

PETROLOGY OF THE HAWAIIAN ISLANDS: VI. MAUI.*

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INTRODUCTION.

Maui lies immediately northwest of Hawaii, from which it is separated by a strait 40 kilometers wide. The island¹ is about 47 miles (76 kilometers) long from northwest to southeast, and its total area is about 730 square miles. Maui consists of two volcanoes, that of West Maui, here called Kukuui, and that of East Maui or Haleakala. Kukuui is the smaller and older and is entirely extinct; whereas Haleakala, the larger and later, was active in 1750 but is now apparently extinct. Pilsbry,² basing his conclusions on the distribution of certain snails, regards West Maui, with Molokai, Lanai, [and Kahoolawe], as the remnants of a comparatively late (Pliocene) land mass.

Although some of its lavas have been studied and briefly described by E. S. Dana,³ Möhle,⁴ Cross,⁵ and Powers,⁶ little is known of the petrology of Maui. A systematic petrographic survey, with collection and study of specimens of the lavas, is much to be desired in the case of Maui, as in that of others of the Hawaiian Islands. Neither of the present writers was able to visit the island, but we have studied a very considerable suite of specimens that was collected by Dr. J.

*For other papers of this series see: this Journal, 5, 465, 1923, (I. Kohala and Mauna Kea, Hawaii); 6, 100, 1923, (II. Hualalai and Mauna Loa); 6, 338, 1923, (III. Kilauea and General Petrology of Hawaii); 6, 409, 1923, (IV. The Formation of Aa and Pahoehoe); 12, 336, 1926, (V. The Leeward Islands). These will be referred to as: Petrol. Hawaii, I, II, III, IV, and V, respectively. It is hoped to describe the rocks of Molokai, Lanai, and Kahoolawe in the next number.

¹For descriptions of Maui see: Dana, J. D., this Journal, 37, 81, 1889, and Characteristics of Volcanoes, 1890, p. 269; Hitchcock, Hawaii and its Volcanoes, (2d ed.), Honolulu, 1911; Bryan, Natural History of Hawaii, Honolulu, 1915. Maps of the island are given by Dana, Hitchcock, Bryan, and by Powers (this Journal, 50, 264, 1920). West Maui is shown on the Lahaina Quadrangle of the U. S. Geological Survey Topographic Map, and sheets covering East Maui are being prepared and issued by the same survey.

²H. A. Pilsbry, Manual of Conchology, Proc. Acad. Sci., Philadelphia, 22, 1914. See Bryan, op. cit., p. 124, and Plate 75, p. 290.

³Dana, this Journal, 37, 463, 1889.

⁴Möhle, Neues Jahrb., Beil. Band 15, 67, 1902.

⁵Cross, U. S. Geol. Survey, Prof. Paper 88, 25, 1915.

⁶Powers, this Journal, 50, 270, 1920.

Allan Thomson in 1920, supplemented by specimens collected by Dr. Sidney Powers, Dr. L. H. Daingerfield, and by Mr. Charles Kraebel. We would express our sincere thanks to these gentlemen for their generosity in furnishing the material for this study.

In the case of Maui, as in that of Hawaii, an effort has been made to describe especially what appear to be the most abundant and most representative rocks. The distinction here made between "andesite" and "basalt," and their classification, follow the lines laid down in *Petrol. Hawaii I*, pp. 468-474. The specific gravities were determined in connection with a study of the average density of Haleakala.⁷

KUKUI VOLCANO (WEST MAUI).

There is uncertainty as to the proper designation of the volcano that makes up West Maui. Brigham⁸ and J. D. Dana⁹ speak of it as Eeka, while neither Hitchcock, Bryan, nor other writers give the volcanic mass a special name. Mr. J. P. Foster, Manager of the Paia Mill, has kindly furnished¹⁰ the following information as to the local usage: "The West Maui Range is indifferently called West Maui Mountains or Wailuku Mountains. * * * * This mountain is locally called Kukui Nui, * * *. I believe that you will be quite correct in terming this range the Wailuku Mountains." Dr. L. H. Daingerfield,¹¹ also in reply to a letter of inquiry as to local usage, favors calling the "major volcanic mass" of West Maui by the name of Kukui. This name will be adopted here for that of this volcano, as being that of its culminating point, in preference to Eeka or Eke (see later) or Wailuku (the name of a town at its foot and of a district).

The culminating point of Kukui Volcano is Puu Kukui, 5,788 feet (1,765 meters) above sea level. The volcano is wholly extinct, but a small "crater,"¹² called Eke, is shown on the Lahaina Quadrangle, about two miles north-northeast

⁷ Washington, *Jour. Washington Acad. Sci.*, 13, 453, 1923.

⁸ Brigham, W. T., *Mem. Boston Soc. Nat. Hist.*, 1, 366, 1866.

⁹ Dana, J. D., *Characteristics of Volcanoes*, 1890, p. 269.

¹⁰ Letter of 19 August, 1927.

¹¹ Letter of 16 September, 1927. His specimens are labeled as coming from "Mt. Eke."

¹² According to Foster this is not a crater, and Daingerfield does not mention a crater in his remarks on Eke, but speaks of it as being covered by swamp.

of Puu Kukui, at an elevation of 4,480 feet (1,469 meters). The upper slopes are densely wooded, making travel difficult, and an extensive bog covers the summits of Eke and Puu Kukui. The mass has been deeply eroded and dissected, especially on the windward side, some eighty deep valleys and gulches radiating from the summit in all directions. Of these the best known is Iao Valley, on the eastern slope, which heads in a large erosion cirque immediately below Puu Kukui. These deep, narrow valleys and gulches, with their accumulation of boulders from the steep and mostly inaccessible walls, furnish rough samplings of the lavas that go to make up the mass of the volcano. We studied specimens collected by Thomson in Iao Valley and from near Lahaina; some collected by Daingerfield in Kahoma Gulch on the west slope and above Honokohau on the north and some collected by Powers. Cross studied specimens collected by him from Iao Valley and also from Waihee Valley, as well as the trachytic lava from near Lahaina, also described by Dana. Powers seems to be the only geologist to have studied the field relations of the flows on the lower slopes, except those to the southwest, near Lahaina.

Gabbro. Among the blocks collected by Thomson in Iao Valley are two that may be called gabbro because of their composition, coarse grain, and holocrystalline ophitic texture. These are of interest, because they probably represent the "core" of the volcano, that is to say, an upwelling of liquid that never reached the surface but solidified in the throat. Similar rocks are found at other Hawaiian volcanoes, as on Molokai and Kauai. A block that apparently resembles the specimen that we analyzed was found by Cross in Iao Valley.

Both of our specimens are, megascopically, 1 to 2 millimeter-grained, brownish black, equigranular, and holocrystalline. One specimen, that which was analyzed, is composed almost wholly of black augite and brownish feldspar, with an occasional grain of olivine and a still rarer one of magnetite. The other specimen is similar but olivine grains are more abundant.

In thin section the analysed specimen shows an ophitic, holocrystalline texture. The rock is composed mostly of pale brownish augite, that for the most part moulds the much less abundant subhedrally tabular andesine (Ab_3An_2), which is occasionally porphyritic. Very few subhedral fresh olivines are present; there are some small, irregular shreds of slightly altered biotite, an occasional grain of magnetite, and a little interstitial nephelite. This specimen was chosen for analysis

because it resembles that which was briefly described by Cross, so that this type appears to be the more abundant. The other specimen, furthermore, is not fresh.

The thin section of the unanalysed specimen reveals a much more mafic composition. The rock is made up largely of colorless olivine, much of it in euhedral or subhedral individuals, with a few inclusions of small magnetite grains. The olivine is much cracked and serpentinized, the serpentine penetrating the cracks and surrounding the crystals. Anhedral, pale brownish augite is present in less amount, some of it surrounding and some of it being interstitial between the olivines. The pyroxene, as in the preceding case, is practically free from inclusions, except for a rare small magnetite grain. Black tables and grains of ore occur here and there which, from their form, are judged to be ilmenite. There is very little feldspar—a finely twinned labradorite—interstitial between the mafic minerals, and a rare small area of what may be nephelite is seen here and there. Indeed, so small is the percentage of silic minerals that the rock deserves the name of peridotite rather than that of gabbro.

An analysis of the fresh, olivine-poor gabbro is given in No. 1 of Table I, with one of a similar gabbro from Molokai (unpublished) in No. 2. The latter is of the original specimen collected by Lindgren and was very briefly described by him.¹³ It will be described by us when dealing with the rocks of Molokai.

The Kukui gabbro is not remarkable chemically, although the Al_2O_3 is low, in accordance with the character of the dominant feldspar. Indeed, if one makes the usual allowance for the normative anorthite molecules that enter the modal augite, the normative composition represents very closely the modal, although the amount of normative olivine appears to be somewhat more than that which is actually present. The Molokai gabbro (No. 2 Table I) is quite different, the SiO_2 and MgO being much lower and the CaO much higher, differences that are in accord with the more feldspathic content of this rock. Somewhat similar core (?) gabbros occur at other volcanoes of the Hawaiian Islands, especially Kauai and Hawaii (Kilauea and Hualalai), but the discussion of their general characters and origin must await a later paper of this series. Similar gabbros are known from some of the more southerly Pacific volcanic islands—Tahiti, Tutuila, etc.

¹³ Lindgren, U. S. Geol. Surv., Water-Supply Paper, 77, 14, 1903.

TABLE I. Lavas of Kukui Volcano, Maui, and others.

	1	2	3	4	5	6	7	8
SiO ₂	48.95	46.39	47.72	48.53	59.74	58.06	61.69	62.02
Al ₂ O ₃ ...	11.11	18.97	15.44	14.26	18.86	18.21	17.33	18.71
Fe ₂ O ₃ ...	2.67	1.85	0.23	2.84	1.94	4.87	5.30	4.30
FeO	7.08	8.12	9.52	9.10	3.75	2.01	0.07	0.10
MgO	11.88	4.02	11.31	5.01	0.90	1.59	0.16	0.40
CaO	10.86	10.99	10.23	11.62	3.00	3.20	1.05	0.86
Na ₂ O	2.38	3.34	2.31	2.60	7.33	6.12	7.47	6.90
K ₂ O	0.27	0.96	0.63	0.66	2.89	2.75	3.47	4.93
H ₂ O+ ..	0.31	0.89	0.46	1.09	0.12	....	1.93	0.80
H ₂ O- ..	0.61	0.16	0.05	0.07	0.26	....	0.42	0.31
TiO ₂	2.44	4.44	1.81	3.72	1.02	1.88	0.67	0.31
ZrO ₂	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.16	0.06
P ₂ O ₅	0.14	0.47	0.15	trace	0.26	0.65	0.05	0.24
MnO	0.16	0.17	0.16	0.11	0.13	0.36	0.21	0.15
BaO	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.07	0.02
	99.76	100.77	100.02	99.61	100.20	99.99 ¹	100.10 ²	100.13 ³
Sp. gr. ...			3.065	2.972	2.680		2.577	2.763
at			25°	25°	23.5°		25°	21°

¹Includes: S 0.05, Cu 0.10.

²Includes: S 0.02, SrO 0.03.

³Includes: Cl none.

Norms.

	1	2	3	4	5	7 ¹	8 ²
Q .....	....	....	....	1.74	....	3.00	1.80
Or	1.67	5.56	3.89	3.89	17.24	20.57	28.91
Ab	20.44	25.15	19.39	22.01	58.16	62.88	58.16
An	18.63	33.92	29.75	25.30	10.01	3.61	2.22
Ne .....	....	1.70	....	....	1.99	....	....
Di	27.74	14.49	16.19	26.31	2.57	0.43	....
Hy	12.27	....	2.72	7.97	....	0.20	1.00
Ol	9.24	6.81	22.37	....	3.50	....	....
Mt	3.94	2.55	0.23	4.18	2.78	....	....
Il	4.56	8.36	3.50	6.99	1.98	0.61	0.15
Ap	0.34	1.01	0.34	....	0.67	....	0.67

¹Includes: Hm 5.30, Tn 0.78.

²Includes: C 1.22, Hm 4.30, Ru 0.24.

- Gabbro, III.5.3(4)."5. Iao Valley, Kukui Volcano, Maui. Keyes analyst.
- Gabbro, II".5.(3)4.4. Wailau Valley, Molokai. Keyes analyst.
- Olivine basalt, III.5.4.4. Iao Valley, Kukui Volcano, Maui. Keyes analyst.
- Andesine basalt, III.5.(3)4.4. Iao Valley, Kukui Volcano, Maui. Keyes analyst.
- Oligoclase andesite, I(II).5.2.4. Iao Valley, Kukui Volcano, Maui. Washington analyst. This Journal, 5, 478, 1923.
- Oligoclase andesite, (norm not calculated). Waimea, Kohala Volcano, Hawaii. Lyons analyst. This Journal, 2, 424, 1896, and 5, 478, 1923.
- Anorthoclase trachyte, I.5.1.4. Launiupoko Hill, Kukui Volcano, Maui. Steiger analyst. Cross, U. S. Geol. Survey, Prof. Paper 88, 27, 1915.
- Anorthoclase trachyte, I.5.1."4. Puu Anahulu, Hualalai Volcano, Hawaii. Washington analyst. This Journal, 6, 108, 1923.

Olivine basalt. Only two specimens of basalt that contain enough olivine to justify their being called olivine basalt were found among Thomson's collection from Kukui, although Cross mentions one or two that probably belong here found by him in Waihee Valley, and Powers speaks of the West Maui basalts as being mostly olivinic.

One specimen is a dense, medium gray lava, showing rather numerous olivine phenocrysts, 1 to 2 mm. in diameter, with fewer of black augite, in a very fine-grained, phaneric groundmass, in which a lens reveals grains of feldspar and of mafic minerals. The thin section shows that the sharply euhedral olivine phenocrysts are almost fresh or only slightly yellow on the edges. The fine-grained groundmass is composed of small grains of pale brownish augite, with fewer of olivine, and many small laths of labradorite. There are some small ore grains, probably of ilmenite. There is a little interstitial orthoclase or nephelite, visible only under high powers, and the rock appears to be holocrystalline.

The texture is not basaltic in the ordinary sense, but is what might be termed grano-basaltic. This texture appears to be of common occurrence in the basalts of Hawaii,¹⁴ as the aphyric basalts of Kohala and Mauna Kea and the olivine basalt of Hualalai, and in basalts of others of the islands.

An analysis of Thomson's specimen of this type gave the results shown in No. 3 of Table I. The SiO_2 , Al_2O_3 , CaO , and alkalis are normal; but the very low Fe_2O_3 and high FeO are to be noted, as well as the percentage of MgO , which serves to distinguish this type from that of the picrite-basalts, which contain almost twice as much of this constituent. The analysis here given may be paralleled by several of similar olivine basalts on Hawaii.

A second variety of olivine basalt found in Iao Valley is a vesicular lava, with the aa form of vesicle. Many phenocrysts of fresh yellow olivine, 1 to 3 mm. in diameter, lie in a dense aphanitic groundmass. There are no augite phenocrysts. The thin section shows many large, euhedral, colorless, and very fresh olivine phenocrysts in a dense brownish groundmass. This is made up of minute plagioclase laths, pale brownish augite anhedral, and ilmenite rods and tables, in what appears to be a colorless glass. The amount of olivine is so great that the rock might well be termed picrite-basalt, that is

¹⁴ Petrol. Hawaii, I, 485, 492, 495; II, 101.

to say, a basalt in which the amount of olivine and augite dominates over the feldspars.¹⁵

Labradorite-andesine basalt. If one may judge from the relative proportion of the specimens collected by Thomson—7 out of 16—one of the most abundant kinds of lava among the boulders of the Iao Valley is olivine-free normal basalt, the feldspar of which is either labradorite or andesine or both. Some of the rocks collected by Cross in the Waihee and the Iao Valleys also appear to belong here, as well as a few from near Lahaina described by Möhle. Although these rocks vary considerably texturally, yet they may be described as one group.

The most common type is phyric, with phenocrysts of labradorite (up to 1 to 2 mm.) in a densely aphanitic, light gray groundmass. Fewer are aphyric and most of these are darker, some almost black, and very dense.

The thin sections show these lavas to be of very simple mode. The labradorite phenocrysts, which vary considerably in abundance and size, are rather simply twinned and euhedral: their general composition is about Ab_1An_2 . Only rare and sporadic phenocrysts of pale brownish augite are occasionally present. The very fine-grained micro-groundmass is typically intersertal, as in the specimen analysed, which is composed of slender laths of andesine, about Ab_1An_1 to Ab_2An_1 , with many small anhedral grains of pale yellow to colorless augite, and some grains of ilmenitic ore. No olivine was seen. There are a few small patches of what appears to be orthoclase. Glass is present in some of the specimens, largely replacing the interstitial augite grains, and in one or two it is dark and almost opaque.

An analysis of an average specimen, with some labradorite phenocrysts, is given in No. 4 of Table I. It is that of a slightly sodic, but otherwise normal basalt.

The most abundant and typical of these lavas greatly resemble modally, texturally, and chemically the lavas from Kohala, Mauna Kea, and Mauna Loa, on Hawaii, that were called feldspar-phyric basalt.¹⁶

Oligoclase andesite. One block collected by Thomson in Iao Valley is of a very light gray, extremely fine-grained but not aphanitic, trachytic rock, which is entirely devoid of pheno-

¹⁵ Petrol. Hawaii, I, 498.

¹⁶ Petrol. Hawaii, I, 482, 496; II, 124.

crysts. Apart from difference in color this slightly bluish gray Maui "trachyte" much resembles the cream-colored trachyte of Puu Anahulu near Hualalai, on Hawaii,¹⁷ but the rock is very firm and does not crumble between the fingers.

In thin section the rock is seen to have a trachytic texture, similar to that of the Lahaina trachyte, next to be described, but with less tendency to flow texture. The rock is composed almost wholly of short laths or thick tables of oligoclase. The section is sprinkled with very small anhedral grains of colorless diopside and of black "ore." No olivine is to be seen. There is some ill-defined, colorless base interstitial between the feldspars, which is birefringent and of low refractive index: this is assumed to be nephelite. The rock is holocrystalline. A hand specimen of the compact rock gave a specific gravity of 2.680 at 23.5°.

An analysis of this rock is given in No. 5 of Table I, it having already been published in connection with the description of a similar rock at Kohala on Hawaii, an analysis of which is cited in No. 6. The percentages of Na₂O, K₂O, and CaO conform to the general composition of the oligoclase feldspar, but those of SiO₂ and of the other constituents are trachytic. The norm shows some olivine, although none is visible in the thin sections. It is probable that a little of the normative albite molecule has been desilicated to modal nephelite, the released silica forming modal hypersthene out of the normative olivine.

Powers¹⁸ observed flows of "trachyte" up to 30 feet thick in Waiolae, Waihee, and other gulches on the east and north sides of Kukui Volcano, and one of Daingerfield's specimens of similar rock is from an elevation of 2,250 feet up the Honokahua gulch on the north slope. The rock also occurs at Puu Paupau¹⁹ on the west slope, above Lahaina. These lavas are composed essentially of oligoclase or of albite-oligoclase, and they, and the trachytes, are regarded by Powers as among the youngest products of the volcanic activity. Most of his specimens appear to be more or less decomposed, that of Puu Paupau less so, but Thomson's specimen from Iao Valley studied and analysed by us is of exceptional freshness.

¹⁷ Petrol. Hawaii, II, 107. It may be worth noting that within five or six years my specimen of this trachyte has become very firm.

¹⁸ Powers, this Journal, 50, 271, 1920.

¹⁹ As was surmised by Cross, this is clearly the "Mt. Ball," above Lahaina, the rock of which was described by Dana.

It may be mentioned that Powers describes a somewhat similar oligoclase trachyte from the island of Molokai.

The rock from the Iao Valley was called "oligoclasite" when its analysis was first published,²⁰ as this name had been used by Sabatini²¹ for somewhat similar lavas of the Cimino Volcano in Italy. Previously, however, Kolderup²² had applied the name to plutonic oligoclase rocks from the Lofoten Islands, and the term had been suggested for certain gabbroic rocks from Monte Cavaloro near Bologna as far back as 1878.²³ The term has, thus, been used with very different significations, and for this reason the avoidance of the use of "oligoclasite" has been recommended by the Committee on British Petrographic Nomenclature.²⁴ We are in full accord with their conclusion in this matter and have, therefore, adopted the name "oligoclase andesite" in place of the previously used "oligoclasite."

Anorthoclase trachyte. Decidedly sodic trachytes occur along the west slope of Kukui Volcano, near the sea.²⁵ The best known of these is that which occurs at Launiupoko Hill, about half way between Lahaina and Olawalu. This rock has been described by Dana,²⁶ Möhle,²⁷ and Cross,²⁸ the last communicating a very complete analysis by Steiger. We have studied specimens of what is probably the same rock, collected by Thomson and labeled: "Rock used for cement, Paia Mill, from between Lahaina and Olawalu." In reply to an inquiry Mr. J. P. Foster, Manager of the Paia Mill, informs us that we are "correct in thinking that it came from Launiupoko, or rather from its immediate vicinity. It was used [for making cement] on account of its high silica content,"²⁹ [clay not being available]. The modal and textural characters closely agree with those of the Launiupoko rock described by Cross.

Thomson's specimens are very light gray, dense and compact, of trachytic feel and aspect, and with a slight tendency to

²⁰ Washington, *Petrol. Hawaii*, I, 477.

²¹ Sabatini, *Vulvani Cimini*, Mem. Cart. Geol. Italia, 15, 143, etc., 1912.

²² Kolderup, *Bergens Mus. Aarb.*, No. 7, 28, 1898. Cf. Rosenbusch-Osann, *Elemente Gesteinslehre*, 4th ed., 244, 1922.

²³ Rosenbusch, *Mikr. Phys.*, II, 1, 341, 1907.

²⁴ *Min. Mag.*, 19, 144, 1921.

²⁵ Powers, this Journal, 50, 270, 1920. Powers in general does not distinguish between anorthoclase trachyte and oligoclase andesite.

²⁶ Dana, E. S., this Journal, 37, 465, 1889.

²⁷ Möhle, *Neues Jahrb.*, Beil. Band 15, 69, 1902.

²⁸ Cross, U. S. Geol. Surv., Prof. Paper 88, 26, 1915, and Plate IIIA.

²⁹ Letter of 19 August, 1927.

schistosity. A few small black pyroxene phenocrysts are scattered through a very fine-grained, phaneric groundmass, made up of abundant small tables of colorless alkali feldspar with very minute black grains. Megascopically the rock closely resembles Thomson's Iao Valley specimen of oligoclase andesite and, like it, except for the bluer gray color, the anorthoclase trachyte of Puu Anahulu on Hawaii.

Thin sections show in general the characters well described by Cross. The general texture is trachytic, but rather indefinitely so and usually with no marked evidence of flow. The rock is composed in very large part of short thick tables of anorthoclase showing no multiple twinning, with fewer and slightly larger ones of oligoclase, distinguished by their somewhat higher refractive index. There is also much anhedral and interstitial, indefinitely granular, alkali feldspar material. Rather numerous, small, anhedral, ragged grains of a brownish pyroxenic mineral occur, which is presumably acmite. The green aegirite noted by Cross is absent from our specimens, and the pyroxene is in part altered to limonitic material. No nephelite is detectable, but the specimens appear to be holocrystalline.

The specific gravity of one of our specimens was found to be 2.577 at 25°.

We made no analysis of any of our specimens of this type, because of the existence of Steiger's analysis, given in No. 7 of Table I, of Cross' specimen and because of the great resemblance in modal and textural characters. The Maui trachyte much resembles, modally and texturally, the anorthoclase trachyte of Puu Anahulu, near Hualalai Volcano, on Hawaii, and the very close chemical similarity is also striking, as may be seen on comparison of Nos. 7 and 8 of Table I.

These trachytes greatly resemble those that occur on other Pacific islands—Tahiti, Tutuila, Huahine, Nukuhiva, Juan Fernandez, San Felix, and others—the resemblances extending to the mode, the texture, and to the chemical composition. All these trachytic lavas are composed essentially of anorthoclase, of the composition of about Ab_2Or_1 , soda dominating over potash in the lava, and with little lime. Such trachytes are spoken of generally as "soda trachyte" or "sodic trachyte," or occasionally as "nephelite trachyte," or phonolite if modal nephelite be prominent. We have used the name "anorthoclase trachyte" as this is in accord with the principles previously adopted in the nomenclature of the andesites and

basalts of the Hawaiian Islands, whereby, in general, a mineral rather than a chemical qualifier of the rock-group name is used.

HALEAKALA (EAST MAUI).

East Maui is made up of the volcano of Haleakala, with its famous and enormous crater. The volcano covers an area six times that of the older Kukui Volcano on West Maui, the altitude of its highest point being 10,032 feet (3,058 meters) above sea level. Although the volcano is generally regarded as extinct, an eruption, with an accompanying flow, took place about 1750, from a small cone near the sea at the southern corner.³⁰ As no fumarolic activity in the main crater or elsewhere is recorded at the present time the volcano appears to be extinct.

Comparatively little is known of the petrography of the lavas of Haleakala, some of which have been studied by the Danas and by Cross. Haleakala has been much less deeply dissected than Kukui, so that almost all of the lavas available for study represent the later or latest flows. With few exceptions these are andesitic, although the resemblance to the lavas of Mauna Kea suggested by Powers does not seem to us to be evident. Most of the Haleakala lavas show a peculiar trachytoidal microtexture and all contain so much Na_2O that nephelinite appears in all the norms and in the mode of some, so that they grade into what might be called tephritic lavas. A few labradorite basalts occur and there are rather abundant picrite-basalts, among them late flows in the main crater and the lava of 1750.

Nephelinic andesite-basalt. Both Dana and Cross remark on the andesitic, rather than the basaltic, character of most of their specimens from Haleakala. Cross speaks of them "as a group of contemporaneous lavas of closely allied types," which he calls essexitic andesite or trachyandesite, remarking that "they might have been termed trachydolerite by Rosenbusch." These remarks apply to most of the specimens examined by us, which form a group of lavas of somewhat variable composition, modally and chemically, but distinguished by a peculiar somewhat trachytic texture (with few exceptions), and high Na_2O and rather high K_2O , so that all the

³⁰ Powers, this Journal, 50, 265, 1920. Dana, Characteristics of Volcanoes, 1890, p. 278. Bryan, Natural History of Hawaii, 1915, p. 147.

norms show notable amounts of nephelite. The microgroundmass is so extremely fine, however, that in most cases the modal nephelite is difficult or impossible to detect, and the various specimens grade into each other to such an extent that almost any division would be arbitrary. They will therefore be described together, although our specimens range from an almost typical oligoclase andesite (II.5.2.4) to salfermic basalt (III.6.2.4) with so much nephelite, both modal and normative, that it might be called tephrite.

Dana and Cross studied specimens from near White Hill, at the southwest angle of the crater wall, and from other localities. Our specimens were collected by Thomson from and near White Hill and Red Hill and the Rest House, and on the Olinda trail—none from inside the crater. We also studied similar lavas which were collected by Powers and by Kraebel in the Keanae Valley.

Megascopically these rocks present no features of special interest. They are of medium to light gray color, and mostly massive, although some of the specimens are vesicular with the aa type of vesicle. Nearly all the specimens are aphyric or show very few and small phenocrysts of augite and olivine in a very dense, fine-grained aphanitic groundmass.

The thin section reveals a microtexture that is fairly uniform and which seems to be characteristic of these lavas. Although the texture is not definitely described by Dana or Cross yet one gathers that most of their specimens showed the same texture as that shown by ours. The texture is markedly trachytoidal, the rock being composed largely of abundant very thin laths of andesine or, less often, of oligoclase-andesine, some up to 0.5 mm. long, with well-developed fluidal arrangement. Very few and small phenocrysts of grayish augite and of euhedral olivine are present. The microgroundmass in which the feldspar laths lie is dark and indefinitely granular, high powers resolving it into a mixture of very minute colorless augite prisms, many black ore grains, a little interstitial orthoclase, and a variable amount of what must be regarded as nephelite. The amount of this is difficult to determine, as indeed is its actual identification generally, although the chemical analyses show that it must be present in considerable amount in most of the specimens; in some cases to such an extent as almost to merit the bestowal of the name of tephrite on some of the lavas. In general these rocks appear to be

holocrystalline, although those whose analyses are given in Nos. 7 and 8 of Table II have a vitreous, almost opaque groundmass.

Chemical analyses of eight of these rocks are given in Table II, two being cited from Cross. These, with their norms, show well the serial character of these Haleakala lavas and, at the same time, the decidedly high alkalis, with rather low magnesia and lime, which rise as silica decreases. The iron oxides are high and are remarkably constant. One peculiarity is the much higher P_2O_5 in the andesites than in the basalts: a similar relation was noted at the Kohala Volcano on Hawaii. The presence of notable amounts of nephelite in the norm is a striking feature—in marked contrast with the lavas of Kukui Volcano.

In Table II the names of the lavas are given as either andesite or basalt, according to whether, normatively, they are dosalic or sulfemic. It must, however, again be emphasized that there is no strict division between these two that is noticeable under the microscope, although in the basalts the olivine phenocrysts are decidedly more euhedral than in the andesites. The groundmass in both is essentially the same.

TABLE II. Nephelinic andesite-basalts, Haleakala, Maui.

	1	2	3	4	5	6	7	8
SiO ₂	51.26	49.55	48.04	47.03	45.46	43.50	43.43	41.89
Al ₂ O ₃	16.74	17.78	17.95	15.57	16.18	15.27	12.01	14.41
Fe ₂ O ₃	2.92	4.65	4.28	3.22	4.40	2.74	4.23	7.32
FeO	7.11	5.89	7.21	8.68	7.38	9.91	10.38	8.26
MgO	2.80	2.49	2.79	4.20	4.07	7.85	6.37	6.73
CaO	6.61	7.01	7.52	8.67	8.56	9.71	10.84	11.69
Na ₂ O	5.86	6.12	5.55	4.88	6.06	3.80	3.78	2.68
K ₂ O	2.21	2.29	1.91	1.84	1.82	1.39	1.36	0.94
H ₂ O+ ...	0.42	0.34	0.14	0.67	0.06	0.31	0.72	0.47
H ₂ O— ...	0.26	0.29	0.08	0.11	0.03	0.06	0.39	0.09
TiO ₂	2.57	2.09	3.27	4.60	5.10	4.84	5.81	4.68
ZrO ₂	none	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
P ₂ O ₅	0.81	1.10	0.88	0.42	0.51	trace	0.26	0.15
Cr ₂ O ₃	none	none	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
MnO	0.23	0.28	0.39	0.18	0.24	0.14	0.22	0.16
BaO	0.10	0.05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
SrO	0.09	0.08	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	100.03 ¹	100.07 ²	100.01	100.16	99.87	99.52	99.80	99.47
Sp. Gr. ...			2.836	2.788	2.718	2.929	2.924	3.067
at			25°	25°	25°	25°	25°	25°

¹Includes: NiO none.

²Includes: FeS₂ 0.03, V₂O₃ 0.02, NiO none.

Norms.

	1	2	3	4	5	6	7	8
Or	12.79	13.34	11.12	11.12	10.56	8.34	8.34	5.56
Ab	38.77	34.84	31.96	24.10	20.96	15.20	14.15	14.15
An	12.79	14.96	18.35	15.01	11.68	25.02	11.68	24.19
Ne	5.96	8.96	8.24	9.37	16.47	4.54	9.66	4.83
Di	11.93	10.42	10.91	20.56	21.52	18.51	32.41	25.92
Ol	5.86	3.80	4.87	4.92	1.36	12.77	4.79	4.53
Mt	4.18	6.73	6.26	4.64	6.50	6.03	6.03	10.44
Il	4.86	3.95	6.23	8.82	9.73	9.12	11.10	8.97
Ap	2.02	2.69	2.02	1.01	1.34	....	0.67	0.34

- Oligoclase andesite, II.5".2.4. Near Vieira Ranch, Pukalale, South slope. Steiger analyst. Cross, op. cit., p. 31, 1915.
- Andesine andesite, II.5(6).2.4. White Hill, Summit. Hillebrand analyst. Cross, op. cit., p. 31, 1915.
- Andesine andesite, II.5(6).(2)3.4". Rest House, Summit. Keyes analyst.
- Nephelinic andesine andesite-basalt. (II)III."6.2(3)4. Two miles above Olinda, North slope. Keyes analyst.
- Nephelite andesine basalt, "III.6.2.4". Three miles from Rest House, Olinda trail, North slope. Keyes analyst.
- Nephelinic labradorite basalt, III.5".3(4).4. Near Rest House, Summit. Keyes analyst.
- Nephelite andesine basalt, III.6.2(3).4. Red Hill, Summit. Keyes analyst.
- Nephelinic labradorite basalt, III.5(6).3(4).4. Rest House, Summit. Keyes analyst.

Chrysophyric basalt. As the elder Dana and Cross point out, there occur at and near the summit of Haleakala and extending down the west slope, as well as on the crater floor, many flows of basaltic rocks that contain abundant olivine, in such amount and in such large prominent phenocrysts that this mineral deserves recognition in the classification and is not to be relegated to the small and sparse olivines produced by the so-called Bowen-Andersen effect, spoken of in preceding papers. Augite phenocrysts accompany those of olivine and occur abundantly scattered on the surface (see page 213). These olivine-rich basalts have been described by the younger Dana³¹ and Cross gives a brief description (with an analysis) of a specimen collected by himself.³² In the absence of sufficient specimens studied by us we are unable to state definitely whether, in all these olivine-rich basalts, the mafic minerals (olivine and augite) are approximately equal to or dominate over the feldspars—that is, whether they are what has been called in former papers chrysophyric basalt or picrite-basalt. To judge from the percentages of SiO₂ reported by Dana

³¹ Dana, E. S., this Journal, 37, 463, 1889.

³² Cross, U. S. Geol. Surv., Prof. Paper 88, 28, 1915.

(48.42 and 50.44) it would appear that the specimens studied by him were not picrite-basalt. On the other hand the specimen studied by Cross is a picrite-basalt according to its norm, although the amount of MgO is not as great as in the typical picrite-basalts of Hawaii,—those of Mauna Kea, Mauna Loa, and Kilauea, described in previous papers. It might best be termed "picritic basalt," the name given to it by Cross.

According to Cross' description, his analysed specimen from a cone within the crater near its western extremity shows many well-formed phenocrysts of augite and olivine, in a dense dark gray groundmass approximately equal in amount. Microscopically, the groundmass is nearly holocrystalline and composed "of an obscure mixture of augite and magnetite with inconspicuous labradorite microlites and a few minute grains of nephelite." A small specimen of this variety collected by Thomson near White Hill, where it is said to form a dike, is very similar. The augite and olivine phenocrysts project considerably from the slightly weathered surface, indicating a stage in the freeing of the loose crystals of these minerals. The analysis of Cross' specimen is cited in No. 1 of Table III, and calls for little comment, except to call attention to the low SiO₂, Al₂O₃, and alkalies, and comparatively low MgO and high CaO as contrasted with similar rocks on the island of Hawaii.

Augite. As a matter of convenient record here, it may be well to present the chief characters of the loose crystals of the Haleakala augite, which have been described elsewhere.³³

Habit: the usual one of volcanic loose augites. Color: jet-black, in thin section pale gray, slightly greenish, pleochroism very faint. Extinction angle $\gamma \wedge c = 47^\circ - 48^\circ$ for red, 49° for blue. $2V = 61^\circ - 62^\circ$, $2V_b = 58^\circ - 60^\circ$. Refractive indices (of material analysed): $\alpha = 1.700$, $\beta = 1.706$, $\gamma = 1.724$. Density (L. H. Adams) = 3.358. Chemical composition: SiO₂ = 47.70, TiO₂ = 1.89, Al₂O₃ = 6.82, Fe₂O₃ = 3.36, Cr₂O₃ = 0.23, FeO = 4.43, MnO = 0.16, MgO = 13.34, CaO = 21.35, Na₂O = 0.65, K₂O = 0.03, H₂O+ = 0.15, Sum = 100.11.

Limburgitic basalt. The lava of the flow of 1750, as represented by a specimen collected by Powers from the flow of the Pimoa cone of that date, is also highly chrysophyric, that is to say, very rich in olivine phenocrysts. These are golden

³³ Washington and Merwin, this Journal, 3, 117, 1922.

yellow, very fresh, and up to about 5 mm. in diameter. They constitute about one-fifth of the rock. There are a few greenish black augite phenocrysts of about the same size. These phenocrysts are imbedded in a dense, aphanitic, dark gray groundmass. The larger olivine phenocrysts, in thin section, are subhedral, prismatic, much cracked, perfectly fresh, and free from inclusions. The subhedral large augite phenocrysts are brownish. In the microgroundmass are many smaller microphenocrysts of olivine which are very sharply euhedral. Some very small and thin laths of untwinned labradorite are scattered through the groundmass, but the total amount is small: they do not show much evidence of flow. These microphenocrysts lie in a dark, almost or quite opaque basis that high powers resolve into some minute augite and ore grains in a blackish glass. No nephelite is definitely visible, although about 9 per cent of this is present in the norm.

An analysis of the limburgitic basalt of the flow of 1750 is given in No. 2 of Table III, with those two others of similar rocks from Niihau and from Hualalai on Hawaii. The chemical resemblance between the Maui and the Niihau lavas is remarkably close. The Hualalai olivine basalt resembles the other two chemically, except in its higher SiO_2 : in spite of which it shows about 8 per cent of nephelite in the norm.

TABLE III. Chrysophyric basalts. Haleakala, etc.

	I	2	3	4
SiO_2	42.99	43.28	43.46	46.76
Al_2O_3	10.21	14.43	15.34	13.78
Fe_2O_3	3.01	0.70	1.46	1.26
FeO	10.28	10.92	8.17	10.43
MgO	14.61	11.68	12.60	11.07
CaO	12.54	11.22	11.39	10.54
Na_2O	1.40	2.40	2.01	3.59
K_2O	0.52	0.83	0.69	0.64
H_2O^+	1.10	0.05	0.59	0.10
H_2O^-	0.82	0.03	0.47	0.10
TiO_2	2.52	4.12	2.21	2.12
P_2O_5	0.20	0.31	0.48	0.32
SO_3	n.d.	0.20	n.d.	n.d.
Cr_2O_3	0.06	0.10	n.d.	n.d.
MnO	0.17	0.13	0.16	0.08
BaO	none	0.05	n.d.	n.d.
	100.58 ¹	100.54	99.63	100.79

¹ Includes ZrO_2 , SrO none; NiO 0.06.

Norms.

	1	2	3	4
Or	3.24	5.00	3.89	3.89
Ab	5.24	4.72	5.76	15.76
An	19.74	36.70	28.08	19.46
Ne	3.69	8.80	8.80	7.95
Di	32.93	8.66	22.92	25.00
Ol	23.82	25.68	22.23	22.02
Mt	4.41	0.93	2.09	1.86
Il	4.86	7.75	4.26	3.95
Ap	0.67	0.67	1.01	0.67

1. Picritic basalt, "IV.(1)2."3.2.2. Namaunekeakua Cone, Crater floor, Haleakala. Steiger analyst. Cross, U. S. Geol. Survey, Prof. Paper 88, 29, 1915.
2. Limburgitic basalt, III."6.4.4. Lava of 1750, Pimoa Cone, Haleakala. Keyes analyst.
3. Limburgitic basalt, III.6."4.4. Nonopapa Landing, Niihau Island. Keyes analyst. Petrol. Hawaii, V, 339, 1926.
4. Olivine basalt, III."6.3.(4)5. Summit of Hualalai, Hawaii. Washington analyst. Petrol. Hawaii, II, 102, 1923.

GENERAL PETROLOGY OF MAUI.

The Island of Maui is, petrologically, one of the most interesting and instructive of the Hawaiian group; although it must be said, at the outset, that the number of specimens available for study was so few that our knowledge of the lavas of the island and of their petrologic relations is but fragmentary and sadly incomplete. Its rocks serve in some ways as checks on those of the other islands, some of them more complex and some more simple petrographically. In dealing with the petrology of the lavas of the Hawaiian and other Pacific volcanic islands it must be borne in mind that only the uppermost tip of a vastly greater mass that is beneath the sea is open to our study. At Maui there are two volcanoes, the older one of which furnishes specimens of lavas from well within the volcano, as well as surface flows, whereas at the other only the lavas of the latest phases of activity are accessible. It is unknown whether these two volcanoes are genetically connected or not—a matter of much importance for the interpretation of the origin of some of the lavas and of those of other Pacific island volcanoes. Yet certain points stand out from the descriptions in the preceding pages.

The lavas of Maui, like those of all the other Hawaiian Islands, are predominantly andesitic and basaltic. At Kukui Volcano some trachytic lavas occur, but these are of comparatively small volume, and only one melilitic lava has been

reported (Möhle), while nephelite occurs modally in many of the lavas of Haleakala and in the norms of all of them. The Maui lavas, in overwhelming preponderance, are composed essentially of plagioclase and augite, with small amounts of "ores," mostly ilmenitic. Apatite is not abundant and its amount is most in the more salic rocks, except the trachytes. There are no quartz-bearing rocks, hornblende is entirely absent, and biotite is present, if at all, only as insignificant small flakes. The plagioclase varies from albite-oligoclase and oligoclase (Ab_7An_1)³⁴ to labradorite (Ab_1An_4),³⁴ the feldspars being more sodic in the most salic rocks and more calcic in the most mafic rocks. Anorthoclase occurs in the trachytes and, in consonance with its highly sodic character (Ab_3Or_1 to Ab_2Or_1), shows little or no multiple twinning. Augite is the mafic mineral par excellence at Maui as at all the other Hawaiian Islands. No orthorhombic pyroxene was seen. Olivine may or may not be present: in some of the lavas it forms a large proportion of the rock in good sized phenocrysts.

Although the lavas of Maui are predominantly andesitic and basaltic yet, as a whole, they show a distinct alkalic tendency. This is indicated by the occurrence of oligoclase andesite and anorthoclase trachyte, with much andesine basalt, at Kukui, and by the constant presence, modal or normative or both, of nephelite in the andesites and basalts of Haleakala. Indeed, this tendency was recognized by Cross in his designation of the most abundant lavas of Haleakala as "essexitic andesite" or "trachyandesite," and his remark that "they would be called trachydolerite by Rosenbusch." This general alkalic, and especially sodic, tendency of the Maui lavas is shown by the averages of the analyses that have been made of them, given in Table IV.³⁵ Inadequate as they may be, it must be remembered that the attempt was made to study more particularly the most abundant rocks—not the most "interesting" ones. At Haleakala, especially, the eight analyses of the most abundant lavas were made purposely to cover as wide a range in composition as was possible, in so far as could be ascertained with the microscope. The high percentage of both alkalis in the Maui and the Haleakala averages as contrasted with those in the averages for Hawaii and the Leeward Hawaiian Islands is obvious.

³⁴ Or is reckoned in with Ab.

³⁵ The number of analyses of the Kukui lavas was too few to warrant the calculation of the average for this volcano.

TABLE IV. Averages of the rocks of Maui and other Hawaiian Islands.

	1	2	3	4
SiO ₂	46.23	48.45	49.73	47.64
Al ₂ O ₃	15.09	15.37	13.71	13.24
Fe ₂ O ₃	3.76	3.42	2.92	3.19
FeO	8.63	7.87	8.64	8.22
MgO	6.39	6.28	8.27	11.28
CaO	9.47	8.85	9.10	9.77
Na ₂ O	4.27	4.36	3.16	2.64
K ₂ O	1.52	1.56	1.02	0.66
TiO ₂	3.96	3.32	2.84	2.92
P ₂ O ₅	0.47	0.36	0.48	0.28
MnO	0.21	0.20	0.13	0.16
	100.00	100.00	100.00	100.00

1. Average of lavas of Haleakala. 10 analyses.
2. Average of lavas of Maui. 15 analyses.
3. Average of lavas of Hawaii. 56 analyses. Petrol. Hawaii, III, 361, 1923.
4. Average of lavas of the Leeward Hawaiian Islands. 16 analyses. Petrol. Hawaii, V, 351, 1926.

This alkalic tendency and the occurrence in considerable abundance of trachytic and nephelinic rocks at Maui is a striking example of the irrationality of the reference of igneous rocks to two "Atlantic" and "Pacific" suites, a view the indefensibility of which has been pointed out by many petrologists and which some of its most ardent supporters are beginning to realize. Indeed, the more that we learn of the lavas of the volcanoes of the Pacific Ocean the more evident it becomes that highly alkalic ("Atlantic") lavas are almost invariably associated with the predominant calcic or subalkalic ("Pacific") basalts. Furthermore, close study and, especially, chemical analysis show that many of these supposed basalts are not basalts, strictly speaking, but that they are transitional to more alkalic rocks. Thus, the distinction between the "Atlantic" and the "Pacific" suites, still insisted on by many European petrologists,³⁶ is greatly weakened if not quite invalidated by the testimony of what has been regarded as its strongest support. Similarly, further study of the rocks of the volcanic islands of other oceans, such as those by Daly of Ascension and St. Helena, and by Lacroix of the Comoro and Kerguelen Islands, indicate that similar relations obtain in the Atlantic and in the Indian Oceans. But further discussion of this topic, which has important bearings on geophysics, must

³⁶ Cf. Niggli, *Gesteins- und Mineralprovinzen*, I, 96, 1923.

be postponed until the general summary of the petrology of the whole Hawaiian group and its relations to that of the other Pacific volcanic islands.

A prominent and perhaps one of the most significant features of the general petrology of Maui is the difference between the lavas and their succession at the two volcanoes. Although most of the specimens from Kukui that have been studied come probably from well within the mass of the volcano, and are olivinic basalt with probably rather more abundant olivine-free labradorite basalt, the products of the closing phase of activity were very salic oligoclase andesite and anorthoclase trachyte. On the other hand, at Haleakala, the comparatively recent flows, studied by Dana, Cross, and by us, are of the series of nephelinic andesites and basalts, with very olivinic picrite-basalts, ending in the latest product of volcanic activity, the flow of 1750, with much olivine as large phenocrysts.

The association of trachytes with basalt and andesite at the Pacific island volcanoes has been noted by several petrographers, and Daly has described a similar association at Ascension,³⁷ and of phonolite with basalt at St. Helena,³⁸ in the Atlantic. Daly gives a long list of such associations among oceanic islands—a list that might be very considerably extended, especially were continental volcanoes included. At a number of these oceanic islands very salic oligoclase andesites occur, as at Kukui on Maui and at Kohala on Hawaii. As such lavas do not occur at Hualalai the suggestion may be made that the trachytes of Puu Waawaa and Puu Anahulu are connected with the volcano of Kohala rather than with that of Hualalai, a point as to which there is some uncertainty.³⁹

Daly discusses the origin of such trachytes and their relation to the associated basalts, presenting (page 75 of his Ascension Island paper) a number of "leading generalizations which apparently should govern thought on this subject." His general conclusion is that the trachytes are differentiates of a basaltic magma by some such process as that of fractional crystallization, in which the "trachytic magma represents the mother-liquor left after the sinking of the crystals which first form." He also suggests that the "trachyandesites" are an intermediate stage, but his views as to the derivation of the phonolites from the basalts of St. Helena are not so definite.

³⁷ Daly, Proc. Amer. Acad. Arts and Sci., 60, 4, 1925.

³⁸ Daly, Proc. Amer. Acad. Arts and Sci., 62, 31, 1927.

³⁹ Cross, op. cit., p. 92. Petrol. Hawaii, II, 105, III, 359, 361.

Although much may, perhaps, be said in favor of some such an origin of these trachytes, yet the matter is surely not such a simple one as is suggested by Daly. While the olivine and augite phenocrysts of the picrite-basalts of Haleakala may represent the first formed and heavy, mafic crystals, yet it has not been shown that Kukui and Haleakala are connected directly: no trachytic lavas are known to occur at Haleakala, and few picritic basalts occur at Kukui. On the Island of Hawaii picrite-basalt is rather abundant at the volcanoes of Kea, Loa, and Kilauea, at which trachytic lavas are conspicuous by their absence. The same appears to be true of Kauai.

The highly sodic and nephelinic character of the "trachyandesitic" lavas of Haleakala raises the query as to why this notable increase in the amount of alkalis during the penultimate phase of activity did not lead to the production of anorthoclase trachyte, or at least of very salic oligoclase andesite, at this volcano as at the other. It may be recalled that anorthoclase trachyte similar to that of Kukui is associated with nephelinite basanite at Masafuera (Juan Fernandez Islands)⁴⁰ and at San Felix,⁴¹ picrite-basalt occurring at the former island but probably not at the latter.

Trachytes similar to those of Maui and of Hawaii occur on Molokai, as well as on Nukuhiva (Marquesas), in both cases associated with andesitic and basaltic lavas of the usual Hawaiian types. As we are studying these rocks it may be best to postpone discussion of the relation of the trachytes to the basalts until this evidence is available, when, also, the negative evidence of the absence of trachytes on Lanai, Kahoolawe, Oahu, and Kauai, may be considered.

In a recent paper Bowen⁴² suggests that the large olivines (and augites) of such rocks as the picrite-basalts of the Hawaiian Islands and elsewhere have not crystallized out of the surrounding liquid, but that they "must originate through the local accumulation of crystals which are not significantly re-melted or re-dissolved." This conclusion is based chiefly on the supposition that no liquids in quenched form (that is to say as aphyric lavas) are known that correspond in composition with the ultra-basic rocks, such as picrite-basalt, peridotite, or dunite.

⁴⁰ Quensel, *Bull. Geol. Inst. Upsala*, **11**, 274, 1912.

⁴¹ Willis and Washington, *Bull. Geol. Soc., America*, **35**, 374, 1924.

⁴² Bowen, *this Journal*, **14**, 89, 1927. He also discusses the case of the anorthite-rich rocks, with which we have nothing to do here.

Bowen mentions several examples from among the Hawaiian lavas that support his view of the origin of these large olivines, a view in which, on the whole, we are inclined to concur. Other points regarding Hawaiian lavas, not brought out by him, that favor this interpretation may be mentioned. One is the distinction between the two groups of olivinic basalts that has consistently been made by Dana and by Cross, as well as throughout this series of papers. The one group is of ordinary basalts with but little olivine, and that mostly microscopic and due to the so-called Bowen-Andersen effect: the other, that of the so-called chrysophyric basalts and picrite-basalt, contains many large olivines and augites, but olivine rarely occurs in the groundmass, which is made up mostly of finely granular augite and ores with some small laths of calcic feldspar. There appear to be few intermediate forms between these two types.

The presence of cognate or homeogenic inclusions of dunite, peridotite, wehrlite, and anorthitic or bytownitic gabbro in the basaltic lavas of the Hawaiian volcanoes where picrite-basalt occurs is also very significant.

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