Mineralogy and petrology of xenoliths in the HueHue flows of Hualalai Volcano, Hawaii

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INTRODUCTION

The HueHue flow was formed as a result of the 1800-1801 eruptions of Hualalai Volcano on the island of Hawaii. Also deposited during the same eruptive sequence was the larger Kaupulehu flow. Xenoliths of mafic composition can be found in both of these flows. The xenoliths of the Kaupulehu flow have been extensively studied and conclusions have been drawn as to their origin. The goal of this study was to provide similar data on the composition of the HueHue xenoliths and thus determine if their origin is similar to that of the Kaupulehu xenoliths.

GEOLOGICAL SETTING

Hawaiian Volcanoes. It has been suggested by Clague (1987) that all Hawaiian volcanoes go through four distinct stages during their lifetimes. These stages are distinguished by the frequency and volume of eruptions, as well as by the type of lavas erupted. The stages include the preshield stage, the shield stage, the postshield stage, and the rejuvenated stage. It is believed that Hualalai Volcano is currently experiencing its postshield stage.

The postshield stage occurs once the entire shield has been built. It consists of sporadic, low volume eruptions of alkalic basalts and related cumulates. These eruptions take place at the summit and along the previously emplaced rift systems which are characteristic of Hawaiian volcanoes. The flows of alkalic basalts found on Hualalai Volcano, including the 1800-1801 flows, originated along the volcano's southwest rift zone (Clague, 1987).

Hawaiian volcanoes also undergo a series of structural changes beneath the surface as they progress through the four eruptive stages. According to Clague (1987), magma chambers form and disappear beneath the volcanoes at different stages of their development. Among other things, these chambers act as filters to remove xenoliths from magmas as they approach the surface. Thus, the presence or absence of xenoliths in lavas of different eruptive stages gives an indication of the state of magma chambers beneath the volcano at that time.

The compositions of xenoliths also provides clues as to the depth of magma chambers. Alkalic lavas of the postshield stage often contain xenoliths of dunite, wehrlite (Cpx and Olivine), and gabbro, but none of lherzolite (Cpx, Opx, and Olivine). It has been suggested that by the postshield stage the shallow magma reservoirs developed during the shield stage have solidified and the subsequent rising magma passes only through a somewhat deeper intermediate reservoir which removes lherzolite xenoliths picked up from the mantle. Any xenoliths which are incorporated into the magma after it leaves the intermediate reservoir (e.g. cumulates from previous tholeiitic magma chambers) are carried to the surface. In the absence of a shallow magma reservoir, there is no opportunity for these upper-level xenoliths to be removed from the magma. (Clague, 1987)

HueHue Flow. The HueHue Flow was formed when a vent opened at an elevation of 500 meters on the volcano's western flank (Bohrson and Clague, 1988). The flow consists of an a'a unit and two pahoehoe units. The a'a unit comprises the north-eastern portion of the flow. It extends for a distance of approximately four miles to the west of the vent, stopping two miles short of the present shoreline. The two pahoehoe sheets can be differentiated on the basis of their relative degrees of inflation. The upper pahoehoe sheet exhibits a relief of about 15 feet due to the prominence of its inflation features. It originates at the vent and is exposed for 6 miles until it reaches the shoreline attaining a maximum width of 4 miles. The surface of the lower pahoehoe sheet is much flatter, showing fewer inflation features. It is first exposed approximately 2 miles from the shoreline where the upper sheet was deflected around it. The exposure continually widens until it reaches the shoreline.

METHODS

A pedestrian survey of the HueHue flow revealed that xenoliths are not ubiquitous, but occur in specific parts of the lower pahoehoe sheet. These occurrences include one exposure along an abandoned lava tube and several places along the shoreline where it is believed that old lava tubes fed into the ocean. These exposures abound in xenoliths which occur in rounded blocks of lava that have been deposited in piles parallel to the shoreline. These blocks range in size from cobbles only a few inches in diameter to boulders more than a foot across. It was our determination that the rounded clasts represent pieces of the lava tube which have been broken off in the water, rounded by wave action, and transported back on top of the lava sheet.

The locality containing the most abundant xenolith populations is located at the southern contact of the upper and lower pahoehoe sheets. The majority of the xenolith samples which were collected were taken from this location. Other samples were collected at locations along the shoreline of the lower sheet. Samples were collected in such a way as to reflect the relative abundances of the different types of xenoliths.

Xenolith names used in this paper are not indicative of the precise mineralogical compositions of the xenoliths, but rather of approximations of those compositions based hand specimen examination. The name dunite refers to a xenolith that appears to be composed mostly or completely of olivine. Wehrlite xenoliths are considered to be composed of olivine, pyroxene and plagioclase and peridotites are xenoliths which appear to be composed only of olivine and pyroxene.

Trace element and rare earth element data were obtained for five samples using neutron activation analysis. These samples included a dunite, a peridotite, a wehrlite, and basalt from both the upper and lower flows. Whole rock compositions were determined for two other dunites and wehrlites using XRF analysis. Two wehrlites and two dunites from the HueHue flow and a wehrlite and a dunite from the Kaupulehu flow were examined in thin section. Major element compositions for minerals in these thin sections as well as minerals in three other polished samples from the HueHue flow were determined by SEM-EDAS analysis. The three additional samples included a dunite, a wehrlite, and a sample containing the contact between an anorthosite and a large crystal of clinopyroxene (3 cm).

RESULTS

Whole Rock Compositions. In attempting to determine the origin of the HueHue xenoliths, whole rock compositional data for xenoliths from the Kaupulehu Flow (Chen et al., 1992) and from the HueHue flow were normalized with typical compositions for mantle-derived xenoliths (Hess, 1989). Figure 1 allows a comparison of the results. Dunite compositions from both of the flows are very similar, both exhibiting slight Al_2O_3 and CaO depletion and enrichment of FeO and MgO. Wehrlites from the two flows also have similar mantle-normalized composition plots, but they appear to differ from the model mantle composition. The wehrlites are strongly enriched in CaO and Al_2O_3 and are somewhat depleted in MgO and FeO.

Mineral Major Element Compositions. Major element compositions for minerals in the xenoliths from the HueHue flow and the Kaupulehu flow (Chen et al., 1992) are summarized in Table 1. Olivines from both dunites and wehrlites in the HueHue flow show major element compositions very close to values from the Kaupulehu flow. MgO is slightly depleted in wehrlite olivines from the HueHue flow with weight percents of about 39 as compared with values of 44% which are typical of the Kaupulehu. Spinels found in dunite and wehrlite from the HueHue are generally slightly enriched in Fe and Ti and depleted in Mg and Al compared to Kaupulehu xenoliths. This is especially apparent in the wehrlite spinels where HueHue values for MgO are near 7% compared with almost 14% for Kaupulehu, Al_2O_3 is 6% compared to 30%, TiO_2 is 10% compared to 1% for Kaupulehu, and FeO is 60% compared to 32%. Clinopyroxene compositions in HueHue wehrlite xenoliths showed depletions of Al and Ti oxides along with relative enrichments of Fe oxide as compared to Kaupulehu values. Al_2O_3 is less than 1% in HueHue samples while being 5% in the Kaupulehu, FeO in the HueHue was 16% compared with 6% for the Kaupulehu, and TiO_2 was 0.2% compared with 0.6%.

Mole percent fosterite in olivine was then calculated for each of the dunite and wehrlite samples for which major element analyses were obtained. These were plotted according to the frequency of occurrence of each value. These plots are shown along with similar ones for Kaupulehu dunite and wehrlite xenoliths from Chen et al. (1992). (Figure 2) The majority of the fosterite contents for both of the flows occur at or above 80%. This was shown by Chen et al. to be characteristic of xenoliths derived from a tholeiitic magma. Chen et al. further stated that the fact that Kaupulehu xenoliths originated in a tholeiitic magma indicates that they are cumulates from an earlier shallow magma reservoir. The similarity of the HueHue fosterite values with the Kaupulehu values suggests a similar origin for HueHue xenoliths.

Concentrations of TiO_2 in clinopyroxenes of the Kaupulehu xenoliths were compared to TiO_2 concentrations for clinopyroxenes in abyssal lherzolite and harzburgite, rocks which are commonly associated with a mantle origin. (Chen et al., 1992) TiO_2 compositions were determined for clinopyroxenes in the HueHue flow (Figure 3). The HueHue xenoliths exhibit TiO_2 concentrations which are more similar to those typically associated with lherzolite and harzburgite which cluster around weight percents of 0.2% and 0.3%. Kaupulehu xenoliths typically have values which are closer to 0.5% and 0.7% but they do show some occurrences in the lower range of HueHue values.

REE Analyses. A limited number of rare earth element abundances were obtained for HueHue xenoliths. La, Ce, Sm, Eu, Yb, Sc were the only elements for which concentrations could be found within detection limits. McDonough and Frey (1989) provide a range of model rare earth element concentrations for the earth's primitive mantle. The minimum and maximum model mantle values, along with those from the HueHue flow, were chondrite normalized and then plotted in Figure 4. The wehrlite shows an overall enrichment by a factor of less than 10 and a slight light REE enrichment. The peridotite lies within the model mantle values. It also shows a slight light REE enrichment and a Ce anomaly. While data for the dunite is incomplete, it does show depletion with respect to model mantle compositions.

CONCLUSIONS

It has been shown by Chen et al. (1992) and by Clague (1987) that Kaupulehu xenoliths are the result of cooling and solidification of tholeiitic lavas in a shallow magma reservoir. Fragments of these solidified magmas were then included in a magma which had already lost its mantle xenoliths in an intermediate reservoir. Analyses of xenoliths from the HueHue flow indicate that their chemical and mineralogical compositions are closely related to the Kaupulehu xenoliths. In addition, HueHue xenoliths show little resemblance to expected compositions for magma xenoliths. Based on the evidence presented here, as well as the contemporaneous nature of the Kaupulehu and HueHue eruptive events, it is concluded that HueHue xenoliths originated along with the Kaupulehu xenoliths in a shallow tholeiitic magma chamber and are not of mantle origin.

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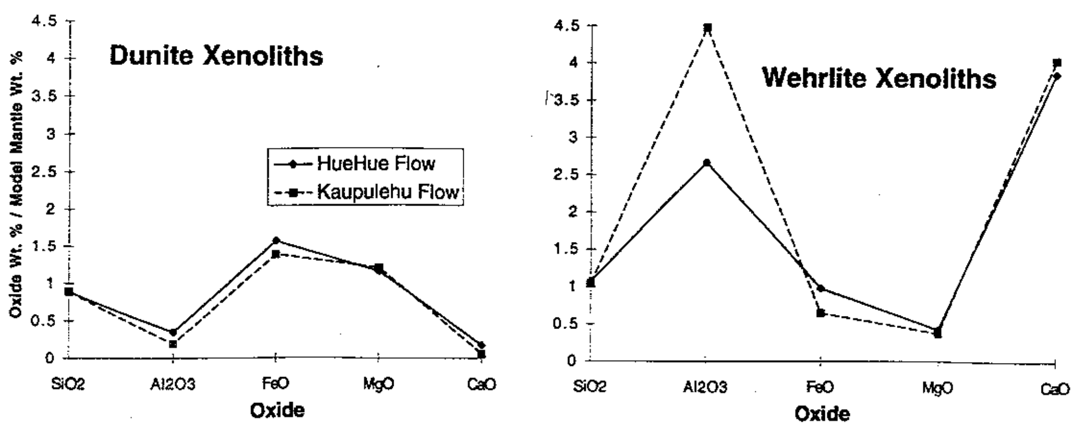

Figure 1 Mantle-normalized major element compositions for HueHue and Kaupulehu dunite and wehrlite xenoliths.

	HueHue Dunites		Kaupulehu Dunites		HueHue Wehrlites			Kaupulehu Wehrlites		
	Olivine	Spinel	Olivine	Spinel	Olivine	Spinel	Clinopyroxene	Olivine	Spinel	Clinopyroxene
SiO_2	38.71	0.754	39.26	0.16	37.63	0.25	53.68	39.23	0.24	50.88
FeO	14.39	37.07	14.22	28.4	17.38	60.14	15.79	16.5	31.77	6.38
MgO	42.71	10.78	46.19	13.4	39.31	6.72	16.85	44.5	13.67	16.37
NiO	0.15	0	0.29	0	0.066	0	0	0.15	0	0
CaO	0.096	0	0.22	0.03	0.018	0	22.14	0.1	0.05	19.88
TiO_2	0	2.31	0	1.43	0	9.8	0.2	0	1.26	0.62
Cr_2O_3	0	28.86	0	30.58	0	10.02	0.066	0	22.16	0.52
Al_2O_3	0	20.06	0	25.22	0	6.13	0.77	0	30.41	5.49

Table 1 Summary of major element composition for minerals in xenoliths from the Kaupulehu and HueHue flows.

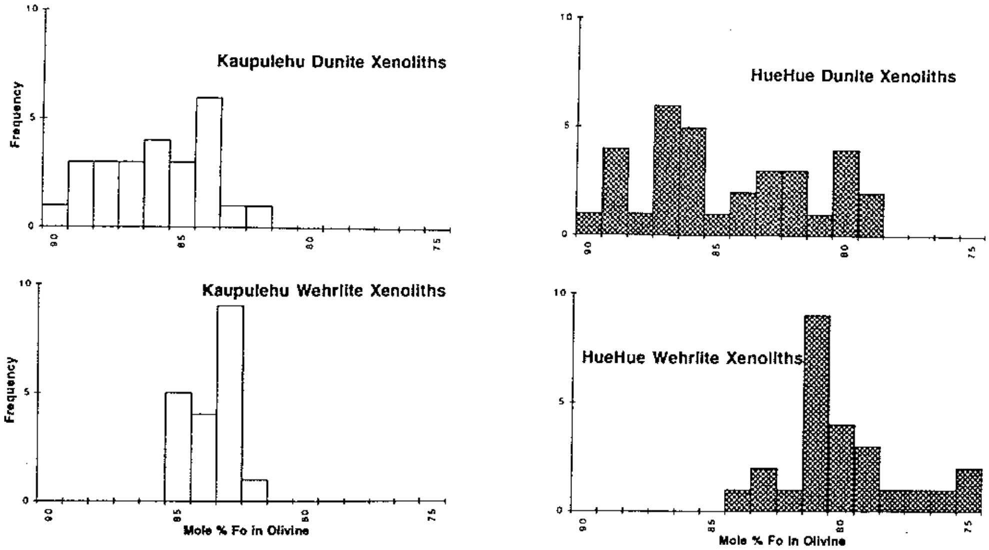

Figure 2 Mole percent fosterite values plotted according to their occurrence in HueHue and Kaupulehu xenoliths.

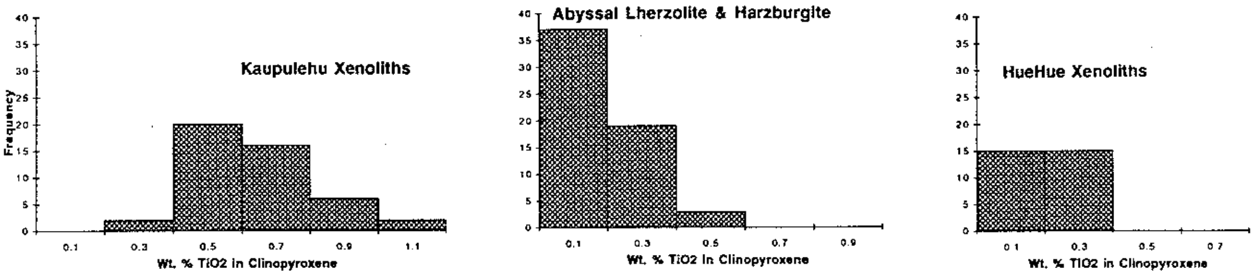

Figure 3 Weight percent TiO_2 in clinopyroxenes from HueHue and Kaupulehu xenoliths and from abyssal lherzolite and harzburgite, minerals commonly associated with a mantle origin.

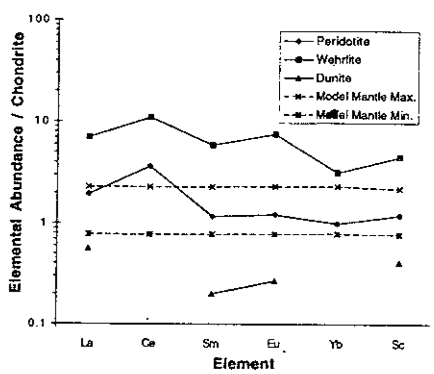

Figure 4 Log plot of chrondrite-normalized rare earth element abundances for HueHue xenoliths and the model mantle.