Source components of the Hawaiian shield lavas and their distribution in the plume

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The Hawaiian-Emperor volcanic island and seamount chain has been created by a hot mantle plume located beneath the Pacific lithosphere. The shield volcanoes of the Hawaiian islands are distributed into two curvilinear parallel trends, termed 'Kea' and 'Loa' (Jackson et al., 1972). Lavas from these two trends are believed to have different geochemical characteristics (Tatsumoto, 1978; Frey et al., 1994; Hauri, 1996; Lassiter et al., 1996; Abouchami et al., 2005). The Kea- and Loa- geochemical trends within the Hawaiian shield volcanoes have been interpreted to reflect melting of a plume that is either concentrically (Hauri, 1996; Lassiter et al., 1996; Kurz et al., 1996; DePaolo et al., 2001) or left-right asymmetrically (Abouchami et al., 2005) zoned in composition. However, numerous geochemical studies have shown that Hawaiian mantle plume is chemically and isotopically heterogeneous and consists of three mantle source components: namely the Kea, Koolau and Loihi components (Blichert-Toft, 2003; Eisele et al., 2003; Huang et al., 2005). Ren et al. (2005), based on the melt inclusion compositions from the Hawaiian shield olivines, suggested that although one mantle source component may dominate a single lava flow, the two (or more) mantle source components are consistently represented to some extent in all lavas, regardless of the specific geographic location of the volcano.

To evaluate the origin and distribution of the components in the Hawaiian mantle plume, we examined major and trace elements and Hf, He isotope compositions of fresh submarine lavas from the Koolau, Kilauea, and Loihi as these three volcanoes are believed to have sampled the three distinct Hawaiian plume components. On the basis of our new data combined with previous whole rock (Ren et al., J. Petrol., 2004; 2006) and melt inclusion data (Ren et al., 2005, Nature), we propose a Hawaiian mantle plume characterized by more random heterogeneity than would be present in a simple compositionally zoned mantle plume. We infer from these data that: the Koolau component consists of a higher proportion of ancient recycled oceanic crust and pelagic sediment; the Kea component contains a higher proportion of ancient recycled peridotitic lithospheric mantle (Lassiter and Hauri, 1998); and the Loihi component is derived from the lower mantle. The plume may have a peridotite matrix from the lower mantle with recycled oceanic crust and lithosphere mantle that may remain distinct geochemistry, forming streaks or ribbons distributed throughout the entire plume. The geochemical differences in the shield volcanoes likely reflect different amounts of mixing proportions of the three components. The dominant component sampled at a given shield volcano is likely to be controlled by the thermal structure of the plume. As the volcano grows, it migrates away from the hot plume axis due to plate motion. During the early stages of shield growth, the magma source is in the plume core. The resulting high temperatures are able to generate melts from not only of the pyroxinite component (that is formed by silica-rich melt from the recycled oceanic crust reaction with the surrounding peridotite), but also of the more refractory component (that is peridotite from the lower mantle) to form Loihi-like melt with alkalic and tholeiitic at relatively deeper depth. This is because, peridotite from the lower mantle is 'wetter' with higher volatiles than the ancient recycled peridotite. Therefore, the former is lower in melting point than that of the later at a given depth. Kea-like melt with tholeiitic would be generated after Loihi-like melt at shallower depth and the proportion of melt from the 'dry' ancient recycled peridotite would be higher. These compositions of melt generated in the plume center have become progressively more silica-saturated with time, reflecting higher degrees of partial melting as the melting occurs progressively shallower. In contrast, lavas from some of the late-stages of the Hawaiian shields are Loa-like with isotopically 'enriched' characteristics (for example, Mauna Loa, the Haleakala shield (Honomanu), and Koolau shield Makapuu stage), implying that the proportion of the subducted oceanic crust component contributing to the melt may be higher relative to the peridotitic matrix. This is because during the generation of the later-stage lavas, their mantle source is located significantly far away from the mantle plume center for the temperature to be lower. Therefore the lower melting point component (e.g. pyroxinite) of the plume is preferentially sampled by the melt.

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