A New Look at Hadean Habitability

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The scientific community's longstanding view of Hadean Earth as a desiccated, continent-free, lifeless, wasteland onto which bolide impacts drove surface petrogenesis has been challenged by geochemical investigations of >4 Ga Jack Hills zircons. The picture that emerges from these studies is of a planet much more similar to today than long believed, including the formation of H_2O-rich granites under geotherms consistent with convergent plate boundary interactions. Given general agreement that life could not have emerged until liquid water appeared at or near Earth's surface, a significant implication is that our planet may have been habitable as much as 500 Ma earlier than previously thought. Indeed, carbon isotopic evidence obtained from inclusions in Hadean zircons is consistent with life having emerged by 4.1 Ga, or several hundred million years earlier than the Late Heavy Bombardment (LHB) – a hypothesized episode of intense impacts into the Earth-Moon system at ~3.9 Ga long assumed to have frustrated the emergence of life. Evidence for what was a bedrock assumption in planetary science for over 40 years grew out of observations of local lunar isotopic disturbances but was later significantly bolstered by histograms of $^{40}Ar/^{39}Ar$ dates of Apollo samples which appeared to many to show distinct peaks at ~3.9 Ga. These histograms in turn were used to constrain a series of dynamical simulations of the solar system (the "Nice" models) in which giant planet migrations unleash massive amounts of asteroidal material into the inner solar system. However, the LHB concept has come under critical scrutiny of late. Rocks returned from Apollo missions represent less than 4% of the Moon's surface while lunar meteorites, which sample both the near- and farside of the Moon, show no such age spike. Since the lunar crust formed in a relatively brief interval between ~4.3 to 4.5 Ga, subsequent impacts onto that surface would systematically reduce K-Ar ages, potentially yielding apparent spikes at ages which do not correspond to bombardment episodes. Indeed, simulations show that the very nature of the $^{40}Ar/^{39}Ar$ evidence used to support the LHB concept has an intrinsic tendency to create illusory age spikes and along with it the temptation to interpret them in terms of impact history. These two developments free us from longstanding lore and should only encourage efforts seeking to find earlier signs of life on this planet and beyond.