Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.36838

Geochemical-Geodynamic Controls on the Mantle's Radiogenic Isotope Distribution

JACKSON COPELAND, THOMAS DUVERNAY AND D. RHODRI DAVIES

Australian National University

The global radiogenic isotope distribution recorded by oceanic basalts is widely used to infer the mantle's structure, composition, and dynamics. Yet it remains unclear how the observed distribution maps onto the mantle's chemical structure and convective mixing regimes, leaving substantial uncertainty in interpretation. Key steps toward resolving this uncertainty are to establish whether the radiogenic isotope distribution can be reproduced in a dynamic context, identify which geochemical and geodynamic parameters exert first-order control on it, and determine which inferences from it are robust.

Here we develop a computationally efficient model of whole-mantle evolution that couples a statistical representation of convective stirring and processing histories with simple models of mid-ocean ridge melting, subduction-zone dehydration, mantle wedge metasomatism, and continental crust production and recycling.

We first demonstrate that our model can reproduce the observed distribution using a range of empirically-derived geochemical parameters. We then perform sensitivity experiments spanning plausible parameter ranges and show that the radiogenic isotope distribution is governed primarily by patterns of chemical fractionation, the extent of melt homogenization, and the rate of mantle stirring and processing. In this framework, geodynamics modulate the spatio-temporal accessibility of mantle materials, while geochemical fractionation patterns dominate their evolved radiogenic isotope compositions.

Our model reproduces key features of the distribution and places constraints on how it is shaped by mantle dynamics, structure, and composition. Results suggest that (i) the mantle hosts a continuous spectrum of radiogenic isotope compositions that spans several times the range expressed in erupted basalts; (ii) the mantle 'zoo' need not reflect sampling of discrete, long-lived mantle 'species' because oceanic basalts emerge from averaging and mixing of distributed heterogeneities, with apparent end-members (including PREMA-like compositions) arising naturally from the statistics of stirring and assemblage mixing; and (iii) isotopically enriched basalts (e.g. HIMU-like and EM1-like) reflect greater contributions from old, compositionally diverse recycled components with HIMU-like signatures linked to dehydrated oceanic crust and EM1-like signatures linked to continental material.

Overall, this framework reproduces the global radiogenic isotope distribution in a dynamic context and provides a lightweight platform for systematically testing coupled geochemical-geodynamic hypotheses.