Secular change in Archean crust formation recorded in Western Australia

by

H Yuan[1,2]

The formation mechanisms for early Archean continental crust are controversial. Continental crust might have accumulated via horizontal accretion in modern-style subduction zones, or via vertical accretion above upper mantle upwelling zones. These end-member models are all able to explain the field and geochemical characteristics of the Archean tonalite–trondhjemite–granodiorites (TTG) in early Archean terranes (e.g. Herzberg and Rudnick, 2012; Polat, 2012). However, the change in characterization of continental crust at the transition between the Archean and Proterozoic eons, suggests that continental crust did not form by subduction processes until the late Archean.

Spatial and temporal clustering in the WA crust

Yuan (2015) used seismic receiver function data to analyse the bulk properties of continental crust in Western Australia (Fig. 1), which formed and stabilized over a billion years in the Archean. The bulk seismic properties of the crust cluster spatially, with similar clusters confined within the boundaries of tectonic terranes (Fig. 2). This spatial clustering of the crustal properties strongly indicates that these tectonic subunits may have formed differently through time.

Local Archean crustal growth models (e.g. Van Kranendonk et al., 2014) show that both plume and subduction processes might have had a role in creating crust throughout the Archean. A correlation between crustal age and the bulk seismic properties of the crust reveals a trend from about 3.5 Ga to the end of the Archean, when the crust gradually thickened and simultaneously became more evolved in composition (Fig. 3). A similar trend of the Archean crust thickening is also found in a global compilation (Keller and Schoene, 2012).

1 ARC Centre of Excellence for Core to Crust Fluid Systems, Department of Earth and Planetary Sciences, Macquarie University, Sydney NSW 2109

2 Centre for Exploration Targeting, School of Earth and Environment, The University of Western Australia, 35 Stirling Highway, Crawley WA 6009

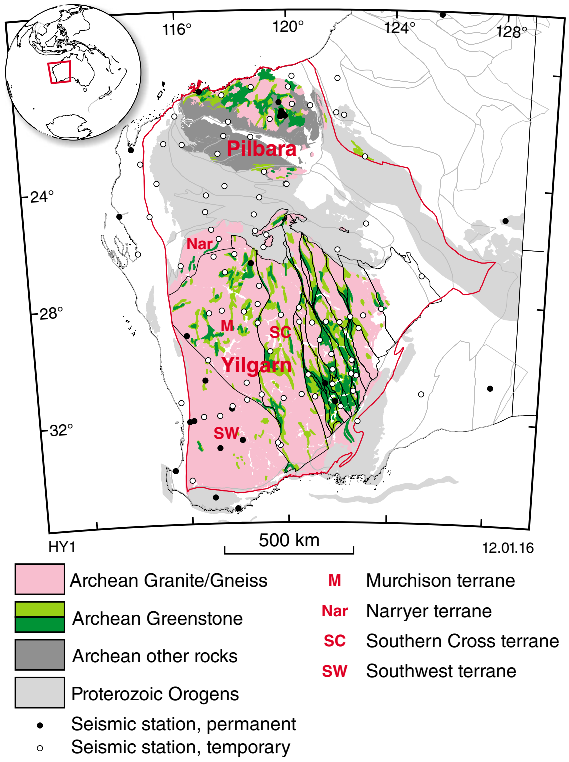

Figure 1. **Simplified Archean and Proterozoic rock ages, crustal elements and seismic stations in Western Australia. Inset shows the location of the study region. Greenstone belts are shaded in green. Rock ages and large-scale crustal elements are based on 1:500 000 State tectonic units map compiled by the Geological Survey of Western Australia (GSWA). Terrane and domain boundaries in the Yilgarn follow Cassidy et al. (2006). Seismic stations are shown by open (temporary deployment) and filled (permanent) circles. Labels are: Nar, Narryer Terrane; M, Murchison Domain; SC, Southern Cross Domain; SW, South West Terrane.**

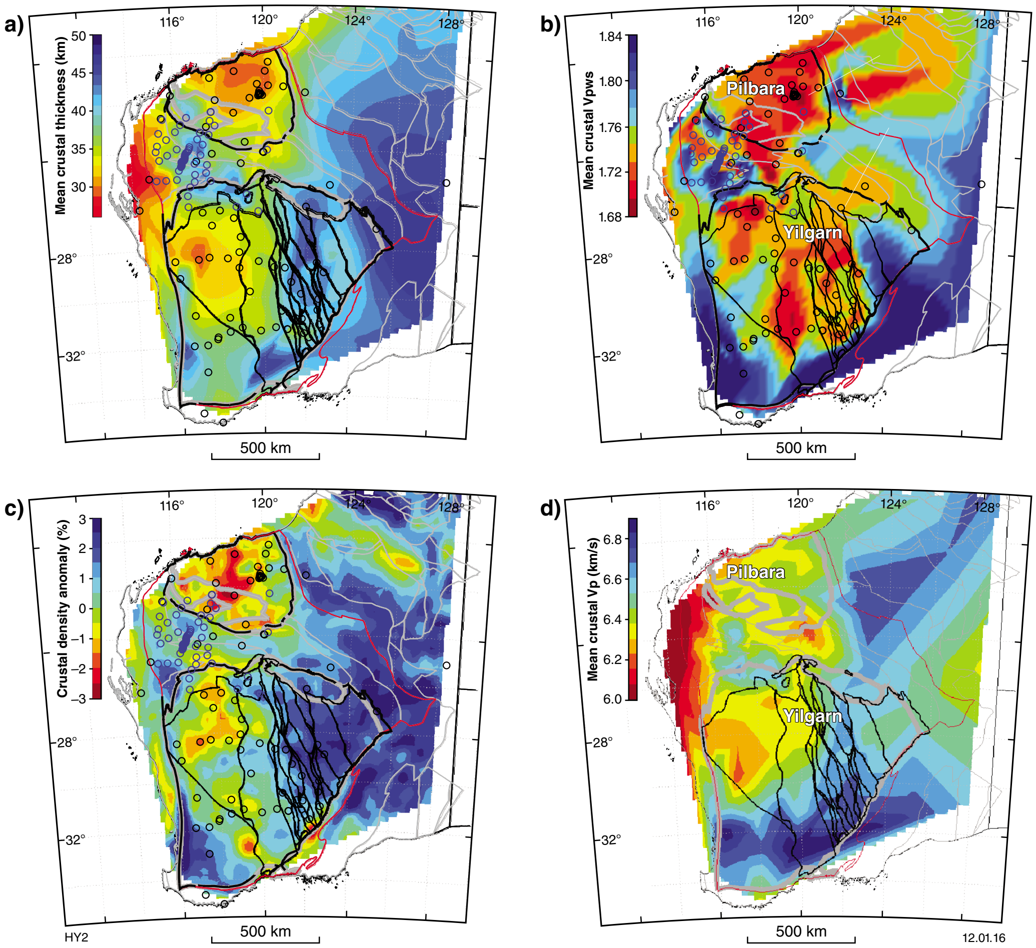

Figure 2. **Spatial distribution of the crustal observations in the West Australian Craton: a) bulk crustal thickness; b) Vp/ Vs ratio; c) crustal density anomaly; d) composite bulk crustal compressional wave (P-wave) velocity (Aitken et al., 2013). The West Australian Craton is outlined in red. Note the image artefact in the northeastern part of Western Australia which is due to the sparse seismic station coverage.**

Earth cooling and secular change in WA crust formation

This trend reflects the transition between crust dominantly formed above mantle plumes, from those formed by subduction processes — a transition that may reflect secular cooling of the Earth's mantle. As shown in numerical simulations (Johnson et al., 2014), such secular mantle cooling, reflected as decreasing mantle potential temperature (Tp), controls the overall efficiency of the Archean lower crustal delamination processes: higher Tp results in rapid and complete removal of the lower crust, while lower Tp makes the removal process less efficient. It is thus likely that the systematic crust thickening in Western Australia might simply reflect the secular mantle cooling process. More efficient lower crustal removal processes in the hotter Paleoarchean led to a thin Pilbara crust; towards the end of the Archean, the delamination processes become sluggish and less lower crust is delaminated, resulting in a gradually thickened crust.

The overall efficiency of the lower crustal delamination processes through time can also readily explain the age-progressive evolution of the Western Australian crustal composition. In the Paleoarchean, the high mantle temperature and radiogenic crust, episodes of plume activities (Van Kranendonk et al., 2014) and catalytic delamination driven melts (Bédard, 2006) are probably the key to generating the extremely felsic crust by multistage crust fractionation in the Pilbara. In the late Archean, if more mafic lower crust is preserved, it would result in a bulk crustal composition that is more intermediate. In addition, by this time the crustal growth in Western Australia might be in transition to a horizontal accretion regime. As the mantle cooled, subduction eventually became more dominant in the late Archean (e.g. Barley et al., 2008); the subduction-related new magmas that were added to the continental crust might have evolved to a more intermediate composition (Christensen and Mooney, 1995).

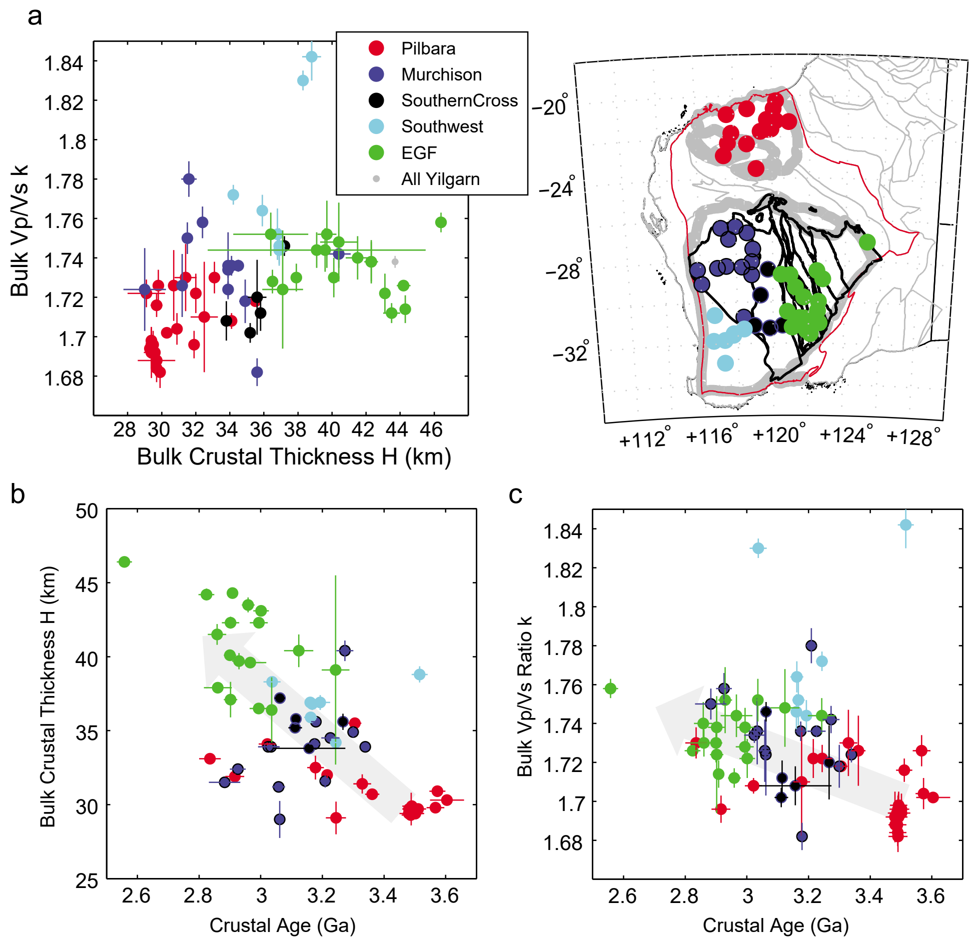

Figure 3. **Clustering and temporal variations in the Western Australian crust: a) bulk crustal thickness versus Vp=Vs ratio. Stations for each subdivision are marked on the map (inset). The measuring errors of seismic observations and the errors associated with the isotopic ages (Champion, 2013) are indicated. Note the large deviation of the South West Terrane and lack of robust measurements from the Narryer Terrane; b) the age correlation of the bulk crustal thickness; c) the age correlation of the bulk Vp=Vs ratio.**

References

Aitken, ARA, Salmon, ML, and Kennett, BLN 2013, Australia's Moho: A test of the usefulness of gravity modelling for the determination of Moho depth: Tectonophysics, v. 609, p. 468–479.

Barley, ME, Brown, SJA, Krapež, B, and Kositcin, N 2008, Physical volcanology and geochemistry of a Late Archaean volcanic arc: Kurnalpi and Gindalbie Terranes, Eastern Goldfields Superterrane, Western Australia: Precambrian Res., v. 161, no. 1–2, p. 53–76.

Bédard, JH 2006, A catalytic delamination-driven model for coupled genesis of Archaean crust and sub-continental lithospheric mantle: Geochimica et Cosmochimica Acta, v. 70, p. 1188–1214.

Cassidy, KF, Champion DC, Krapež, B., Barley, ME, Brown, SJA, Blewett, RS, Groenewald, PB and Tyler, IM, 2006, A revised geological framework for the Yilgarn Craton, Western Australia: Geological Survey of Western Australia, Record 2006/8, 8p.

Champion, DC 2013, Neodymium depleted mantle model age map of Australia: explanatory notes and user guide: Geoscience Australia, Record 2013/044, http://dx.doi.org/10.11636/Record.12013.11044.

Christensen, NI and Mooney, WD 1995, Seismic velocity structure and composition of the continental crust; a global view: Journal of Geophysical Research, v. 100, p. 9761–9788.

Herzberg, C and Rudnick, R 2012, Formation of cratonic lithosphere: An integrated thermal and petrological model: Lithos, v. 149, p. 4–15.

Johnson, TE, Brown, M, Kaus, BJP, and VanTongeren, JA 2014, Delamination and recycling of Archaean crust caused by gravitational instabilities: Nature Geoscience, v. 7, p. 47–52.

Keller, CB and Schoene, B 2012, Statistical geochemistry reveals disruption in secular lithospheric evolution about 2.5 Gyr ago: Nature, v. 485, p. 490–493.

Polat, A 2012, Growth of Archean continental crust in oceanic island arcs: Geology, v. 40, p. 383–384.

Van Kranendonk, MJ, Smithies, RH, Griffin, WL, Huston, DL, Hickman, AH, Champion, DC, Anhaeusser, CR and Pirajno, F 2014, Making it thick: a volcanic plateau origin of Palaeoarchean continental lithosphere of the Pilbara and Kaapvaal cratons: Geological Society, London, Special Publications, v. 389, p. 83–111.

Yuan, H 2015, Secular change in Archaean crust formation recorded in Western Australia: Nature Geoscience, v. 8, p. 808–813.