Heterogeneous Hadean hafnium: Evidence of continental crust by 4.5 Ga?

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The paradigm for continent formation long favoured by isotope geochemists is that growth began at ~4 Ga and was ~80% of its present mass by 2.5 Ga. This view reflects the absence of a >4 Ga rock record and the systematic post-4 Ga evolution of depleted mantle $^{143}Nd/^{144}Nd$ and $^{176}Hf/^{177}Hf$. The observations of some early Nd and Hf isotopic heterogeneities leave open the possibility of earlier global fractionations and a minority view has persisted that continental crust was widespread in the early Hadean (e.g., Armstrong, 1981; Reymer and Schubert, 1984). In this regard, the relative lack of evidence of earlier depletions (from a magma ocean or continent formation) reflects remixing of these heterogeneities. Detrital zircons from Jack Hills, Australia, with 4.0-4.4 Ga U-Pb ages transcend this ambiguity as they represent pieces of crust that have been sequestered for up to ~4.4 Ga. Zircons have very low Lu/Hf and thus record near initial $^{176}Hf/^{177}Hf$ at the time given by the U-Pb age. Amelin et al. (1999) used Jack Hills zircons as old as 4.14 Ga to investigate early crustal evolution and inferred the existence of re-melted Hadean crust. We have carried out $^{176}Hf/^{177}Hf$ analyses by both solution and laser ablation MC-ICPMS on over 70 Jack Hills zircons ranging in age from 3.96 to 4.35 Ga. These results indicate very large positive and negative $\varepsilon_{Hf(T)}$ deviations from CHUR (λ_{176} = 0.01867/Ga; $^{176}Hf/^{177}Hf$ = 0.282772; $^{176}Lu/^{177}Hf$ = 0.0332). Negative values of $\varepsilon_{Hf(T)}$ equivalent to $(^{176}Hf/^{177}Hf)_{4.5\ Ga}$ observed between 4.35 and 4.2 Ga are consistent with development of a Lu/Hf = 0 reservoir by 4.5 Ga. Positive $\varepsilon_{Hf(T)}$ deviations in the same age interval imply a depleted reservoir with Lu/Hf up to 0.08. We interpret these results as indicating either 1) that the remains of original mantle heterogeneities from accretion were not yet well mixed by mantle convection by 4.35 Ga, or 2) that significant continental crust had formed by ~4.5 Ga. The latter interpretation is consistent with inferences from $\Delta^{142}Nd$ systematics (Caro et al., 2003; Boyet et al., 2003).

Crystallization temperatures of Hadean zircons: Plate tectonics at 4.35 Ga?

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As the sole know survivors from the Hadean Eon, the detrital zircons of Western Australia's Narryer Gneiss Complex have already provided intriguing glimpses into the state of the very early Earth. Given the significance of the chemical and isotopic information these crystals contain, it is crucial to understand the circumstances under which they grew. Knowledge of their crystallization temperatures, in particular, would place useful constraints on the types of magmas being produced during the Hadean. Toward this goal—and to provide information on zircons of all ages—we have calibrated a new thermometer based on the concentration of Ti in zircons coexisting with rutile, using both high P-T experiments and analyses of natural zircons of well-constrained provenance. Zircon Ti content varies by three orders of magnitude over the temperature range ~600°–1450°C, and is insensitive to changes in pressure. In applying this new thermometer to zircons removed from their original context (such as detrital Hadean zircons), coexistence with rutile cannot be assumed. However, thermodynamic considerations show that TiO_2 activities generally range from 0.5 to 1.0 in igneous and metamorphic systems capable of crystallizing zircon. That range of TiO_2 activities affects calculated temperatures by only a few 10's of °C. Sixty-eight analyses of 55 Jack Hills zircons from 4.0 to 4.35 Ga in age yield temperatures ranging from 791° to 659°C (710±32°). This range is indistinguishable from that expected of granitoid zircon formation today, and strongly suggests a limited range of regulated mechanisms producing zircon-bearing rocks during the Hadean. Combined with the suite of mineral inclusions observed by previous workers, these temperatures substantiate the existence of wet, minimum-melting conditions within 200 m.y. of solar system formation. They further suggest that by 4.35 Ga, the Earth had settled into a pattern of crust formation, erosion, and sediment recycling similar to that produced during the known era of plate tectonics.