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The effect of weathering on U–Th–Pb and oxygen isotope systems of ancient zircons from the Jack Hills, Western Australia

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Abstract

We report the result of a SIMS U–Th–Pb and O–OH study of 44 ancient zircons from the Jack Hills in Western Australia with ages ranging from 4.3 Ga to 3.3 Ga. We have investigated the behaviour of oxygen isotopes and water in the grains by determining $\delta^{18}O$ and OH values at a number of locations on the polished surfaces of each grain. We have divided the zircons into five groups on the basis of their U–Th–Pb and OH-oxygen isotopic behaviour. The first group has concordant U–Th–Pb ages, minimal common Pb, $\delta^{18}O$ values consistent with zircons derived from mantle source rocks and no detectable OH content. U–Th–Pb systems in zircons from Groups 2, 3 and 4 vary from concordant to extremely discordant where influenced by cracks. Discordia intercepts with concordia at approximately zero Ma age are interpreted as disturbance of the zircon U–Th–Pb systems by weathering solutions during the extensive, deep weathering that has affected the Archean Yilgarn Craton of Western Australia since at least the Permian. Weathering solutions entering cracks have resulted in an influx of Th and U. $\delta^{18}O$ values of Group 2 grains fall approximately within the "mantle" range and OH is within background levels or slightly elevated. $\delta^{18}O$ values of Group 3 grains are characterised by an initial trend of decreasing $\delta^{18}O$ with increasing OH content. With further increase in OH this trend reverses and $\delta^{18}O$ becomes heavier with increasing OH. Group 4 grains have a distinct trend of increasing $\delta^{18}O$ with increasing OH. These trends are explained in terms of the reaction of percolating water with the metamict zircon structure and appear to be independent of analytical overlap with cracks. Group five zircons are characterised by U–Pb systems that appear to consist of more than one age but show only minor U–Pb discordance. Nevertheless trends in $\delta^{18}O$ versus OH in this group of grains resemble trends seen in the other groups. The observed trends of $\delta^{18}O$ with OH in the Jack Hills zircons are similar to those reported in a previous study of zircons from an Archean granite from south-western Australia.

Keywords: Jack Hills zircons; Weathering of zircon; Zircon oxygen isotopes; Zircon Th-U-Pb discordance; Water in zircon

1. INTRODUCTION

The only surviving fragments of the Hadean period of Earth history are >4 Ga detrital zircons found in ~3 Ga quartzites and quartz pebble conglomerates from Mt Narryer, The Maynard Hills and the Jack Hills in Western Australia (Froude et al., 1983; Compston and Pidgeon, 1986; Nelson, 2000) (Fig. 1). The >4 Ga zircons have been subjected to numerous chemical and isotopic investigations including Hf isotope studies (e.g. Amelin et al., 1999; Harrison et al., 2005, 2008; Kemp et al., 2010), Ti thermometry (e.g. Harrison and Schmitt, 2007), lithium (e.g. Ushikubo et al., 2008), REE studies (e.g. Maas and McCulloch, 1991; Maas et al., 1992; Peck et al., 2001) and oxygen isotope analyses (e.g. Mojzsis et al., 2001; Peck et al., 2001; Cavosie et al., 2004, 2005; Trail et al.,

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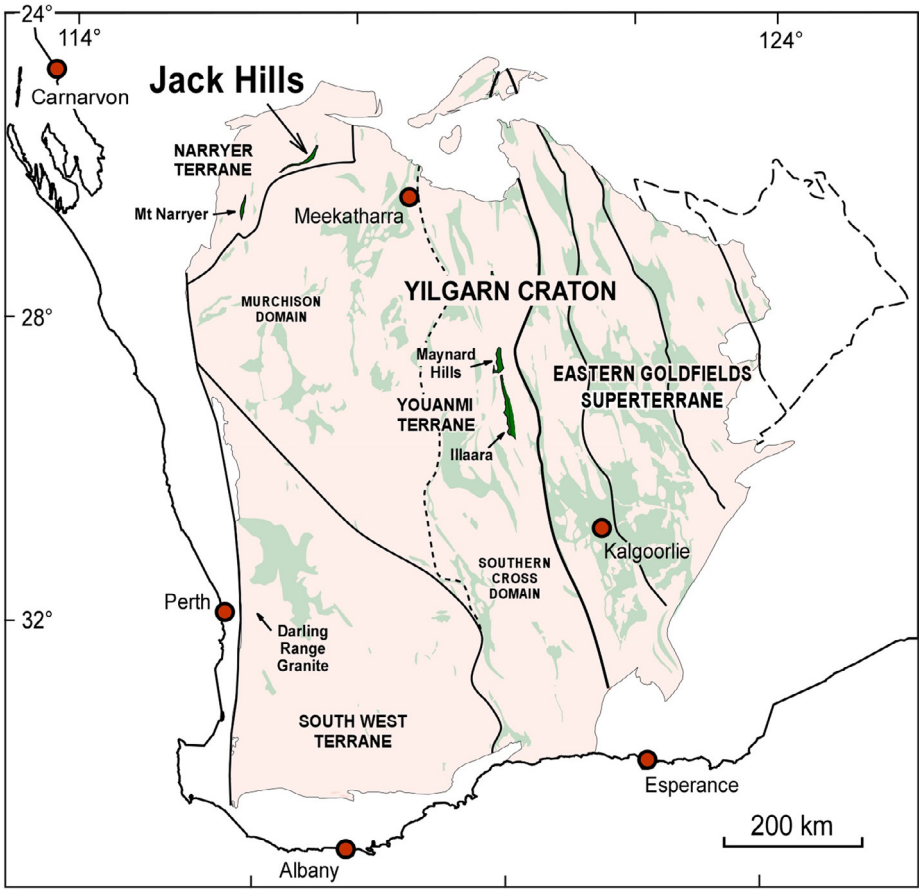

Fig. 1. Map of the Yilgarn Craton in south-western Australia showing the major terrane subdivisions, greenstone belts (green) and the locations of the Jack Hills and Darling Range granite sample W388. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2007; Harrison et al., 2008) in attempts to identify their parent rocks and to investigate the Hadean history of the Earth.

These studies have generated a number of sometimes conflicting conclusions on the nature of parent rocks of the >4 Ga zircons and the evolution of the Hadean. The oldest zircons in the Jack Hills conglomerate, with ages of about 4370 Ma (Wilde et al., 2001; Nemchin et al., 2006a, b; Holden et al., 2009; Valley et al., 2014) represent the earliest consolidation of the Earth's crust. From their Nd, U–Pb and geochemical (including REE) results Maas et al. (1992) and Maas and McCulloch (1991) proposed a granitic parent for the >4 Ga zircons indicating a differentiated continental source of substantial thickness rather than a provenance of felsic differentiates within a dominantly mantle ocean-type crust. Harrison et al. (2005) reported Hf data that supported formation of continental crust by 4.4–4.5 Ga. Kemp et al. (2010) concluded, from the results of a concurrent Hf and Pb isotope study of Jack Hills zircons, that Hadean history consisted of crustal reworking of an enriched mafic magma extracted from primordial mantle at 4.4–4.6 Ga. From studies of oxygen isotopes of Jack Hills zircons Wilde et al. (2001), Mojzsis et al. (2001), Peck et al. (2001), Cavosie et al. (2004), Trail et al. (2007) and Harrison et al. (2008) showed that $\delta^{18}O$ values in some 4.4–3.9 Ga zircons are significantly heavier than expected for zircons formed from mantle sources and proposed that they crystallised from evolved granitic melts where "the protoliths of the magmas were altered by low temperature interaction with liquid water near Earth's surface" (Cavosie et al., 2005). The model was questioned by Hoskin (2005) who proposed that the high $\delta^{18}O$ signatures, and flat REE patterns of Jack Hills zircons (Wilde et al., 2001; Peck et al., 2001) and other Hadean Jack Hills zircons, could result from localized exchange with a light-REE-bearing, heavy $\delta^{18}O$ (6–10‰ or higher) hydrothermal fluid at about 4.27 Ga. Cavosie et al. (2006) discussed at length the evidence for a hydrothermal origin for flat LREE patterns in some Jack Hills zircons and concluded that this did not support the case for external fluid interaction and that the role of fluids in the LREE enrichment process is minor. The report by Harrison and Schmitt (2007) that "Ti contents associated with very high apparent temperatures (Ti thermometry) were introduced into the crystal along cracks and are thus unrelated to zircon formation" suggests external fluid penetration into cracks depositing Ti. Valley et al. (1994) proposed that hydrothermal fluids exchange oxygen with high magnetism (radiation damaged) zircons from Adirondack gneisses lowered the $\delta^{18}O$ in some grains. The potential for low temperature hydrothermal