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The sulfur isotope compositions of the marble cake-mantle

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Mantle outcrops show pyroxenite layers embedded within peridotites, with pyroxenites possibly linked with recycled oceanic crust. This observation underpins the "marble cake" mantle analogy, as discussed by Allègre and Turcotte in 1986. It describes the upper mantle as dominantly peridotitic with “elongated strips of subducted oceanic lithosphere”. While pyroxenite in massifs have diverse origins, their presence as recycled crust in the mantle may explain the radiogenic isotope heterogeneity observed in mid-ocean ridge basalts (MORB).

The marble cake notion also provides a framework for understanding mantle volatile budgets and stable isotope compositions, distinguishing juvenile from recycled components. Sulfur isotope data from MORB reveal significant $^{34}S/^{32}S$ variations, consistent with the incorporation of subducted materials. These variations are accompanied by near-invariant ^{33}S signatures (average $\Delta^{33}S = +0.004 \pm 0.012$‰, 2 s.d.), ruling out substantial Archean contributions and suggesting that the marble cake ingredients are predominantly post-Archean. In contrast, plume-related samples, such as those from Mangaia, exhibit more variable $\Delta^{33}S$ values. Sulfide inclusions from olivines and pyroxenes, ran via isotope ratio mass spectrometry, show $\Delta^{33}S$ values up to $+0.049 \pm 0.016$‰. These signatures are distinct from MORB but still within the realm of post-Archean values. They point to heterogeneous recycled oceanic crust in the Mangaia plume source. Strikingly, similar S isotope signatures are observed in graphite-bearing garnet pyroxenites from the Beni Bousera Massif (Morocco), which share key geochemical features with the Mangaia plume source. This parallel provides direct evidence for the inherent heterogeneity of recycled crust in mantle sources, linking the deep mantle sampled by plumes to the pyroxenite-rich lithologies exposed at the surface.

Together, these findings illustrate how recycled oceanic crust contributes to the chemical and isotopic heterogeneity of Earth's mantle. Originally sketched to explain radiogenic isotope variability, the marble cake mantle analogy is also relevant for interpreting stable isotopes of volatiles, such as sulfur, in mantle derived rocks. This analogy offers insights into the long-term recycling processes that shape the composition and dynamics of Earth's interior, bridging the gap between mantle geochemistry and geodynamics.