Early Cambrian metamorphic zircon in the northern Pinjarra Orogen: Implications for the structure of the West Australian Craton margin

Vanessa Markwitz1, Christopher L. Kirkland2,3, and Noreen J. Evans3
1SCHOOL OF EARTH AND ENVIRONMENT, UNIVERSITY OF WESTERN AUSTRALIA, CRAWLEY, WA 6009, AUSTRALIA
2CENTRE FOR EXPLORATION TARGETING–CURTIN NODE, CURTIN UNIVERSITY, WA 6102, AUSTRALIA
3JOHN DE LAETER CENTRE, TIGER, DEPARTMENT OF APPLIED GEOLOGY, CURTIN UNIVERSITY, WA 6045, AUSTRALIA

ABSTRACT

The Mesoproterozoic Pinjarra Orogen formed when present-day India and Australia amalgamated to form Gondwana. Outcrop of the Pinjarra Orogen is limited to the Leeuwin, Mullingarra, and Northampton Complexes, which are exposed as basement inliers in the Paleozoic to Mesozoic Perth and Southern Carnarvon Basins. We used U-Pb zircon geochronology to date Pinjarra Orogen basement rocks from the Wendy-1 drill core, which intersects the Paleozoic Tumblagooda Sandstone and its underlying paragneiss basement east of the Northampton Complex. Our results suggest an Early Cambrian (526.3 ± 12 Ma) metamorphic age for this basement domain, which is uncharacteristic for the nearby Northampton Complex, but correlates well with the much more distant Leeuwin Complex. Detrital ages between 1120 Ma, 1210 Ma, and 1530 Ma dominate the zircon cargo of this basement sample, which may have been sourced from the Albany-Fraser Orogen to the south and east. An Archean detrital zircon component is also identified from one concordant analysis, and from radiogenic Pb-loss modeling. These results have important implications for the crustal architecture of the western margin of the West Australian craton and for correlating domains of the Mesoproterozoic Pinjarra Orogen in reconstructions of Gondwana. Our data suggest that the basement below the Perth Basin is more segmented than previously assumed. Evidence for a common Indian-Australian tectonometamorphic event in the Late Neoproterozoic to Early Cambrian is not limited to the Leeuwin Complex in the southwest corner of present-day Western Australia but also now identified in basement rocks in the Northampton area. These results confirm the in situ formation of Pinjarra Orogen basement complexes in the Mesoproterozoic with a metamorphic reactivation in the Neoproterozoic–Cambrian during the collision with present-day India.

INTRODUCTION

East Gondwana included the present-day continents of Australia, Antarctica, and Greater India. The Pinjarra Orogen is partly exposed on the west coast of Western Australia and defines an orogenic belt that formed during the assembly of Gondwana. Due to limited basement exposure, the spatial extent of the Pinjarra Orogen and its subdomains is unclear (Hall et al., 2013, and references therein). It contains three basement inliers, the Leeuwin, Mullingarra, and Northampton Complexes, which are overlain by Phanerozoic sediments of the Perth Basin and Paleozoic strata of the Southern Carnarvon Basin (Fig. 1; Myers, 1990). Previous geochronological studies in basement rocks of the Pinjarra Orogen suggest a prolonged and complex tectonic history, including ca. 1090–1060 Ma metamorphism during the Mesoproterozoic Pinjarra Orogeny, when Gondwana amalgamated (Bruguier et al., 1999; Fitzsimons, 2003; Collins and Pisarevsky, 2005; Boger, 2011; Ksienzyk et al., 2012). The latest stage of East Gondwana amalgamation occurred during the collision between India–Africa and Australia–Antarctica during the Neoproterozoic–Cambrian (750–520 Ma; Kuunga Orogeny; Meert and Van der Voo, 1997; Meert and Boger, 2011), when some basement rocks experienced metamorphic reworking. The Kuunga metamorphic event has so far only been recognized in the Leeuwin Complex in the extreme southwest of Australia (Collins, 2003). Tectonic interpretations of the Northampton and Mullingarra Complexes vary from autochthonous collisional models where the basement inliers experienced in situ metamorphism in the Mesoproterozoic (Bruguier et al., 1999; Wilde, 1999; Boger, 2011; Ksienzyk et al., 2012) to allochthonous models in which Mesoproterozoic crustal fragments were transposed to their present position during the Neoproterozoic collision (Fitzsimons, 2003). Previous provenance studies of metasediments exposed in the Northampton Complex suggest that detrital zircon grains were mainly derived from the Albany-Fraser Orogen in Western Australia, and additionally from the Mawson Continent and the northern West Australian Craton, particularly the Capricorn Orogen (Bruguier et al., 1999; Ksienzyk et al., 2012).

The comparison between new U-Pb zircon ages from the Wendy-1 drill core with those previously obtained from the Northampton Complex allows us to reframe our understanding of the spatial extent of the Pinjarra Orogen and to provide constraints on the timing of metamorphism in the region. Our data suggest that a previously unidentified basement domain, which experienced Early Cambrian metamorphism at a similar time to the Leeuwin Complex, exists in close proximity to the Northampton Complex. This implies that the Neoproterozoic–Cambrian Kuunga Orogeny...
affected a much larger part of the West Australian Craton margin than previously thought.

REGIONAL GEOLOGY AND GEOCHRONOLOGY

The N-S–oriented Proterozoic Pinjarra Orogen extends for over 1000 km along the western margin of the West Australian Craton (Fig. 1). It comprises three fault-bounded basement inliers within Paleozoic basins, as well as low-grade metasedimentary rocks located at the eastern margin of the orogen. Most of the Pinjarra Orogen is buried beneath sediments of the Perth Basin and Southern Carnarvon Basin.

Significant basement faults separate individual basement inliers of the Pinjarra Orogen, including the prominent N-S–trending Darling fault to the east, the Dunsborough fault to the east of the Leeuwin Complex, and the Urella fault, which cuts across Northern Perth Basin sediments west of the Mullingarra Complex (Fig. 1). Due to the proximity of surface outcrops, the Northampton Complex was assumed to extend below the early Paleozoic Tumblagooda Sandstone east of Northampton (Hocking, 1991; Trewin and Fallick, 2000). The Northampton Complex (Fig. 1; locality 4) is bounded by the Hardabut and Geraldton faults in the west and the Yandi fault in the east and experienced multiple thermal-tectonic events (D1–D5; after Byrne, 1997). D1 has been related to NW-SE shortening and the granite intrusion at 1083 Ma; D2 to activation of regional fault systems such as the Hardabut fault during NE-SW crustal shortening, which has been related to the formation of Rodinia. D3 produced E-W–trending thrusts as a result of N-S shortening (Yandi fault); during the D4 event, the complex was intruded by dolerite dikes that are probably related to the breakup of Rodinia; finally, D5 produced conjugated shear zones with sinistral movements at 650–550 Ma; these zones are related to the formation of East Gondwana.

The Northampton Complex typically comprises high-grade amphibolite to granulite-facies gneisses and migmatites including a common biotite-garnet-quartz-feldspar paragneiss cut by late tectonic granitoids (Myers, 1993), the protolith of which was deposited in an intracontinental rift between Greater India and Australia (Byrne, 1997). Detrital zircon ages from paragneisses of the Northampton Complex yielded ages between 2040 Ma and 1150 Ma, and the majority of zircon ages peak between 1400 and 1150 Ma and 1900–1600 Ma (Bruguier et al., 1999; Kriegsman et al., 1999). No evidence for Archean detrital components has been documented, despite the proximity to the Archean Yilgarn Craton. The peak of granulite-facies metamorphism has been constrained by U-Pb zircon ages to ca. 1079 Ma (Bruguier et al., 1999), and metamorphism occurred between 1090 and 1020 Ma (Ksienzyk et al., 2012). Dolerite dikes intruded the granulite-facies paragneisses at ca. 989 Ma (Myers, 1993; Bruguier et al., 1999). In addition, posttectonic dolerite dikes intruded the Northampton Complex during the Neoproterozoic at ca. 750 Ma (K-Ar age; Embleton and Schmidt, 1985).

The Mullingarra Complex southeast of the Northampton Complex is bounded to the east by the Darling fault and to the west by the Urella fault (Fig. 1). Cobb et al. (2001) reported a secondary ion mass spectrometry (SIMS) U-Pb zircon crystallization age of 2181 ± 10 Ma in an unmetamorphosed monzogranite, which represents the oldest magmatic age measured in the Pinjarra Orogen so far. Detrital zircon age populations within rocks from the Mullingarra Complex are very similar to those from the Northampton Complex, implying similar source regions. Furthermore, the Mullingarra Complex experienced an amphibolite-facies deformation history comparable to the Northampton Complex. However, dolerite dikes and sinistral shear zones that are common in the Northampton Complex are not detected in the Mullingarra Complex, which could be related to sparse outcrop rather than a significant difference between the two basement domains (Fletcher et al., 1985; Myers, 1990).

The 1090–1020 Ma Mesoproterozoic metamorphic event in the Pinjarra Orogen postdates the Albany-Fraser Orogeny, which includes the 1345–1260 Ma Stage I and 1214–1140 Ma Stage II events (Spaggiari et al., 2015). The Albany-Fraser Orogen yields magmatic ages between 1710 Ma and 1650 Ma in the Biranup Zone (Kirkland et al., 2011), between 1330 Ma and 1280 Ma in the Recherche Supersuite (Clark et al., 2000; Smithies et al., 2014), at ca. 1300 Ma in the Fraser Zone (Fletcher et al., 1991; Clark et al., 2000; De Waale and Pisarevsky, 2008; Smithies et al., 2014), and between 1170 Ma and 1190 Ma in the Albany Zone (Pidgeon, 1990; Black et al., 1992). The Mesoproterozoic detrital zircon ages of the Pinjarra Orogen have been interpreted to be sourced from: (1) the
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Albany-Fraser Orogen; (2) the Mawson Continent yielding Paleoproterozoic metamorphic ages of ca. 1.7 Ga (zircon U-Pb; Goodge et al., 2001); and (3) the West Australian Craton, particularly the Capricorn Orogen, yielding ages between 2.0 and 1.96 Ga (Glenburgh Orogeny; Johnson et al., 2010) and 1.83–1.78 Ga (Capricorn Orogeny) (Bruuguier et al., 1999; Goodge et al., 2001; Evans et al., 2003; Fitzsimons, 2003; Boger, 2011; Ksienzyk et al., 2012). Johnson (2013) suggests that Mesoproterozoic ages may correlate with basement rocks from the Woodleigh core ca. 230 km north of Northampton (Fig. 1), rather than from the Albany-Fraser Orogen some 1000 km south. U-Pb zircon ages indicate that basement rocks from Woodleigh crystallized at ca. 1300 Ma and experienced deformation and metamorphism between 1205 Ma and 1150 Ma (Johnson, 2013).

The Leeuwin Complex is exposed along the coast in the far-southwest corner of Western Australia, where on its eastern margin, it is separated from the Perth Basin by the Dunsborough fault. The Leeuwin Complex consists of amphibolite-granulite-facies gneisses and a layered mafic intrusion (Myers, 1993). An extended magmatic history occurred in the complex between 1090–520 Ma in which the youngest tectonic event at 522 ± 2 Ma (Collins, 2003) marks the assembly of Gondwana (Boger, 2011).

SAMPLE DESCRIPTION

In this study, basement rocks were sampled between 1241.3 m and 1246.75 m core depth from the 1250 m deep stratigraphic Wendy-1 well. The well was drilled in 2004, ~30 km east of Northampton (115°01.00'E, 28°17.94'S), in the transitional region between the northern Perth Basin and Southern Carnarvon Basin, and between basement outcrops of the Neoproterozoic Northampton Complex to the west, and the Neoproterozoic Yilgarn Craton to the east (Fig. 1). The core is archived in the Perth Core Library of the Geological Survey of Western Australia.

The cored basement rocks consist of finely banded gray garnet-bearing paragneisses crosscut by narrow pegmatitic veins. Between 1246.75 m and 1246.6 m core depth, thin mm-scale dark layers in the banded paragneiss comprise small garnets (<1 mm), K-feldspar, quartz, biotite, and finely scattered hornblende, whereas the lighter bands are dominated by quartz and discrete feldspar grains, including both potassium feldspar and plagioclase (Fig. 2A; 214830). The compositional layering of garnet-rich and feldspar-quartz-biotite sequences suggests that the garnet-bearing gneiss formed from a sedimentary protolith. Between 1244.5 m and 1244.3 m,

![Figure 2. Basement core samples (A–C) and corresponding thin section images at different scales. Mineral abbreviations: Hbl—hornblende; Bt—biotite; Grt—garnet; Qtz—quartz; Pl—plagioclase; Kfs—K-feldspar; My—myrmekite.](image-url)
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A garnet-quartz gneiss is intersected. This rock has a porphyroblastic texture in which large (>10 mm) pinkish garnets sit within a fine-grained quartz-rich matrix with large K-feldspar (~3 cm) phenocrysts (Fig. 2B; 214831). Biotite inclusion trails within garnets define a relic foliation. Large K-feldspar crystals are generally altered and replaced by micas (most likely sericite) and chlorite. Epidote is developed as a replacement mineral associated with feldspar, mica, pyroxene, amphibole, and garnet. Decimeter-wide pegmatitic veins cut across the garnet gneiss and are parallel to the main foliation trend. Between 1241.4 m and 1241.3 m depth, small-scale pegmatitic veins crosscutting the garnet gneiss commonly consist of coarse-grained quartz, large feldspar crystals, small garnets, and biotite flakes, with a distinct Ca-K metasomatic alteration of plagioclase to myrmekite (Fig. 2C; 214832). Minor galena-sulfide mineralization occurs between 1240 m and 1243 m core depth.

The upper 8 m of basement rocks, below the unconformity that separates the crystalline rocks from the Ordovician Tumblagooda Sandstone, is deeply weathered, Fe-oxide enriched, highly fragmented, and friable. Steeply dipping fracture planes become more frequent toward the unconformity surface.

RESULTS

A total of 122 analyses were obtained on zircon grains from sample 214830. Results are listed in Table DR1 and shown in a concordia diagram (Fig. 3A) and a probability density diagram (Fig. 3B). Due to the change in chromometric power, dates younger than 1000 Ma were calculated using the 238U/206Pb ratio, whereas older grains have their age calculated based on the 207Pb/206Pb ratio.

We obtained concordant to highly discordant ages from our analyses (Fig. 3). For the evaluation and interpretation of results, the following identification scheme is used: (1) Group S: concordant detrital-zircon analyses; Group S_Ma: concordant detrital-zircon analyses that appear to have sampled multiple growth domains. (2) Group M: concordant analyses with homogeneous CL response interpreted to reflect metamorphic zircon overgrowth; (3) Group D: analyses outside discordance threshold of ±10% (Table DR1).

Group S: Detrital

Zircon grains assigned to this group are elongated-prismatic, with aspect ratios up to 3:1, are up to 250 µm long, are rounded to subrounded, and have stubby morphologies. In CL images, well-developed finely spaced oscillatory zonation is prolific. Homogeneous low CL luminescence response is less common. The grains are interpreted as detrital, and some show both patchy metamorphic overgrowthss and thin bright CL luminescence rims. A selection of features is shown in Figure 4.
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Sample 214830 - garnet-paragneiss (Pinjarra Orogen)

Figure 3. (A) Tera-Wasserburg concordia diagram for sample 214830 plotted as 1σ error bars (concordant data in black, discordant in white). (B) Combination of probability density plot (gray fill), kernel density estimation (black line), and histogram (rectangles) of concordant zircon ages.

Figure 4. Cathodoluminescence (CL) images on selected zircon grains of Group S (A, B, C, D, and G) and Group D (E and F). In all images, the laser ablation–inductively coupled plasma mass spectrometry (LA-ICPMS) analytical spot size was 33 μm. Errors on 206Pb/238U and 207Pb/206Pb ages are ±1σ. (A) Equant metamorphic zircon with patchy zonation; (B) elongated metamorphic zircon; (C) elongated igneous zircon showing typical oscillatory zonation; laser spot is located in a mixed growth zone; (D) elongated zircon with igneous core showing alteration between core and wide metamorphic overgrowth; laser spot is located in a mixed growth zone; (E) elongated zircon with metamorphic core and broad metamorphic overgrowths with radial cracks; (F) elongated zircon with igneous core and broad metamorphic overgrowth; (G) abraded detrital zircon with truncated sector zonation and CL bright overgrowth.
S comprises 14 analyses on 14 different zircons yielding ages between 1065 Ma and 2845 Ma. Main age peaks are recorded at 1119 Ma (n = 5), 1211 Ma (n = 4), and 1533 Ma (n = 4). The youngest detrital grain yields an age of 1066 ± 70 Ma (1σ error). Group S MA comprises 13 analyses yielding ages between 553 Ma and 1088 Ma, which appear to have been sampled mixed growth domains (Table DR1).

Trace-element ratios can be used to enhance the understanding of the source of detrital zircons (Belousova et al., 2002). Trace-element concentrations are given in Table DR2 and chondrite normalized diagrams in Figure 5. The Yb/Sm ratio of detrital zircons in this study yields an average of 82, representing a typical value for zircons derived from granitoids (Belousova et al., 2002; Fig. 6). The rare-earth element (REE) pattern of the majority of detrital-zircon grains is consistent with a typical igneous origin with strong positive Ce anomalies, steep slopes of the light rare-earth element (LREE) to heavy rare-earth element (HREE), and negative Eu anomalies. Two zircon grains, however, have a flat LREE pattern characteristic of hydrothermal or altered zircon (Hoskin and Schaltegger, 2003). One grain has a depleted HREE portion of the pattern compared to all other zircon grains, suggesting growth with garnet in high-grade rocks (Rubatto, 2002). Notably, the concordant Archean zircon grain shows a steeper HREE trend, strong depletion of Pr, and weak enrichment in Ce. Overall, these results document that detrital-zircon grains were derived from a heterogeneous source region.

Group M: Metamorphic

Metamorphic rims are present on some detrital grains and are composed of low-CL zones that are up to 50 µm thick. Some grains may also show the effects of metamorphic recrystallization where homogeneous patches traverse into core regions (Fig. 7). Some discrete grains have low-CL response and are internally featureless. The trace-element pattern of Group M zircon typically shows a relatively flat HREE pattern and steeper LREE pattern, accompanied by an enrichment of Ce and depletion of Pr and Eu (Fig. 5B; data supplied in Table DR2). One Group M zircon grain yields a different REE pattern with enrichment in the LREE portion of the pattern, as characteristic for altered zircon (Hoskin and Schaltegger, 2003). In comparison to detrital-zircon grains (Fig. 5A), the REE pattern is broadly similar and suggests that the metamorphic event did not involve synchronous growth of zircon and garnet.

The single analysis of a zircon grain with a LREE-enriched signature yields a 238U/206Pb age of 514 ± 17 Ma. The remaining six analyses yield a weighted mean 238U/206Pb age of 527 ± 14 Ma. However, all seven analyses with various CL texture yield a concordia age of 526 ± 12 Ma (mean square of weighted deviates [MSWD] of concordance and equivalence = 2.1; Fig. 7). All three calculated ages are identical within uncertainty, which is consistent with coeval minor recrystallization, alteration, and metamorphic zircon growth.

Group D: Discordant

A significant number of discordant data were recorded in sample 214830, accounting for 68% of the total zircon population (Fig. 3A). The
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discordant grains have high to very high U concentrations (median 743 ppm; 95 percentile = 2050 ppm). Calculated apparent alpha doses range to values indicative of strongly metamict structures (apparent alpha dose: 2.21 mg*10^{15}; 95 percentile = 13.48 mg*10^{15}). A diagram of 238U/206Pb age versus U content reveals that younger 238U/206Pb ages are associated with higher U concentrations. A similar plot of 207Pb/206Pb age versus U content reveals a flat trend (Fig. 8). Such a distribution of data is consistent with enhanced radiogenic Pb loss in higher U zircon grains that have a damaged crystal structure due to metamictization. The U-Pb and Pb-Pb ages indicate that the timing of radiogenic Pb loss was predominantly recent because the 207Pb/206Pb age of the discordant data replicates the age spectrum of the concordant results more closely. Recent Pb loss is also evident from the horizontal trends on the inverse concordia diagram (Fig. 3A). Pb-loss modeling following the procedure of Reimink et al. (2016) shows upper intercept lines representing the crystallization event and lower intercept lines that represent the maximum time of Pb loss.

A lower intercept at ca. 390 Ma corresponds to an upper intercept peak of ca. 1140 Ma, whereas lower intercept ages at ca. 534 Ma and ca. 440 Ma relate to the upper intercept ages at ca. 1900 Ma and ca. 1680 Ma (Fig. 9A). A Pb-loss event is indicated by the modeling from ca. 534 Ma to recent times as illustrated by a blue area in the “discordia likelihood map” (Fig. 9B), which supports the view that Pb loss was prolonged likely due to protracted fluid flow during basin formation. Pb-loss modeling also suggests the presence of an Archean zircon component between ca. 2750 Ma and 2995 Ma Ga, an age prevalent within the Archean Yilgarn Craton. This Archean component shows a large Pb loss from 2750 Ma (upper intercept) to 145 Ma (lower intercept) and from 2995 Ma (upper intercept) to 244 Ma (lower intercept), which probably indicates multiple reworking processes (Fig. 9B).

DISCUSSION

Indian-Australian Metamorphic Event in the Early Cambrian

We obtained an age of 526 ± 12 Ma from seven analyses of metamorphic zircon (and one altered domain) from sample 214830, a finely banded gray garnet-bearing paragneiss that underlies the Paleozoic Tumblagooda Sandstone in the Wendy-1 stratigraphic well. Although the sample is located near the Northampton Complex segment of the Pinjarra Orogen,
the distinct age of metamorphic zircon indicates an event of Cambrian age similar to the Kuunga Orogeny, which has been recognized in the Leeuwin Complex (Collins, 2003) and has been interpreted to relate to the amalgamation of East Gondwana (Boger, 2011).

The metamorphic rims on detrital zircon grains yield a Kuunga age; however, the growth of garnet was not synchronous with these zircon rims because they are not HREE depleted (Schaltegger et al., 1999). In addition, the detrital zircon population also is not HREE depleted but rather shows REE patterns consistent with crystallization in an original melt volume in which garnet did not sequester the HREE cargo (Fig. 5). There is little textural evidence to further constrain the growth sequence of garnet and metamorphic zircon, as all zircon inclusions in garnets appear to be detrital in morphology rather than metamorphic. Based on the eroded appearance of garnet, it can be speculated that garnet grew before metamorphic zircon and underwent minor resorption rather than growth during the Kuunga event. Previous geochronology in the Northampton Complex identified metamorphic U-Pb zircon ages ranging from 1090 Ma to 1020 Ma with crosscutting dolerite dikes dated at 750 Ma (Embleton and Schmidt, 1985). In addition, no Archean zircon ages were reported in the basement of the Northampton Complex. In the northern part of the Leeuwin Complex, an Early Cambrian metamorphic event at 522 Ma was reported from granulite-facies granitic gneisses (U-Pb age; Collins, 2003); the age of this event correlates well with results of this study on a deeply buried basement sample taken ~500 km farther north.

Our observations of high-U contents in zircons of basement rocks of the Pinjarra Orogen match previously reported high-U zircons in paragneisses of the Northampton Complex (Bruguier et al., 1999; Ksienzyk et al., 2012) and high-grade gneisses of the Leeuwin Complex (Wilde and Murphy, 1990; Nelson, 1996, 1999; Collins, 2003).

The large spread of concordant detrital ages (Fig. 3) in our data set shows major age peaks at 1119 Ma, 1211 Ma, and 1533 Ma, which can be interpreted as the ages of zircon crystallization within their source regions (Albany-Fraser Orogen or unexposed basement ca. 230 km north of the Northampton Complex), whereas minor Neoproterozoic and Paleoproterozoic age components may indicate detrital sources from the Mawson Continent and Capricorn Orogen. Because zircon is a refractory phase, it is possible that much of the population reflects multi-cycle material. Large degrees of radiogenic Pb loss are indicated in the Archean detrital-zircon component. Nevertheless, the presence of a single concordant Archean detrital zircon grain is important because it may reflect material that was initially derived from the Yilgarn Craton, potentially then reworked in the Albany-Fraser Orogen. In addition, discordance modeling supports the presence of Archean crust in the source region for this basement rock (Fig. 9).

Crustal Architecture of the Western Margin of the West Australian Craton

Structural interpretation of potential field data allows a clear distinction between the basement of the Northampton Complex and the basement unit described here from the Wendy-1 drill core. By blending gravity and magnetic anomaly maps (Fig. 10), we highlight the importance of the N-S-trending Yandi fault, which separates not only the Mullyingarra Complex
Figure 10. Combination of potential field data (gravity—400 m grid and magnetic—80 m total magnetic intensity grid; Brett, 2014, 2015) and structural data (transfer zones after Hall et al., 2013) as a (A) detailed map of the Northern Perth Basin and (B) regional overview map. Gravity data are represented in color (high—red; low—blue), and magnetic data are displayed in grayscale to enhance contrast in the textures. Map (A) features (1) the depth structure of the Urella fault; (2) contrasting basement domains on the eastern margin of the Northampton Complex bounded by the Yandi fault; (3) NE-SW–trending dolerite dike systems of the Northampton Complex; (4) smoother textured crystalline Mullingarra Complex without dikes. Map (B) features (1) the western boundary of the Archean Yilgarn Craton; (2) segmentation of basement domains; (3) general NW-SE trend of transfer faults.
from the Northampton Complex, but may also separate the Northampton Complex from an unknown basement domain described in this study. Furthermore, the Urella fault constitutes the boundary between different basement domains and offsets the eastern margin of the Northampton Complex. Hall et al. (2013) correlated the NW-SE–trending transfer faults (dextral strike-slip faults) throughout the Perth Basin to the breakup of Greater India in the Cretaceous (Fig. 10B). The NW-SE trend of the Perth Basin transfer faults is similar to the trend of basement signatures expressed in the geophysical data sets from the Northampton Basement. Basement units in the Pinjarra Orogen such as the Northampton Complex may therefore constitute different domains that were separated by the reactivation of older structures such as the Urella fault during the Late Jurassic onset of continental drift. It is unlikely that Mesoproterozoic domains such as the Mullingarra and Northampton Complex were transported along the western Yilgarn margin during ca. 530 Ma metamorphism (Fitzsimons, 2003), because a N-S–trending tectonic displacement of such a magnitude could only have occurred during the opening of the Indian Ocean. If this were the case, then the displacement would have occurred parallel to the NW-SE transfer directions.

This study shows that Kuungga-age Early Cambrian metamorphism along the eastern margin of Gondwana was not limited to the Leeuwin Complex but also affected the northern part of the Pinjarra Orogen. Although the Leeuwin Complex and the newly discovered basement domain in the Northampton region have a similar age signature, they need not be the same domain.

CONCLUSIONS

The Pinjarra Orogen consists of segmented basement domains that formed during the Mesoproterozoic breakup of Rodinia and were reworked during the amalgamation of eastern Gondwana. We report the discovery of an Early Cambrian metamorphic overprint within an undeformed segment of the northern Pinjarra Orogen. The results of U-Pb zircon geochronology of a paragneiss from a drill core imply an inherited Archean detrital component, linking this basement initially to the Yilgarn Craton. Mesoproterozoic detrital zircons in this paragneiss may have been derived from the Albany-Fraser Orogen (Bruguier et al., 1999; Ksienzyk et al., 2012) or from unexposed basement rocks ~230 km north of the Northampton Complex (Johnson, 2013). The identification of Early Cambrian metamorphism at 526 ± 12 Ma metamorphism (Fitzsimons, 2003), because a N-S–trending tectonic displacement of such a magnitude could only have occurred during the opening of the Indian Ocean. If this were the case, then the displacement would have occurred parallel to the NW-SE transfer directions.

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This study shows that Kuungga-age Early Cambrian metamorphism along the eastern margin of Gondwana was not limited to the Leeuwin Complex but also affected the northern part of the Pinjarra Orogen. Although the Leeuwin Complex and the newly discovered basement domain in the Northampton region have a similar age signature, they need not be the same domain.
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