NEW ANALYSES OF DIVERSE HADEAN ZIRCON INCLUSIONS FROM JACK HILLS, WESTERN AUSTRALIA.

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Introduction: The geological record is the only direct source of information regarding physical/chemical processes that may have ultimately been responsible for the origin of life. Known terrestrial rocks have ages that span from present day to ~4.0 Ga [1]. This leaves a time gap of more than 500 Myr between lunar formation, and preservation of the oldest terrestrial crust. What were planetary conditions like wherein the prebiotic chemistry leading to life took place? The recent discovery of up to 4.37 Ga detrital zircons from Western Australia represents the only tangible record of the time period termed the Hadean Eon (4.5-4.0 Ga). Knowledge of the paragenesis of the oldest zircons potentially contributes information regarding the origin of the atmosphere, hydrosphere, continental lithosphere and the potential for life on the Hadean Earth.

Zircon Paragenesis: During its formation, zircon ($ZrSiO_4$) incorporates U (and Th) at the exclusion of Pb and has a high closure temperature (~900ºC) for radiogenic Pb* [e.g. 2]. Thus, zircon can “see through” high-grade metamorphism, making it the ideal crustal geochronometer. In addition, zircon can survive sedimentary re-working up to several sedimentary cycles and is a common accessory phase in many rocks – especially granitic melts – but can also sometimes be found in syenites, kimberlites, carbonates and mafic rocks, and can form during high-grade metamorphism [3].

Geological Background: The Narryer Gneiss Complex (*NGC*) in Western Australia is mostly composed of deformed and thermally metamorphosed granitoids and belts of supracrustal rocks. Metasedimentary rocks in the *NGC* include *ca.* 3.0 Ga fuchsitic quartz-pebble conglomerates of the Erawondoo Hill [4] outcrop (locality JH992) [5] of the Jack Hills; this rock contains the oldest known terrestrial zircons [5, 6]. Presently, several hundred detrital zircons from the original Jack Hills JH992 outcrop have been identified that exceed 4 Ga in age [7]. The geochemistry of mineral inclusions in zircon has direct application to understanding characteristics of the source melt, and thereby the rock type, from which the zircons were derived [3,5,8]. We have sampled another separate outcrop (sample JH0101) approximately 250 m west along strike from the original JH992 [5] and W74-X localities [6] and find that ~10% of the zircons examined from this new locality contain diverse mineral inclusions (rich in K-feldspar) different from those reported in previous zircon inclusion studies from the *NGC* [3]. We interpret these to be melt inclusions incorporated into the zircons during formation.

Methods: Due to its high density (~4.3 g cm^{-3}) and hardness, zircon is readily separable using standard heavy liquid techniques. Zircon-enriched heavy mineral separates are hand-picked; the grains are then mounted and cast in epoxy for analysis. Extreme care is taken during polishing as inclusions are easily lost from the host grain. Prior to inclusion studies, all zircons are rapidly screened for ages using the ANU SHRIMP-II in multicollector mode by measuring ^{204}Pb, ^{206}Pb, ^{207}Pb and ^{208}Pb on separate collectors. The oldest zircons were then selected for conventional U-Th-Pb zircon geochronology using the UCLA Cameca ims 1270 high resolution ion microprobe following our normal procedures [9]. Out of 1100 zircons analyzed in this study, 85 are concordant and greater than or equal to 3.8 Ga. Hadean grains targeted for zircon inclusion studies were imaged in transmitted and reflected light and analyzed using the OSU JEOL 733 electron microprobe.

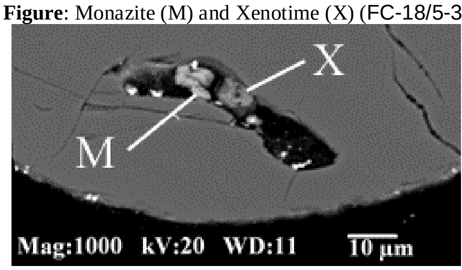
Results: In our Hadean zircon survey, several grains containing multiple inclusions were identified; 49 separate inclusions were found in 28 different zircons. It was common to see subsurface inclusions in transmitted light, which became analyzable with re-polishing. Inclusions discussed below are divided into two categories: those that were likely incorporated into the grain during crystallization and those which were likely incorporated later, predominantly via fluid infiltration through cracks.

The **Table** summarizes the compositional analysis of surface inclusions likely incorporated into the grain during crystallization. The age of the host zircon as well as the inclusion size are listed next to the mount/grain and inclusion identifier. Most inclusions were <5 µm in diameter and lacked a preferred orientation. The most common phases were quartz, K-feldspar (microcline or sanidine) and ubiquitous Fe-oxyhydroxides (FeOOH, likely hematite). Xenotime (YPO_4) was also present, often as small (~2 µm) sub-circular forms but remnants of a acicular ~2×50 µm inclusion in a 4.0 Ga grain was noted. Monazite ($(Ce, La, Th)PO_4$) was found in two different grains; one as a ~4 µm inclusion another in a larger inclusion pit (~40×10 µm) with xenotime (**Figure**).

Table: Zircon inclusions identified in this study

mount /grain	***inclusion***	***(7/6) age in Ga***	***inclusion size(µm)***
JH992_CU11/9-6	K-feldspar + (Ca)	3.8	~5
JH992_FC-08/5-3	xenotime	4.0	2x50
JH992_FC-08/5-3	monazite	4.0	~4
JH992_FC-08/5-3	K-feldspar	4.0	~2
JH992_FC-08/5-3	FeOOH	4.0	~2
JH992_FC-13/3-1	K-feldspar	4.2	~15
JH992_FC-15/9-2	FeOOH	3.9	~4
FC-16/6-1	xenotime	3.9	~2
FC-18/2-9	K-feldspar	3.9	~2
FC-18/2-9	xenotime	3.9	~6
FC-18/5-3	monazite xenotime	3.8	~40X10
FC-18/6-1	FeOOH	4.3	~2
FC-18/6-1	quartz	4.3	~10
FC-18/6-1	FeOOH	4.3	~3
FC-18/8-6	K-feldspar	4.1	~2
JH0101-1/3-19	quartz	4.0	~2
JH0101-1/6-10	K-feldspar	3.9	~2
JH0101-1/9-20	quartz	3.9	~3
JH0101-2/3-12	K-feldspar	4.0	~2
JH0101-2/3-15	quartz	4.3	~4
JH1010-2/9-8	ThO_2	4.1	~2
JH0101-2/9-15	K-feldspar	4.0	~2

Figure: Monazite (M) and Xenotime (X) (FC-18/5-3)



A small ~2 µm inclusion of thorite (ThO_2) was also found in a 4.1 Ga grain. Some inclusions, predominantly FeOOH, quartz, F-feldspar, TO_2 and xenotime appear in cracks of the grain. Xenotime also appears near grain edges.

Discussion: A recent study examined paleo-magnetics of zircon [10 unpublished]; a potentially measurable signal could be obtained from FeOOH inclusions as FeOOH has been shown to preserve paleomagnetic signals [e.g. 11]. Xenotime has been found to be a rapidly forming diagenetic phase on detrital zircons [12] and it is possible that some of the xenotime on edges as well as xenotime in the **Figure** may have worked into an old inclusion pit shortly after sedimentary deposition. Since this inclusion appears large enough that the surface may have been exposed prior sample preparation, a likely scenario is that the inclusion was once entirely monazite and upon deposition xenotime worked into a partially pitted inclusion hole. We note that monazite is considered a mineral diagnostic of peraluminous melts [13], but may also be an exsolution product of zircon. Clearly zircon-incompatible compositions such as K-feldspar are likely derived from an original melt inclusion. A ~15 µm K-feldspar inclusion in grain JH992_FC-13/3-1 is a good target based on size and the antiquity (~4.2 Ga) of the host grain. Work in progress seeks to determine the oxygen isotope composition of such inclusions in an effort to better constrain the source characteristics of the oldest known terrestrial solids.

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