Evidence for water on Hadean Earth

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The criteria thought necessary for life are: an energy source, organic molecules, and liquid water. Since the necessary energy sources and molecular building blocks for life were surely available during the formative stages of planetary evolution, the question of when life could first have emerged on Earth reduces to: When did liquid water first appear at the Earth's surface? While exposure of >3.83 Ga marine sediments indicates the presence of oceans by that time, strategies to assess an earlier hydrosphere are limited by the fact that there is no known Hadean (4.5-4.0 Ga) rock record. However, detrital zircons as old as nearly 4.4 Ga from the Jack Hills, Western Australia, present four kinds of evidence that suggest the presence of liquid water at or near the Earth's surface during the Hadean. Oxygen isotopes analyses of zircon provides a means to assess the isotopic composition of the protolith. High $\delta^{18}O$ values of some Hadean zircons, indicative of a clay-rich protolith, are interpreted as indicating crust-hydrosphere interactions prior to 4 Ga. Inclusion assemblages in Hadean zircons characteristic of hydrated, peraluminous parent magmas are suggestive of the melt protolith having originated at the Earth's surface and further suggest early development of sedimentary cycling in the presence of a hydrosphere. While specific circumstances could be convolved to create a high $\delta^{18}O$ signal along with peraluminous inclusions outside a surficial environment, they represent exceptional occurrences. Crystallization temperatures of >4 Ga granitoid zircons cluster strongly at 680±25°C from which we infer a regulated mechanism producing wet, minimum-melting conditions throughout the Hadean. This distribution is indisputably different from that produced by cooling of mafic and intermediate magmas and we conclude that the vast majority of Hadean zircons could not plausibly be derived from such sources. Instead, the simplest explanation for the dominant low temperature Hadean peak is that it reflects prograde melting under shallow conditions at or near water saturation. In effect, as soon as the source reached anatectic conditions, the majority of melt fertility was lost in the presence of excess water. Comparisons of U-Pb and U-Xe ages in Hadean zircons show varying degrees of Xe loss, but in some cases are concordant within uncertainty. Variable plutonium/uranium ratios in these zircons suggest that Pu and U could be mobile with respect to each other during the Hadean. As Pu and U can be strongly fractionated in aqueous systems, this may indicate, at least locally, the presence oxidized aqueous fluids in the Hadean crust. Although circumstantial, the four lines of evidence discussed above provide a cogent case for the presence of liquid water at or near the Earth's surface during much of the Hadean.

Rutile 207Pb-206Pb ages in the Jack Hills quartzite, Western Australia

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The Narryer Gneiss Complex of Western Australia is comprised of 3.73–3.30 Ga orthogneisses and ~3 Ga supracrustal rocks that experienced regional metamorphism and local granite emplacement at ~2.5 Ga. In the western Jack Hills, upper greenschist grade quartzites contain detrital zircons approaching 4.4 Ga and thus efforts have been made to date other detrital phases (e.g., monazite, chromite) but as yet the age distribution of rutile has not been assessed. The significance of discovering >4 Ga rutile grains is heightened by possible application of the recently calibrated Zr-in-rutile thermometer which permits a test the Hadean minimum-melting hypothesis of Watson & Harrison (2005). However, the lower bound of estimates of T_c for Pb in rutile, which range from 400-600°C, overlaps with the estimated peak metamorphic temperature in which case the potential for rutile to retain its primary crystallization age would be greatly reduced.

388 $^{207}Pb/^{206}Pb$ SIMS multi-collector analyses of 369 rutile grains from Jack Hills quartzite sample JH0113 yield an distinct age peak at ca. 2.5 Ga and an average age of 2.3±0.2 Ga. Age uncertainty for a 1 min analysis is typically ±2%. A traverse across one large grain revealed significant $^{207}Pb/^{206}Pb$ age variability. 33 of the dated grains were also analyzed for Zr by EMPA, counting with four spectrometers simultaneously. [Zr] was converted into crystallization temperature using the Watson *et al*. (2006) thermometer yielding a broadly normal distribution at 665±18°C. The highest recorded temperature (718°C) was obtained near the rim of a ~200 µm rutile grain with the core of the grain closer to the average value.

Given that crystallization temperatures are substantially higher than that attained during greenschist metamorphism, one interpretation is that the Zr-in-rutile thermometer has not been reset but that essentially complete Pb isotope exchange occurred at ca. 2.5 Ga. Alternatively, the very high Ti contents in cracks in detrital zircons from the Jack Hills suggests high Ti mobility during regional metamorphism due to dissolution/reprecipitation of Ti-bearing detrital grains. Evidence supporting this view comes from 2.5 Ga EMPA chemical Pb ages of monazites included in rutile which further suggest fluid-mediated dissolution/reprecipitation reactions at that time. This would explain the substantial disturbance to the $^{142,143}Nd$ systems in Hadean zircons (Caro *et al*., 2006) if monazite inclusions are the principal host of LREE's. This interpretation, however, does not explain the level and uniformity of the Zr-in-rutile temperatures and could suggest non-equilibrium Zr abundances in rutile.