OLIVINE: I. FROM THE HAWAIIAN ISLANDS; II. PURE FORSTERITE

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Olivine has several modes of occurrence in the Hawaiian Islands: it is an essential constituent of picritic basalts,[1] and an accessory constituent in many basalts of ordinary composition,[2] where it represents the unresorbed residuum of olivine of early crystallization; it forms dunitic nodules or xenoliths, as at Mauna Loa[1] and Hualalai[2]; it appears as loose crystal fragments at many localities on various islands (as in tuffs on Oahu,[3] and in the ash plain southwest of Halemaumau at Kilauea) which have been more or less concentrated from one or more of the sources just mentioned.

A knowledge of the composition of the various solid phases of igneous rocks is essential to a study of genetic relationships. Little is known of the compositions of crystals in the Hawaiian lavas beyond the nature of the feldspars. Two reliable analyses of olivine and one of augite are on record.

The new analyses presented in Table I, 1 and 2, were made on samples furnished by Dr. H. S. Washington. Analyses 3, 4 and 5 are given to show the similarity of the olivines of Hawaii.

In the new analyses great precautions were taken in precipitating the iron-alumina group, three precipitations being carried out, to insure complete separation of magnesia and alumina. In the first analysis small amounts of lime and manganous oxide were recovered from the magnesia precipitate; in the second corresponding corrections were made. Titanic oxide, chromic oxide and manganous oxide were determined colorimetrically. Copper was determined by the sulfide method, and nickel by the sulfide method or by precipitation by dimethyl-glyoxime. Large clear grains were powdered for the analyses, and the limiting values of the refractive indices were obtained by immersion methods on the powders.

Two prisms were ground on one of the darkest grains, and measurements were made to show the relation of dispersion to re-

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[1] H. S. Washington; *Am. Jour. Sci.*, **5**, 501 (1923); R. A. Daly, *Jour. Geol.*, **19**, 301 (1911).

[2] W. Cross; *U. S. Geol. Survey, Prof. Paper* **88**, 53, 55 (1915); H. S. Washington, *Am. Jour. Sci.*, **5**, 470, 486 (1923).

[3] J. D. Dana; Characteristics of Volcanoes. *New York*, **1890**, p. 298.

[4] *Neues Jahrb.; Beil. Bd.*, **52**, 113 (1925).

fractive indices. The measurements fall in precisely with those of Ernst[4] on Icelandic olivines. Densities were obtained on several selected grains by suspension in Clerici's solution.

TABLE I

	1	2	3	4	5
SiO_2	40.43	39.54	40.42	40.01	—
TiO_2	0.07	0.09	0.08	0.12	—
Al_2O_3	0.27	0.66	0.32	0.38	—
Cr_2O_3	0.14	0.13	0.18	—	—
Fe_2O_3	2.23	1.03	0.15	0.11	—
FeO	8.75	10.87	11.44	11.12	10.30
MnO	0.10	0.13	0.10	—	—
NiO CoO	0.10	0.38	0.34	0.16 0.06	— —
CuO	trace	none	—	—	—
MgO	47.45	46.57	47.08	48.09	—
CaO	0.25	trace	0.23	—	—
Na_2O	0.12	0.46	—	—	—
K_2O	0.04	0.15	—	—	—
H_2O+	0.16	0.18	—	—	—
H_2O-	0.01	0.04	—	—	—
Sum	100.12	100.23	100.34	100.05	—

	1	2	3
Density	3.35–3.36	3.36–3.38	3.369
Refractive indices	$\gamma \leqq 1.709$ $\alpha \geqq 1.660$	1.707 1.659	

1. Olivine, eruption of Kilauea, 1789, Hawaii. M. Aurousseau, analyst. Fo 82.7, Fa 12.4, Δ 4.9. (Wt. per cent).
2. Olivine, eruption of Kilauea, 1840, Hawaii. M. Aurousseau, analyst. Fo 81.0, Fa 15.4, Δ 3.6.
3. Olivine, eruption of Mauna Loa, 1852, Hawaii. G. Steiger, analyst. Fo 81.9, Fa 16.2, Δ 1.9.
4. Olivine, "Sandwich Islands." F. W. Mar, analyst. Fo 83.9, Fa 14.2, Δ 1.9.
5. Olivine, southeastern shore, south of Hilo, Hawaii. S. L. Penfield, analyst.

OLIVINE FROM THE ERUPTION OF KILAUEA, 1789. The material consisted of loose grains 3 to 6 mm. in diameter collected by E. S. Shepherd from the plain southwest of Halemaumau. Many of the grains showed two cleavages, (010) distinct and (001) less distinct.[5] The color of pieces 2 mm. thick was a dull dark yellow (21^1k of Ridgway).

OLIVINE FROM THE ERUPTION OF KILAUEA, 1840. Loose irregular dull yellow grains 2 to 3 mm. in diameter in volcanic sand hills at the end of the Nanawale flow of 1840, Kilauea, were collected by H. S. Washington.

OLIVINE FROM THE ERUPTION OF MAUNA LOA, 1852. This olivine, separated from a fresh picrite basalt, is discussed by Daly.[6] It would be of interest to know how the nickel was determined.

OLIVINE, SANDWICH ISLANDS. Dana has published two analyses of olivine designated as above. One is by F. W. Mar, the other by E. O. Hovey.[7] The analyses, so far as comparable, are almost identical and were probably made on the same material, but Dr. Hovey is unable to provide any information on the source of his material.[8] His analysis did not extend beyond the determination of silica, iron oxide, and magnesia. Mar's analysis is complete as to essential points and is of superior quality. It is quoted, No. 4, Table I.

OLIVINE, SOUTHEASTERN SHORE, SOUTH OF HILO, HAWAII. Penfield and Forbes[9] have published a determination of the ferrous iron and of the optic axial angle of this olivine.

DISCUSSION. The lavas extruded in 1789, 1840, and 1852 all carried olivine as an essential and important constituent. For reasons indicated in the opening paragraph, it is most probable that the olivines analyzed by Mar and by Penfield were derived from similar olivine-bearing basalts of the kind called "picritic basalt" by Cross.[2] The relations of olivine in basalts have been discussed by Washington[10] in his series of papers on the Hawaiian Islands. We may state, from the five examples considered, that the olivine of the true olivine basalts of the island of Hawaii is of fairly uniform composition, and carries regular and easily determinable amounts of TiO_2,[11] Cr_2O_3,[11] and MnO. It contains also NiO, CaO, and Al_2O_3 in less regular quantities; notable amounts of alkalies have been found when sought; copper has been detected

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[5] We find no original record of other cleavages in the forsterite—fayalite series.

[6] R. A. Daly; *Jour. Geol.*, **19,** 295 (1911).

[7] J. D. Dana; A System of Mineralogy. 6th Ed., New York, **1892,** p. 453.

[8] Letter of May 16 (1921).

[9] *Am. Jour. Sci.*, [4] **1,** 129 (1896).

[10] *Am. Jour. Sci.*, **5,** 465; **6,** 100, 338 (1923).

[11] The abundant TiO_2 in Hawaiian lavas goes into augite rather than olivine. Cr_2O_3 has been found in about equal amounts in both augite and olivine. See H. S. Washington and H. E. Merwin, *Am. Jour. Sci.*, **3,** 117 (1922).

in one sample; and the variability of ferric oxide is especially noteworthy.[12]

THE OCCURRENCE OF COPPER. Copper was sought in the olivines of 1789 and 1840 at the request of Dr. E. G. Zies. There is little room for doubt that copper is present in minute quantity in the olivine of 1789, as a concurrent determination on a Finnish olivine, under identical conditions, gave a negative result. Copper in some of the incrustations collected in Hawaii was first noted by Dana,[13] and Washington and Merwin have determined the presence of 0.94 per cent of $CuSO_4$ in aphthitalite from the incrustations at Kilauea.[14] Ferguson has reported the absence of copper from two typical recent lavas of Kilauea.[15]

The presence of such amounts of oxides other than SiO_2, MgO and FeO in olivines raises questions as to the synoptic statement of analyses, and as to the applicability of measured physical properties to the statement of composition. At the foot of Table I the compositions are stated in the form used by Washington and Merwin[16] for acmitic pyroxenes. After reduction to 100 per cent as much of each chief molecule in weight per cent as the silica permitted was calculated, in descending order of abundance. Δ represents the difference between 100 per cent and the sum of the percentages of the stated molecules.

In order to have one end member well defined, measurements were made on pure forsterite prepared by Allen and Clement[17] in $MgCl_2$ melts. Although the crystals were small, measurements of indices of refraction could be made by minimum deviation for the brightest mercury lines. With these as guides, measurements for weaker mercury and helium lines were then made by covering the faces with selected bits of microscope cover glass held on with such thin films of α-bromo-naphthalene or S-tetrabromoethane that the prism angle was maintained and did not change sig-

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[12] F. S. Starrabba argues that in many cases Fe_2O_3 in olivines has not been formed by weathering. (*Mem. Ac. Zelanti*, **9,** 41, 1917). In two of his analyses and in one by Dittrich (*Z. Krist.*, **49,** 144) of European olivines the following maximum percentages of some minor constituents are reported: Fe_2O_3 5.82, TiO_2 1.19, Al_2O_3 1.01, CaO 1.00, alkalies 0.42. Dark color is related to ferric iron content.

[13] J. D. Dana; Characteristics of Volcanoes, *New York*, **1890,** p. 73.

[14] *Am. Mineralogist*, **6,** 121 (1921).

[15] J. B. Ferguson; *Am. Jour. Sci.*, **37,** 400 (1914).

[16] *Am. Mineralogist*, **12,** 233 (1927).

[17] *Am. Jour. Sci.*, **22,** 389 (1906).

nificantly during the measurement. Two sets of readings for the series of lines were made rapidly in reverse order to insure against errors due to shifting of the glasses. Some oriented prisms of large angle (*ca* 70°) were ground. Twelve sets of observations on β, four on α, and five on γ were made, and the values in Table II are probably correct within ±0.00015.

TABLE II

	Forsterite				Olivine from Fayal		
	α	β	γ	$+2V^a$ calc. from α, β and γ	α	β	γ
G (431)	1.6492+	1.6645+	1.6829	85.7°	1.6860+	1.7061+	1.7253+
Hg 436	1.6486	1.6639	1.6822		1.6853	1.7054	1.7246
F	1.6431	1.6582	1.6764				
Hg 546	1.6385	1.6534	1.6715				
Hg 578	1.6365	1.6513+	1.6694+		1.6709	1.6904	1.7093
D	1.6359	1.6507	1.6688	85.1^b	1.6702	1.6897	1.7086
C	1.6329	1.6475	1.6655	84.9			
He 668	1.6324+	1.6470	1.6650				

[a] Dispersion of 2V as measured by Arzruni[1] and by Des Cloizeaux,[2] $2V_{Na}$ by Magnusson[3] on nearly pure forsterite and by[b] Bowen and Andersen[4] on pure forsterite accords well with these calculated values. (3 per cent by wt. FeO or 3 mol. per cent fayalite increases 2V about 1°.)

[1] *Z. Krist.*, 25, 471, (1896).

[2] *Mem. Inst. France*, 43, 591 (1899).

[3] *Geol. För. Förh.*, 40, 601 (1918).

[4] *Am. Jour. Sci.*, 37, 498 (1914).

A direct determination of true density by a Westphal balance of microscopically clear crystals, made by suspension in Clerici's solution, gave the value 3.223±.002.

As previously stated, dispersions of the darkest grains of the Hawaiian olivines fall on the dispersion curves determined by Ernst on materials containing about 10 to 20 per cent FeO. But Ernst's materials were only incompletely analyzed.

A single small crystal of very light colored olivine, presumably containing much less Fe_2O_3 than the Hawaiian crystals, was ground into two prisms to give the dispersions recorded in the last part of Table II. Compared with the Icelandic crystals for similar values of α_D, the dispersions G–D are the same, but for β and γ the dispersions are 0.0005 less. This is a second indication that the Icelandic crystals contained undetermined Fe_2O_3. The density of the perfectly clear prism was 3.452, which falls on Ernst's curve correlating β_D and density. Thus, in such olivines determinations of density and refractive index do not aid in detecting small amounts of ferric oxide, but ferric oxide raises the dispersion of β and γ about four times as much as does an equal weight of ferrous oxide.[18] On dispersion, and probably refraction, the effects of titania are much like those of ferric oxide, and on these properties and density the various oxides of the ferrous oxide group are like ferrous oxide. The effects of lime, alumina and alkalies can not be stated definitely until more is known about the mechanism of their presence in the crystal, but the small amounts which the analyses show, together with titania and water, may be assumed not materially to modify the properties of forsterite.

Density and refractive index should be correlated with weight per cent of the two oxides of iron instead of weight or mol. per cent of fayalite. By combining the data of this paper with those of Ernst (and those cited in Ernst's paper) the uncertainties over the range 0 to 20 per cent of these oxides should not be greater than ± 2 per cent of oxides if the physical properties are definitely known. Zoning, which is almost universal in rock-forming olivines, presents the greatest difficulty to accurate determinations. A special study of zoning has been made by H. G. Backlund,[19] and S. Tsuboi[20] has recognized two sets of zoned olivines in the rocks of the volcano Oshima. He states the compositions as $\mathrm{Fo}_{87-81}\ \mathrm{Fa}_{13-19}$ for the older rocks, and $\mathrm{Fo}_{75-70}\ \mathrm{Fa}_{25\ 30}$ for the somma ring.

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[18] Compare the dispersions of ferric and ferrous garnets, ferric and ferrous sulfates, siderite and acmite.

[19] See *Z. Krist.*, **56,** 440 (1922).

[20] *Jour. Coll. Sci., Tokyo Imp. Univ.*, **43,** Art. 6, 1920.