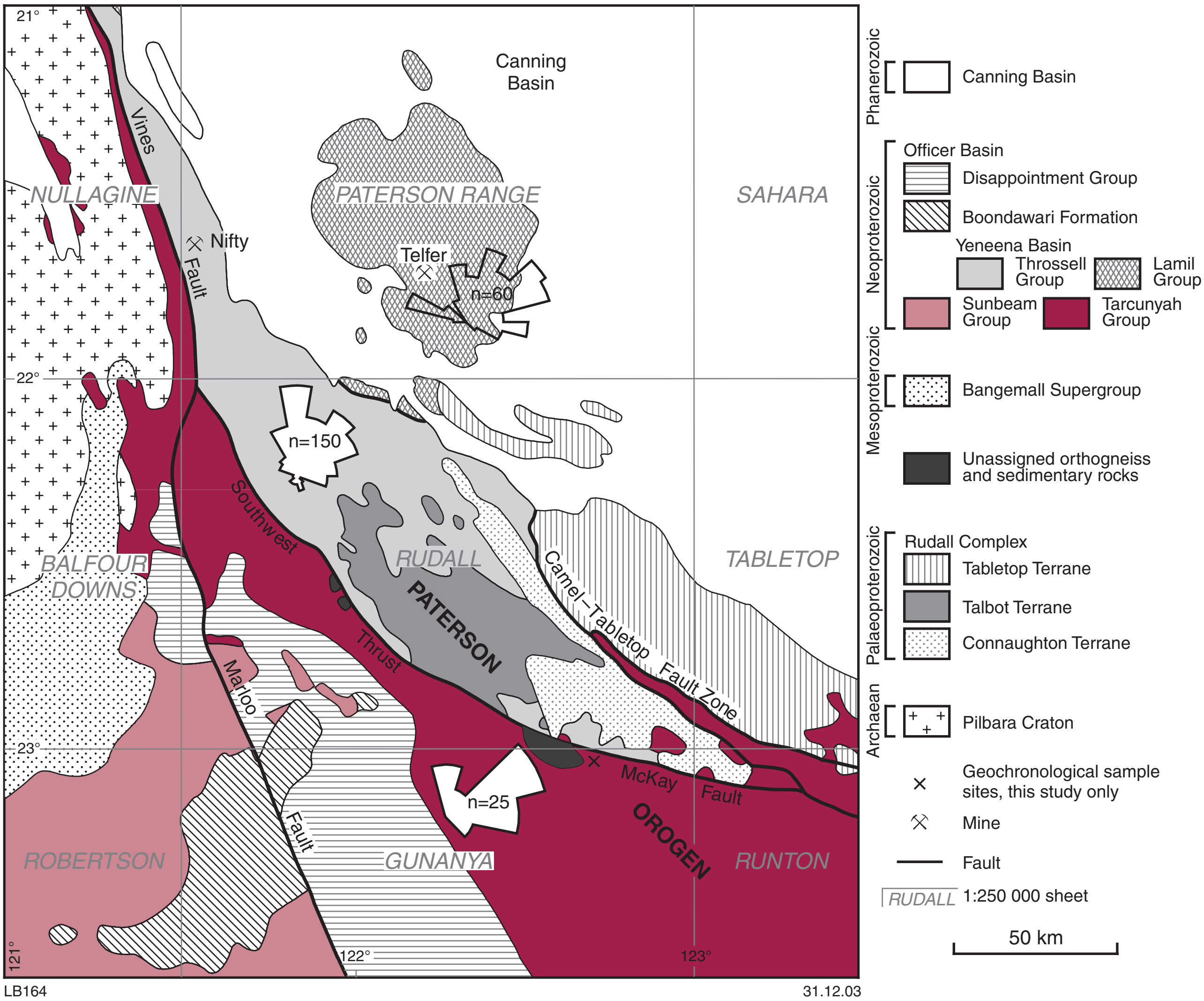

Figure 2. Regional geological setting of the northwestern Paterson Orogen. Rose diagrams show palaeocurrent directions from the Tarcunyah, Throssell, and Lamil Groups

this age are those of the orogens around the Archaean Pilbara and Yilgarn Cratons. These orogens are briefly described below and their relative cumulative zircon age profiles are compared with the detrital zircon age profile for the Gunanya Sandstone (Fig. 4).

Relative cumulative-probability plots are commonly used to visually represent detrital zircon age data. This statistical technique is complementary to concordia plots and is normally used to visually assess the similarities or differences between samples and potential source regions. The vertical peaks in the graphs represent mean values, and the horizontal spread for each peak relates to the standard deviation and reflects the accuracy of the data. The height of each peak is relative and has no fixed scale. The probability of the sample containing zircons of any particular age is determined by calculating the area under each peak and dividing by the area under the whole curve (which is equal to 1).

This study highlights the potential value in comparing detrital-zircon age populations in order to fingerprint otherwise indistinct sedimentary rocks within structurally complex regions. When accompanied with palaeocurrent data for a formation, zircon-age distribution plots can be powerful tools in identifying possible provenances for the formation.

Northwestern Paterson Orogen and Officer Basin

The northwestern-most part of the Paterson Orogen consists of the Palaeoproterozoic Rudall Complex basement, unconformably overlain by or faulted against the Neoproterozoic Tarcunyah, Throssell, and Lamil Groups (Fig. 2; Bagas et al., 1995; Bagas, in press). These units were deformed during the c. 550 Ma Paterson Orogeny, and for this reason are included in the Paterson Orogen. The other Neoproterozoic units

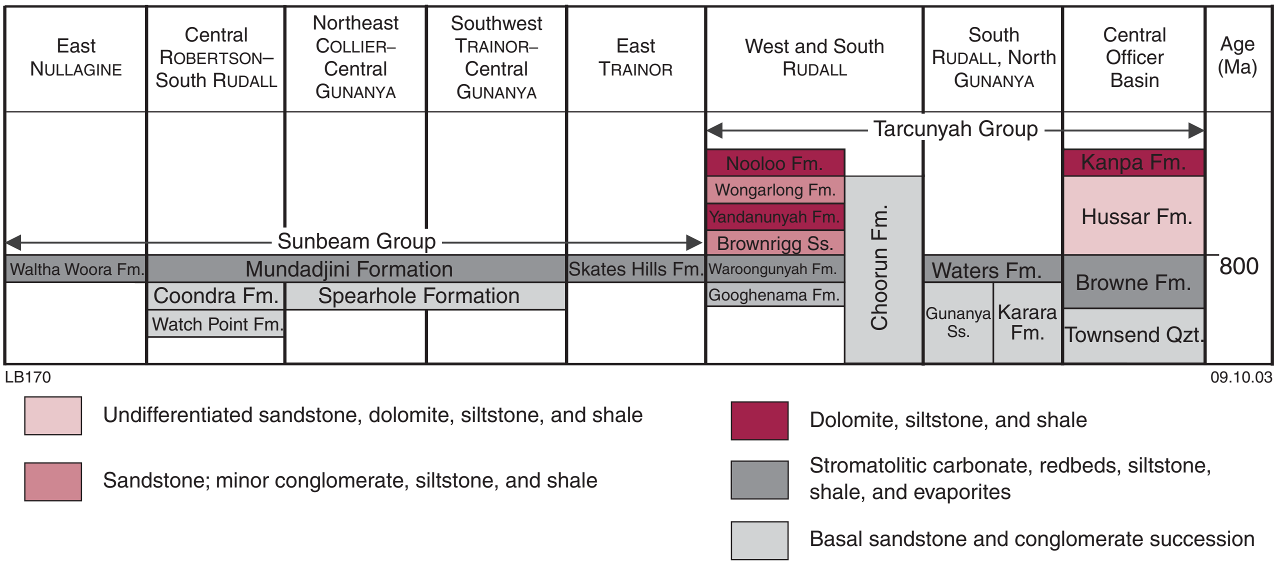

Figure 3. Generalized stratigraphic correlations between units of Supersequence 1 in the northwestern Officer Basin. Capitalized names refer to standard 1:250 000 map sheets (modified from Bagas et al., 1999; see also Hocking and Jones, 2002)

shown in Figure 3, which were not significantly affected by the orogeny, are not included in the orogen. The Tarcunyah Group, which is also included in the northwestern Officer Basin (Bagas et al., 1995, 1999), unconformably overlies the Archaean Pilbara Craton and Mesoproterozoic Bangemall Supergroup (Williams and Trendall, 1998), and is in faulted contact with the Throssell Group along the Vines–Southwest–McKay fault system (Fig. 2).

The Officer Basin (Fig. 1) is one of a number of intracratonic basins interpreted by Walter et al. (1995) as remnants of the once continuous Centralian Superbasin in central Australia. These basins developed after amalgamation of several segments of Precambrian crust to form the Mesoproterozoic supercontinent, named Rodinia by McMenamin and McMenamin (1990), between 1300 and 1100 Ma (Myers et al., 1996).

Basal part of the Tarcunyah Group

To better constrain the maximum age for the basal part of the Tarcunyah Group (Fig. 3) and define possible source regions, 107 detrital zircon grains from three samples of the fluvial to deltaic Gunanya Sandstone (Fig. 3) were analysed using SHRIMP to provide U–Pb ages (Nelson, in prep.). The sandstone is 500 m thick and consists of medium- to coarse-grained arkosic sandstone with interbeds of coarse-grained, pebbly feldspathic sandstone that are common in the uppermost 100 m of the unit. The sandstone exhibits abundant trough cross-bedding, which provide palaeocurrent data (Fig. 2), and indicate that the source region was to the west or southwest (Hickman and Bagas, 1998).

The relative cumulative-probability distribution diagram for zircons from the lower part of the Tarcunyah Group (Fig. 4a) shows that the maximum age of the group is less than 1000 Ma, and assists in fingerprinting the possible source regions for the group. There are two major zircon populations from the group at c. 1780 and 1680 Ma, with a significant proportion between 1310 and 1000 Ma, and a less significant proportion between 1670 and 1310 Ma. The remaining 4% of detrital zircons range from lowermost Palaeoproterozoic to Archaean in age. The presence of both Proterozoic- and Archaean-aged zircons in these samples indicates multiple provenances, a single complex provenance, or multi-cyclic zircons. The primary provenances for these samples are regions containing c. 1800 to 1000 Ma zircons (Fig. 4a).

Geochronological data have been compiled from the literature for the Palaeoproterozoic to Mesoproterozoic terranes around the Pilbara and Yilgarn Cratons that may have contributed detritus to the Tarcunyah Group. This was done because, from the discussion above, the source region of the lower part of the Tarcunyah Group contains Proterozoic rocks and the group contains palaeocurrents that indicate a provenance to the west or southwest. The data are presented as relative cumulative-probability distribution diagrams to provide visual fingerprints (Fig. 4)

Possible source regions for the basal part of the Tarcunyah Group

Regions containing Palaeoproterozoic and Mesoproterozoic rocks that are possible sources for the Neoproterozoic sedimentation in the basal part of the Tarcunyah Group are the orogens around the West Australian Craton to the west and south of the Paterson Orogen (Fig. 1). These orogens are considered sufficiently distinct to be identified as discrete source regions.

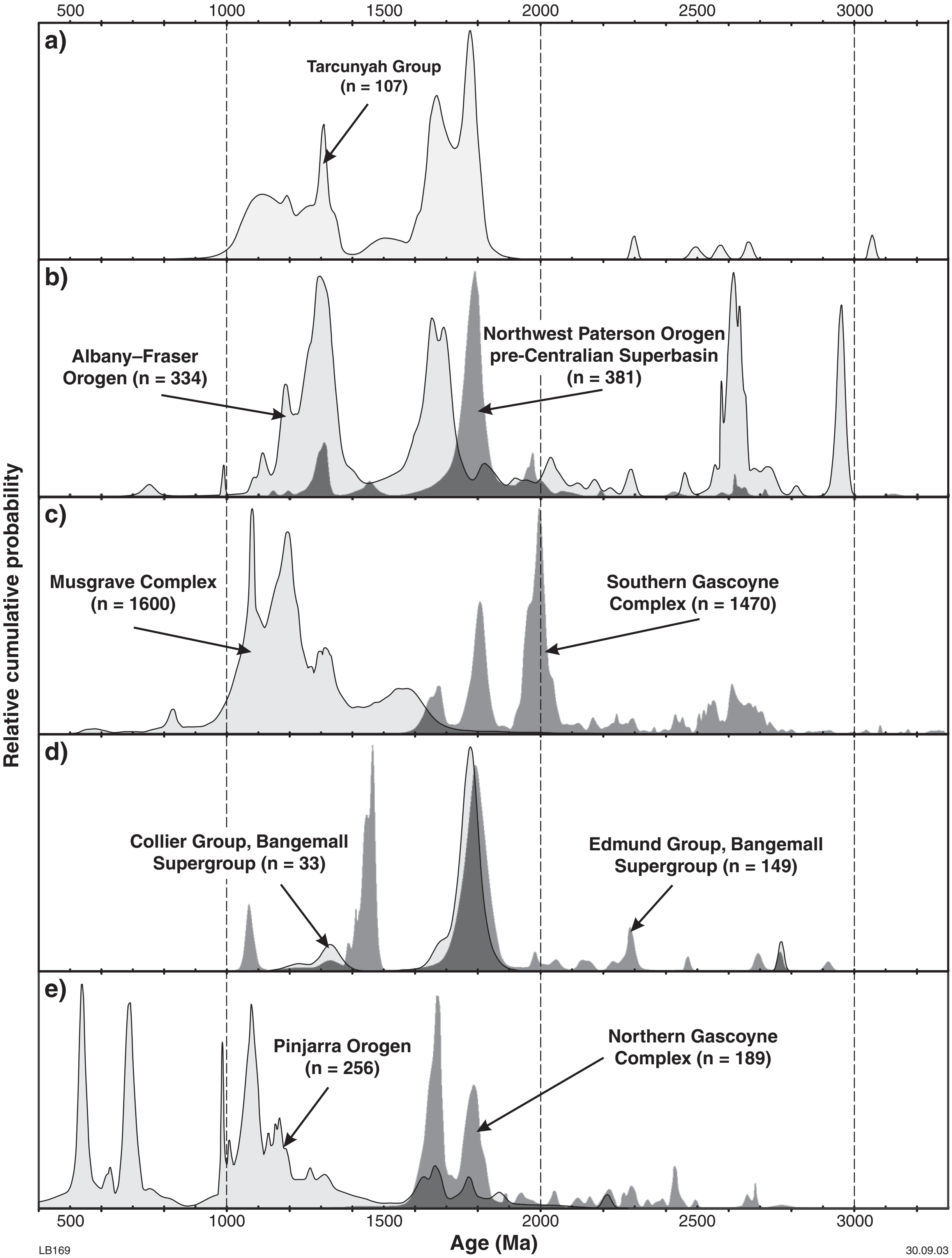

Figure 4. Relative cumulative-probability diagrams of U–Pb SHRIMP ages of zircons from a) the Gunanya Sandstone in the lower part of the Tarcunyah Group (Nelson, in prep.); and potential source areas for these zircons:
b) Albany–Fraser Orogen (Nelson, 1995a, 1996) and northwestern Paterson Orogen (Nelson, 1995a, 1996);
c) Musgrave Complex (Camacho et al., 2002) and southern Gascoyne Complex (Nelson, 1998, 1999, 2000, 2001, 2002);
d) Collier and Edmund Groups of the Bangemall Supergroup (Nelson, 2002; Wingate, 2002); and
e) Pinjarra Orogen (Bruguier et al., 1999; Nelson, 1995b, 1996, 1999) and northern Gascoyne Complex (Nelson, 2002)

The West Australian Craton comprises the Archaean Pilbara and Yilgarn Cratons sutured along the intervening Palaeoproterozoic Capricorn Orogen (Myers, 1990a). It is bound to the north by the Phanerozoic Northern Carnarvon Basin, to the northeast by the Paterson Orogen, to the south and southeast by the Albany–Fraser Orogen, and to the west by the Pinjarra Orogen (Fig. 1).

The Palaeoproterozoic rocks of the Capricorn Orogen comprise plutonic and medium- to high-grade metamorphic rocks of the Gascoyne Complex and Ashburton, Blair, Yerrida, Bryah, Padbury, and Earaheedy Basins, together with deformed Archaean to Palaeoproterozoic rocks at the margins of the Pilbara and Yilgarn Cratons (Cawood and Tyler, in press). Deformation, metamorphism, and associated magmatism took place in the orogen during the c. 2200 Ma Ophthalmian Orogeny (at the northern margin), the 2000–1960 Ma Glenburgh Orogeny (at the southern margin), the 1830–1780 Ma Capricorn Orogeny, and a more localized unnamed event between c. 1670–1620 Ma (Cawood and Tyler, in press). In this part of Western Australia, 1670–1620 Ma felsic magmatism (Pearson et al., 1996; Nelson, 1998, 2002; Cawood and Tyler, in press) is only known from the northern part of the Gascoyne Complex; the nearest known granitic rocks of this age elsewhere are found in the Arunta Orogen of central Australia (e.g. Bagas, in press).

The Mesoproterozoic Edmund and Collier Groups (Bangemall Supergroup) unconformably overlie Archaean and Palaeoproterozoic rocks in the central part of the orogen (Fig. 1), and were deformed during the poorly defined Neoproterozoic Edmundian Orogeny (Martin and Thorne, 2001). The Edmund and Collier Groups are intruded by extensive dolerite sills emplaced during at least two distinct magmatic events, with SHRIMP U–Pb zircon and baddeleyite ages of c. 1465 and c. 1070 Ma (Wingate, 2002).

The Paterson Orogen is a 2000 km-long arcuate belt of folded and metamorphosed sedimentary and igneous rocks that range in age from Palaeoproterozoic to Neoproterozoic and have a linked tectonic history (Williams and Myers, 1990; Tyler et al., 1998). The orogen is exposed in the northwest of Western Australia along the eastern margin of the Palaeoproterozoic West Australian Craton (Myers et al., 1996), and 400 km to the southeast in the Mesoproterozoic Musgrave Complex (Williams and Myers, 1990; Camacho and Fanning, 1995; Camacho et al., 2002) of central Australia (Fig. 1).

The Proterozoic Albany–Fraser Orogen (Myers, 1990b) is faulted against the southern and southeastern margins of the West Australian Craton, and is truncated by the Pinjarra and Paterson Orogens (Fig. 1). The Albany–Fraser Orogen is characterized by polyphase deformation, and consists of reworked Archaean to Palaeoproterozoic high-grade gneiss with c. 1300 Ma layered-gabbroic intrusions, and intensely deformed high-grade orthogneiss and paragneiss intruded by sheets of c. 1300 Ma granite (Myers, 1990b; Nelson, 1995a; Fitzsimons, 2003). Rocks representing four major magmatic events at c. 2630, 1700–1600, c. 1300, and 1160 Ma have been identified in the orogen (Clarke et al., 2000). The orogen also records two tectonic events at c. 1350–1260 (Stage I of Clarke et al., 2000) and c. 1210–1140 Ma (Stage II of Clarke et al., 2000).

The late Neoproterozoic Pinjarra Orogen (Myers, 1990b) truncates the Archaean Pilbara and Yilgarn Cratons, the Palaeoproterozoic Capricorn Orogen, and the Palaeoproterozoic to Mesoproterozoic Albany–Fraser Orogen. Its northern extent is concealed by Phanerozoic sedimentary rocks of the Carnarvon Basin (Fig. 1). It is part of an orogenic belt that can be traced to East Antarctica (Fitzsimons, 2000), and probably relates to a Neoproterozoic suture zone between India and Australia (Fitzsimons, 2000, 2001). The orogen includes isolated and relatively small gneissic basement inliers of the Northampton, Mullingarra, and Leeuwin Complexes, which are unconformably overlain by Phanerozoic sedimentary rocks of the Carnarvon and Perth Basins (Fig. 1). The Northampton and Mullingarra Complexes consist of granulite-facies paragneiss and minor mafic gneiss, pegmatite, granite, and migmatite or their equivalents (Myers, 1990b). The Leeuwin Complex consists of intensely deformed orthogneiss, anorthosite, and minor metabasite, metamorphosed to granulite facies.

Paragneiss from the Northampton Complex has detrital zircons ranging from 1059 ± 32 to 2043 ± 136 Ma, with significant populations at c. 1000–1300 Ma and c. 1600–1700 Ma (Bruguier et al., 1999), and paragneiss from the Mullingarra Complex has detrital zircons with peaks at c. 1200, 1300–1450, and 1600–1800 Ma (Cobb et al., 2001). Metamorphic zircons in gneisses from the Northampton and Mullingarra complexes have SHRIMP U–Pb ages of 1079 ± 3 and 1058 ± 83 Ma, respectively (Bruguier et al., 1999; Cobb et al., 2001). Porphyritic granites from the Northampton Complex have SHRIMP U–Pb zircon crystallization ages of 1068 ± 13 Ma, whereas younger pegmatites have SHRIMP U–Pb zircon crystallization ages of 989 ± 2 Ma (Bruguier et al., 1999).

Zircons in felsic gneiss from the Leeuwin Complex have SHRIMP U–Pb dates of between 779 and 524 Ma (Nelson, 1995b). Orthogneiss in the complex has zircon crystallization ages of 1091 ± 8 and 1091 ± 17 Ma (Nelson, 1999), similar to those in the Northampton Complex.

Possible assignments of zircon populations from the basal part of the Tarcunyah Group

The minor zircon population from the Tarcunyah Group in the range c. 2700–2600 Ma (Fig. 4a) is similar to possible sources from the Yilgarn Craton (not shown in Fig. 4), but detrital zircons with a c. 2500 Ma age are rare in Western Australia and known only in the Yelma Formation of the Earaheedy Basin (Halilovic et al., in press; not shown in Fig. 4), northern Gascoyne Complex (Nelson, 2002; Fig. 4e), and Albany–Fraser Orogen (Nelson, 1995a, 1996; Fig. 4b). The Yelma Formation is not considered a possible single source for the lower Tarcunyah Group because the youngest zircons in the formation are c. 1800 Ma (Halilovic et al., in press).

The possible provenance of detrital zircons with a c. 2300 Ma age in the Tarcunyah Group are limited in Western Australia to metasedimentary rocks in the southern part of the Gascoyne Complex (Kinny et al., in press; Fig. 4c) and in the Earaheedy Basin (Halilovic et al., in press) of the Capricorn Orogen. As mentioned above, the youngest detrital zircon dated from the Earaheedy Basin is c. 1800 Ma (Halilovic et al., in press), making it an unlikely single provenance for the Tarcunyah Group.

The major age populations for zircons from the Tarcunyah Group at 1780 and 1670 Ma best match those from the northern Gascoyne Complex (cf. Figs 4a and 4e). The c. 1780 Ma detrital zircons may have been sourced from granitic rocks of the southern Gascoyne Complex. However, zircons from the southern Gascoyne Complex show a unique and prominent peak at c. 2000 Ma (Nelson, 1998, 1999, 2000, 2001, 2002; Occhipinti et al., 2001) that is not present in the detrital zircon populations from the Tarcunyah Group (cf. Figs 4a and 4c). Alternatively, the c. 1780 Ma detrital zircons may have come from the Rudall Complex (Fig. 4b) in the northwest Paterson Orogen (Bagas, in press). Similar aged detrital zircons are known in the Collier and Edmund Groups (Fig. 4d) of the Bangemall Supergroup (Nelson, 2002), but no detrital zircons with a c. 1670 Ma age have been found in these two groups. Significant zircon populations with an age c. 1670 Ma are found only in the Albany–Fraser Orogen (Nelson, 1995a, 1996; Fig. 4b) and northern Gascoyne Complex (Fig. 4e), and a minor population is found in the southern Gascoyne Complex (Fig. 4c), but the Albany–Fraser Orogen lacks the c. 1780 Ma zircon population.

Dolerite sills that intrude the Edmund Group have magmatic zircons with SHRIMP U–Pb zircon ages of c. 1465 and c. 1070 Ma (Wingate, 2002; Fig. 4d). The Collier Group also has dolerite sills that are yet to be dated and probably contain similar populations of magmatic zircons. Even though detrital zircons with c. 1465 Ma age are relatively rare in the Gunanya Sandstone, both the c. 1465 and c. 1070 Ma ages are represented in the formation, suggesting that the Edmund Group (and probably the Collier Group) could be a source for at least some of the detrital zircons in the basal part of the Tarcunyah Group. The younger age range of detrital zircons in the lower Tarcunyah Group, between 1300 and 1050 Ma, coincides with zircons from the poorly exposed Pinjarra Orogen (cf. Figs 4a and 4e), which extends north beneath the Phanerozoic Perth and Carnarvon Basins. This age range also partly correlates with zircon ages from the Bangemall Supergroup (cf. Figs 4a and 4d). Therefore, the most likely source of these younger zircons is either buried under Phanerozoic sedimentary units immediately west of the northern Gascoyne Complex, or lies to the east in the Bangemall Supergroup. The Musgrave Complex and Albany–Fraser Orogen have similar age distribution profiles to the Pinjarra Orogen (cf. Figs 4b, 4c, and 4e), but the Musgrave Complex has a significant peak at c. 1200 Ma that is not developed in either the Pinjarra Orogen or the basal part of the Tarcunyah Group. Furthermore, both the Musgrave Complex and Albany–Fraser Orogen, which are now exposed to the southeast and south of the Tarcunyah Group respectively, seem to be unlikely provenances for these younger zircons because the palaeocurrent data indicate a westerly provenance.

Discussion and conclusion

From these observations, it is most likely that the northern Gascoyne Complex is the source for the Palaeoproterozoic detrital zircons in the lower Tarcunyah Group. The paucity of detrital zircons with Archaean ages implies that the Tarcunyah Group was not derived by erosion of the Pilbara and Yilgarn Cratons. This suggests that Proterozoic sediments covered the Archaean cratons at the time, and the few Archaean zircons in the lower Tarcunyah Group samples were probably recycled through Palaeoproterozoic sedimentary rocks.

If a combination of the northern Gascoyne Complex, Bangemall Supergroup, and Pinjarra Orogen were the source of sedimentary rocks in the basal part of the Tarcunyah Group, these units must have been exposed at c. 1000 Ma. Furthermore, Figure 4 shows that the Pinjarra Orogen and lower Tarcunyah Group share similar zircon profiles until c. 900 Ma, suggesting that if the provenance included the Pinjarra Orogen (which has younger zircon populations not found in the lower Tarcunyah Group), then the minimum age of this part of the group is c. 900 Ma.

The ‘Gascoyne biotite domain’ of Libby et al. (1999), which coincides with the northern edge of the Yilgarn Craton and southern edge of the southern Gascoyne Complex, is an area that records biotite Rb–Sr ages of c. 800 Ma. One interpretation of this age is that it records cooling after extensive and rapid uplift of rocks previously buried at depths greater than 10 km (assuming a modern geothermal gradient of about 30°C/km; Allen and Allen, 1990). At this depth the ambient temperature would have exceeded the Rb–Sr blocking temperature of biotite, which Cliff (1985) places at 300 ± 50°C. However, Figure 4 shows that the southern Gascoyne Complex did not contribute to the filling of the basal part of the northwestern Officer Basin, 800 km east of the complex. This suggests that the region covering the northern Gascoyne Complex and Pinjarra Orogen must have been exposed or uplifted earlier than the southern Gascoyne Complex (i.e. between 800 and 1000 Ma) if it was the provenance for the sedimentary rocks in the basal part of the Tarcunyah Group.

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