V51B-0553

Geochemical Constraints on the Enriched End-member of the Hawaiian Plume: Temporal Geochemical Variation Within the Koolau Shield

Shichun Huang (huangs@mit.edu) and Frederick A. Frey (fafrey@mit.edu)
Department of Earth, Planetary and Atmospheric Sciences
Massachusetts Institute of Technology
Cambridge, Massachusetts

Introduction:

Although shield-stage lavas of Hawaiian volcanoes are derived from the Hawaiian hotspot, commonly inferred to be a mantle plume, many Hawaiian shields are distinct in major and trace element abundances, as well as isotopic ratios. Some of these geochemical differences may be related to melting processes, but there is no doubt that the mantle source for Hawaiian shield lavas is geochemically heterogeneous. Compositions of lavas collected from subaerial exposures of the Koolau shield on Oahu (hereafter referenced as Makapuu-stage lavas) (Fig. 1) define an extreme endmember. They are characterized by relatively high SiO_2 content, SiO_2/Fe_2O_3*, Al_2O_3/CaO, La/Nb, Sr/Nb, $^{87}Sr/^{86}Sr$, $^{187}Os/^{188}Os$, $\delta^{18}O$ and low total iron and CaO contents, $^{143}Nd/^{144}Nd$, $^{176}Hf/^{177}Hf$ and $^{206}Pb/^{204}Pb$ (e.g., Fig. 2; Frey et al., 1994; Roden et al., 1994; Lassiter and Hauri, 1998; Blichert-Toft et al., 1999). These geochemical characteristics have provided support for recycled oceanic crust, including sediments, in the source of Koolau lavas.

Important Questions:

1. Does the entire Koolau shield have the end-member geochemical characteristics manifested by the subaerially exposed Makapuu-stage of Koolau lavas ?

2. What is the origin of Makapuu-stage of Koolau lavas?

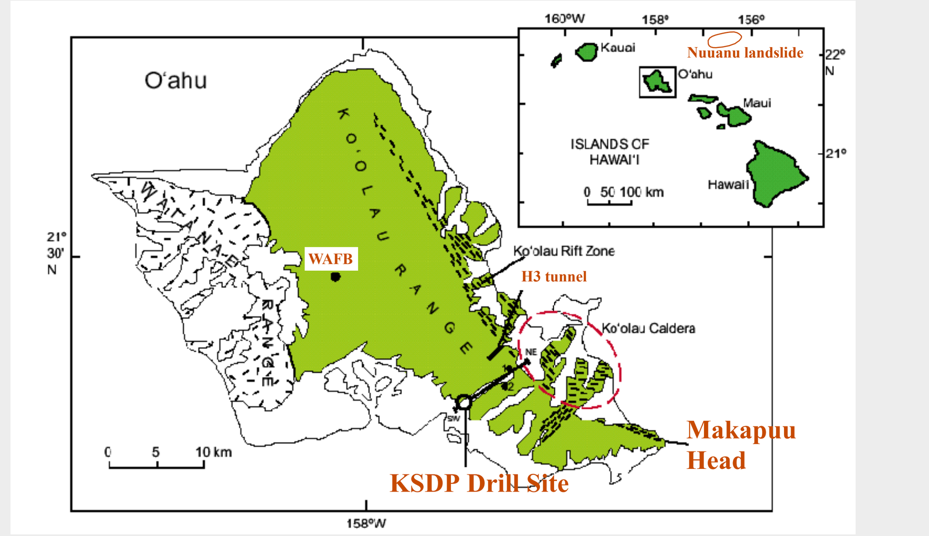


Fig. 1 Map of the island of Oahu shows the drill site of Koolau Scientific Drilling Project (KSDP) and locations of previously studied surface samples (Makapuu Head), tunnel section (H3) and drill hole (WAFB) (from Haskins and Garcia, 2004). The insert shows the Hawaiian Island Chain and the position of Nuuanu landslide blocks studied by Tanaka et al. (2002).

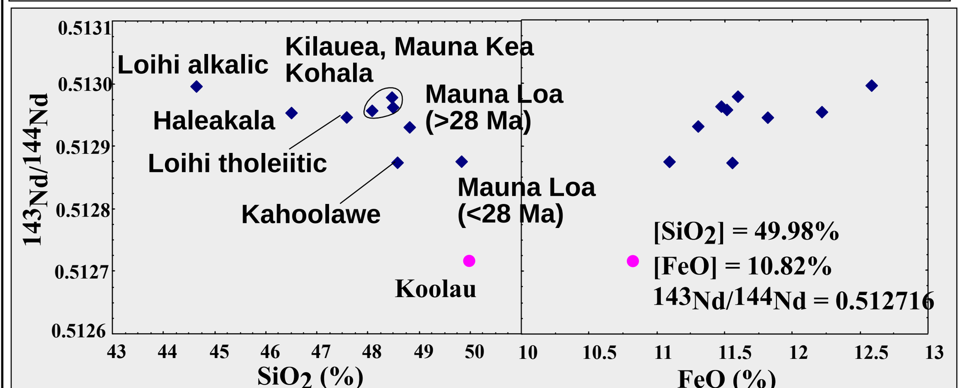


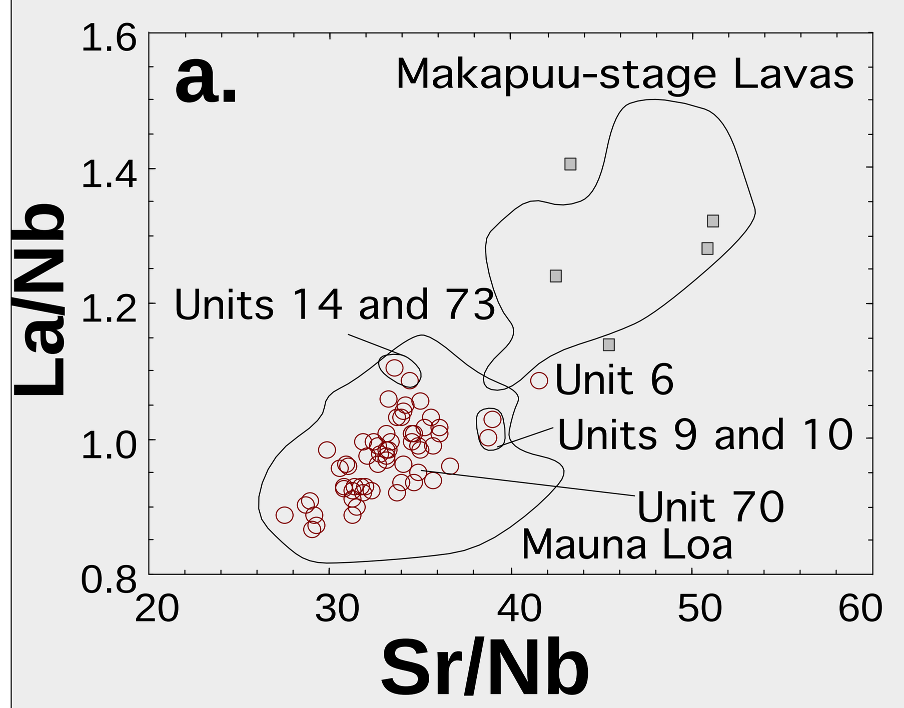
Fig. 2 SiO_2 and total iron contents vs $^{143}Nd/^{144}Nd$ for Hawaiian shields. Taken from Hauri (1996). Each point stands for average composition of a single Hawaiian shield or distinctive stratigraphic section of a Hawaiian shield. Among Hawaiian shields, Makapuu-stage lavas are characterized by high SiO_2 content but low total iron content and $^{143}Nd/^{144}Nd$. The average SiO_2 content and $^{143}Nd/^{144}Nd$ of Koolau lavas estimated by Hauri (1996) are labeled in the figure, and the high SiO_2 is inferred to result from addition of a dacitic melt with 64% SiO_2 and 6% MgO and $^{143}Nd/^{144}Nd$ = 0.5113.

Koolau Scientific Drilling Project (KSDP)

A deeper sampling of the Koolau shield was obtained by deepening and coring a ~350 m water well to a depth of ~678 m (Haskins and Garcia, 2004). The core includes ~103 lava flows from the lowermost ~328 m of the hole. Based on petrography and compositions of whole-rocks and glasses, Haskins and Garcia (2004) conclude that the distinctive geochemical features of uppermost Koolau lavas (Makapuu-stage) "**form a veneer only 175-250 m thick at the drill site**".

In this project we report ICP-MS data for 26 trace elements in 91 KSDP samples and 15 Makapuu-stage samples. We use these data, in conjunction with major element compositions and Nd-Hf-Pb isotopic ratios (Haskins and Garcia, 2004; Fekiacova et al., in prep.; Salters et al., in prep.), to understand the temporal evolution of Koolau shield lavas.

Are KSDP lavas Similar to Makapuu-Stage of Koolau Lavas? - No!



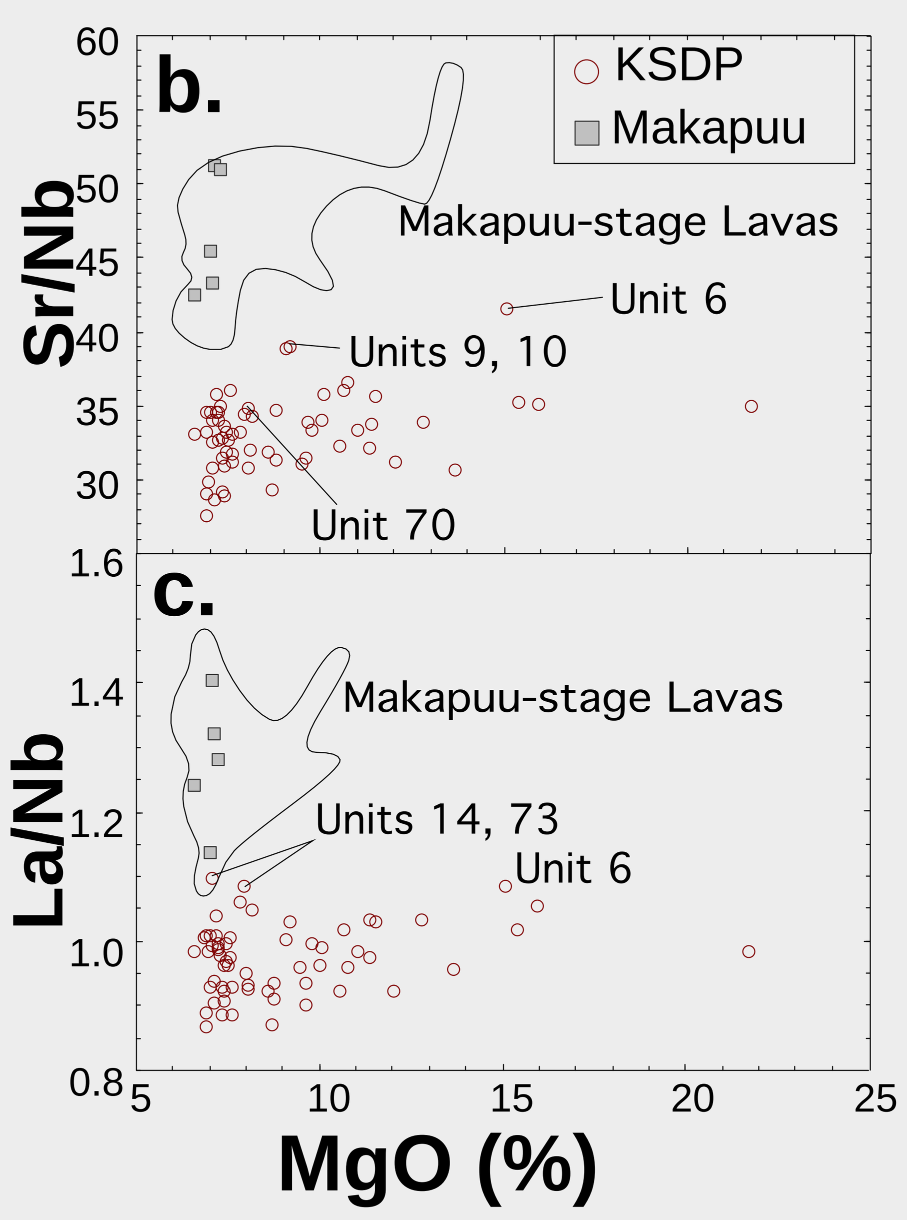


Fig. 3. Relative to other Hawaiian shield lavas, Makapuu-stage lavas have high La/Nb and Sr/Nb (Squares in figure are our new analyses, and the field labeled as "Makapuu-stage Lavas" is defined by data from Frey et al. (1994)). In contrast KSDP lavas (circles in figures) do not have relatively high ratios; their ratios are similar to Mauna Loa lavas. However, a few KSDP lavas (especially uppermost Units 6, 9 and 10) have ratios which are close to Makapuu-stage lavas. The differences in Sr/Nb and La/Nb are not a function of MgO content.

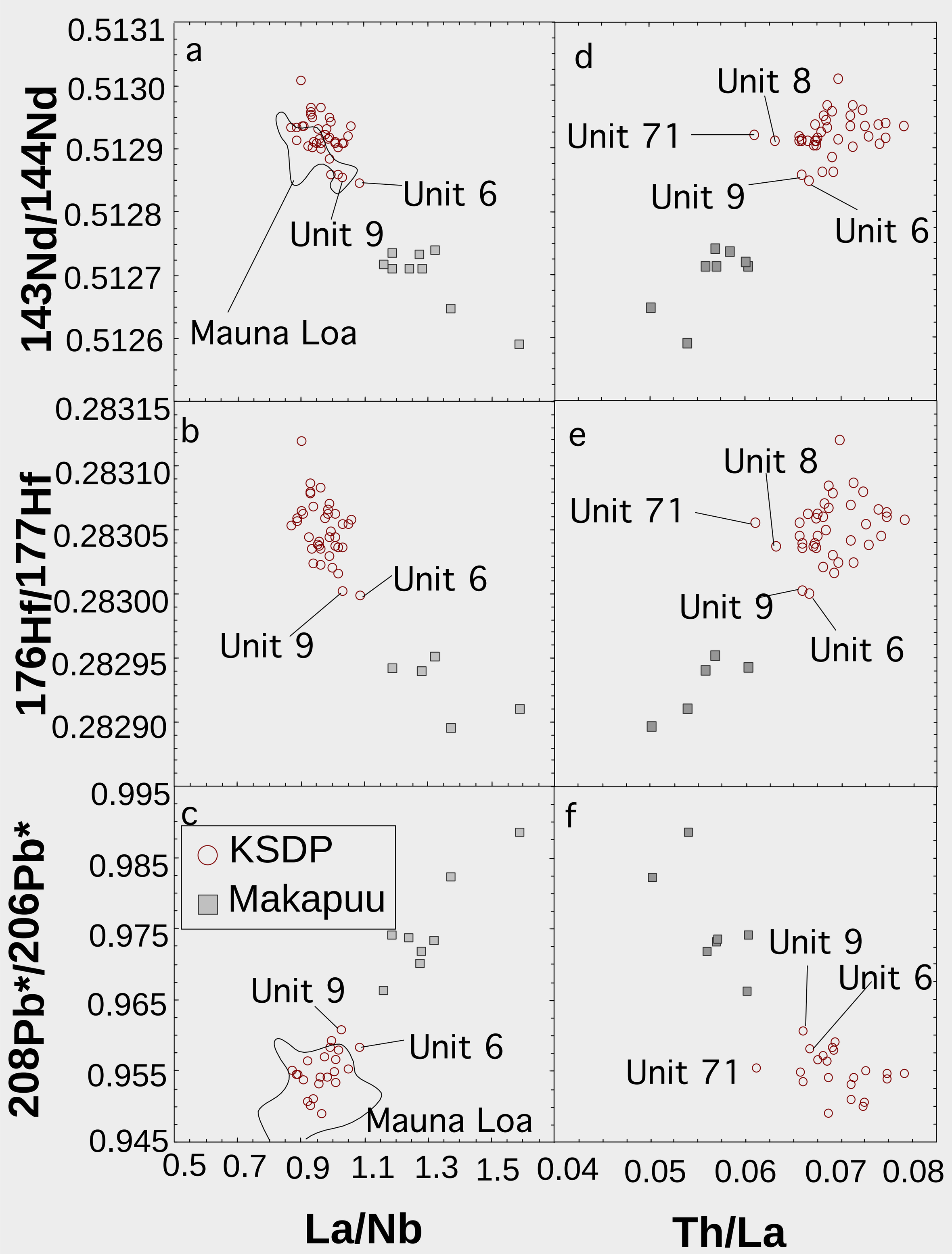


Fig. 4. La/Nb and other ratios of highly incompatible elements (e.g., Th/La) are correlated with radiogenic isotopic ratios. If the most extreme Makapuu-stage lavas contain the largest amount of a sedimentary component (i.e., relatively high La/Nb and low Th/La coupled with low $^{143}Nd/^{144}Nd$, $^{176}Hf/^{177}Hf$ and high $^{208}Pb^*/^{206}Pb^*$), the trends reflect a variable but increasing amount of this component from KSDP to Makapuu-stage lavas.

The Distinctive Makapuu-Stage Signature Is only a Surface Feature

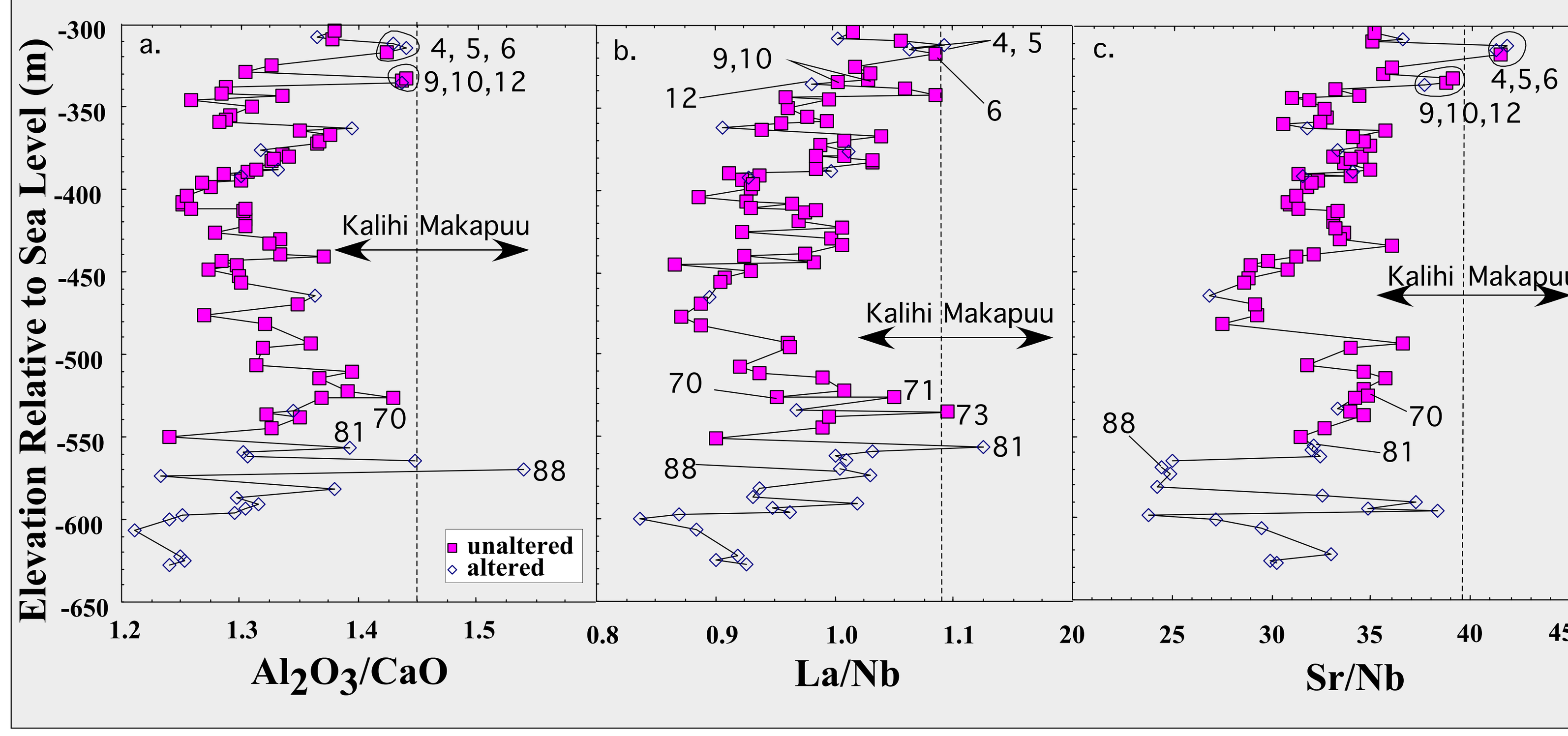


Fig. 5. Depth profiles of Al_2O_3/CaO, La/Nb and Sr/Nb for KSDP drill hole. These ratios generally increase upwards from an elevation of ~470 m below sea level, but there are superimposed high frequency variations. Several lavas with geochemical characteristics similar to Makapuu-stage lavas, e.g., high Al_2O_3/CaO, La/Nb and Sr/Nb, occur in the interval of 304 to 336 m. In addition, a few lavas at ~525 m have some geochemical characteristics similar to Makapuu-stage lavas. The Makapuu/Kalihi-stage compositional boundary, vertical dashed line, is taken as Al_2O_3/CaO = 1.45 (Haskins and Garcia, 2004), La/Nb = 1.09 and Sr/Nb = 39.4 (lowest values in Makapuu-stage lavas; Fig. 3). Following Haskins and Garcia (2004), unaltered lavas are defined as with $2.2>K_2O/P_2O_5>1.2$ and L.O.I.<0.8%.

Correlations Among Major, Trace Elements and Isotopic Ratios

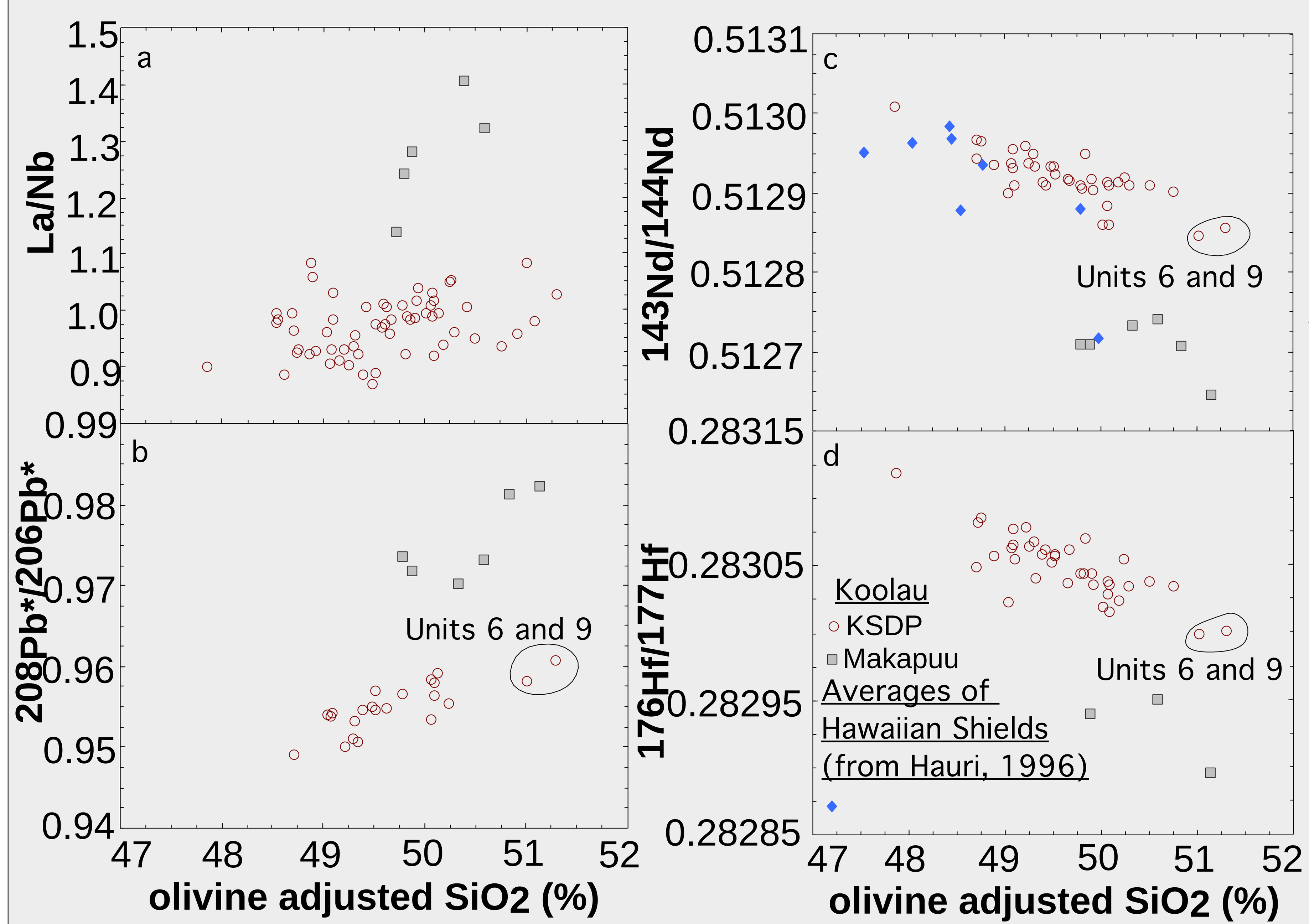


Fig. 6. Olivine adjusted SiO_2 (%) vs La/Nb, $^{208}Pb^*/^{206}Pb^*$, $^{143}Nd/^{144}Nd$ and $^{176}Hf/^{177}Hf$ for Makapuu-stage and KSDP lavas.

Major element contents are adjusted to be in equilibrium with mantle olivine (Fo_{90}) by adding or subtracting equilibrium olivine at 0.1% steps assuming $(Fe/Mg)_{olivine}/(Fe/Mg)_{melt}=0.30$. Only lavas with $2.2>K_2O/P_2O_5>1.2$ and MgO>6.5% are plotted.

These linear trends show that variations in olivine adjusted major element contents are not artifacts of olivine adjustment, but reflect source heterogeneity in major element composition. Surprisingly, Makapuu-stage and KSDP lavas form subparallel trends in these panels. An interpretation is that both lava suites contain a SiO2-rich component (dacitic melt?), but only Makapuu-stage lavas reflect the extreme isotopic characteristics of a sediment component.

Averages of Hawaiian shields or stratigraphic sections (excluding Loihi alkalic section) from Table 1 of Hauri (1996) are shown in **panel c**. Interestingly, these averages largely overlap with Koolau (Makapuu-stage and KSDP) lavas, implying that the geochemical heterogeneity of Koolau source mimics that seen in all Hawaiian shields.

Summary

Geochemical and petrographic studies of surface lavas erupted on the Koolau shield and drill core from the Koolau Scientific Drilling Project show that the shield lavas changed markedly near the end of shield-building (Frey et al., 1994; Roden et al., 1994; Jackson et al., 1999; Haskins and Garcia, 2004; this paper). Specifically, as shield building ended, tholeiitic shield basalt changed gradually from a Mauna Loa-like composition (Kalihi-stage of Haskins and Garcia, 2004) to the well known geochemical endmember that characterizes subaerially exposed Koolau lavas (Makapuu-stage of Haskins and Garcia, 2004). Haskins and Garcia (2004) argue that this transition in lava composition occurred over "the 60-m-thick lava from the H3 tunnel"; consequently, this transition lasted over 2,600–4,600 years assuming a lava accumulation of 13-23 mm per year (DePaolo and Stolper, 1996). However, we infer that the transition from typical Kalihi-stage composition to Makapuu-stage composition began at the elevation of ~470 m below sea level in the KSDP drill hole, and continued to the top of the cored section (Fig. 5). Consequently, we infer that the transition in composition from Kalihi-stage composition to Makapuu-stage composition occurred over at least 170 m which is about three times longer than the estimate of Haskins and Garcia (2004).

The transition from Kalihi-stage to Makapuu-stage lavas reflects changes in source material that presumably occurred as Koolau volcano migrated away from the hotspot:

1. With decreasing age a garnet pyroxenite component was increasingly important in generating Koolau shield lavas. The relatively high SiO_2 content and Al_2O_3/CaO (Figs 5 and 6) in Makapuu-stage lavas are consistent with an increasing amount of melt (dacite) derived from partial melting of garnet pyroxenite.

2. Makapuu-stage lavas also have relatively high La/Nb, Sr/Nb and low Th/La which are correlated with $^{143}Nd/^{144}Nd$, $^{176}Hf/^{177}Hf$ and $^{208}Pb^*/^{206}Pb^*$ (Fig. 4). These reflect a small amount of ancient recycled pelagic carbonate and apatite-rich sediment in the source of Makapuu-stage lavas. Such sediments occur in the Central America trench (DSDP Site 495, Plank and Langmuir, 1998).