Triple-spike Pb isotope data on Hawaii Scientific Drilling Project (HSDP) lavas: The roles of upper mantle and lower oceanic crust

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The Hawaiian plume, which is presently located between Mauna Loa, Kilauea Volcanoes of the Island of Hawaii and Loihi seamount SE of the island, produces basalts with a large range of isotopic compositions. Three features of these have been discussed in the literature (1) There is a consistent pattern in which late stage, post-shield alkali basalts and nephelinites have lower $^{87}Sr/^{86}Sr$ and higher $^{143}Nd/^{144}Nd$ ratios than the tholeiitic shield basalts. This is attributed to progressively increasing contributions to the melt composition from depleted-upper-mantle, non-plume sources, as each volcano moves away from the plume-fed magma supply (Chen and Frey, 1983). (2) Two isotopically distinct trends have been defined, the 'Loa trend' and 'Kea trend', which have been interpreted as samples from the central (Loa trend) and more peripheral (Kea trend) parts of a radially zoned plume (e.g. Lassiter et al., 1996; Hauri et al., 1996). However, Eiler et al. (1996) have recently shown that actually not two but three isotopically distinct components, labeled Loihi, Koolau and Mauna Kea components are needed to explain the available data for the shield lavas alone. These authors showed that the Kea source component is characterized by low $\delta^{18}O$ values and suggested that it represents gabbros from the present-day, lower oceanic crust. In contrast, Hofmann and Jochum (1996) inferred from trace element characteristics common to all Hawaiian tholeiites that a recycled, formerly gabbroic source component is present in all Hawaiian volcanoes.

The Hawaiian Scientific Drilling Project (HSDP) offers the opportunity to study the temporal evolution of the lavas within an individual volcano. The future drill hole, planned for a penetration depth of 4500 m, will provide the opportunity to test the zoned-plume model, because Mauna Kea has migrated from peripheral to more central to again more peripheral parts of the plume, and it is therefore expected to provide a systematic record of the zoning. The previous HSDP samples provide a record to a depth of only 1000 m, which is, however, sufficient to examine the relationship between the late-stage alkali basalts and the underlying shield-forming, tholeiitic lava. Lead isotope ratios have the unique property that all binary mixtures form straight linear arrays in, $^{207}Pb/^{204}Pb$-$^{206}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$-$^{206}Pb/^{204}Pb$ space. They therefore also provide the opportunity to separate individual end members in mixtures of more than two components. In the past, however, it has normally been difficult to exploit this intrinsic advantage of the system, because the analytical error of lead isotope measurements may be on the order of 1 ‰ per mass unit as a result of instrumental isotope fractionation. For $^{207}Pb/^{204}Pb$ ratios, this error is frequently of the same order of magnitude as, or larger than, the natural variations of a given sample suite.

We present Pb isotope data obtained using the Pb triple spike (TS) to correct for instrumental isotope fractionation on Mauna Loa and Mauna Kea lavas from the HSDP. The TS Pb isotopic data are compared with previously published Pb data obtained by conventional methods (Hauri et al., 1996; Lassiter et al., 1996). Sr and Nd isotopes were also measured on separate dissolutions for Mauna Loa and for Mauna Kea samples when no Sr and Nd isotopic data were already available. The external reproducibility for Pb isotope ratios based on 5 duplicate analyses of samples is similar to that reported for the NBS-981 standard (Galer and Abouchami, This volume) and is of the order of 100 ppm for all three ratios $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$. Our new Pb isotope data for both volcanoes compare relatively well with previously reported $^{206}Pb/^{204}Pb$ ratios. As expected, however, the scatter in $^{207}Pb/^{204}Pb$ ratios reported for Mauna Kea lavas (15.43 to 15.52) is reduced to a small range of 15.47 to 15.49. The deviation on the $^{207}Pb/^{204}Pb$ ratio can be as high as 3‰ in the case of sample R-160 reported by Lassiter et al. (1996).

The Mauna Loa lavas have lower Pb isotope ratios compared with Mauna Kea in agreement with previously published data. Only a single sample of HSDP alkali basalts has previously been analysed for Pb isotopes. The isotope ratios recorded in the upper

200 m of drill core, in which the transition from tholeiites to alkali basalts occurs, show a trend toward low $^{87}Sr/^{86}Sr$ (= 0.70345) and $^{206}Pb/^{204}Pb$ (= 18.40) ratios (along with high Nd ratios). This trend reverses the general negative correlation between these two parameters in Hawaiian shield lavas. Such a positive Sr-Pb isotope correlation for the tholeiite to alkali basalt transition is also evident in published data from Haleakala and Honolulu Series from Oahu (Chen and Frey, 1983). We infer that this low-$^{87}Sr/^{86}Sr$ - low-$^{206}Pb/^{204}Pb$ component represents depleted upper mantle, irrespective of whether it is located in the outer part of a zoned plume (which has entrained some depleted asthenospheric mantle) or in the lower part of the oceanic lithosphere (which may be partially melted by the plume).

In contrast, the 'Kea component' of Hawaiian shield lavas, identified by the principal-component analysis of Eiler *et al.* (1996), is characterized by high $^{206}Pb/^{204}Pb$ (= 18.64) and low $^{87}Sr/^{86}Sr$ (= 0.7034). If the Kea component did indeed represent present-day oceanic crust (as proposed by Eiler *et al.*), it should have the isotopic characteristics of the upper mantle beneath Hawaii, from which this oceanic crust was created, and this mantle is characterized by low rather than high Pb ratios. However, the question remains whether the $^{206}Pb/^{204}Pb$ ratio of the Kea component might have been raised from a depleted-mantle value of about = 18.40 to 18.64 by *in situ* decay of uranium within the lower oceanic crust (as suggested by Eiler *et al.*, 1996). To assess this, we estimate the maximum U/Pb ratio of the Kea component from the observed U/Pb ratios of Mauna Kea lavas, assuming that the U/Pb ratio of the source is equal to or less than the ratio in the melt. Mauna Kea lavas have U/Pb ratios about 2.0 times the primitive mantle value (Hofmann and Jochum, 1996). Within the available time of about 100 Ma, this will raise the $^{206}Pb/^{204}Pb$ value by about

0.14. This is significantly less than the increase of 0.24 required by the observed ratio of the Kea component. Consideration of the measured U/Th ratios of the lavas yields the same result. Any significant uptake of uranium by hydrothermal alteration, invoked by Eiler *et al.*, should also increase the U/Th ratio of the source and the lavas derived from this. In fact, however, Mauna Kea U/Th ratios are indistinguishable from Mauna Loa U/Th ratios within the scatter of about 10 % (e.g. Hofmann and Jochum). Thus there is no evidence for hydrothermal U uptake either from Pb isotopes or from U/Th ratios. We conclude that in-situ decay within the present-day oceanic crust cannot account for the high $^{206}Pb/^{204}Pb$ ratio of the Kea component. Instead, the above considerations of the available lead isotope systematics from Mauna Kea and other Hawaiian volcanoes show that the special isotopic and chemical characteristics of the Mauna Kea component are most likely inherited from ancient, recycled oceanic crust. On the other hand, the trend toward MORB-like compositions with low $^{206}Pb/^{204}Pb$ ratios seen in the transition from shield to alkalic stages reflects an increasing involvement of depleted source material from the upper-mantle asthenosphere or lithosphere.

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