

Early Earth

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Events during the first billion years of Earth History include formation of the Earth, Moon, Earth's core, a differentiated crust, oceans, and life¹. The first report of a 4.4 Ga terrestrial zircon² has been confirmed in multiple SIMS labs³⁻⁵. Atom probe tomography shows concentration of unsupported radiogenic Pb in 5-10-nm clusters, but that Pb mobility does not bias the age of a 4.4 Ga zircon crystal³. The Hadean zircon suite proves that Earth had a differentiated crust within 150 million years of the formation of Earth. Tectonics during the first billion years are uncertain. The pre-4-Ga zircons give evidence of intermediate composition parent magmas, like TTGs of the Archean, but not for wet or S-type granites. This interpretation is consistent with plume, stagnant-lid or subduction-related magmatism in the Hadean. Meteorite bombardment was intense during this period, but the occurrence of a late heavy bombardment at ca 3.9 Ga is unproven. Shocked or impact-melt zircons have not been located in the Hadean suite^{6,7}. There is no evidence that these events would have sterilized Earth. The Moon was in closer orbit to the early Earth, and may have received and preserved terrestrial debris from major impacts. The pre-4-Ga zircon oxygen isotope record shows that prevalent low temperature aqueous alteration caused mildly elevated $\delta^{18}\text{O}$ in magmas, and thus that the early steam atmosphere condensed to form liquid-water oceans before 4.3 Ga^{2,8,9}. Solar luminosity was $\sim 70\%$ as intense as today suggesting either that a heavy greenhouse atmosphere existed or that the Hadean Earth was a snowball world. In the later case, volcanoes and hot-springs were active, creating liquid water locally. Small sub-ice melt-pools are a more attractive environment for concentration of components for the first life than an open ocean¹⁰. Either way, the Earth was habitable to life before 4.3 Ga.

[1] Early Earth issue of *Elements* 2006, v2, #4 [2] Wilde *et al* 2001 *Nature* [3] Valley *et al* 2014 *Nature Geosci* [4] Holden *et al* 2009 *IJMS* [5] Nemchin *et al* 2006 *EPSL* [6] Montalvo *et al* 2014 *LPSC* [7] Wielicki *et al* 2012 *EPSL* [8] Valley *et al* 2002 *Geology* [9] Cavosie *et al* 2005 *EPSL* [10] Valley 2008 *Geology*.