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Hawaiian mantle xenoliths and magmas: Composition and thermal character of the lithosphere

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Abstract

Recent seismological investigations into the Hawaiian mantle and geophysical studies of the Hawaiian Swell have led to divergent models regarding the thermal structure and role of the lithosphere in Hawaiian magmatism. Whereas some models require that the Hawaiian plume erodes the lower lithosphere and replaces it with plume-derived residues and cumulates, others do not require any thinning of the lithosphere. In this paper, we develop a model for the physical and thermal characteristics of the oceanic lithosphere beneath Oahu, Hawaii, from the mantle xenoliths included in the rejuvenated stage lavas (Honolulu Volcanics, HV) that erupted through the Salt Lake Crater (SLC) and Kaau-Pali-Kalihi (KPK) vents. Three main xenolith suites are found at Oahu: spinel peridotite, garnet pyroxenite, and dunite. Dunites are generally shallow cumulates, whereas the peridotite and pyroxenite xenoliths are from the mantle. Plagioclase peridotite (harzburgite) is rare, and represents a ~15 km thick lithospheric layer below the ~15 km thick crust (MOR-generated oceanic crust + thickened crust formed by Koolau shield volcano activity). The harzburgite layer is underlain by a spinel peridotite layer. Spinel peridotites from SLC and KPK differ in chemical and isotopic composition. SLC spinel peridotites have unusually enriched $^{176}Hf/^{177}Hf$ but highly nonradiogenic $^{187}Os/^{188}Os$ isotopic compositions, likely indicating that they are metasomatized, recycled (previously subducted) oceanic lithospheric fragments. On the other hand, KPK spinel peridotites exhibit compositional characteristics of the 90 m.y. old lithosphere beneath Oahu that has been variably metasomatized by passing HV magmas. We suggest that the lower lithosphere beneath SLC and KPK are very different in their petrologic composition. The lower lithosphere (60–90 km) beneath SLC is extensively veined and fragmented by garnet clinopyroxenite intrusives and mixed with spinel peridotite blobs that are recycled subducted lithospheric fragments. For the KPK lithosphere, we favor a model in which the lower part is peridotitic. The thickness of our model lithosphere beneath Oahu is ~90 km. The seismic low-velocity zone beneath Oahu is likely due to the presence of small amounts of hydrous-alkalic and carbonatitic (+kimberlitic) melts. The isotopic data suggest little or no interaction between the basal lithosphere and Koolau shield magmas (mostly plume-derived, particularly those with near bulk-earth Nd- and Sr-isotope ratios), suggesting that during shield-stage volcanism, magmas used well-insulated (i.e., a reaction zone of <2 km radius) narrow conduits that reached down to the base of the lithosphere. All of the deeper (>60 km) xenoliths are isotopically depleted and lack the typical Koolau-like signature. Therefore, the lower lithosphere was not significantly eroded by Koolau magmatism. KPK spinel peridotites give temperatures of 900–1040 °C for the intermediate lithosphere, which is about 200–400 °C hotter than what would be expected of a normal 90 Ma lithosphere. We suggest that such an anomalously high temperature is due to heating of the wall rocks (lithosphere) by ascending HV magmas and not due to simple basal heating of the lithosphere by the hot spot/plume followed by gradual (conductive) upward transport of heat. Thermobarometry of garnet-bearing xenoliths suggests that these rocks equilibrated at ~2–3 GPa and 1200–1350 °C. This temperature range is 50–200° less than that predicted by a recent model (Ribe and Christensen 1999). The plume that generated the Koolau shield magmas was a complex mixture composed predominantly of Koolau source materials at its center and blocks of old recycled lithosphere in its outer fringes that were later rafted into the lithosphere beneath SLC.