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The mantle source of thermal plumes: Trace and minor elements in olivine and major oxides of primitive liquids (and why the olivine compositions don't matter)

Keith Putirka[1,*], Yan Tao[2], K.R. Hari[3], Michael R. Perfit[4], Matthew G. Jackson[5], and Ricardo Arevalo Jr.[6]

[1]Department of Earth and Environmental Sciences, California State University, Fresno, 2576 E. San Ramon Avenue, Fresno, California 93740, U.S.A.
[2]State Key Laboratory of Ore Deposit Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, 550002, China
[3]School of Studies in Geology and Water Resource Management, Pt. Ravishankar Shukla University, Raipur-492010, Chhattisgarh, India
[4]Department of Geological Sciences, University of Florida, Box 112120, Gainesville, Florida 32611-2120, U.S.A.
[5]Department of Earth Science, University of California Santa Barbara, Santa Barbara, California 93106-9630, U.S.A.
[6] Planetary Environments Lab, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, U.S.A.

Abstract

We estimate the mantle source compositions for mantle plumes and, by implication, Earth's lower mantle by: (1) measuring trace (e.g, Sc, V, Cu) and minor (e.g., Ca, Mn, Ni) element concentrations of high-forsterite olivine grains from several plume localities, (2) estimating the parent liquid compositions from which they crystallized, (3) calculating mantle potential temperatures and degrees of partial melting, and (4) estimating trace element compositions of depleted and enriched mantle sources. Our sample set includes two continental flood basalt provinces (Emeishan and Deccan), a flood basalt that erupted in a continental rift setting (Baffin Island), our type example of a thermal mantle plume (Hawaii), and lavas from the Siqueiros Transform at the East Pacific Rise, which represent the mid-ocean ridge system. We also present olivine (Ol) compositions for peridotite xenoliths from Kilbourne Hole, New Mexico, U.S.A., which are commonly used as primary and secondary analytical standards. We find that trace elements in lava-hosted olivine grains are too far removed from their mantle source to provide anything but greatly hindered views of such. Olivine compositions reflect not only evolving liquid compositions (including partial melting conditions and later fractionation), but also evolving Ol+liq partition coefficients, which mostly increase with decreasing T during crystallization. Mantle compositions, delimited by maximum forsterite contents and estimates of parental magmas (and experimentally determined partition coefficients) indicate that our selected plumes reflect some combination of (1) a depleted mantle source that is quite similar to that obtained by other methods and (2) a variably enriched plume source that is more enriched than current estimates of pyrolite. The enriched plume mantle sources can be explained remarkably well as a mixture of subducted mid-ocean ridge basalt (MORB; Gale et al. 2013) and depleted MORB mantle (DM; Salters and Stracke 2004), with MORB:DMM ratios of 1:5 to 1:4. These ratios are most sensitive to estimates of melt fraction where plume parental magmas are last equilibrated with their mantle source, but are nonetheless consistent across a wide range of chemically very different elements, and estimates of MORB and DM obtained by very different means. Baffin Island is of particular interest. Like prior studies, we verify a high mantle potential temperature (T_p) of 1630 °C (compared to T_p = 1320–1420 °C for MORB from Cottrell and Kelley 2011 for Ol of $Fo_{89.3–91.4}$). The Baffin source is also within error the same as DM with respect to trace elements, although still isotopically distinct; Baffin appears to be sourced in something that is akin to DMM that lies at the base of the mantle, where plumes acquire their excess heat. Thus while part of our analysis supports the concept of a "slab graveyard" at the bottom of the lower mantle (e.g., Wyession 1996), that cemetery is by no means ubiquitous at the CMB: subducted slabs are either unevenly interred, or efficiently excavated by later upwellings.

Keywords: Olivine, plumes, mantle composition, lower mantle, Baffin Island, Hawaii, Deccan, Emeishan