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Depleted peridotite in the Hawaiian plume caused an increase in buoyancy and magma flux

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Mantle plumes are known to be both thermally and compositionally distinct from the ambient mantle [1]. However, the relative balance between the contribution of excess heat and plume composition to plume density, and thus the buoyancy force of upwelling, is not known. For instance, geophysical observations of the Hawaiian–Emperor chain reveal a sharp increase in magma volume flux since ~3.5 Ma that remains unexplained [2]. Here, we use radiogenic isotope data of plume-derived melts to investigate temporal changes in Hawaiian plume dynamics with two important innovations: (1) we present the first comprehensive radiogenic Ce isotope dataset on Hawaii (n=32: Kaua‘i, Ni‘ihau, O‘ahu, Kaho‘olawe, Big Island), and (2) we use computational tools to quantify plume density from isotope data through a thermochemical model.

Our Ce–(Sr–Nd–Hf) isotope systematics of Hawaiian lavas reveals recycled mafic crust in the plume that was previously concealed within the wide recycled sediment – peridotite melt mixing trend. These data also better constrain the nature of isotopically depleted source components of the Hawaiian plume. We find that the degree of (time-integrated) melt depletion of upwelling plume peridotite varies through time along the chain, with a sharp increase in depletion (DM + 10%) between 3 and 1 Ma. We calculate that the density anomaly associated with this increased depletion is about –20 kg/m^3, equivalent in magnitude to the anomaly caused by excess temperature (~200 K). In contrast, recycled oceanic crust sustains a modest density anomaly in opposite sense of +5 kg/m^3.

Our results suggest thermal anomaly and degree of partial melting remain mostly constant through time. Rather, we find that the increased magma volume flux since ~3.5 Ma is a result of increased plume buoyancy flux around 3 Ma caused by increasingly depleted, and thus compositionally buoyant peridotite in the plume. Our work reveals that anomalies in peridotite depletion in the convecting mantle can have first-order consequences on upwelling dynamics, illustrating the importance of a multidisciplinary approach to study mantle dynamics and evolution.

[1] Farnetani and Samuel (2005), *GRL, 32*(7).

[2] Vidal and Bonneville (2004), *JGR: Solid Earth 109*(B3).