Exploring the Hadean Earth

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There is little question that the first 500 million years of Earth evolution, known as the Hadean Eon, was the most geodynamically vigorous in our planet's history. During this time, it is variously speculated that the Earth may have experienced collision with a Mars-sized-object, formed a global magma ocean, grown the first continents, and seen the emergence of life. It is also entirely possible, and consistent with the geochemical record, that none of these events took place. The fundamental problem is that we have no rock record from this interval to learn about these processes as the oldest firmly dated rock is only 4 Ga. How then are we to gain further insights into the formative stages of Earth evolution? While no Hadean rocks are documented, we are not entirely without a geochemical record during this period.

The existence of zircons with U-Pb ages of >4 Ga preserved in Early Archean metasediments at Jack Hills, Western Australia, has been known for 20 years. Recent studies have begun to glean information from these zircons regarding the nature of the Hadean Earth. For example, O isotopes have been interpreted as indicating that protoliths of magmas from which Hadean zircons crystallized were formed in the presence of water at the Earth's surface. Crystallization temperatures of >4 Ga zircons cluster strongly at 680±25° from which we infer a regulated mechanism producing wet, minimum-melting conditions throughout the Hadean. Xe isotopic studies of these ancient zircons permit estimates of the initial terrestrial Pu/U, a parameter key to understanding the origin and evolution of the atmosphere. $^{176}Hf/^{177}Hf$ ratios of Hadean Jack Hills zircons show large heterogeneities indicating a major differentiation of the silicate Earth at ~4.5 Ga. A possible consequence of this differentiation is the formation of continental crust of similar order to the present.

Together these data suggest that the Earth had settled into a pattern of crust formation, erosion, and sediment recycling by ~4.3-4.4 Ga similar in many respects to the known era of plate tectonics. New ideas regarding the feasibility of plate-like tectonic behaviour during the Hadean and independent evidence of widespread mantle depletion within 30 m.y. of Earth formation permit development of quantitative models which compare possible Hadean plate boundary interactions with the contemporary plate tectonic system.