THE HADEAN EARTH. T. M. Harrison (Institute of Geophysics and Planetary Physcis & Dept. of Earth and Space Sciences, UCLA, Los Angeles, CA 90095, U.S.A.) and Project MtREE.

Introduction: The Hadean Eon (4.5-4.0 Ga) is the dark age of Earth history; there is no known rock record from this period. However, detrital zircons as old as nearly 4.4 Ga from the Jack Hills, Western Australia, offer unprecedented insights into this formative phase of Earth history. Investigations using these ancient zircons suggest that they formed by a variety of processes involving a hydrosphere within ~200 m.y. of planetary accretion and challenge the view that continental and hydrosphere formation were frustrated by meteorite bombardment and basaltic igneous activity until ~4 Ga.

The Mission to Really Early Earth (MtREE): MtREE is an international consortium using Hadean zircons to investigate the earliest evolution of the atmosphere, hydrosphere, and continental lithosphere. However, these experiments require large quantities of >4 Ga zircons which are both small (typically 1-5 μg) and rare (~3%) in the detrital zircon population. To this end we have dated over 80,000 Jack Hills zircons to identify some 2500 Hadean grains which are being used in a variety of studies including: stable isotope analyses, single crystal Xe isotopic analyses to document the terrestrial Pu/U ratio, and initial ^{176}Hf/^{177}Hf and ^{142}Nd/^{144}Nd studies. The inclusion mineralogy of these ancient zircons points towards their origin in diverse but seemingly familiar petrogenetic settings. Xe isotopic results indicate that mantle-derived Xe isotopes cannot be interpreted in terms of the age of the atmosphere in a straightforward manner, but Hf isotopes indicate the existence of terrestrial continental crust as early as 4.5 Ga and that a mature sedimentary cycling system operating throughout the Hadean. In general, these first direct observations of the Hadean Earth appear to contradict most of our familiar assumptions about this period.

Origin of the hydrosphere: The observation of a heavy oxygen isotope signature in some Hadean zircons led Mojzsis et al. [1] to propose that the protolith of these grains contains ^{18}O-enriched clay minerals which in turn implies that liquid water was present at or near the Earth's surface by ca. 4.3 Ga. The presence of hydrated mineral inclusions of peraluminous character was taken as further evidence of a Hadean hydrosphere [1]. Using a new crystallization thermometer, Watson and Harrison [2], found that Hadean zircon crystallization temperatures cluster strongly at 680±25°C, similar to that of granitoid zircon growth today, substantiating the existence of wet melting conditions throughout the Hadean. This peak further suggests that an excess of water was available during prograde melting relatively close to the Earth's surface.

Origin of the continental crust: The long favored paradigm for continent formation is that initial growth was forestalled until ~4 Ga and then grew slowly until present day. However, a minority view [3] has persisted that continental crust was widespread during the Hadean. Initial ^{176}Hf/^{177}Hf ratios of Jack Hills zircons ranging in age from 3.96 to 4.35 Ga show surprisingly large positive and negative isotope heterogeneities indicating that a major differentiation of the silicate Earth occurred at ~4.5 Ga [4]. A likely consequence of this differentiation is the formation of continental crust with a volume of similar order to the present, possibly via the mechanism described by Morse [5].

Hadean plate boundary interactions?: The inclusion mineralogy of these ancient zircons include meta- and peraluminous assemblages suggestive of two forms of convergent margin magmatism. We interpret the 680±25°C zircon crystallization peak as due to minimum-melting during prograde heating, consistent with thrust burial. These data, and the seeming disappearance of the strongly positive and negative ^{176}Hf/^{177}Hf ratios by the early Archean, suggest that the Earth had settled into a pattern of crust formation, erosion, and sediment recycling by ~4.3 Ga similar in many respects to the known era of plate tectonics. New ideas regarding the feasibility of plate boundary interactions during the Hadean and independent evidence of widespread mantle depletion within 50 m.y. of Earth formation attract comparisons between >4 Ga plate interactions and the contemporary plate tectonic system. Our data tends to support the view of Armstrong [3] that the Earth almost immediately differentiated into relatively constant volume core, depleted mantle, enriched crust, and fluid reservoirs. Our results support the view that continental crust was a component of the enriched counterpart that formed at 4.5 Ga, but that this original crust had largely been recycled back into the mantle by the onset of the Archean.

References: [1] Mojzsis S.J., Harrison, T.M. and Pidgeon R.T. (2001) *Nature*, *409*, 178. [2] Watson E.B. and Harrison T.M. (2005) *Science*, *308*, 841. [3] Armstrong R.L. (1981) *Phil. Trans. Roy. Soc. Lond. Series, A* 301, 443. [4] Harrison T.M. et al. (2005) *Science*, *310*, 1947. [5] Morse S.A. (1987) *EPSL*, *81*, 188.