

New constraints on the seismic structure of West Australia: Evidence for terrane stabilization prior to the assembly of an ancient continent?

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ABSTRACT

We present a new, near-comprehensive survey of the variations in seismic structure across the West Australian craton at the scale of the main terrane groups. Analyzing data from distant earthquakes recorded at temporary and permanent stations located across the region, we found the best-fitting structure by modeling the conversions from P- to S-wave motion (the receiver function) that take place as the seismic energy travels upward through the lithosphere. Such methods can be used to delineate the extent of cratonic and orogenic terranes in regions where geological exposure of the surface is limited, and they provide an effective alternative to active-source seismic techniques for deep crustal targets. The seismic structure is consistent within several of the individual Archean terranes, most notably the Pilbara, Murchison, and Southern Cross. These terranes are underlain by lower crust of low seismic velocity and show a sharp seismic Moho. The structure shows significant contrasts between neighboring terranes; thus, major tectonic units have a velocity profile that is a signature of that terrane or terrane group. We infer that the seismic structure of the Archean crust and upper mantle was fixed before craton assembly and preserved through the subsequent collision and accretion of the tectonic units that formed the West Australian craton.

Keywords: Archean, craton, Australia, seismic structure, receiver function.

INTRODUCTION

For the first time, sufficient coverage of high-fidelity broadband seismic stations exists to undertake a comprehensive survey of crustal thickness and seismic velocity structure across the West Australian craton at the scale of the main terrane groups (Fig. 1; Myers and Hocking, 1998) using a closest interstation spacing of ~70 km. The concept of relating seismic velocity structure to the terrane boundaries observed on the surface was introduced, as a tentative interpretation of a limited Australian data set, by Reading et al. (2003a). This approach implies that early plate tectonic processes were dominant in the construction of the craton. Such an implication remains controversial when applied to the Archean of Australia, although it is more widely accepted when applied to other Archean regions, such as the North American shield. We shorten the terms “superterrane” and “terrane group” to “terrane” herein with the understanding that allochthonous units may be present within.

STUDY AREA

The Pilbara and Yilgarn cratons joined through the greater Capricorn orogeny to form the West Australian craton by 1.8 Ga (Betts et al., 2002). The Pilbara craton is a well-exposed block of granitoid-greenstone and metasedimentary rocks with ages from 3.52 Ga (Barley, 1998). The east Pilbara craton exhibits a dome-and-basin geometry that was controlled

in part by gravity-driven processes. The west Pilbara craton has no dome structures and was arguably formed under a contrasting tectonic regime (Hickman, 2004). By 3.2 Ga, the Pilbara craton was a coherent block and was modified in a series of subsequent extensional and compressive events that can be correlated across the Pilbara craton after this time (Blewett, 2002).

The Yilgarn craton is one of the largest areas of Archean crust on Earth. The Narryer terrane to the northwest contains the oldest rocks, which are gneiss of ages up to 3.7 Ga (Betts et al., 2002). In the central Yilgarn craton, the Murchison and Southern Cross terranes are granitoid-greenstone belts older than 3.0 Ga bounded by major faults, although a recent interpretation by Cassidy et al. (2006) combines the Murchison and Southern Cross as the “Youanmi terrane.” The Eastern Goldfields terrane (Myers, 1997) contains slightly younger greenstones, aged 2.7 Ga, while the Southwest terrane is mostly gneiss of a similar age. Proposed global-scale overturn in Earth’s mantle during the Late Archean provided a strong intrusive component (Nelson, 1998). The domains defined by the analysis of aeromagnetic data (Whitaker, 2001) are dominated by magmatic rocks in the top kilometer and are not directly comparable to the seismic data in this broad-scale study. The northern Yilgarn craton, as discussed in recent work by Griffin et al. (2004), is not sufficiently well sampled by the stations in this survey for further analysis but provides a good incentive for further, denser deployments in this key area. Over the Yilgarn craton as a whole,

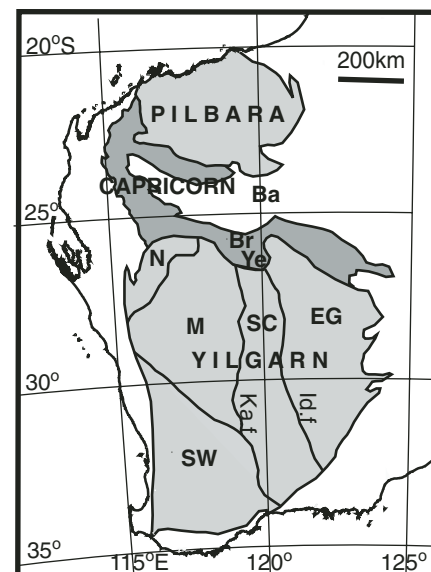


Figure 1. Geological terrane map (major tectonic units) for West Australia. Pale gray—Archean craton, darker gray—Proterozoic orogen. Terranes: SW—Southwest, N—Narryer, M—Murchison, SC—Southern Cross, EG—Eastern Goldfields, Ye—Yerrida, Br—Bryah, Ba—Bangamall. Ka.f—Kawana fault, Id.f—Ida fault.

there is considerable evidence for regional-scale shortening in an east-west direction, other deformation, and metamorphism (Chen et al., 2001).

The Capricorn orogen, which joins the Pilbara and Yilgarn cratons, formed in a series of distinct episodes (Cawood and Tyler, 2004, and references therein) that took place from 2.2–2.0 Ga (the Glenburgh orogeny) to 1.8 Ga (the Capricorn orogeny) to 1.6 Ga (unnamed). The margin of the adjacent northern Yilgarn craton includes high-grade metamorphism and syntectonic granite (Reddy and Occhipinti, 2004). A number of basins have been identified, including the Yerrida, which overlies Archean basement, and the Bangamall of the central Capricorn orogen.

Early reflection/refraction seismic work (Drummond, 1988) found the crust of the cratons to be 25–35 km thick with a sharp Moho, while the crust beneath the orogens is much thicker at 45–50 km with a less-distinct Moho. The Moho is modeled at 35 km in the southwest Yilgarn craton and at nearly 40 km in the north of the Southwest terrane (Dentith et al., 2000; Wilde et al., 1996). In the Eastern Goldfields, focus

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has been on the structure of the upper few kilometers (Drummond et al., 2000; Goleby et al., 2002). Collins et al. (2003) provided a summary of crustal structure across Australia. Analysis of seismic data from SKIPPY, and later deployments, has revealed details of mantle structure within the West and Central Australian cratons (Fishwick et al., 2005).

Closer-spaced stations were deployed across the Yilgarn craton (WT stations, 2000–early 2001; WV, 2001), and from the Pilbara craton across the Capricorn orogen (WS, 2000) to the Yilgarn craton (Reading et al., 2003a; Reading and Kennett, 2003). The resulting coverage, including the most recently deployed stations (WR, 2000–2001; WP, 2003), represents a comprehensive survey across the Yilgarn craton, although stations are more widely spaced across the Pilbara and Capricorn areas (Figs. 2 and 3). We investigated the crustal thickness and seismic velocity structure using the extended data set in the context of the surface tectonic boundaries. Significant features were interpreted in light of the published ages of these major tectonic units and compared with similar terranes in other continents. New constraints from observations of deep crustal structure are thus placed on the assembly and evolution of the ancient continental crust of West Australia.

SEISMIC DATA AND METHODS

Twenty earthquakes, at a suitable epicentral distance for receiver function analysis (30°–80°) and with sufficient signal-to-noise ratio for receiver function work, were recorded at each WR station, and eight were recorded at each WP station. Figure 2 shows the source-receiver paths into an example station, WR06. The sources are mainly in the southwest Pacific region and represent a spread of back azimuths, dominated by

10°–110°. The observed receiver functions (for RF method, see Shibutani et al., 1996; Reading et al., 2003a) are stacked for each station to further improve the signal-to-noise ratio. The best-fitting one-dimensional (1-D) shear wave-speed profile is modeled from each stacked waveform by searching the solution space using an algorithm that is suited to the nonlinear relationship between waveform and Earth structure and that also provides a means of assessing the best-fitting structure against other possible solutions (Sambridge, 1999). Figure 2 also shows the stacked receiver functions from WR06. After the initial P pulse at 0 s, the highest-amplitude arrival is associated with energy converted from P-wave to S-wave propagation at the Moho.

SUMMARY OF TERRANE STRUCTURE

Characteristic seismic velocity structures for each terrane well covered by stations are shown in Figure 3. In this work, the seismic Moho is taken to be the base of the high-velocity gradient zone in the lower crust (i.e., deeper than 30 km). Except where noted explicitly, our results are in agreement with the earlier, less-detailed receiver function work of Clitheroe et al. (2000) and the active source studies of Drummond (1988) and/or Collins et al. (2003).

The Pilbara craton shows a very sharp, shallow Moho at 32 km with a velocity gradient in the lower crust. The Moho becomes deeper toward the south of the craton beneath the Hamersley Basin. The Murchison terrane shows a very sharp Moho at a depth of 34 km, and low velocities in the lower crust produce the large Moho velocity discontinuity. Previously published structures for the Yilgarn craton are based on seismic sections across the central Yilgarn craton and include very few results from the Murchison terrane. The Southern Cross terrane exhibits a characteristic structure with a large discontinuity at the Moho at a depth of 38 km, a discontinuity in the upper crust at 14 km, and a lower crust that shows little or no velocity increase with depth (see also Reading et al., 2003a). As both the Murchison and Southern Cross terranes are of similar age and both show a sharp Moho, combining these two terranes (as the “Youanmi Terrane,” with Murchison and Southern Cross domains within; Cassidy et al., 2006) remains in accord with the results presented in this work. The Southwest terrane shows a Moho depth of 38 km (Reading et al., 2003a). There is a discontinuity in the upper crust at around 10 km depth and a high-velocity gradient above the Moho that thickens markedly toward the western edge of the craton. Clitheroe et al. (2000) found the Moho depth beneath station NWA0 (Fig. 3) to be at 42 km, but we found that the structure at that station cannot be approximated by a 1-D model. The Eastern Goldfields terrane characteristically shows a

sharp Moho at 42 km depth and a very variable upper crust. A 7 km discontinuity has been interpreted as a detachment surface of variable depth by Drummond et al. (2000) and Goleby et al. (2002). Lower crustal discontinuities and velocity gradients are very variable and not easy to generalize. This variability is in full agreement with the recent identification (Cassidy et al., 2006) of many terranes within the Eastern Goldfields terrane. The Moho becomes consistently deeper moving eastward toward central Australia and shallower toward the southeast edge of the craton. The Capricorn orogen shows a deep Moho, ~44 km, and a low-velocity contrast between lower crust and mantle that sometimes manifests as a broad Moho discontinuity, or, in some cases, the Moho can be hard to define at all (Reading et al., 2003b). The structure is variable, but there is generally a moderate velocity gradient throughout the lower crust. The Moho depth of 33 km reported previously (Clitheroe et al., 2000) may be reinterpreted as a lower crust discontinuity resulting from the complex crustal structure beneath the Bryah Basin.

DISCUSSION AND CONCLUSIONS

Seismic velocity and Moho depth is characteristic of a given terrane, and so, we infer that the underlying structure of the Archean blocks investigated in this study was determined prior to, and preserved through, accretion and craton stabilization. The Pilbara and Murchison blocks show consistent structure, a sharp and relatively shallow Moho. The Southern Cross terrane also shows characteristic crustal structure and a consistently sharp Moho. The variability in character of the Eastern Goldfields terrane is markedly different from the Pilbara, Murchison, and Southern Cross terranes. The Southwest terrane, in contrast, shows a broader Moho. There seems to be little doubt that assembly of these terranes took place dominantly by a process of accretion in an early plate-tectonic setting. Geochemical evidence is consistent with the accretion of allochthonous terranes, pointing to, for example, the tectonic severance (Krapez et al., 2000) of many of the source terranes for Yilgarn metasedimentary sequences.

If the seismic structure is such a long-lived feature of Archean crust, there must be a mechanism for preserving that structure. O’Reilly et al. (2001) investigated changes to the subcontinental lithospheric mantle over time. They suggested that Archean lithosphere is very buoyant and is less prone to delamination, and it is better at protecting the crust above. The terranes retain their own crustal characteristics and have not been overprinted by a homogenizing event across the West Australian craton. The formation of discontinuities in the upper crust is not systematic. Nevertheless, without knowing the exact mechanism for their

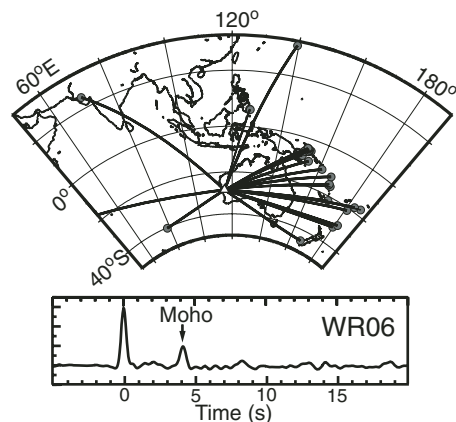


Figure 2. Earthquake locations of events (dark-gray circles) available for receiver function analysis at example station WR06 and (below) receiver function (20 stacked records). Signal due to Moho is pulse near 4 s.

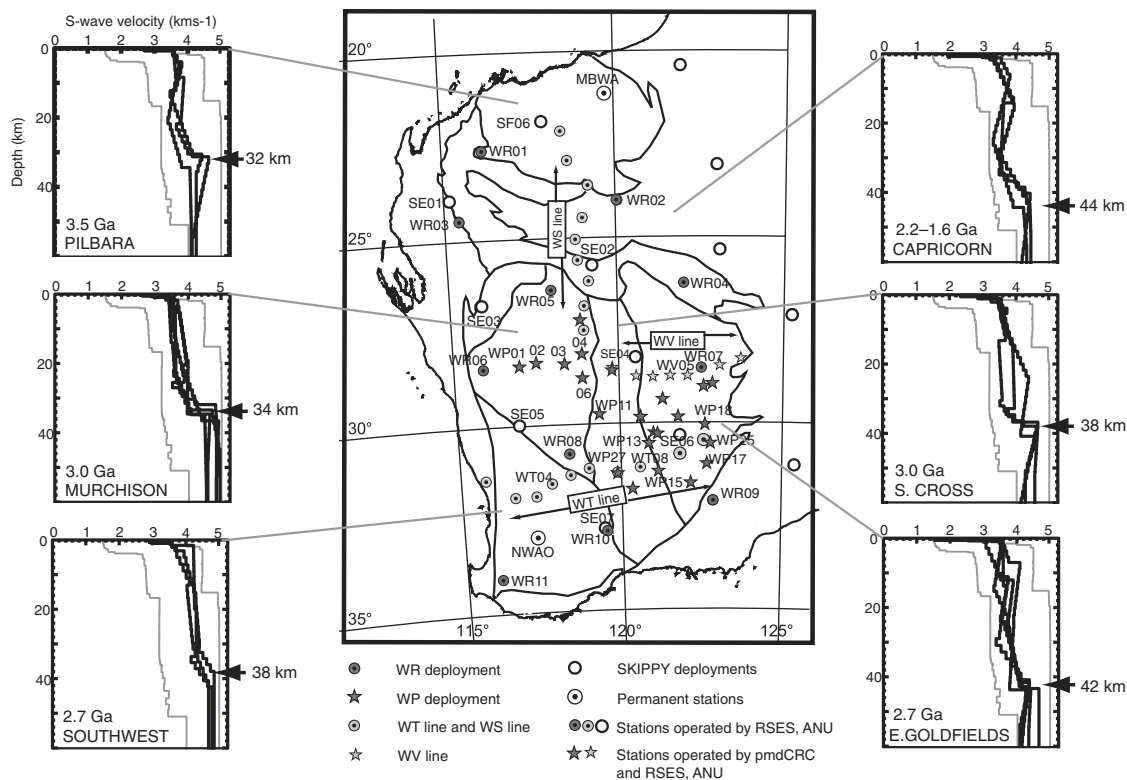


Figure 3. Station location map and S-wave velocity profiles (solid black lines) characteristic of given terranes. See text for age references. Uncertainties are ± 2 km (depth) and ± 0.2 km⁻¹ (velocity) in lower crust, higher in top few kilometers, and poorly constrained below Moho. Arrows indicate Moho depth. Fine gray lines show bounds of model search. Profiles with features obviously attributable to Kawana and Ida faults or problematic receiver functions have been omitted. RSES—Research School Earth Sciences; ANU—Australian National University; pmdCRC—Predictive Mineral Discovery Cooperative Research Centre.

formation, they can be useful in characterizing a given terrane and mapping its extent beneath regions of no exposure.

The most significant result from this study is the characterization of each terrane by a seismic velocity profile. Using the seismic velocity profiles, we are also able to add to the database of S-wave velocity determinations and thus provide an insight into the composition of the lowermost crust of West Australia (Fig. 3). The implications of such inferred compositions are the subject of extended debate that is beyond the scope of this short contribution. However, the spatial extent of our study and the relatively well-defined geochronology of West Australia together provide a significant new contribution to such a debate. The Pilbara and Murchison terranes show lower-crust seismic velocity values of ~ 3.8 km⁻¹, and the Southern Cross terrane shows values from 3.6 to 4.0 km⁻¹. The Southwest and Eastern Goldfields terranes show lower-crust velocities of ~ 4.2 km⁻¹. Discussions relating seismic velocity to composition and metamorphic grade (e.g., Durrheim and Mooney, 1994; Rudnick and Fountain, 1995) indicate that the lower velocities are most plausibly associated with a lower crust that contains a high proportion of felsic minerals. Alterations in Moho depth to the west of the Southwest terrane and in the southeast of the Eastern Goldfields terrane probably correspond to the influence of the adjacent, later Pinjarra and Albany-Fraser orogenies respectively (Fitzsimons, 2003). The later Capricorn

orogen shows a more complex crustal structure, higher seismic velocities in the lower crust, and an indistinct Moho discontinuity.

The low seismic velocity of the lower crust and sharp Moho observed in the older terranes suggest the following possibilities: (1) The younger Archean terranes were formed only shortly before accretion and craton stabilization, and the lithosphere did not have time to evolve the sharp Moho that is observed in the older Archean terranes; (2) lower crustal compositions in the older terranes were more felsic at formation; and/or (3) mantle dynamics in the Late Archean were heterogeneous (and the age relations we observe are coincidental). Seismic studies from other continents include work on the Kaapvaal craton of southern Africa, which shares a suggested early history with the Pilbara craton (Bleeker, 2003, and references therein). The Archean crust of the Kaapvaal (35–40 km) shows a sharp Moho and little variability in upper- or lower-crustal structure (Niu and James, 2002). Density calculations are consistent with a lower crust of felsic to intermediate composition. Thin crust and a sharp Moho are also observed in Archean provinces in Canada (e.g., 32–35 km in the Slave Province, Viejo and Clowes [2003]; 34–36 km in the main shield, Darbyshire [2003]). Late Archean terranes in Quebec, 2.7 Ga and younger, were assembled by accretion (Mueller et al., 1996), which suggests that this style of tectonics was widespread. Condie and Chomiak (1996) made the

observation that the younger Canadian Archean terranes existed for a relatively short time, ~ 20 –80 m.y., between formation and collision (compare Mesozoic terranes at mostly 50–200 m.y.). It is recognized that Earth changed in geochemical character at the end of the Archean (when komatiitic volcanism ceased; Durrheim and Mooney, 1994), and we acknowledge the possibility that a transitional stage in lower-crust formation may have occurred between 3.0 Ga and 2.7 Ga. Coincidental age relations seem unlikely given the worldwide spread of observations. However, it is wise to keep in mind the limited sample of preserved Archean crust remaining for present-day studies.

In summary, we infer that the seismic structure was preserved in each terrane prior to the assembly of the craton. The Archean terranes of the West Australian craton show structures that are characteristic of each of the large terrane groups, and there is notable consistency of character through each of the Pilbara, Murchison, and Southern Cross terranes. The later terranes, in contrast, show more variable structure. Terranes of the West Australian craton younger than 2.8 Ga do not show the low velocities in the lower crust and very sharp Moho of the earlier terranes. Characterization of the seismic velocity structure as a whole, using receiver functions from several different stations in each tectonic unit under investigation, is a robust approach for analyzing the deep structure of different terranes.

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REFERENCES CITED

- Barley, M.E., 1998, The tectonic and metallogenic evolution of the Pilbara craton: Preface: *Precambrian Research*, v. 88, p. 1–2, doi: 10.1016/S0301-9268(97)00060-0.
- Betts, P.G., Giles, D., Lister, G.S., and Frick, L.R., 2002, Evolution of the Australian lithosphere: *Australian Journal of Earth Sciences*, v. 49, p. 661–695, doi: 10.1046/j.1440-0952.2002.00948.x.
- Bleeker, W., 2003, The Late Archean record: A puzzle in ca. 35 pieces: *Lithos*, v. 71, p. 99–134, doi: 10.1016/j.lithos.2003.07.003.
- Blewett, R.S., 2002, Archean tectonic processes: A case for horizontal shortening in the North Pilbara granite-greenstone terrane, Western Australia: *Precambrian Research*, v. 113, p. 87–120, doi: 10.1016/S0301-9268(01)00204-2.
- Cassidy, K.F., Champion, D.C., Krapez, B., Barley, M.E., Brown, S.J.A., Blewett, R.S., Groenewald, P.B., and Tyler, I.M., 2006, A revised geological framework for the Yilgarn craton, Western Australia: *Western Australia Geological Survey Record* 2006/8, 8 p.
- Cawood, P.A., and Tyler, I.M., 2004, Assembling and reactivating the Proterozoic Capricorn orogen: Lithotectonic elements, orogenies, and significance: *Precambrian Research*, v. 128, p. 201–218, doi: 10.1016/j.precamres.2003.09.001.
- Chen, S.F., Libby, J.W., Greenfield, J.E., Wyche, S., and Riganti, A., 2001, Geometry and kinematics of large arcuate structures formed by impingement of rigid granitoids into greenstone belts during progressive shortening: *Geology*, v. 29, p. 283–286, doi: 10.1130/0091-7613(2001)029<0283:GAKOLA>2.0.CO;2.
- Clietheroe, G., Gudmundsson, O., and Kennett, B.L.N., 2000, The crustal thickness of Australia: *Journal of Geophysical Research*, v. 105, p. 13,697–13,713, doi: 10.1029/1999JB900317.
- Collins, C.D.N., Drummond, B.J., and Nicholl, M.G., 2003, Crustal thickness patterns in the Australian continent, in Hillis, R.R., and Muller, R.D., eds., *Evolution and Dynamics of the Australian Plate: Geological Society of Australia Special Publication 22 and Geological Society of America Special Publication 372*, p. 121–128.
- Condie, K., and Chomiak, B., 1996, Continental accretion: Contrasting Mesozoic and Early Proterozoic tectonic regimes in North America: *Tectonophysics*, v. 265, p. 101–126, doi: 10.1016/S0040-1951(96)00148-5.
- Darbyshire, F.A., 2003, Crustal structure across the Canadian High Arctic region from teleseismic receiver function analysis: *Geophysical Journal International*, v. 152, p. 372–391, doi: 10.1046/j.1365-246X.2003.01840.x.
- Dentith, M.C., Dent, V.F., and Drummond, B.J., 2000, Deep crustal structure in the southwestern Yilgarn craton, Western Australia: *Tectonophysics*, v. 325, p. 227–255, doi: 10.1016/S0040-1951(00)00119-0.
- Drummond, B.J., 1988, A review of crust/upper mantle structure in the Precambrian areas of Australia and implications for Precambrian crustal evolution: *Precambrian Research*, v. 40, p. 101–116, doi: 10.1016/0301-9268(88)90063-0.
- Drummond, B.J., Goleby, B.R., and Swager, C.P., 2000, Crustal signature of Late Archean tectonic episodes in the Yilgarn craton, Western Australia: Evidence from deep seismic sounding: *Tectonophysics*, v. 329, p. 193–221, doi: 10.1016/S0040-1951(00)00196-7.
- Durrheim, R.J., and Mooney, W.D., 1994, Evolution of Precambrian lithosphere: Seismological and geochemical constraints: *Journal of Geophysical Research*, v. 99, p. 15,359–15,374, doi: 10.1029/94JB00138.
- Fishwick, S., Kennett, B.L.N., and Reading, A.M., 2005, Contrasts in lithospheric structure within the Australian craton—Insights from surface wave tomography: *Earth and Planetary Science Letters*, v. 231, p. 163–176, doi: 10.1016/j.epsl.2005.01.009.
- Fitzsimons, I.C.W., 2003, Proterozoic basement provinces of southern and southwestern Australia, and their correlation with Antarctica, in Yoshida, M., Windley, B.F., and Dasgupta, S., eds., *Proterozoic East Gondwana: Supercontinent Assembly and Breakup: Geological Society of London Special Publication 206*, p. 93–130.
- Goleby, B.R., Korsch, R.J., Fomin, T., Bell, B., Nicholl, M.G., Drummond, B.J., and Owen, A.J., 2002, Preliminary 3-D geological model of the Kalgoorlie region, Yilgarn craton, Western Australia, based on deep seismic-reflection and potential-field data: *Australian Journal of Earth Sciences*, v. 49, p. 917–933, doi: 10.1046/j.1440-0952.2002.00967.x.
- Griffin, W.L., Belousova, E.A., Shee, S.R., Pearson, N.J., and O'Reilly, S.Y., 2004, Archean crustal evolution in the northern Yilgarn craton: U-Pb and Hf-isotope evidence from detrital zircons: *Precambrian Research*, v. 131, p. 231–282, doi: 10.1016/j.precamres.2003.12.011.
- Hickman, A.H., 2004, Two contrasting granite-greenstone terranes in the Pilbara craton, Australia: Evidence for vertical and horizontal tectonic regimes prior to 2900 Ma: *Precambrian Research*, v. 131, p. 153–172, doi: 10.1016/j.precamres.2003.12.009.
- Krapez, B., Brown, S.J.A., Hand, J., Barley, M.E., and Cas, R.A.F., 2000, Age constraints of recycled crustal and supracrustal sources of Archean metasedimentary sequences, Eastern Goldfields Province, Western Australia: Evidence from SHRIMP zircon dating: *Tectonophysics*, v. 322, p. 89–133, doi: 10.1016/S0040-1951(00)00059-7.
- Mueller, W.U., Daigneault, R., Mortensen, J.K., and Chown, E.H., 1996, Archean terrane docking: Upper crust collision tectonics, Abitibi greenstone belt, Quebec, Canada: *Tectonophysics*, v. 265, p. 127–150, doi: 10.1016/S0040-1951(96)00149-7.
- Myers, J.S., 1997, Preface: Archean geology of the Eastern Goldfields of Western Australia—Regional overview: *Precambrian Research*, v. 83, p. 1–10, doi: 10.1016/S0301-9268(97)00002-8.
- Myers, J.S., and Hocking, R.M., 1998, *Geological Map of Western Australia* (13th edition): Perth, Australia, Geological Survey of Western Australia, scale 1:2,500,000.
- Nelson, D.R., 1998, Granite-greenstone crust formation on the Archean Earth: A consequence of two superimposed processes: *Earth and Planetary Science Letters*, v. 158, p. 109–119, doi: 10.1016/S0012-821X(98)00049-1.
- Niu, F., and James, D.E., 2002, Fine structure of the lowermost crust beneath the Kaapvaal craton and its implications for crustal formation and evolution: *Earth and Planetary Science Letters*, v. 200, p. 121–130, doi: 10.1016/S0012-821X(02)00584-8.
- O'Reilly, S.Y., Griffin, W.L., Poudjom Djomani, Y.H., and Morgan, P., 2001, Are lithospheres forever? Tracking changes in subcontinental lithospheric mantle through time: *GSA Today*, v. 11, no. 4, p. 4–10.
- Reading, A.M., and Kennett, B.L.N., 2003, Lithospheric structure of the Pilbara craton, Capricorn orogen and northern Yilgarn craton, Western Australia, from teleseismic receiver functions: *Australian Journal of Earth Sciences*, v. 50, p. 439–445, doi: 10.1046/j.1440-0952.2003.01003.x.
- Reading, A.M., Kennett, B.L.N., and Dentith, M.C., 2003a, Seismic structure of the Yilgarn craton, Western Australia: *Australian Journal of Earth Sciences*, v. 50, p. 427–438, doi: 10.1046/j.1440-0952.2003.01000.x.
- Reading, A.M., Kennett, B.L.N., and Sambridge, M.S., 2003b, Improved inversion for seismic structure using transformed, S-wavevector receiver functions: Removing the effect of the free surface: *Geophysical Research Letters*, v. 30, doi: 10.1029/2003GL018090.
- Reddy, S.M., and Occhipinti, S.A., 2004, High-strain zone deformation in the southern Capricorn orogen, Western Australia: Kinematics and age constraints: *Precambrian Research*, v. 128, p. 295–314, doi: 10.1016/j.precamres.2003.09.005.
- Rudnick, R.L., and Fountain, D.M., 1995, Nature and composition of the continental crust: A lower crustal perspective: *Reviews in Geophysics*, v. 33, p. 267–309, doi: 10.1029/95RG01302.
- Sambridge, M.S., 1999, Geophysical inversion with a neighbourhood algorithm. I. Searching a parameter space: *Geophysical Journal International*, v. 138, p. 479–494, doi: 10.1046/j.1365-246X.1999.00876.x.
- Shibutani, T., Sambridge, M., and Kennett, B., 1996, Genetic algorithm inversion for receiver functions with application to crust and uppermost mantle structure beneath Eastern Antarctica: *Geophysical Research Letters*, v. 23, p. 1829–1832, doi: 10.1029/96GL01671.
- Viejo, G.F., and Clowes, R.M., 2003, Lithospheric structure beneath the Archean Slave Province and Proterozoic Wopmay orogen, northwestern Canada, from a LITHOPROBE refraction/wide-angle reflection survey: *Geophysical Journal International*, v. 153, p. 1–19, doi: 10.1046/j.1365-246X.2003.01807.x.
- Whitaker, A.J., 2001, Components and structure of the Yilgarn craton, as interpreted from aeromagnetic data, in Cassidy, K.F., Dunphy, J.M., and VanKranendonk, M.J., eds., *4th International Archean Symposium*, 24–28 September 2001, Perth, Western Australia [extended abs.]: AGSO Record, v. 37, p. 536–538.
- Wilde, S.A., Middleton, M.F., and Evans, B.J., 1996, Terrane accretion in the southwestern Yilgarn craton: Evidence from a deep seismic crustal profile: *Precambrian Research*, v. 78, p. 179–196, doi: 10.1016/0301-9268(95)00077-1.

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