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On the origin and significance of Archean crustal Pb isotope heterogeneity

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The existence of substantial initial Pb isotope heterogeneity in many Archean terranes is well documented, yet, the origins of this heterogeneity are poorly understood. Here, new in-situ Pb isotope data from orthoclase in >100 granite samples from across the Archean Yilgarn Craton are used to evaluate the Pb isotope variability of the craton's silicate rocks and to illuminate its Pb isotope evolution. The Pb isotope variability of the granites require three Pb distinct sources, a mantle-derived Pb component and two crustal Pb reservoirs, distinguished by their implied ^{232}Th/^{238}U ratios (). Some granites have ^{208}Pb/^{204}Pb ratios >33.7. These "High-" granites are largely co-located with Eoarchean–Paleoarchean crustal sources and require a super-chondritic source with ^{232}Th/^{238}U ratios (~4.7). Pb isotope compositions for most granites, and those of several types of ores, define a mixing array between a mantle Pb source and the "High-" granites. This scatter indicates the Pb isotope variability within the craton reflects mixing between mantle-derived material and pre-existing high-Th/U crust. Pb isotope modelling indicates that these older crustal source rocks experienced Th/U fractionation at 3.3-3.2 Ga or earlier. On modern Earth, Th and U have identical geochemical behaviour in magmatic environments but are fractionated during weathering and erosion as under oxidising surface conditions U^{4+} is converted into the water-soluble hexavalent species while Th remains tetravalent and immobile. However, Th/U fractionation in the Yilgarn Craton must have occurred long before Earth's atmosphere became oxygenated at 2.5–2.4 Ga. Hence, subaerial weathering cannot explain the difference in apparent geochemical behaviour of Th and U. Instead, we posit that the high- source reflects Eoarchean-Paleoarchean rocks that experienced prior high-temperature metamorphism, partial melting, and melt extraction in the presence of a Th-sequestering residual mineral such as monazite. Thus, it appears that Archean Pb isotope variability originated from open-system high-temperature metamorphic processes that were responsible for the differentiation and stabilization of Earth's first continental nuclei.