Terrestrial upper mantle I-Pu-Xe and the age of the Moon

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As Earth accreted, volatiles were delivered by incoming material and lost by degassing and impact-driven ejection to space. The Moon-forming giant impact initiated the final catastrophic outgassing and bulk volatile ejection event on the early Earth. Lithophile short-lived radionuclides with volatile, atmophile daughters are particularly well-suited to probe the degassing of the early Earth, as mantle budgets of the products should have largely been generated after the last giant impact (LGI). Radiogenic ^{129}Xe was produced by β-decay of the extinct nuclide ^{129}I ($t_{1/2}$ = 15.7 Ma) in the first ~90 Myr of Earth history. Fissiogenic ^{131}Xe, ^{132}Xe, ^{134}Xe, ^{136}Xe were produced in distinct, characteristic proportions by the fission of extinct short-lived ^{244}Pu ($t_{1/2}$ = 80.0 Myr) and extant long-lived ^{238}U ($t_{1/2}$ = 4.468 Gyr). By pairing radiogenic (^{129}Xe) and plutogenic (^{244}Pu-derived) $^{136}Xe_{Pu}$, one may compute a closure age for the upper mantle.

I-Pu-Xe closure age calculations are based on a model where outgassing during accretion effectively removes all gaseous species from the silicate Earth until the Moon-forming giant impact, after which point the mantle is closed and thus retains radiogenic and fissiogenic Xe. Based on the ratio of radiogenic ^{129}Xe to plutogenic ^{136}Xe determined for the upper mantle, we calculate an I-Pu-Xe closure age for the upper mantle of ~44-70 Myr after the start of the Solar System. Our closure age is significantly older than previous upper mantle Xe closure age determinations of ~100 Myr [1], as well as direct radiometric ages of lunar crustal samples [e.g., 2].

In order to explore the effects of accretion timescales, partial retention of Xe during accretion, and long-term degassing associated with mantle processing on the Xe closure age, we present a new model of I-Pu-U-Xe systematics. We find that for LGI's between ~35 and 70 Myr after the start of the Solar System, we are able to satisfy constraints on I-Pu-U-Xe systematics simultaneously. For late Moon-forming giant impacts (after ~80 Myr), a high degree of volatile retention during accretion is required.

[1] Pepin, R.O., Porcelli, D., 2006. *EPSL*, 250(3-4): 470-485. [2] Borg et al., *Nature*, 477, 70–72.