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Earth after the Moon-forming impact

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The Hadean Earth is widely and enduringly pictured as a world of exuberant volcanoes, exploding meteors, gaping craters, infernal heat, and billowing clouds of sulfurous steams; i.e., a world of fire and brimstone punctuated with blows to the head. In the background a gigantic Moon looms over the sky. The popular image has given the Hadean a name that celebrates our mythic roots. A hot early Earth appears to be an inevitable consequence of accretion.

The Moon-forming impact left Earth enveloped in a hot silicate atmosphere that cooled and condensed over $\sim$1000 years. As it cooled the Earth degassed its volatiles into the atmosphere. It took another $\sim$2 Myrs for the magma ocean to freeze at the surface. The cooling rate was determined by atmospheric thermal blanketing, and tidal heating by the new Moon was a major energy source. After the mantle solidified geothermal heat quickly became climatologically insignificant, allowing the water vapour to condense and leaving a $\sim$100 bar, $\sim$500 K CO_2 atmosphere.

The next stage of cooling was controlled by how quickly CO_2 was removed from the atmosphere into the mantle or into stable crustal rocks. If carbonate subduction were efficient this could have taken as little as 10 Myrs. In this case the faint young Sun suggests that a lifeless Earth should have quickly become habitable and indeed quite cold, its oceans white with ice. But if carbonate subduction were inefficient the CO_2 would have mostly stayed in the atmosphere and the surface would have held near 500 K for many tens of millions of years. Hydrous minerals are harder to subduct than carbonates and there is a good chance that the Hadean mantle was dry.

Hadean heat flow, augmented by tidal heating, was locally high enough to ensure that any ice cover would have been thin in places. Moreover hundreds or thousands of asteroid impacts would have been big enough to melt the ice triggering brief impact

summers. We suggest that plate tectonics as it works now was inadequate to handle typical Hadean heat flows of 0.2-0.5 W/m^2. In its place we hypothesize a convecting mantle capped by a $\sim$100 km deep basaltic mush that was relatively permeable to heat flow. Recycling and distillation of hydrous basalts produced granitic rocks very early, which is consistent with preserved 4 Ga detrital zircons.