

HADEAN CRUSTAL PROCESSES REVEALED FROM OXYGEN ISOTOPES AND U-TH-PB DEPTH PROFILING OF PRE-4 GA DETRITAL ZIRCONS FROM WESTERN AUSTRALIA. D. Trail¹, S. J. Mojzsis¹, T. M. Harrison² and MtREE (Mission to Really Early Earth) ¹Department of Geological Sciences and Center of Astrobiology, University of Colorado, Boulder, Colorado 80309-0399 USA. ²Research School of Earth Sciences, Australian National University, Canberra ACT 0200 Australia. dustin.trail@colorado.edu

Introduction: Because physical and chemical processes of the past are determined from analysis of a preserved geologic record, little is known about terrestrial crustal processes of the first 500 Ma during the so-called Hadean Eon. What is known from direct measurements has been derived almost exclusively from the study of >4.0 Ga detrital zircons from the Jack Hills, Western Australia [1-10]. The geochemistry of these zircons has direct application to understanding the origin and evolution of the rocks during the Hadean because: (i) U-Th-Pb age determinations by ion microprobe suggests the presence of crust as early as 4.37 Ga, or shortly after lunar formation [7,10,12]; (ii) high-resolution U-Th-Pb zircon depth profiles [11,13] reported here reveal several episodes of zircon growth in the Hadean previously unrecognized; (iii) core regions of pre-4.0 Ga zircons with igneous compositions are enriched in ¹⁸O and contain metaluminous and peraluminous mineral inclusions, both features indicative of S-type granitoid protoliths [5-8,10,12]. Study of these ancient zircons provides a unique window into the first half billion years that permits assessment of the potential of the Hadean Earth to host an emergent biosphere.

Methods: Zircons from the quartz-pebble conglomerate unit JH92 [5] are readily isolated using standard heavy mineral separation techniques. Grains are subsequently hand-picked, mounted on double sided adhesive tape and cast into 2.5 cm epoxy discs. Grain cores exposed during polishing are further polished to an optical finish using 0.05 μm alumina paste and cleaned in 0.5M HCl for ~30 sec to remove common Pb contamination.

Geochronology. All isotopic analyses were performed by high-resolution ion microprobe. Because >4.0 Ga zircons are relatively rare in the Jack Hills sediment (~50‰), all zircons were rapidly (~6 s/analysis) screened using the ANU SHRIMP II in multicollector mode [12]. This technique provides age estimates by measuring ²⁰⁴Pb, ²⁰⁶Pb, ²⁰⁷Pb and ²⁰⁸Pb on adjacent Faraday collectors. Zircons with high ²⁰⁷Pb/²⁰⁶Pb ratios (>0.4) were targeted for follow-up analyses by conventional U-Th-Pb ion microprobe geochronology on the ANU SHRIMP RG and ULCA Cameca ims1270 high-resolution ion microprobes [5].

U-Th-Pb Depth Profiling. Following age determinations, selected >4.0 Ga zircons were carefully plucked

from their mounts and an original prism surface placed face down on adhesive tape along with standards, recast and cleaned – without polishing – following our usual procedures [11,13]. The depth profiling mode obtains a continuous age profile as well as geochemical compositions that bear on conditions of zircon growth at a spatial scale (sub-μm) inaccessible to spot analysis of polished grains. In cases where symmetrical overgrowths record thermal events, features that are normally polished away to expose zircon cores may now be analyzed (Figure 1a, b).

Oxygen isotope determination. A subset of >3.8 Ga zircons was targeted for O-isotope analyses following sample repolishing and cleaning. All δ¹⁸O_{SMOW} zircon determinations were made on the UCLA Cameca ims1270 ion microprobe in multicollector mode [5]. Zircons with multiple age analyses have correlative O isotope spots. For all analyses, cracks and metamict areas were avoided and retrospective imaging was used to reject problematic data. To correct for instrumental mass fractionation, we used two oxygen isotope standards for zircon: KIM5 δ¹⁸O = +5.09‰ [14] and 91500 δ¹⁸O = +9.86‰ [15].

Results: In this study, we identified ~100 zircons that are at least 90% concordant and more than 3.8 Ga in age from the JH92 locality of the Jack Hills. Within this population, fifty-five grains were 4.0 Ga or older, including a 4.36 Ga zircon with slight reverse discordance; this result further confirms the existence of continental crust by ~4.37 Ga [7, 10, 12].

Our U-Th-Pb depth profiles of two zircons (JH92_fc08_5_3, and _104b) revealed common metamorphic events at 3946±9 Ma, 3943±6 Ma, and another event at 4036±2 Ma, that are chemically distinct from the (older) crystallization ages for these grains. We performed 150 separate oxygen isotope measurements on 100 zircons older than 3.8 Ga with standards intercalated between unknowns. Results show that 15 zircon cores have δ¹⁸O ≥ +7.0‰, and some have values as high as +10‰, in agreement with previous reports [5-8].

Conclusions: Based on results arising from the study, granitoid-type crust and hydrosphere-lithosphere interactions apparently were already in place within 100 Myr after lunar formation. Earth appears to have cooled rapidly, but why are there so few >4.3 Ga zircons?

- U-Th-Pb depth profiling demonstrates that zircons retain numerous overgrowth features recording responses to thermal/fluid events. Whether these were episodes of crustal growth or simply metamorphic events in the zircon protolith remains unknown. One intriguing possibility is that the overgrowths record thermal events related to impacts associated with the Late Lunar Cataclysm [17]. Rocks on the Moon (and presumably the Hadean Earth) were thermally metamorphosed within or under large, hot impact ejecta. The >4.0 Ga zircons are the only known terrestrial materials to have passed through the bombardment epoch; the common depth profile ages obtained here correspond remarkably well with age estimates for the peak mass-flux for the bombardment of the inner solar system at ~3.95 Ga [18].

- Oxygen isotope data show that the rock cycle evolved early, before *ca.* 4.37 Ga; $\delta^{18}\text{O}$ zircon values are as high as +10‰ (much higher than average mantle values) and estimates of $\delta^{18}\text{O}_{\text{WR}}$ are as high as +12‰. These zircons were not derived exclusively from a TTG-type protolith, but instead included some portion of hydrated, reworked crust.

Due to the scarcity of the >4.3 Ga age component (6/50,000), one goal of MtREE is to age characterize 100,000 Jack Hills zircons. So far, Western Australian zircons represent the only confirmed detrital minerals older than 4.0 Ga but we are also in the process of investigating other potential source terranes.

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