Geophysical Research Abstracts
Vol. 21, EGU2019-6214, 2019
EGU General Assembly 2019

Ancient Origin of LLSVPs from the Contrasted distribution of Primitive Helium and recycled Lead in the Lowermost Mantle

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A major goal in Earth Science has been to understand how geochemical characteristics of lavas at the Earth's surface relate to the location and formation history of specific regions in the Earth's interior. The strongest evidence for the preservation of primitive material comes from the low 4He/3He ratios of helium in ocean island basalts, but the location of the primitive reservoir(s) remains unknown. Recent seismic tomographic studies have documented the presence of vertically oriented low shear velocity conduits rooted at the core-mantle boundary, in the vicinity of some hotspots, confirming the plume hypothesis of Morgan (1971), although the conduits are broader than predicted by pure thermal convection models. In the uppermost 1000 km of the mantle, these conduits become narrower and meander towards the hotspots, manifesting the effect of mantle wind in the lower viscosity of this part of the mantle. As a consequence, the deep mantle roots of these conduits are frequently offset laterally with respect to the corresponding hotspots. Remarkably, these conduits all originate in the lowermost mantle large low shear velocity provinces (LLSVPs).

Here we combine whole-mantle seismic tomography models, simulations of mantle flow, and a combination of new and compiled measurements of the helium isotopic composition of ocean island basalts to examine the relationship of the source region within the lowermost mantle hosting primitive 4He/3He material in the mantle to the LLSVPs. When the lateral deflection of plume conduits by ambient mantle flow is accounted for, a strong relationship emerges between minimum 4He/3He ratios in oceanic basalts and regions that are significantly slower than average in the lowermost mantle, while ocean island basalts derived from areas outside anomalously slow seismic regions in the lowermost mantle do not exhibit primitive 4He/3He ratios. In contrast, no significant relationship is observed between maximum 208Pb*/206Pb* ratios (which is a gauge of how enriched a material is with respect to recycled crustal and/or lithospheric materials) and these seismically slow regions in the deep mantle. This suggests that primitive material is spatially restricted to the LLSVPs, while recycled materials are more broadly distributed across lower mantle provinces. Since primitive 4He/3He ratios are also associated with xenon and tungsten isotopic anomalies, this also suggests that the primitive portion of these seismically slow regions formed during Earth's accretion and survived the Moon-forming giant impact along with 4.5 billion years of mantle convection.