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Estimating the carbon budget of the Earth's deep mantle from petrogenesis of silica-poor ocean island basalts

RAJDEEP DASGUPTA[1] AND CHENGUANG SUN[2]

[1]Rice University

[2]The University of Texas at Austin

Presenting Author: rajdeep.dasgupta@rice.edu

Earth's convective mantle is the largest carbon reservoir in the Bulk Silicate Earth (BSE), but its carbon content remains highly uncertain due to limited constraints on carbon inventory of the deep mantle. This knowledge gap can be filled by a global assessment of CO_2 in ocean island basalts (OIBs), which are associated with upwelling mantle plumes from the deep mantle. However, this approach is hindered by the limited samples of undegassed, primary melts from intraplate magmatic settings and the debate on the origin of volatile-rich alkaline OIBs from plume versus lithospheric mantle. Here we examine the origin of silica-poor, alkaline OIBs and constrain CO_2 in the primary melts of global OIBs by taking advantage of a newly developed liquid-based thermobarometer [1], primary melt correction scheme, and the well-established correlation between melt SiO_2 and CO_2 contents for silica-poor mantle-derived magmas [e.g., 2]. The averaged primary melt compositions of alkaline OIBs from individual island groups are more CO_2-rich (~3–11 wt% CO_2) than those of subalkaline OIBs (~0–7 wt% CO_2), but both series from the same island groups yield final equilibration with the mantle at ~100–150 km and mantle potential temperatures of ~1430–1530 °C. Our findings indicate that alkaline and subalkaline OIBs are generated from carbon-rich and carbon-poor domains, respectively, in the mantle plume sources, rather than deriving from two different sources in the plume and lithospheric mantle or variable extents of melting of a homogeneous source. Despite the source heterogeneity, CO_2 in the primary melts of individual island groups displays strong positive correlations with Nb and Ba, which define robust CO_2/Nb (1850±196) and CO_2/Ba ratios (226±22) for the less-degassed deep, OIB source mantle. Combining these ratios with primitive mantle Nb and Ba contents, we estimate that the deep mantle on average has ~330–400 ppm carbon. If the OIB source mantle carbon budget is mostly primordial, our estimation provides a useful reference point for undifferentiated BSE to further examine carbon distribution and/or loss through Earth's history.

[1] Sun & Dasgupta (2020) EPSL; [2] Dasgupta et al. (2007) JPet