Zircon oxygen isotope map of Western Australia

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Abstract

The Geological Survey of Western Australia (GSWA) released its first zircon oxygen isotope map under the Accelerated Geoscience Program in 2021 (Lu et al., 2021). These zircon oxygen isotope data shed new light on the evolution of Western Australian continental crust since the early Archean (Johnson et al., 2017; Smithies et al., 2021). Here we present a revised zircon oxygen isotope map of Western Australia that updates previously released data with 880 new analyses from 49 samples, for 3909 analyses from 231 samples (Figs 1, 2).

The primary oxygen isotope compositions of igneous rocks are preserved in zircon crystals from the time of crystallization. The $^{18}O/^{16}O$ ratios are reported in delta notation as $\delta^{18}O$ (‰) values, normalized to Vienna Standard Mean Ocean Water (V-SMOW). Zircons crystallized from uncontaminated mantle-derived magmas have homogeneous $\delta^{18}O$ values (5.3 ± 0.6‰, 2σ; Valley et al., 2005). Higher and lower $\delta^{18}O$ values are diagnostic signatures of low-temperature (<300 °C) and high-temperature (>300 °C) water-rock interaction at Earth's surface, respectively (Valley et al., 2005; Troch et al., 2020). Therefore, zircon $\delta^{18}O$ values can be used to fingerprint reworking (partial melting and/or assimilation) and recycling (re-incorporation into the mantle) of supracrustal rocks that have interacted with the hydrosphere, and can be related to specific geodynamic processes (e.g. Mole et al., 2021; Smithies et al., 2021).

The oxygen isotope map of Western Australia (Fig. 2) is based on primary zircon $\delta^{18}O$ data from igneous rocks. Zircon $^{16}O^{1}H/^{16}O$ ratios, together with cathodoluminescence texture and zircon age discordance, are used to assess whether the measured ratios represent primary magmatic compositions, or potentially reflect alteration or weathering, or contamination by inclusions (Pidgeon et al., 2017). After filtering, the zircon $\delta^{18}O$ data show no correlation with $^{16}O^{1}H/^{16}O$, U, Th, Th/U or discordance on an individual sample basis, and are regarded as preserving primary magmatic compositions. Although zircon oxygen isotope data from altered, xenocrystic, metamorphic and detrital grains were not used in constructing the isotope map, this sample-level information is presented as a separate layer. All spot-level zircon data are provided as a CSV file.

The median $\delta^{18}O$ values of primary magmatic zircons from igneous samples are visualized on the map using graduated symbols (Fig. 2). The Archean Pilbara and Yilgarn Cratons are dominated by mantle-like $\delta^{18}O$ values (4.7 – 5.9‰), consistent with reworking of igneous material that had not been exposed at the surface. Some igneous rocks in the Pilbara and Yilgarn Cratons exhibit weakly elevated zircon $\delta^{18}O$ values (6.0 – 6.5‰) which, together with trace element enrichment, are attributed to minor enrichment of source regions by surface-derived material. The Capricorn, Paterson and Albany–Fraser Orogens, the Rudall, Madura and Coompana Provinces, and the North Australian Craton contain rocks that host zircons with mainly elevated $\delta^{18}O$ values (6.6 – 10.4‰), suggesting significant reworking and/or recycling of upper crustal material subjected to weathering or low-temperature hydrothermal alteration (Johnson et al., 2017; Gardiner et al., 2018; Kirkland et al., 2020). Sub-mantle $\delta^{18}O$ values (1.7 – 4.6‰) are found in zircons from igneous rocks in the Pilbara Craton, the Narryer, Youanmi and South West Terranes of the Yilgarn Craton, the Albany–Fraser Orogen, Coompana and Musgrave Provinces and the Halls Creek Orogen, suggesting reworking in those areas of crustal material subjected to high-temperature hydrothermal alteration, such as observed in rift systems or calderas (Smithies et al., 2015; Hammerli et al., 2018; Petersson et al., 2019; Kirkland et al., 2020).

Insights into crustal evolution can be gained by visualizing the variation with age of primary $\delta^{18}O$ values for individual zircons (Fig. 3). Igneous and xenocrystic zircons show similar trends, with both groups exhibiting larger variations for samples younger than 2.5 Ga (1.1 – 11.3‰) than in Archean rocks (3.0 – 7.5‰), consistent with secular crustal maturation observed elsewhere (Valley et al., 2005). There are few primary igneous zircons dated between 2.5 and 2.0 Ga, reflecting the general lack of dated felsic magmatic rocks of that age in Western Australia (Fig. 3). However, 2.5 – 2.0 Ga xenocrystic zircons are common and yield mainly heavy $\delta^{18}O$ values, indicating that felsic magmatism during this time involved significant reworking of supracrustal materials, and that those magmatic rocks were mostly emplaced at depth and not exposed at the surface (Fig. 3). The sub-mantle $\delta^{18}O$ values from igneous and xenocrystic zircons occur semi-continuously since at least c. 3.6 Ga, suggesting that high-temperature water-rock interactions likely developed throughout Earth's history and that low-$\delta^{18}O$ is not as rare as previously thought (cf. Troch et al., 2020).

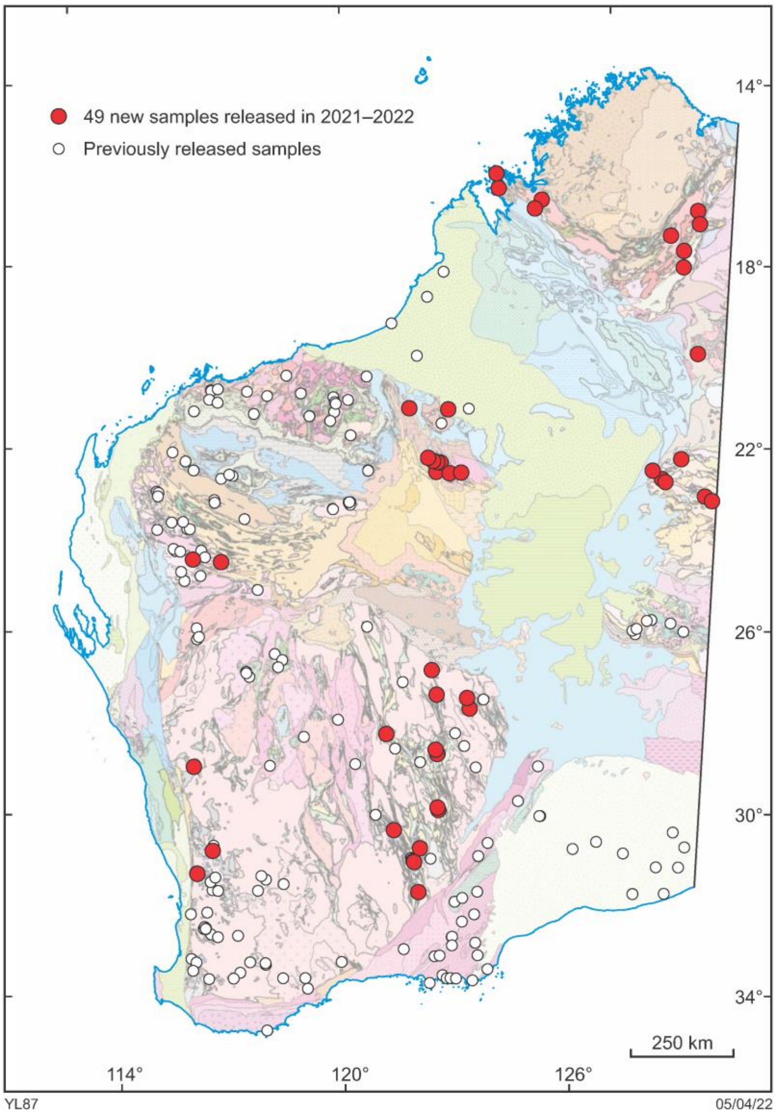

Figure 1. **Locations of new and previously released zircon oxygen isotope samples, shown on the 1:2.5 million interpreted bedrock geology map**

The oxygen isotope data were compiled as part of a collaboration between GSWA and Geoscience Australia (GA). Acquisition of GSWA's oxygen isotope data was funded by the Exploration Incentive Scheme (EIS), and measurements were conducted using a Cameca IMS 1280 ion microprobe with the scientific and technical assistance of Microscopy Australia at the Centre for Microscopy, Characterization and Analysis (CMCA), a facility at The University of Western Australia (UWA) funded by UWA and by State and Commonwealth Governments.

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 GSWA and GA geochronology data, geological maps and mineral exploration datasets. The Zircon oxygen 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 oxygen isotope map, as ESRI shape files 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.

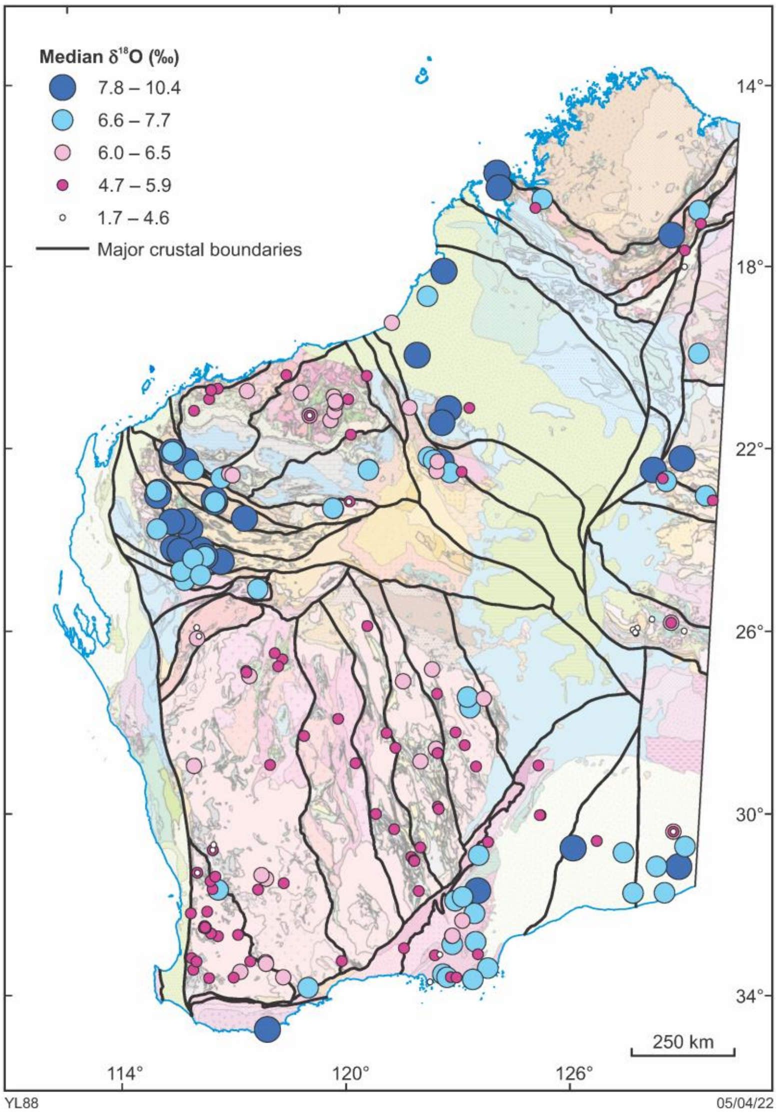

Figure 2. **Zircon oxygen isotope map for igneous rocks, showing median $\delta^{18}O$ values of primary magmatic zircons from each igneous rock sample. Major crustal boundaries are from Martin et al. (2021)**

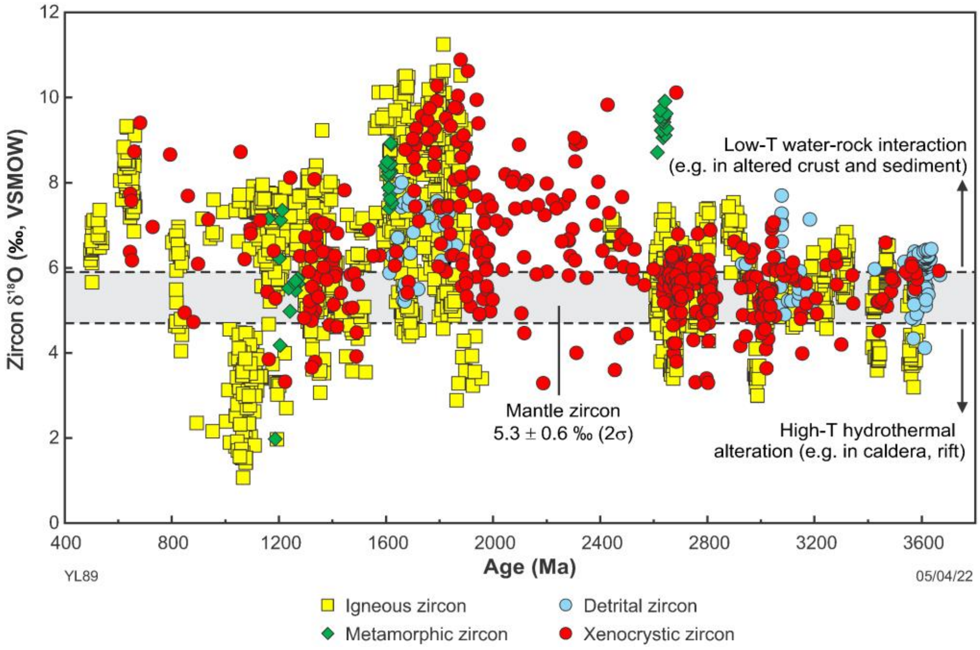

Figure 3. **Values of $\delta^{18}O$ vs age for zircons with primary oxygen isotope compositions in Western Australia. The grey band indicates the field for mantle zircons (Valley et al., 2005). Abbreviation: VSMOW, Vienna standard mean ocean water**

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EXPLORATION INCENTIVE SCHEME

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