Zircon lutetium–hafnium isotope map of Western Australia

by

Y Lu, MTD Wingate, SS Romano, DR Mole[1], CL Kirkland[2], AIS Kemp[3], EA Belousova[4], RH Smithies, K Gessner and SP Johnson

Abstract

Time-constrained isotope maps are used to characterize the evolution of lithospheric architecture as well as understand crustal development and mineralization. Such isotope maps play an increasingly important role in exploration targeting, and statistically significant relationships between different types of mineralization and isotopic signatures over time have been found. The Lu–Hf isotope maps of Western Australia (Fig. 1) are based on Lu–Hf data for dated magmatic zircons from felsic igneous rocks, which provide a window into evolution and architecture of the middle and lower continental crust. Zircons from granitic rocks are used because they provide a useful tool to sample the deeper sections of lithosphere that form the foundations of our continents.

Initial $^{176}Hf/^{177}Hf$ and εHf values of all zircons were calculated using the ^{176}Lu decay constant of Söderlund et al. (2004) and the CHUR (CHondritic Uniform Reservoir) value of Bouvier et al. (2008). For each analysis, a two-stage depleted mantle model age (T_{DM}^2) is calculated, which assumes that the parental magma of the zircon was produced from a volume of average continental crust ($^{176}Lu/^{177}Hf$ ratio of 0.015) extracted from depleted mantle (Griffin et al., 2000, 2002). T_{DM}^2 estimates the average age of the crustal source of the igneous rocks (Griffin et al., 2002). Crustal residence time (T_{CR}), the difference between T_{DM}^2 and magmatic crystallization age, is also calculated for each analysis, and provides an estimate of the average length of time the source of the igneous rocks has resided in the crust.

The evolution of the mantle is a topic of debate in isotope geoscience (including whether mantle depletion occurred at 4.56 or 3.8 Ga; Griffin et al., 2002; Kemp et al., 2015; Vervoort and Kemp, 2016; Fisher and Vervoort, 2018), and the model chosen affects values calculated for T_{DM}^2 and T_{CR}, particularly for zircons older than 3.8 Ga. Furthermore, the $^{176}Lu/^{177}Hf$ ratio used in isotopic evolution is solely an estimate and imparts significant uncertainty to any model age (see Vervoort and Kemp, 2016). Therefore, T_{DM}^2 and T_{CR} are used here mainly for qualitative comparative purposes because any gradients in T_{DM}^2 and T_{CR} may be more insightful than their absolute values. Moreover, model ages potentially highlight underlying patterns related to crustal composition and structure.

Lu–Hf isotope data for zircons from mafic igneous, sedimentary, and metamorphic rocks, and for xenocrystic zircons, were not used in constructing the isotope maps, although their sample-level information is included as a separate layer. Spot-level data for all samples are provided as a CSV file. The Lu–Hf isotope data have been filtered to exclude data with U–Pb age discordance >10%, $^{176}Yb/^{177}Hf$ >0.1, and εHf 2σ uncertainty >4 epsilon units (Belousova et al., 2010; Mole et al., 2019). The isotope maps are constructed from median T_{DM}^2 and T_{CR} values, using the Natural Neighbour interpolation tool in ArcGIS Spatial Analyst, and presented as both stretched (histogram equalize type, Fig. 1a,c) and classified (natural breaks classification, Fig. 1b,d) raster images.

The model age (T_{DM}^2) maps highlight the distinction between Archean cratons (T_{DM}^2 >2.6 Ga) and Proterozoic orogens (T_{DM}^2 <2.4 Ga). T_{CR} maps highlight the predominance of moderate to short residence times (<0.5 Ga) for the Pilbara and Yilgarn Cratons, and much longer crustal residence times (>0.8 Ga) in the Paterson, Albany–Fraser, and Capricorn Orogens, consistent with an increased role for reworking of ancient crust in these orogens.

1 Geoscience Australia, GPO Box 378, Canberra, ACT 2601, Australia
2 Timescales of Mineral Systems Group, School of Earth and Planetary Sciences, Curtin University, Bentley, WA 6102, Australia
3 School of Earth Sciences, The University of Western Australia, Crawley, WA 6009, Australia
4 ARC Centre of Excellence for Core to Crust Fluid Systems (CCFS) and GEMOC, Macquarie University, New South Wales 2109, Australia

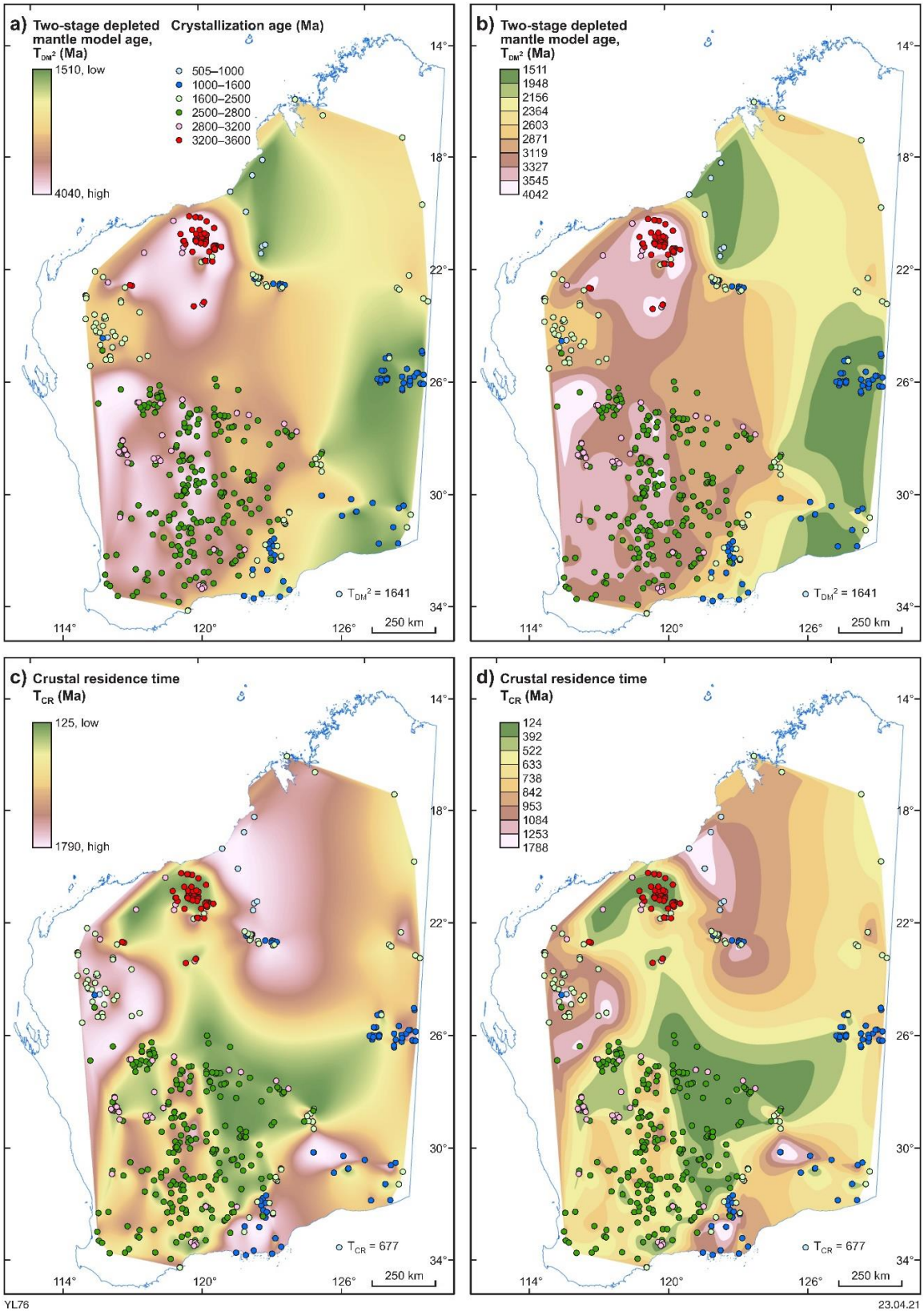

Figure 1. Zircon Lu–Hf isotope maps for felsic igneous rocks in Western Australia. Median two-stage depleted mantle model age (T_{DM}^2) and crustal residence time (T_{CR}) maps are presented as stretched (a and c) and classified (b and d) raster images. Symbols show the locations of Lu–Hf samples used for isotope mapping and are colour coded to indicate their magmatic crystallization ages

Granitic samples from basement rocks beneath the Canning Basin show similar T_{DM}^2 to those in the Musgrave, Madura and Coompana Provinces, but are different to those from the North and West Australian Cratons (NAC and WAC), suggesting the existence of a subsurface Proterozoic terrane between the NAC and WAC possibly related to the Mirning Ocean (Kirkland et al., 2017; Fig. 1a,b).

The isotope maps also image two rift-like structures in the Yilgarn Craton: the Kalgoorlie–Kurnalpi rift in the Eastern Goldfields and the Cue rift in the Murchison similar to those observed in whole-rock Sm–Nd isotope maps (Lu et al., 2021).

Map colours in areas where there are no samples reflect interpolated values and may have little or no relationship with underlying crust. Some isotope gradients may not be as pronounced in the statewide map as they might be on more detailed maps of individual regions. It is therefore recommended that users download the isotope data and create their own contour maps for particular areas to examine the isotope gradients in those areas.

Acquisition of Lu–Hf isotope data by the Geological Survey of Western Australia (GSWA) was funded by the Exploration Incentive Scheme (EIS), and conducted using multi-collector inductively coupled plasma mass spectrometry (MC-ICPMS) in the Centre for Geochemical Evolution and Metallogeny of Continents (GEMOC) and ARC Centre of Excellence for Core to Crust Fluid Systems (CCFS) at Macquarie University and in the Centre for Microscopy, Characterization and Analysis (CMCA) at The University of Western Australia.

How to access

The data layer is best accessed using GeoVIEW.WA. This online interactive mapping system allows data to be viewed and searched together with other datasets, including Geological Survey of Western Australia and Geoscience Australia geochronology data, geological maps and mineral exploration datasets. The Zircon lutetium–hafnium isotope map digital data are also available as a free download from the Data and Software Centre via Datasets — Statewide spatial datasets — Geochronology & Isotope Geology — Zircon lutetium-hafnium isotope map, as ESRI shapefiles and MapInfo TAB files. All spot-level zircon data are provided as a CSV file. These datasets are subject to ongoing updates as new data are generated.

References

Belousova, EA, Kostitsyn, YA, Griffin, WL, Begg, GC, O'Reilly, SY and Pearson, NJ 2010, The growth of the continental crust: Constraints from zircon Hf-isotope data: Lithos, v. 119, p. 457–466.

Bouvier, A, Vervoort, JD and Patchett, PJ 2008, The Lu-Hf and Sm-Nd isotopic composition of CHUR: constraints from unequilibrated chondrites and implications for the bulk composition of terrestrial planets: Earth and Planetary Science Letters, v. 273, p. 48–57.

Fisher, CM and Vervoort, JD 2018, Using the magmatic record to constrain the growth of continental crust–The Eoarchean zircon Hf record of Greenland: Earth and Planetary Science Letters, v. 488, p. 79–91.

Griffin, WL, Pearson, NJ, Belousova, EA, Jackson, SE, O'Reilly, SY, van Achterberg, E and Shee, SR 2000, The Hf isotope composition of cratonic mantle: LAM-MC-ICPMS analysis of zircon megacrysts in kimberlites: Geochimica et Cosmochimica Acta, v. 64, p. 133–147.

Griffin, WL, Wang, X, Jackson, SE, Pearson, NJ, O'Reilly, SY, Xu, X and Zhou, X 2002, Zircon chemistry and magma genesis, SE China: in-situ analysis of Hf isotopes, Pingtan and Tonglu igneous complexes: Lithos, v. 61, p. 237–269.

Kemp, AIS, Hickman, AH, Kirkland, CL and Vervoort, JD 2015, Hf isotopes in detrital and inherited zircons of the Pilbara Craton provide no evidence for Hadean continents: Precambrian Research, v. 261, p. 112–126.

Kirkland, CL, Smithies, RH, Spaggiari, CV, Wingate, MTD, Quentin de Gromard, R, Clark, C, Gardiner, NJ and Belousova, EA 2017, Proterozoic crustal evolution of the Eucla basement, Australia: Implications for destruction of oceanic crust during emergence of Nuna: Lithos, v. 278–281, p. 427–444.

Lu, Y, Wingate, MTD, Champion, DC, Smithies, RH, Johnson, SP, Mole, DR, Poujol, M, Zhao, J, Maas, R and Creaser RA 2021, Samarium–neodymium isotope map of Western Australia: Geological Survey of Western Australia, digital data layer, <www.dmirs.wa.gov.au/geoview>.

Mole, DR, Kirkland, CL, Fiorentini, ML, Barnes, SJ, Cassidy, KF, Isaac, C, Belousova, EA, Hartnady, M and Thébaud, N 2019, Time-space evolution of an Archean craton: A Hf-isotope window into continent formation: Earth-Science Reviews, v. 196, 102831.

Söderlund, U, Patchett, PJ, Vervoort, JD and Isachsen, CE 2004, The 176Lu decay constant determined by Lu-Hf and U-Pb isotope systematics of Precambrian mafic intrusions: Earth and Planetary Science Letters, v. 219, p. 311–324.

Vervoort, JD and Kemp, AIS 2016, Clarifying the zircon Hf isotope record of crust–mantle evolution: Chemical Geology, v. 425, p. 65–75.

Recommended reference

Lu, Y, Wingate, MTD, Romano, SS, Mole, DR, Kirkland, CL, Kemp, AIS, Belousova, EA, Smithies, RH, Gessner, K and Johnson, SP 2021, Zircon lutetium–hafnium isotope map of Western Australia: Geological Survey of Western Australia, digital data layer, <www.dmirs.wa.gov.au/geoview>.