Chapter 5

GUIDE TO THE MAUNA KUWALE-KAUAOPUU RIDGE RHYODACITE OCCURRENCE, OAHU, HAWAII*

Glenn R. Bauer
Board of Water Supply
Honolulu City and County
Honolulu, Hawaii 96813

INTRODUCTION

The presence of a siliceous volcanic rock (~66 wt.% SiO_2) on the northern extremity of Mauna Kuwale Ridge, Oahu, Hawaii, was first reported by Stearns and Vaksvik (1935), who labelled it hornblende-biotite trachyte. Several bulk chemical analyses and a petrographic description of the rock (Macdonald, 1940; Macdonald and Katsura, 1962) showed it to be the most siliceous rock in the Hawaiian volcanic province. Because of the relatively low total-alkali:silica ratio and the high silica content of the Mauna Kuwale rock, which differs from the trachytes of the Hawaiian province, Macdonald and Katsura (1964) renamed it rhyodacite and classified it as the most highly differentiated member of the tholeiitic volcanic suite in the Hawaiian volcanic province. In contrast to the Hawaiian alkalic suite, rocks belonging to the tholeiitic suite and having SiO_2 contents greater than about 52 wt.% are indeed rare.

During a detailed study of Mauna Kuwale Ridge and the surrounding area, a new occurrence of similar rhyodacite was found. This outcrop occurs on Kauaopuu Ridge, approximately one-half mile north of Mauna Kuwale Peak (Fig. 1).

Geographic Location and Field Geology

Kauaopuu Ridge and Mauna Kuwale Rodge are located near the western edge of Oahu, about 35 miles west of Honolulu (Fig. 1). Both ridges are part of a large, somewhat continuous, ridge system that separates Waianae Valley from Lualualei Valley. There is a gap in the ridge between Kauaopuu Ridge and Mauna Kuwale Peak. Macdonald (1940) thought that a concealed fault may be present in this area, possibly a boundary fault of a pit crater. Macdonald (1940) also suggested that the presence of a pit crater would explain the unusual thickness

*This guide to the Mauna Kuwale-Kauaopuu Ridge rhyodacite occurrence is taken from the following papers:

Bauer, G.R., R.V. Fodor, J.W. Hustler, and K. Keil, 1973. Contributions to the mineral chemistry of Hawaiian rocks. III. Composition and mineralogy of a new rhyodacite occurrence on Oahu, Hawaii. Contrib. Mineral. Petrol., v. 40, p. 183-194.

Fodor, R.V., K. Keil, and G.R. Bauer, 1977. Contributions to the mineral chemistry of Hawaiian rocks. V. Compositions and origin of ultramafic nodules and megacrysts in a rhyodacite from Oahu, Hawaiia Islands. Pacific Sci., v. 31, p. 211-222.

(400 feet) of the Mauna Kuwale rhyodacite. The Mauna Kuwale rhyodacite is thought to belong to the middle member of the Waianae Volcanic Series (Macdonald, 1949). Compared to the Mauna Kuwale flow, the Kauaopuu rhyodacite flow is thinner and is at the most only 200 feet thick; on the eastern side of the flow, it thins to less than 50 feet.

The Kauaopuu rhyodacite overlies clinkery tholeiitic basalt of the middle member of the Waianae Volcanic Series (Fig. 1). Due to erosion and dense vegetation it is unknown whether the Kauaopuu rhyodacite represents more than one flow. Macroscopic textural variations do, however, exist between the lower and upper parts of the unit.

The basal section of the rhyodacite appears lithologically homogeneous. In hand specimen, the rock is dense and, depending upon the degree of weathering, gray to black in color. Phenocrysts of hornblende, plagioclase and biotite are visible in a glassy groundmass. The rock is vitreous in hand specimen, and the glassy matrix weathers to either a pink or white clayey rock. In these weathered samples, ferromagnesian silicates have commonly been replaced by opaque oxides.

Flow banding is present near the upper part of the unit. Varying proportions of glass and feldspar apparently form bands of different relief that average from 0.5 to 1.0 cm across; flow bands with high relief have a greater amount of glass than bands with low relief. The bands are generally parallel to the base of the flow, but in some instances form small overturned folds.

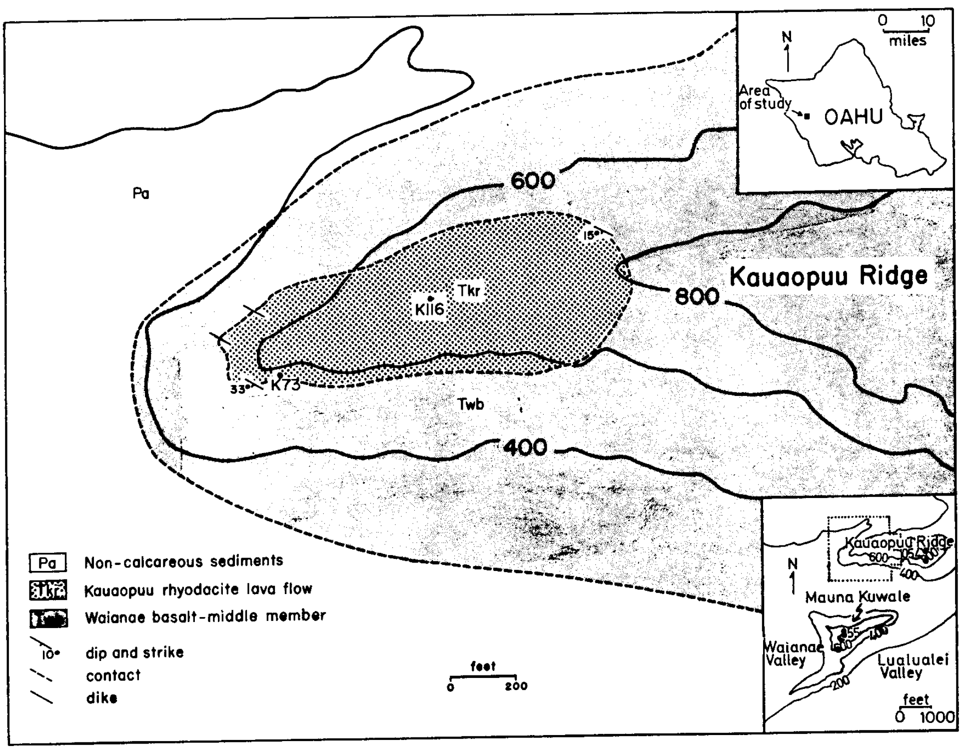


Figure 1. Geologic map of Kauaopuu Ridge, Oahu, Hawaii. Inset maps show the location of Kauaopuu Ridge on Oahu and its relation to Mauna Kuwale. The dotted area in the lower insert is the approximate area shown on the geologic map.

One outcrop of vesicular rhyodacite was found near the top of the flow but no vesicular rock was seen near the base. Both horizontal and vertical joints were observed.

Basaltic dikes and sills, and small tachylitic veinlets intrude the rhyodacite. These basaltic intrusives are presumably associated with the middle member of the Waianae Volcanic Series, although some of the dikes belong to the northwest-trending dike system of the Waianae Volanic Series (Stearns and Vaksvik, 1935). Usually the basaltic intrusives weather more easily than the rhyodacite. No dikes of rhyodacitic composition are found in the area.

Petrography

Macdonald (1940) described one rhyodacite specimen from Mauna Kuwale Ridge. Petrographically, the rhyodacite from Kauaopuu Ridge is nearly identical to that of Mauna Kuwale. Although only two Kauaopuu samples were chemically analyzed and examined by electron microprobe in this study, an additional eight were carefully examined microscopically. Throughout the entire unit at Kauaopuu Ridge, the mineralogy is remarkably similar in thin section, varying only slightly in the proportion of phenocrysts to groundmass and in the development of flow banding within the groundmass. Modal analyses of three Kauaopuu samples are presented in Table 1.

Approximately 75% of the rock is glassy groundmass with microlites of feldspar, apatite, and Fe-Mg silicates. Primary phenocrysts (and microphenocrysts) are plagioclase, amphibole, biotite, and titaniferous magnetite. Orthopyroxene is also present, but in small quantities. Phenocrysts are moderately oriented with the direction of flow. Microlites of feldspar in the groundmass create a vague trachytic texture, but the overall texture is vitrophyric.

Plagioclase is the most abundant phenocryst. Euhedral to subhedral laths of plagioclase, 0.07 to 1.0 mm long, are normally zoned with some oscillatory zoning between core and rim. Much of the plagioclase contains glassy inclusions that give the crystals a mottled appearance. Optically, these inclusions are isotropic, although small acicular microlites of a weakly birefringent mineral are sometimes present. Plagioclase crystals show varying degrees of resorption from reaction with surrounding liquid. For example, perfectly euhedral phenocrysts are present next to crystals that are highly resorbed.

Amphibole phenocrysts and microphenocrysts are strongly pleochroic: X = yellow tan, Y and Z = dark brown. There is a subtle darkening of the amphibole at the top of the flow, suggesting a greater Fe^{+3}/Fe^{+2} ratio (this is confirmed by bulk rock composition). Crystals are euhedral in shape and laths range in length from 0.05 to 1.5 mm. Occasionally there is some zoning, the core being less birefringent. Extinction angles range from 0^o to 10^o; $2\ V_X \sim 80^o$. Twinning on (100) was observed in a few phenocrysts of every thin section.

Biotite phenocrysts are euhedral to subhedral and are strongly pleochroic: X = buff, Y = reddish brown, Z = greenish brown. The $2\ V_X$ ranges from 0^o to 10^o. Acicular and lath-shaped crystals of apatite included in biotite as described by Macdonald (1940) are also present in amphibole phenocrysts.

Orthopyroxene is present as phenocrysts and microphenocrysts in amounts of less than 1 vol.%.

A reaction relationship appears to exist between orthopyroxene and amphibole where laths of orthopyroxene are seen mantled by amphibole. Titaniferous magnetite is abundant and euhedral to anhedral crystals average about 0.01 mm in size. Minor amounts of ilmenite are also present.

Table 1. Modal compositions of three rhyodacite lavas from the bottom (K73), middle (K112) and top (K116) of Kauaopuu Ridge, Oahu, Hawaii (in volume percent; 1000 counts per sample)

	K73	K112	K116
Plagioclase	12.7	13.1	11.2
Amphibole	6.0	8.2	7.3
Biotite	2.1	4.7	2.4
Orthopyroxene	0.7	0.2	0.8
Opaques	1.1	1.7	1.1
Matrix	77.4	72.1	77.2
	100.0	100.0	100.0

Chemical Composition

Whole-Rock Composition. Two whole-rock analyses of rhyodacite from Kauaopuu Ridge are presented in Table 2 (columns 1 and 2) together with an analysis of the Mauna Kuwale rhyodacite (Macdonald and Katsura, 1964) (Table 1, column 3). The three analyses are essentially identical although there are small differences in MgO and P_2O_5 contents and in the Fe_2O_3/FeO ratios. The darker amphibole in sample K116 (top of flow) probably has a higher Fe_2O_3 content than the lighter amphibole of sample K73 (bottom of flow) and, thus, may account for the higher bulk Fe_2O_3 ratio in K116.

As pointed out by Macdonald (1940) and Macdonald and Katsura (1962, 1964), the total alkali content of the Mauna Kuwale rhyodacite (~8.1 wt.%) is significantly lower than the total alkali content of soda trachytes of the Hawaiian province (~11.6 wt.%; Macdonald, 1968a). It is primarily because of the lower alkali contents relative to that of trachytes that Macdonald and Katsura (1964) classified the Mauna Kuwale rhyodacite as a tholeiitic differentiate and not a member of the Hawaiian alkalic suite. Similarly, the new analyses of Kauaopuu rhyodacite indicate that the rock is a tholeiitic differentiate.

Electron microprobe analyses of the glassy groundmass (matrix) of the Kauaopuu Ridge rhyodacite (columns 4, 5) and of glassy inclusions in plagioclase (column 6) are also presented in Table 2, along with an analysis of rhyolite obsidian from Easter Island that was originally presented by Bandy (1937) (column 7); this obsidian is one of the few analyzed rhyolites from the Pacific volcanic provinces. Compared to whole-rock compositions, groundmass glass in the rhyodacite is enriched in SiO_2 and K_2O, and depleted in FeO, MgO, and CaO. The Na_2O content of groundmass glass in sample K73 is similar to that of its representative whole rock, but Na_2O in the glass of K116 is slightly depleted relative to the whole-rock composition of sample K116. The lower CaO and higher K_2O contents of the groundmass glass relative to the whole rock is a result of the crystallization of only plagioclase and not K-feldspar from the magmatic fluid.

Compositional differences between the groundmass glass of the rhyodacites from Oahu, Hawaii, and the bulk rock composition of a rhyolite from Easter Island are higher CaO and lower total Fe and Na_2O contents in the rhyodacite glass. Despite these differences, however, the overall similarity in composition is remarkable.

Table 2. Bulk compositions of rhyodacite from Kauaopuu Ridge (samples K73 and K116, columns 1 and 2; this paper) and Mauna Kuwale, Oahu, Hawaii (column 3; Macdonald and Katsura, 1964), and electron microprobe analyses of glass matrices of rhyodacite samples K73 and K116 (columns 4 and 5; this paper) and of glassy inclusions in plagioclase of rhyodacite from Kauaopuu Ridge (sample K73, column 6; this paper), compared to the bulk composition of a rhyolite from Easter Island (column 7; Bandy, 1937) (in weight percent). Norms of previously published analyses have been recalculated.

	1	2	3	4	5	6	7
SiO_2	66.14	66.53	66.78	72.5	71.8	73.4	72.51
TiO_2	0.54	0.56	0.59	0.34	0.34	0.41	0.21
Al_2O_3	15.25	15.25	15.69	14.7	14.3	12.8	13.35
Fe_2O_3	1.38	2.17	1.45	a	a	a	1.35
FeO	1.68	0.93	1.40	1.3	1.3	0.84	1.99
MnO	0.06	0.06	0.05	0.02	0.03	0.01	--
MgO	1.66	1.56	1.28	0.24	0.23	0.11	0.16
CaO	2.82	2.80	2.61	1.1	1.1	0.48	0.47
Na_2O	4.47	4.30	4.49	4.5	3.8	3.1	4.81
K_2O	3.66	3.60	3.60	4.2	4.6	6.1	4.48
H_2O^-	0.10	0.01	0.66	n.d.	n.d.	n.d.	--
H_2O^+	1.94	1.93	0.59	n.d.	n.d.	n.d.	0.47
P_2O_5	0.18	0.17	0.58	0.06	0.06	0.02	--
SrO	0.028	0.028	n.d.	n.d.	n.d.	n.d.	n.d.
Total	99.91	99.90	99.77	98.96	97.56	97.27	99.80
Norms (weight percent)							
q	18.42	20.53	21.08	26.75	29.43	31.31	25.44
or	22.13	21.75	21.61	25.77	27.88	37.10	26.68
ab	38.65	37.13	38.55	38.53	32.93	26.96	40.97
an	10.98	11.93	9.30	5.11	5.18	2.32	1.62
di wo	0.88	0.47	--	--	--	--	0.30
di en	0.62	0.41	--	--	--	--	0.05
di fs	0.18	--	--	--	--	--	0.27
hy en	3.60	3.57	3.23	0.61	0.58	0.29	0.35
hy fs	1.01	--	0.50	1.93	1.93	0.90	1.93
mt	2.05	1.61	2.14	--	--	--	1.98
hm	--	1.11	--	--	--	--	--
il	1.05	1.09	1.13	0.65	0.67	0.80	0.41
ap	0.43	0.40	1.38	0.15	0.14	0.04	--
c	--	--	1.07	0.49	1.26	0.28	--

[a]All iron calculated as FeO.

n.d. = not determined

Mineral Composition

Feldspar. Compositions of feldspar phenocrysts and microphenocrysts range from sodic labradorite to intermediate oligoclase (An_{53} to An_{23}). Although the feldspar as a whole is compositionally zoned over about 20 weight percent An, individual crystals are normally zoned no more than about 7 weight percent An.

Assuming feldspar-glass (magmatic liquid) equilibrium in siliceous volcanic rocks, the plagioclase geothermometer of Kudo and Weill (1970) can be applied to estimated equilibration temperatures. Application of this geothermometer to the rhyodacites, where it was assumed that the most sodic areas of the feldspar are in equilibrium with glass, revealed the following:

Sample	Most sodic feldspar	Equilibration Temperatures (°C)		
		dry	0.5 kb P_{H_2O}	1.0 kb P_{H_2O}
K73	$An_{26}Ab_{69.8}$	1027	977	924
K116	$An_{23}Ab_{72.5}$	968	921	864

The presence of biotite and amphibole in the rhyodacites indicates at least nominal P_{H_2O} and, hence, on the basis of the feldspar-glass geothermometer, crystallization temperatures were probably well below 1000°C.

Some glassy inclusions in feldspar crystals were also analyzed and an average composition is presented in Table 2 (column 6). Compositions of the inclusions do not resemble bulk rock compositions (i.e. original rhyodacite liquid), but instead resemble highly differentiated liquid. Compared to groundmass glass, the inclusions are depleted in Al, Ca, and Na (An and Ab components) and enriched in K, indicating that the glass inclusions probably represent magmatic liquid from which the enclosing plagioclases precipitated.

Fe-Mg Silicates. Compositions of orthopyroxene, amphibole, and biotite from the Kauaopuu rhyodacite are presented in Table 3. An orthopyroxene phenocryst (only one phenocryst was observed) is compositionally homogeneous (within standard deviation of the analyses), whereas orthopyroxene microphenocrysts are strongly zoned, with Fe increasing and Mg decreasing from core to margin. Relative to the phenocryst, orthopyroxene microphenocrysts are enriched in Fe. The Fe/(Fe+Mg) ratio indicates that the orthopyroxene is bronzite in composition.

Among the amphiboles (Ti-rich hornblendes), not much difference in composition was noticed between phenocrysts and microphenocrysts and the compositions presented in Table 3 are for crystals of varying sizes. The low summations are due primarily to the presence of volatiles such as H_2O which cannot be determined with the electron microprobe. There is slight compositional zoning in the amphiboles, but no systematic pattern was detected. These amphibole compositions are similar to those of amphiboles in siliceous volcanic rocks from continental areas (e.g. Carmichael, 1967; Ewart, 1971).

The biotite of the rhyodacite is rich in MgO, but similar compositions have been reported from other rocks in which biotite is associated with pyroxene and amphibole (Nockolds, 1947). The biotite does not vary much in composition and the average analyses presented are for grains of varying sizes. The low summations are due primarily to the presence of volatiles such as H_2O which cannot be determined with the electron microprobe.

Table 3. Electron microprobe analyses of orthopyroxene, amphibole, and biotite in rhyodacite from Kauaopuu Ridge, Oahu, Hawaii (samples K73, bottom of flow; K116, top of flow). Each analysis is the average of 50 point analyses (in weight percent).

	Orthopyroxene			Amphibole		Biotite	
	K73 p	K73 mp	range mp	K73	K116	K73	K116
SiO_2	56.6	55.6	(54.5-55.9)	44.0	44.5	38.3	38.8
TiO_2	0.21	0.26	(0.20-0.44)	3.1	3.0	4.6	4.5
Al_2O_3	0.95	1.2	(0.74-2.0)	10.2	9.9	14.2	14.6
Cr_2O_3	0.22	0.14	(0.03-0.28)	<0.01	<0.01	n.d.	n.d.
FeO	9.7	12.7	(9.7-18.1)	11.2	11.4	12.5	12.4
MnO	0.30	0.41	(0.24-0.79)	0.32	0.32	0.11	0.08
MgO	31.0	28.3	(24.8-32.0)	14.5	14.5	17.1	17.0
CaO	1.5	1.6	(1.0-2.4)	11.3	11.5	0.11	0.08
Na_2O	0.02	0.03	(0.01-0.08)	2.4	2.3	1.3	1.1
K_2O	n.d.	n.d.	--	0.69	0.70	8.5	8.3
Total	100.5	100.24		97.59	98.12	96.72	96.86

	Number of cations on the basis of					
	0 = 6		0 = 23[a]		0 = 23[a]	
Si	1.978	1.977	6.457	6.501	5.816	5.855
Al^{IV}	0.022	0.023	1.543	1.499	2.184	2.145
Al^{VI}	0.017	0.027	0.221	0.206	0.358	0.353
Cr	0.006	0.004	--	--	--	--
Ti	0.006	0.007	0.342	0.330	0.525	0.511
Fe	0.284	0.378	1.375	1.393	1.588	1.565
Mn	0.009	0.012	0.025	0.040	0.014	0.010
Mg	1.615	1.499	3.171	3.157	3.870	3.823
Ca	0.056	0.061	1.777	1.800	0.018	0.013
Na	0.001	0.002	0.683	0.652	0.383	0.322
K	--	--	0.129	0.131	1.647	1.598
Z	2.000	2.000	8.000	8.000	8.000	8.000
XY	1.994	1.990	7.723	7.709	8.403	8.195
Σ	3.994	3.990	15.723	15.709	16.403	16.195
Fs	14.5	19.5				
En	82.6	77.3				
Wo	2.9	3.1				

[a]Because H_2O cannot be determined with the electron microprobe, the structural formulae were calculated on the basis of 23 instead of 24 oxygens.

p = phenocrysts; mp = microphenocrysts

Fe-Ti Oxides. Titaniferous magnetite is abundant throughout the rhyodacite as microphenocrysts, but ilmenite crystals are quite rare. Average compositions of these oxides are presented in Table 4 and, as shown by compositional ranges, the titaniferous magnetite is rather variable. The ulvöspinel contents calculated from the average titaniferous magnetite compositions are 25 and 27 mole percent, which are considerably lower than the ulvöspinel contents of titaniferous magnetite (with less than 0.50 weight % Cr_2O_3) in the tholeiitic, alkalic, and nephelinic volcanic rocks of the island of Maui, Hawaii; the alkalic differentiates (trachytes) of Maui have titaniferous magnetite with ulvöspinel contents of about 60 mole percent (Fodor et al., in prep.). By using the average ulvospinel content of the titaniferous magnetite together with the molecular percent hematite in coexisting ilmenite and the data of Buddington and Lindsley (1964), equilibration temperatures of about 860° were estimated for the rhyodacites (Table 4). This value is somewhat lower than the estimated equilibration temperatures at 1 kb water pressure using the plagioclase geothermometer.

Table 4. Electron microprobe analyses (in weight percent) of coexisting magnetite (Mt) and ilmenite (Ilm) in two rhyodacite samples from Kauaopuu Ridge, Oahu, Hawaii (K73, bottom of flow; K116, top of flow). Averages of 50 point analyses for magnetite and 20 for ilmenite

	K73			K116		
	Mt		Ilm	Mt		Ilm
SiO_2	0.91		0.81	0.88		0.80
TiO_2	9.8	(7.5-14.4)	42.8	9.9	(8.1-12.2)	42.2
Al_2O_3	3.3	(2.6-3.9)	0.57	3.1	(2.3-3.8)	0.52
V_2O_3	0.26		0.06	0.26		0.07
Cr_2O_3	0.18		<0.01	0.19		<0.01
FeO	76.7	(63.0-82.8)	50.2	76.6	(71.7-81.0)	50.8
MnO	0.52		0.70	0.58		0.64
MgO	1.2	(0.42-1.6)	2.5	1.9	(0.80-2.2)	2.2
CaO	0.13		0.10	0.13		0.11
ZnO	0.60		<0.01	0.43		<0.01
Sum	93.60		97.74	93.97		97.34
Recalculated analyses, assuming stoichiometric Fe^{2+}/Fe^{3+} ratios						
Fe_2O_3	44.8		17.8	45.6		18.3
FeO	36.4		34.2	35.6		34.2
Total	98.10		99.54	98.57		99.04
Mole % Usp	27.1		--	25.2		--
Mole % Hem	--		19.0	--		19.4
Temp °C		855			865	
f_{O_2}		$10^{-11.7}$			$10^{-11.7}$	

[a]Total iron as FeO.

Inclusions

Dunite nodules (Fo_{85}) and megacrysts of olivine (Fo_{83-84}) and clinopyroxene ($Fs_{13}Wo_{43}En_{44}$) are present as rare inclusions in the rhyodacte (~66 wt.% SiO_2) of Kauaopuu Ridge.

Dunite. The two examined inclusions of fresh dunite, each about 1 cm in diameter, consist almost entirely of anhedral olivine grains (xenomorphic-granular) in a slightly recrystallized texture, including triple-point junctures. Their texture is metamorphic rather than cumulate. Small amounts of chrome spinel and, in one sample, a few interstitial grains of clinopyroxene were observed. Olivine is nearly constant in composition (Fo_{85}) (Table 5) but at the margin (10-15 microns), Fo decreases to ~ Fo_{80}. There is also enrichment in MnO and a slight increase in CaO at the margin. These increases in Fe, Mn, and Ca apparently resulted from a reaction between the dunite nodules and the rhyodacite magma. Also indicative of a reaction relationship is a discontinuous ring of amphibole around the dunite. This amphibole has a composition identical to that of the amphibole present as phenocrysts throughout the rhyodacite.

Olivine Megacrysts. Olivine megacrysts range from 3 to 6 mm in size, and are highly resorbed. There is no noticeable increase in iron content at the margins of two and only a slight increase at the margin of one olivine grain; thus, this olivine differs from that in the dunite nodules. Each grain has near-constant composition; they range from Fo_{85} to Fo_{83} (Table 5). Olivine megacrysts are only slightly richer in FeO, MnO, and CaO than are the dunite olivine (excluding dunite rims) (see Fig. 2).

Clinopyroxene Megacrysts. The two clinopyroxene megacrysts studied are 1 cm and 6 mm in size. One clinopyroxene is highly resorbed and both are nearly constant in composition (Table 5). However, at the unresorbed margins of each grain is a rim enriched in Mg and depleted in Fe. Compare to clinopyroxene in the dunite, the megacrysts are enriched in FeO, TiO_2, Al_2O_3, and MnO, and are depleted in CaO and Cr_2O_3 (Table 5).

Discussion

The similarity in composition between the Mauna Kuwale rhyodacite (Macdonald, 1949; Macdonald and Katsura, 1964) and the Kauaopuu rhyodacites, and the proximity of the Mauna Kuwale and Kauaopuu Ridge indicate that the previously unmapped Kauaopuu rhyodacite is part of the same flow as that at Mauna Kuwale.

The two new bulk-rock compositions and the composition of the glassy groundmasses of the two new samples are plotted on an alkali:silica diagram in Fig. 3. Also plotted are the compositions of other oceanic siliceous differentiates (rhyodacites, trachytes, and rhyolites) of Easter Island, the Galapagos Islands, Samoa, and Iceland. The compositions of the groundmass glass in the Kauaopuu rhyodacite lies between that of the bulk compositions of rhyolites of the Thingmuli province and most of the rhyolites of Easter Island. The similarity between the groundmass glass of the Kauaopuu rhyodacite and Easter Island rhyolite bulk-composition is also shown in Table 2. The rhyodacites of the Galapagos Islands are richer in alkalis compared to those

Table 5. Results of electron microprobe analyses of inclusions in rhyodacite from Kauaopuu Ridge, Oahu Hawaiian Islands

Compound	Olivine in Dunite Nodule	Fe-Enriched Rim of Nodule	Olivine Megacryst	Chrome Spinel in Dunite Nodule	Chrome Spinel in Olivine Megacryst	Clinopyroxene in Dunite Nodule	Clinopyroxene Megacryst
SiO_2	40.00	39.2	40.0	0.45	0.63	53.7	52.2
TiO_2	--	--	--	2.2	2.4	0.36	1.2
Al_2O_3	--	--	--	11.1	6.5	2.1	2.8
FeO	15.1	19.6	15.6	45.4	38.8	4.0	7.6
Cr_2O_3	0.01	<0.01	0.02	29.5	40.9	0.39	0.08
V_2O_3	--	--	--	0.29	0.16	--	--
MgO	44.9	41.2	44.5	6.9	6.0	16.6	15.5
MnO	0.19	0.68	0.27	0.31	0.43	0.09	0.18
NiO	0.30	0.23	.48	0.29	0.38	--	--
ZnO	--	--	--	0.14	0.33	--	--
CaO	0.05	0.11	0.12	0.03	0.08	23.4	21.0
Na_2O	--	--	--	--	--	0.41	0.37
Total	100.55	101.02	100.99	96.61	96.61	101.05	100.93
Fo	84.1	78.9	83.6				
Fa	15.9	21.1	16.4				
				Recalculated Data			
FeO				23.9	24.2		
Fe_2O_3				23.9	16.2		
				99.01	98.29		
Fs						6.3	12.2
En						46.5	44.5
Wo						47.2	43.3

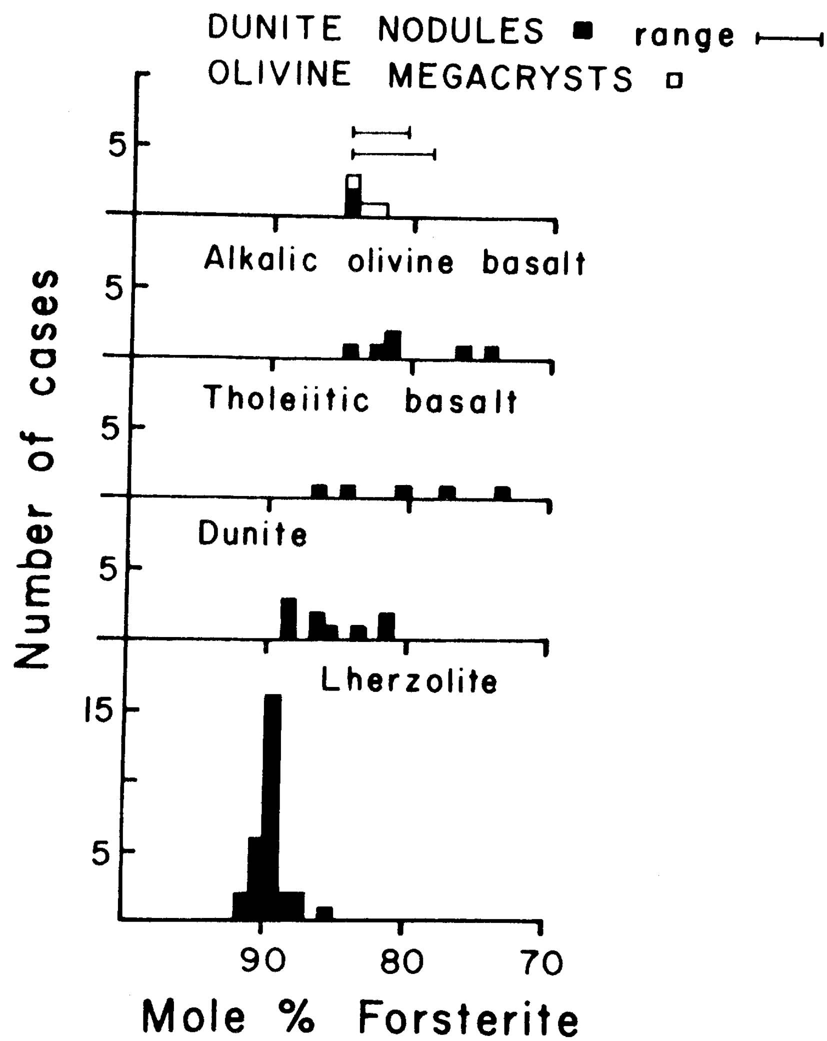
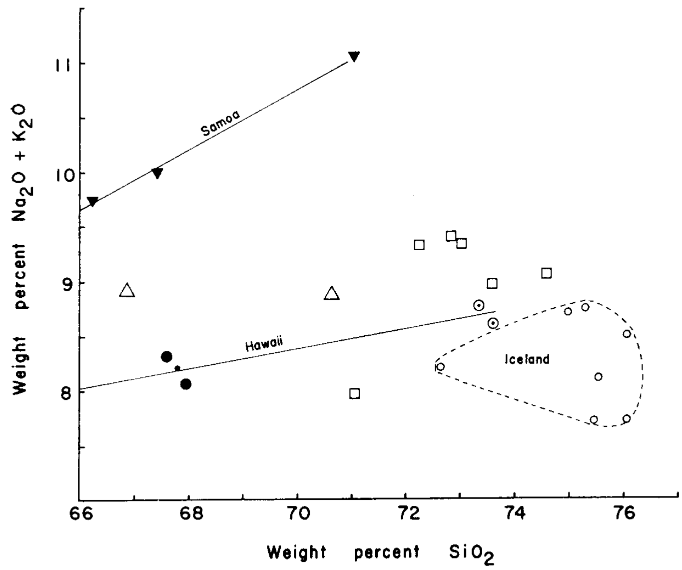


Figure 2. Histogram comparing compositions (mole percent forsterite) of olivine in dunite and olivine megacrysts (Kauaopuu Ridge, Oahu, Hawaiian Islands) to olivine in lherzolites and dunites of Hawaii (White, 1966), and phenocrysts in basalts of Maui and Molokai, Hawaii (Fodor, Keil, and Bunch, unpublished; Hlava,1974).



Bulk rock compositions:

- • Mauna Kuwale, Oahu, Hawaii, rhyodacite
- ● Kauaopuu Ridge, Oahu, Hawaii, rhyodacites
- △ Galapagos, rhyodacites
- □ Easter Island, siliceous differentiates
- ○ Thingmuli, Iceland, rhyolites
- ▼ Samoa, quartz trachytes

Groundmass glass compositions: ⊙ Kauaopuu Ridge, Oahu, Hawaii, rhyodacites

Figure 3. Total alkalis: silica diagram comparing compositions of oceanic siliceous differentiates to groundmass glass composition of Kauaopuu Ridge, Oahu, Hawaii, rhyodacite. Data, which were recalculated H_2O-free to 100%, are from the following references: Mauna Kuwale, Oahu, Hawaii, hyodacite, Macdonald and Katsura, 1964; Kauaopuu Ridge, Oahu, Hawaii, rhyodacite, this paper; Galapagos, McBirney and Williams, 1969; Easter Island, Bandy, 1937; Iceland, Carmichael, 1964; Samoa (Tutuila), Macdonald, 1944.

of Hawaii, yet they are considered to be differentiates of a tholeiitic suite (McBirney and Williams, 1969). In constrast, the quartz trachytes of Samoa are highly alkalic and are end-members of an alkalic suite (Macdonald, 1968b). Whereas the rhyolites of Iceland have tholeiitic affinities, the rhyolite obsidian of Easter Island is probably a member of an alkalic suite, as indicated by the absence of true oceanic tholeiitic basalts on the island (Bandy, 1937; Macdonald, 1968b) [the Easter Island alkalic suite, however, is probably a derivative from oceanic tholeiitic basalt (Tatsumoto, 1966)].

The similarity in composition between the groundmass glass of the Kauaopuu rhyodacite and bulk compositions of oceanic rhyolites from Easter Island and Iceland suggests that oceanic rhyolitic material could conceivably have formed by crystal fractionation of a rhyodacitic magma.

The dunite nodules in the rhyodacite are probably of the same type and origin as are dunite nodules found in alkalic basaltic rocks of Hawaii. According to White (1966), dunite nodules in Hawaiian volcanic rocks may simply be cumulates of early formed crystals from basaltic magmas. But the nodules in the rhyodacite have a "metamorphic" texture, which Jackson (1968) believes to be characteristic of a mantle regime; that is, recrystallized dunite nodules may represent residuum in the mantle left after melting to form tholeiitic magma. The forsterite content of the olivine in the nodules, however, is not high enough (e.g., $> Fo_{88}$) to represent residuum or true mantle material. Recrystallized textures can probably develop in the lower crust on the floor of magma chambers where early phenocrysts accumulate to form olivine-rich zones. It can be stated with certainty, however, that the dunite nodules are accidental inclusions, as indicated by the reaction relationship between the dunite and the host rhyodacite, where Fe-enrichment occurred in the olivine and amphibole formed at the margin.

Olivine-rich zones are probably present in the crust beneath Hawaiian volcanic centers, as is indicated by gravity data for the Waianae volcanic center in which Kauaopuu Ridge lies (Strange, Machesky, and Woollard, 1965). Therefore, it is suggested that dunite nodules in the rhyodacite are accidental inclusions that were entrapped within the rhyodacite magma as it passed through the olivine-rich zones within Waianae Volcano. The slightly metamorphic textures of the nodules may be the result of recrystallization at moderate depth under the Waianae volcanic center.

The resorption of the megacrysts and their compositions indicate that they are probably remnant phenocrysts of basaltic magma from which the rhyodacite formed by igneous differentiation. Rhyodacite magma was derived from a basaltic parent and it later incorporated dunite fragments, probably during ascent.

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