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The Moon-Forming Giant Impact and Earth's Early Evolution from Xenon and Tungsten Isotopes

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Even in the absence of a rock record, Earth's accretion and its early evolution can be probed using decay systems that are now extinct, such as Hf-W and I-Pu-Xe. For example, plume and MORB sources show different xenon isotopic compositions that suggest these reservoirs had developed different histories by the end of accretion and the isotopic anomalies were not subsequently erased by mantle convection. Here we explore Earth's accretion, the timing of the Moon-forming giant impact and early outgassing by coupling the Hf-W and the I-Pu-Xe systems and varying the degree of core-mantle equilibration. We assume that there are three phases during Earth's accretion: a main phase of exponentially decaying growth; a late giant impact; and a final addition of ~10% material in smaller, differentiated bodies. The latter phase is justified by the relative concentrations of moderately volatile to volatile elements, including iodine. We assume that the whole mantle undergoes partial core re-equilibration during a late giant impact, but that the late addition of material is only to the upper 80% of the mantle, the proto-MORB source, while the bottom 20% is the plume source. We find that a giant impact later than 90 Ma does not develop a sufficient Xe isotope difference between the plume and MORB reservoirs, thus placing an upper bound on the timing of the giant impact while a lower bound of 50 Ma is placed by the tungsten isotopes. Under our assumptions, matching the present-day xenon isotopic values requires that at most 8% of the ^{129}Xe produced through the decay of ^{129}I in the mantle was retained through accretion, indicating intense degassing of interior volatiles during accretion and suggesting that Earth's volatiles may have been concentrated in the surface reservoirs in the aftermath of accretion. Finally, we find that between the end of Earth's accretion and the beginning of the Archean, at least 65% of the Earth's mantle was processed through partial melting. This result indicates that a substantial volume of crustal material was generated by the end of the Hadean.