Missing Pb, High $^3He/^4He$, Ancient Sulfides and Continental Formation

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The classical "Pb isotope paradox", that major crustal and mantle reservoirs have Pb isotopes more radiogenic than bulk silicate Earth, requires a missing reservoir with sufficiently unradiogenic Pb [1]. This missing unradiogenic Pb has been argued to be in the lower continental crust or dissolved in the core early in Earth's history, but granulite terranes are not sufficiently unradiogenic and the timing of core formation implied by Pb sequestration into the core is too young compared to that determined by ^{182}Hf-^{182}W systematics. Here, we propose that the formation of continental crust requires the formation of a large complementary reservoir of sulfide-bearing mafic cumulates, consistent with observations of sulfide-rich pyroxenite cumulates in volcanic arcs, where continental crust is forming today [2]. Because Pb strongly partitions into sulfides and U is negligible in these cumulates, the formation of continents over Earth's history must have simultaneously generated a time-integrated unradiogenic Pb reservoir composed of sulfide-bearing cumulates, now recycled back into the mantle or stored in the continental lithosphere. Because ^4He are key products of the U-Th-Pb decay system, the generation of an unradiogenic Pb reservoir should lead to coupled He-Pb isotopic systematics. We show that He is soluble in sulfide melts, such that sulfide-bearing cumulates would be enriched in both Pb and He relative to U and Th, "freezing" in $^3He/^4He$, $^{206}Pb/^{204}Pb$ and $^{207}Pb^*/^{206}Pb^*$ (the ratio of radiogenic ingrowth of ^{207}Pb and ^{206}Pb since the Earth formation) of the ambient mantle at the time of sulfide formation. Tapping of ancient sulfide-bearing cumulates may thus provide a simple explanation for why the high-$^3He/^4He$ endmember in ocean island basalts (OIBs) is commonly associated with low-$^{206}Pb/^{204}Pb$ and high-$^{207}Pb^*/^{206}Pb^*$ [3, 4]. Therefore, the high-$^3He/^4He$, -$^{207}Pb^*/^{206}Pb^*$ and low-$^{206}Pb/^{204}Pb$ reservoirs in the OIB source may represent the complements of continent formation rather than primordial parcels of the mantle that have remained unprocessed through Earth's entire history.

[1] Allegre, C. J. (1968) *EPSL* **5,** 261-269. [2] Lee, C.-T. A. *et al* (2012) *Science* **336,** 64-68. [3] Class, C. & Goldstein, S. L. *Nature* **436,** 1107-1112. [4] Jackson, M. G. *et al* (2010) Nature **466**, 853-856.