The Bombardment of the Earth During the Hadean and Early Archean Eras

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Our knowledge of the Earth during the Hadean and early Archean eons (ca 4.5-3.5 Ga) is very limited, mainly because few rocks older than 3.8 Ga have been found (e.g. Harrison 2009). Hadean-era zircons have allowed us to glean important insights into this era, but their data has led to considerably different evolution models for the evolution of the early Earth; some predict a hellish world dominated by a molten surface with a sporadic steam atmosphere (e.g. Pollack 1997), while others have predicted a tranquil, cool surface with stable oceans (e.g. Wilde et al 2001; Valley et al 2002). To understand whether either model (or both) could be right, we believe it is useful to quantitatively examine the post Moon-forming impact bombardment of the early Earth.

Over the last several years, through a combination of observations (e.g., Marchi et al 2012), theoretical models (e.g., Bottke et al 2012), and geochemical constraints from lunar rock (e.g. highly siderophile elements -HSE- abundances delivered to the Moon by impactors; the global number of lunar basins; the record of Archean-era impact spherule beds on Earth; Walker 2009; Neumann et al 2012), we have constructed a calibrated model of the early lunar impactor flux (Morbidelli et al 2012). Our results have now been extrapolated to the Earth, where they can make predictions about its post-Moon formation bombardment, the so called *late accretion*.

Using a Monte Carlo code to account for the stochastic nature of major impacts, and constraining our results by the estimated HSE abundances of Earth's mantle (that were presumably delivered by impactors; Walker 2009; Bottke et al. 2010), we find the following trends. In the first ~100-200 Myr after the formation of the Moon, which we assume was created ~4.5 Ga, the Earth was almost entirely resurfaced by impacts. This bombardment, which included numerous D > 1000 km diameter impactors, should have vigorously mixed the crust and upper mantle. Between ~4.1-4.3 Ga, the impactor flux steadily decreased; though an uptick near ~4.1 Ga caused by the so-called Late Heavy Bombardment should have delivered a new round of large impactors striking at a mean velocity ~1.5 times higher than in previous epochs. Overall, only a relatively small fraction of ancient terrain survives unscathed all the way to the early Archean. We speculate that if impacts are involved with Hadean zircon formation, a scenario we find plausible, the apparent preference for ~4.1 Ga ages among Hadean zircons may be a combination of (i) terrain (and zircon) preservation and (ii) the ability of large impactors to create zircons (i.e., ~4.1 Ga would potentially be the "sweet spot" in this competition).

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