HADEAN INCLUSIONS IN ZIRCON AND RUTILE MAY HOLD KEYS TO UNDERSTANDING EARLY EARTH CONDITIONS

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Introduction: Understanding and constraining the earliest events on Earth are important steps towards interpreting early geologic processes ultimately responsible for the origin of life. Meteorite inclusions have determined the age of the solar system to be approximately 4.57 Ga [e.g. 1]. This places an upper constraint on the age of the Earth, which cannot be dated statically because it actively recycles rocks, resetting their ages. Known terrestrial rocks range from present day to ~3.8 Ga. This leaves a significant gap of more than 700 Ma in Earth's early timeline where conditions developed which eventually lead to biotic chemistry. Our research addresses this period of time in Earth's history.

Background: The Narryer Gneiss Complex located in Western Australia is one of the few remaining Archean rock outcrops, which has 3.73-3.3 Ga granitic to tonalitic gneisses and 3.0 Ga metasedimentary rocks [2]. Hadean detrital zircon and rutile, which have formed in other rock assemblages, have been identified and analyzed at Jack Hills and Mt. Narryer; both localities of The Narryer Gneiss Complex.

Zircon Paragenesis: Zircons ($ZrSiO_4$) have the unique ability to withstand high-grade metamorphism and sedimentary transport [3, 4]. They contain information from the Hadean partially because of a high closure temperature of ~900ºC [e.g. 4]. Remarkably, several detrital grains have been identified over 4 Ga with the oldest at 4.404 Ga [3]; only 150 Ma younger than the solar system. With an age so close to the formation of the solar system, zircon is an important mineral for understanding early Earth. For example, oxygen isotope analysis has shown conclusive evidence for crust hydrosphere interaction in the Hadean [2, 3]. During zircon formation, uranium becomes incorporated within the grain, thus zircons are dated using the U-Pb method.

The range of Hadean zircon ages and the percent of Hadean zircons out of all analyzed are shown in Table 1. Taken from different locations in The Narryer Gneiss Complex, it is clear that Hadean zircons are not equally distributed either in age or frequency.

Table 1: Number of Hadean (3.8-4.45 Ga) zircons and their age range in The Narryer Gneiss Complex.

Mount name	Zircon tot.	Age range (Ga)	%Hadean
FC-16	100	3.9-4.3	10%
JH299 fc08	100	3.95-4.23	5%
FC-18	100	3.8-4.0	6%
JH992_CU11	100	3.8-4.3	13%
JH992_CU8	100	3.8-4.1	6%
JH0101-1	200	3.81-4.13	5%
JH0101-2	200	3.81-4.27	9%
TOTAL	900	3.8-4.3	7.6%

Rutile Paragenesis: Rutile (TiO_2) is also dated using the U-Pb method. Although a durable mineral, rutile's 600ºC closure temperature [6] is significantly less than zircon, making it unlikely to have survived high grade metamorphism events of ~700ºC without sustaining lead loss. Thus, it is possible that rutile may contain a U-Pb age younger than zircon in the same locality [6]. We have found rutile to contain inclusions of both monazite ((Ce, La, Th)PO_4) and zircon.

This Study, Methods, and Results: Recently, studies of Hadean zircon inclusions have focused on techniques for identifying inclusions [7]. Inclusions are minerals foreign to the zircon, which have become incorporated within the crystal structure. This study focuses on the identification and interpretation of inclusions. Additionally, the previously unexamined Narryer Complex rutile has been compositionally analyzed for inclusions.

Zircon and rutile were mounted in epoxy and polished to expose the surface of the grains. Using an Olympus BX51 petrographic microscope, transmitted and reflected light pictures were taken of the grains appearing to have inclusions. Analyzing the inclusions has been done with the OSU JEOL 733 Electron Microprobe (EMP). The EMP is an effective, non-destructive way to compositionally analyze these inclusions.

Table 2 summarizes the compositional analysis of surface inclusions for zircons in mount FC-18. A single grain can contain multiple inclusions as shown by grains 5-3 and 6-1. These grains have given a variety of inclusions: ((Ce, La, Th)PO_4), SiO_2, and YPO_4. We also see elemental iron spectrum lines in

Table 2: Data from FC-18 analyzed for inclusions using the OSU EMP.

Grain (inclusion #)	Inclusion	size (um)
2-9 (#1)	quartz + Sr, Rb	~3
5-3 (#1)	Monazite	~10
5-3 (#2)	xenotime, U	~10
6-1(#1)	quartz	~10
6-1 (#2)	Fe	~1
6-1(#3)	Fe	~3
8-6(#1)	quartz + Sr, Rb	~1

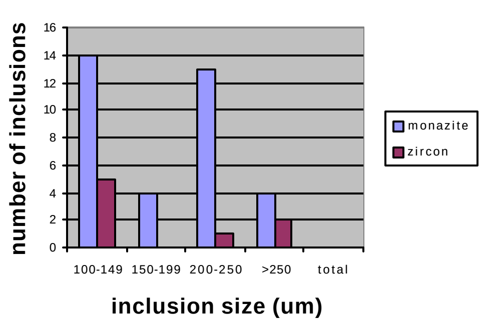
grain 6-1 from two different inclusions. At this time, no correlation between size and inclusion type is noticeable.

In the xenotime, uranium was found to exist in trace proportions. The quartz in grains 2-9 and 8-6 appear to have the parent-daughter rubidium-strontium pair. Other workers speculate (Valley and Peck) that rubidium and strontium can be present in quartz. This is indeed probable as the Si Ká1 line emits at 1.74eV, Rb Lá1 at 1.694eV, Rb Lâ1 at 1.752eV, and Sr Lá1 at 1.804eV. This would show considerable overlap in an EMP Energy Dispersive System (EDS) analysis, which we see in our results. Some quartz inclusions e.g. 2-9(#1) and 8-6(#1) analyzed appear to have uncharacteristically high spectrum peaks relative to other quartz inclusions e.g. 6-1(#1) implying Rb and Sr may be contributing to this high peak.

Mount JH0113 contains 372 grains of rutile. Of these, 49.5% contained inclusions with several grains containing multiple inclusions.

Although several inclusions were identified, those larger than 100 ì m^2 were rare. Figure 1 shows the number of monazite and zircon inclusions found with an exposed surface area greater than 100 ìm^2 and are thus large

Figure 1: Zircon and monazite incluisons in rutile



enough to date using an ion microprobe. Potentially 43 (35 monazite and 8 zircon) datable inclusions were found in 41 grains.

Potential Applications of Zircon/Rutile Inclusions: From past work, we know zircons and their inclusions crystallized in rocks different from which they reside in now. Oxygen isotope compositions in inclusions may hold the key to understanding the source melts for the zircons and thus melts present in the Hadean. The inclusions may also hold information about their buried or destroyed host rock.

As mentioned previously, Rb and Sr potentially exist in quartz inclusions of zircons and monazite and zircon exist in rutile inclusions. It may be possible to use the rubidium-strontium or U-Pb dating method respectively to possibly narrow the timeframe in which the hypothesized Earth-moon impact occurred [5]. For example, it is now thought this event occurred at 4.45 Ga hence the upper age limit of the Hadean Eon. Finding a terrestrial mineral with an age of 4.47 Ga would provide conclusive evidence that this event occurred earlier than previously thought.

Conclusion: Careful analysis of Hadean zircons inclusions may eventually help answer questions about early Earth. We have also identified rutile as a potentially useful mineral for Hadean Earth study.

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