ART. X.—*Petrology of the Hawaiian Islands; II. Hualalai and Mauna Loa;* by HENRY S. WASHINGTON.

HUALALAI.

The volcano of Hualalai, 8,269 feet high, lies west of Mauna Kea and northwest of Mauna Loa, occupying the northwestern corner of the Island of Hawaii. It has been visited comparatively seldom, and the few descriptions of it are brief.[1] Through the kindness of Professor Daly I have been able to see a copy of the notes made on his ascent in 1909. Like Mauna Kea, the volcano of Hualalai possesses no central crater, but many ash cones and pit craters occur on the summit and on the slopes. The last known eruption of Hualalai occurred in 1801, when two lava flows, issuing from high up the mountain, reached the sea; and what were possibly eruptions are reported as having occurred in 1823 and 1840-41.[2]

The specimens studied were, in part, collected by me along the Kona-Waimea road; in part, by Messrs. Clark and Thomson from the summit and from Puu Waawaa; and a few were kindly given me by Prof. Daly. Dr. Powers has no specimens from Hualalai among his collections.

Olivine basalt.—The lavas of Hualalai, so far as known, seem to be generally olivine-bearing basalts, and this most abundant type may be first described. To it belongs the lava of the 1801 flows, collected by me where the western flow is crossed by the road; as well as specimens collected by Daly, one at the elevation of 7,400 feet on the south slope, which he calls the ''average rock of the slope,'' and one from the west Hualalai summit signal.

This aa lava is medium to dark gray, very dense and compact, except that some vesicles of varying size and irregular shapes are usually present. The rock is almost aphyric, but all the specimens show some phenocrysts of

[1] W. T. Brigham, Mem. Boston Soc. Nat. Hist., 1, 380, 1866; C. E. Dutton, U. S. Geol. Survey, 4th Ann. Rep., 173, 1884; W. T. Brigham, Mem. Bishop Mus., 2, No. 4, 8, 1909; C. H. Hitchcock, Hawaii and its Volcanoes, 2d ed., 1911, p. 158; W. A. Bryan, Natural History of Hawaii, 1915, p. 152.

[2] S. Powers, Notes on Hawaiian petrology, this Journal, 50, 266, 1920.

yellow olivine up to one centimeter long, and usually with rare, small feldspar phenocrysts, in the aphanitic groundmass. This lava, especially that of the 1801 flow, carries numerous xenoliths, of dunite, lherzolite, and gabbro, which have been briefly described by Cross, and similar inclusions in the summit lavas of Kea are discussed by Daly,[3] while Powers[4] also discusses those from the island of Kauai. Their consideration will be taken up later, as they are met with in various lavas on several of the islands.

The thin sections show that the specimens of this type are typical basalts. Well-shaped and very fresh olivine phenocrysts are present in varying amounts, being most abundant, microscopically as well as megascopically, in Daly's specimen of the "average lava." The groundmass is very fine-grained, and is almost identical with that of the aphyric basalts of Kohala and Mauna Kea or the groundmass of the olivine basalt of Kaula Gulch at Kea. It is composed in large part of very small grains of slightly brownish augite with fewer grains of olivine, many (but subordinate) small laths of labradorite, and many grains of magnetite. A small amount of glass seems to be present in some of the sections.

The chemical composition of this type is shown by three analyses given in Table I. The material used for the analysis of the 1801 flow (No. 3) was carefully selected so as to be free from xenoliths. In general, these lavas are more femic than those which were described in the preceding paper, with the exceptions of the Kaula olivine basalts. In most respects they show a great uniformity, alumina and magnesia being the most variable constituents. The higher magnesia of Daly's "average lava" is connected with the greater abundance of olivine phenocrysts in this rock. The remarkable similarity between the 1801 lava and the Kaula olivine basalt (which also carries dunite xenoliths) will be noted; we shall meet several similar cases in the course of our study of Hawaiian lavas. It is notable that, in these decidedly femic basalts, the amounts of titanium and phosphorus are not high, at least for Hawaiian rocks. The absence of chromium in the 1801 lava may also be noted.

[3] R. A. Daly, Magmatic differentiation in Hawaii, Jour. Geol., 19, 301, 1911.

[4] S. Powers, Notes on Hawaiian petrology, this Journal, 50, 275, 1920.

TABLE I.

	1	2	3	4
SiO_2	46.01	46.76	46.43	47.19
Al_2O_3	15.40	13.78	10.91	10.95
Fe_2O_3	1.22	1.26	3.15	3.31
FeO	8.15	10.43	10.26	10.21
MgO	13.25	11.07	11.08	10.52
CaO	10.74	10.54	10.09	9.73
Na_2O	2.30	3.59	3.16	4.69
K_2O	0.67	0.64	0.54	0.93
H_2O+	0.19	0.10	0.66	0.17
H_2O-	0.07	0.10	0.15	0.17
TiO_2	1.80	2.12	2.59	2.27
ZrO_2	n.d.	n.d.	none	n.d.
P_2O_5	0.62	0.32	0.67	0.55
SO_3	n.d.	n.d.	0.07	n.d.
Cr_2O_3	n.d.	n.d.	none	n.d.
MnO	0.08	0.08	0.09	0.16
BaO	n.d.	n.d.	none	n.d.
	100.50	100.79	99.85	100.65
Sp.gr.	3.080*		3.045	
at	21°		24°	

* Determined with the pycnometer on the rock powder.

Norms.

	1	2	3
Or	3.89	3.89	3.34
Ab	15.72	15.72	23.84
An	29.75	19.46	13.90
Ne	1.99	7.95	1.56
Di	16.03	25.00	25.31
Ol	26.22	22.02	19.97
Mt.	1.86	1.86	4.64
Il	3.50	3.95	4.86
Ap	1.34	0.67	1.68

1. Olivine basalt, III.5.4.4″. "Average lava," elevation 7,400 feet, North slope, Hualalai. (Daly coll.), Washington analyst.
2. Olivine basalt, III.″6.3.(4)5. Block from pit crater, Summit of Hualalai. (Daly coll.). Washington analyst.
3. Olivine basalt, III(IV).5.3.(4)5. Lava of 1801, Hualalai. Washington analyst.
4. Olivine basalt, III.6.2.5. Kaula Gulch, near Ookala, Mauna Kea. Washington analyst. This Journal, **5,** 500, 1923.

Summit flows and blocks.—Messrs. Clark and Thomson collected many specimens from the summit of Hualalai, which an accident prevented my visiting. The specimens are of various kinds of rock, but it seems to be scarcely worth while here to describe more than what appear to be the most prominent types which have been analysed, as a thick fog at the summit forbade any exact specification of locality.

A black basalt occurs in flows and is apparently very abundant. The several specimens of this are uniformly black or very dark brownish black, without any phenocrysts or with only a few inconspicuous ones of feldspar, and with a very fine-grained dense groundmass. Some specimens, as is that analysed, are finely vesicular, with the pahoehoe form of vesicle.

In thin sections the specimens of this basalt present no specially noteworthy features. One or two are rather coarse-grained, with intersertal texture, made up of plates of labradorite and grains of brownish augite and of magnetite, without glass. Others are finer grained and contain some glass; the specimen analysed is one of these, with many tables of labradorite and some ill-defined brownish augite grains and a little magnetite in a dull brownish dusty glass base.

Another type, which seems also to be common, is a phyric basalt occurring in blocks, as noted by Cross. This shows numerous small phenocrysts of labradorite in a dense aphanitic groundmass which in some specimens is pinkish gray, as in those described by Cross and the one analysed by me, while in other specimens the groundmass is pure black and very finely vesicular.

In thin section the specimen analysed shows a holocrystalline, rather coarse groundmass, with typical diabase texture. The abundant, thick tabular phenocrysts of labradorite are much twinned and this mineral makes up also much of the groundmass, in large, thin plates, divergently arranged. There is much granular brownish augite and many magnetite grains are present. Olivine is rare and I could see none of the hornblende or biotite mentioned by Cross as being found in this type.

A third type of considerable interest is what Daly refers to as a coarsely granular lava like the picrite-basalt of the Uwekahuna mass at Kilauea. According to Daly's notes and the information supplied by Clark and Thomson this rock forms loose angular blocks, which are quite abundant over the summit.

The freshest rock is light gray, rough and granular, with fine granitic texture, the grains being from one to almost two millimeters across; small miarolitic cavities are present. Grains of white labradorite are much more abundant than grains of black augite, with very few of magnetite. Neither olivine, hornblende, nor biotite is present. In short, the rock is a fine-grained augite gabbro.

The thin section confirms the appearance of the hand specimen. The texture is typically gabbroic and the rock is perfectly holocrystalline. The abundant labradorite in subhedral thick plates, is twinned in the usual way and there are a few patches of untwinned orthoclase. Augite is less abundant than feldspar. It forms subhedral grains and is mostly brownish, a few grains being purplish. There are few large irregular grains of magnetite. No olivine, hornblende, or biotite is present in any of my sections, and there is no quartz, granophyric with orthoclase or otherwise.

Chemical analyses were made of representative specimens of these three types, all collected by Clark and Thomson. The pinkish specimen of the feldspar phyric basalt was selected for analysis rather than the black, bacause it is evidently the same kind of rock as that mentioned by Cross.

TABLE II.

	1	2	3
SiO_2	48.04	47.69	48.17
Al_2O_3	15.35	16.92	15.45
Fe_2O_3	5.72	3.69	3.98
FeO	7.67	8.83	8.67
MgO	5.77	4.02	3.97
CaO	10.13	10.73	11.00
Na_2O	3.26	2.89	3.04
K_2O	0.79	1.17	0.98
H_2O+	0.27	0.57	0.25
H_2O-	0.04	0.09	0.06
TiO_2	3.13	2.79	4.32
P_2O_5	0.33	0.67	0.35
MnO	0.10	0.13	n. d.
	100.60	100.29	100.24
Sp.gr.	3.001	2.984	2.994
at	22.3°	19.2°	22.3°

Norms.

Q	....	....	2.58
Or	4.45	6.67	5.56
Ab	27.77	24.63	25.68
An	24.74	29.75	25.58
Di	18.65	15.33	21.00
Hy	8.91	9.69	3.62
Ol	0.76	1.14	....
Mt	8.35	5.34	5.80
Il	5.93	5.32	8.21
Ap	0.67	1.68	1.01

1. Aphyric basalt, III.5.3″.4(5). Flow, Summit of Hualalai. Washington analyst.
2. Feldspar phyric basalt, (II)III.5.″4.4. Block, Summit of Hualalai. Washington analyst.
3. Gabbro, (II)III.5.3(4)4″. Block, Summit of Hualalai. Washington analyst.

All three analyses are evidently of rocks typically basaltic in modal and chemical composition and they are much like most of the analyses of the phyric and aphyric basalts of Kohala and Mauna Kea which have been given in the preceding paper. The most remarkable feature is the close similarity in chemical composition between rocks of such diverse texture, one being a glassy phyric basalt, another a basalt with many labradorite phenocrysts, and the third a fine-grained gabbro. The higher titanium of the gabbro is to be connected with the presence of some purplish augite; apart from this the differences are insignificant. One of them is a recent flow; the others are blocks brought up from below, probably from very considerable depths and specimens of early flows of the volcano. The much lower magnesia of these rocks and the consequent very small amount of normative and modal olivine, as contrasted with the preceding basalts, is to be noted. They also contain a little more silica and titanium and ferric oxide is higher relative to ferrous oxide.

Trachyte.—The trachytes of Puu Waawaa and Puu Anahulu may be described with the rocks of Hualalai, as they are in the immediate vicinity of this volcano, although their genetic connection with it has not been established. These trachytes have been described by Cross[5] so well and in such detail, that little can be added to his descriptions.

[5] Cross, Jour. Geol., **12**, 510, 1904; U. S. Geol. Survey, Prof. Paper, 88, 35, 1915.

Puu Waawaa, Canoe or Furrowed Hill, is a small tuff cone, a few hundred feet high, on the north slope of Hualalai, near its base. As stated by Cross, and confirmed by the specimens collected by Messrs. Clark and Thomson, the cone is made up wholly of trachytic material. Some of the blocks are a black glassy obsidian, such as that described by Cross and analysed by Hillebrand; others are dark gray, somewhat rough but aphanitic and aphyric, and look like dark oligoclase andesite; while others are yellowish, dull in luster, and lithoidal.

The thin section shows that all are obsidian. The black specimens are almost wholly of colorless glass, with many thin tables of orthoclase arranged in flow lines. The dark gray specimen shows many very small and thin plates of alkali feldspar, mostly arranged in small stellate groups of divergent individuals, in a colorless to very light brownish glass; while the yellowish specimens show fewer feldspar tables in a dirty yellowish glass. Hillebrand's excellent analysis of the black obsidian of Puu Waawaa is given in Table III.

The terrace called Puu Anahulu (although the name applies strictly to a small cone at its northern end) extends northward from about 2 miles north of Puu Waawaa. The western cliff face appeared to me to be a fault scarp, such as is seen elsewhere on Hawaii. The trachyte occurs at the upper edge of this terrace and forms a thick flow, according to our observations, although Cross speaks of it as forming only large blocks. Below it are basalt flows, and a stream of olivine basalt has formed a cascade over it at a point along the road: whether this basalt comes from Hualalai or from Mauna Kea is unknown.

Much of the trachyte, such as that analysed, is a light cream color. It is very fine-grained, but rough and friable, crumbling rather readily between the fingers, and so doubtless giving rise to Cross' supposition that it is not fresh. It is aphanitic and practically aphyric, although glistening faces of alkali feldspar are seen here and there; these affect a parallel arrangement due to flow, which is shown also by a somewhat platy texture of the rock. Other specimens of the trachyte are decidedly darker and a rather yellowish gray, but otherwise are like the chief type.

The thin sections show the features described by Cross. The rock is composed very largely of alkali feldspar in thin laths and small rather ill-defined microlites, with a texture that is not typically trachytic because of the preponderance of equant anhedral feldspars. The feldspar very rarely shows twinning and then not that of anorthoclase. Dr. Merwin determined the refractive indices of the feldspar to be as follows: $\alpha = 1.525$, $\gamma = 1.534$. These are almost the values for albite, and correspond with the composition deduced from the analysis of the rock, namely, a mixture of albite and orthoclase, about Or_1Ab_2; that is, a sodic anorthoclase without the typical anorthoclase twinning. There are many widely scattered and very small prisms and grains of a bright yellow or colorless mineral of high refractive index and birefringence. The extinction is parallel or inclined but a few degrees, and the yellow prisms show no pleochroism. Cross came to the conclusion that this could not be acmite or lavenite, because of the lack of pleochroism, and suggested that it may be a zircon- or titano-silicate. Dr. Merwin and I think that it is acmite, as we have found that this mineral (as distinct from aegirite) may be colorless, and that the yellow acmite may show either none or only very slight pleochroism. This identification is confirmed by the refractive indices determined by Merwin, who found: $\alpha =$ about 1.75, $\gamma =$ about 1.81. The corresponding values (determined by Merwin) for the acmite of Rundemyr are 1.770 and 1.824. Both are optically negative. Some grains of what appears to be magnetite or, more probably, ilmenite are present; some of them are slightly transparent with a brownish color. The trachyte is holocrystalline, and none of my specimens shows signs of the alteration or weathering spoken of by Cross. The dark gray variety is like that just described, except that acmite and magnetite are rather more abundant.

A complete chemical analysis was made of the cream-colored Puu Anahulu trachyte, as the analysis made by Hillebrand for Cross was incomplete, because of the supposed altered condition of the rock. The two will be found in Table III, with Hillebrand's analysis of the Puu Waawaa obsidian.

TABLE III.

	1	2	3
SiO_2	62.19	62.02	62.11
Al_2O_3	17.43	18.71	
Fe_2O_3	1.65	4.30	22.97
FeO	2.64	0.10	
MgO	0.40	0.40	n.d.
CaO	0.86	0.86	0.85
Na_2O	8.28	6.90	6.89
K_2O	5.03	4.93	4.82
H_2O+	0.39	0.80	1.60
H_2O-	0.14	0.31	
CO_2	0.02	none	trace
TiO_2	0.37	0.31	n.d.
ZrO_2	0.04	0.06	n.d.
P_2O_5	0.14	0.24	n.d.
SO_3	none	0.02	n.d.
Cl	n.d.	none	n.d.
Cr_2O_3	trace	none	n.d.
MnO	0.32	0.15	n.d.
BaO	0.03	0.02	n.d.
	99.93	100.13	99.24
Sp.gr.		2.763	
at		21°	

Norms.

	1	2
Q	....	1.80
Or	29.47	28.91
Ab	51.87	58.16
An	....	2.22
Ne	5.40	....
C	....	1.22
Ac	4.62	....
Ns	0.73	....
Di	2.88	....
Hy	....	1.00
Ol	3.35	....
Il	0.76	0.15
Hm	....	4.30
Ru		0.24
Ap	0.34	0.67

1. Trachyte, obsidian (I)II.5.1.4. Puu Waawaa, Hualalai. Hillebrand analyst. Cross, Jour. Geol., **12**, 514, 1904.
2. Trachyte, I.5.1.″4. Puu Anahulu, near Hualalai. Washington analyst.
3. Trachyte. Puu Anahulu, near Hualalai. Hillebrand analyst. Cross, Jour. Geol., **12**, 514, 1904.

The three analyses show a remarkable similarity. Hillebrand's incomplete analysis of the Anahulu trachyte (No. 3) is almost a duplicate of mine, so far as the determinations go; his unseparated Al_2O_3, Fe_2O_3, TiO_2, etc., amount to 22.97 per cent, while the corresponding sum in my analysis is 23.72. His low summation is to be ascribed to the non-determination of MgO, MnO, and BaO. Analysis No. 2, therefore, represents unquestionably the Anahulu trachyte. The analysis of the Anahulu trachyte also is remarkably like that of the obsidian of Puu Waawaa. The only notable differences are the higher soda of the obsidian and the diverse relations of the iron oxides. With almost the same total amount (reduced to either oxide) the holocrystalline trachyte shows high ferric and almost no ferrous oxide, while the obsidian contains much more ferrous and less ferric oxide. This is another example of the relation of the iron oxides to the crystallinity of the rock. The presence of small amounts of zirconia and baryta may be noted.

Mauna Loa.

Mauna Loa (Long Mountain), with an altitude of 13,675 feet and the second highest Hawaiian volcano, occupies the whole southwestern part of Hawaii, the volcano of Kilauea being situated on its southeastern flank. There is considerable literature concerning it and its eruptions,[6] but the petrography of its lavas seems to have been somewhat neglected, and the study of them has been confined mostly to the recent flows.[7] The lavas of

[6] For descriptions of Mauna Loa see: W. T. Brigham, Mem. Boston Soc. Nat. Hist., **1**, 384, 1866; C. E. Dutton, U. S. Geol. Survey, Ann. Rep. 4, 129, 1884; J. D. Dane, Characteristics of Volcanoes, 1890, p. 180; W. T. Brigham, The Volcanoes of Kilauea and Mauna Loa, Mem. Bishop Mus., 2, No. 4, 1909; C. H. Hitchcock, Hawaii and its Volcanoes, 2d ed., 1911, p. 56; W. A. Bryan, Natural History of Hawaii, 1915, p. 153; S. Powers, this Journal, **50**, 267, 1920.

[7] E. Cohen, Neues Jahrb., 1880, II, p. 49; E. S. Dana, this Journal, **37**, 441-458, 1889; R. A. Daly, Jour. Geol., **19**, 294, 1911; W. Cross, U. S. Geol. Survey, Prof. Paper, **88**, 39, 1915.

the great terminal crater, Mokuaweoweo, in particular, have not been studied petrographically in recent years, and there is no good analysis of them. The absence of ravines on the slopes of Mauna Loa, such as are found on Mauna Kea, precludes study of the earlier flows lower down the mountain. My study has been confined to that of specimens from some of the recent lava flows of known date, which were collected by me along the Kilauea-Kona and Kona-Waimea roads. The collection of Sidney Powers contains a few specimens from Mauna Loa, some being of the modern flows and duplicates of mine, and others from the Pahala region studied by Clark and Noble, whose work will be described on a later page.

Lavas of Mokuaweoweo.

The only information that we have on the petrography of the lavas of the great crater of Mokuaweoweo is that furnished by E. S. Dana,[8] who studied a large collection made by E. P. Baker of Hilo. It will be well to begin with a summary of Dana's observations on these lavas, as they show some interesting relations to the older and to the modern ones.

There appear to be three main types of lava at Mokuaweoweo, which may be taken up in the same order as that adopted for the modern flows.

The first type is what Dana calls "clinkstone-like basalt." This "has a uniform fine-grained texture, for the most part free from vesicles. The color varies from a dark bluish gray to light gray, and to dull brick-red or brown, the grayish kinds being the most common. The specific gravity varies from 2.82 to 3.00 [an average of seven kinds giving the value 2.92]. * * * * The rocks of this type are most strongly marked by the fact that the chrysolite, which is so common in large grains in the other specimens to be described, is absent or only sparingly present. The microscopic characters of this group of fine-grained compact rocks are also such as readily to distinguish them from the other forms. In general they consist of augite and plagioclase,[9] and titanic or magnetic iron or both, prominent, but with little or no chryso-

[8] E. S. Dana, this Journal, 37, 441, 1889.

[9] At the time of Dana's study the modern easy and rapid methods of diagnosing the various feldspars were not known.

lite.'' Dana describes the peculiar plumose augites in great detail; it may be mentioned here that I have found none of these forms in my specimens of modern lavas from Mauna Loa, so they may be peculiar to the lavas of Mokuaweoweo.

The second type to be described is called by Dana ''lavas with minute crystals of feldspar and augite in their cavities.'' These are light gray, mostly compact rocks, showing ''grains of chrysolite scattered through the mass,'' the groundmass being apparently aphanitic. Small, thin tabular crystals of feldspar, determined by the extinction angle to be labradorite, and some crystals of yellow augite project into and line minute cavities. There is also present in the cavities ''a mineral in very minute nearly spherical forms of a milk-white color.'' This mineral is considered to be a zeolite. Dana does not describe the microscopic characters of this type, which megascopically is said by him to be very similar to blocks of early lava found at Kilauea, to be described later.

The third type is the ''chrysolitic basalt'' of Dana. This is ''of coarse grain, often open cellular, and very highly chrysolitic; on this account the specific gravity is much higher, varying from 3.00 to 3.20.'' (An average of seven specimens gives the value 3.09.) ''The color varies from light gray to dull reddish gray or brown. The mineral constituents present are those of normal basalt; and chrysolite is the most prominent among these; in some specimens it must make up nearly half the mass of the rock; and in one case probably more, this particular specimen having the unusual specific gravity of 3.20. * * * * The plagioclase feldspar is present in the ordinary forms, and presents no unusual features. The augite forms irregular grains crowded among the feldspars.'' He also states that there are a few phenocrysts of augite, a little magnetite or ilmenite, a little apatite, but an almost entire absence of glass.

Dana mentions also a few minor varieties of lava, of which may be mentioned one (from the north brink), light gray, with a little olivine, and ''porphyritic with patches of glassy feldspar.'' Another appears to be an olivine-bearing, rather coarse-grained, somewhat ophitic diabase. Dana describes also the various forms of volcanic glass at Mokuaweoweo, with their inclosed crystallites, but we need not concern ourselves with these.

Recent Lavas.

The recent lavas of Mauna Loa, so far as they are represented by my specimens, are all basalts. They may be referred to three types: aphyric andesine basalt (olivine-free), chrysophyric oligoclase basalt, and chrysophyric picrite-basalt. The general resemblance to the three types of Dana will be noted.

Aphyric andesine basalt.—This type appears to be the most abundant among the recent, historic, lava flows and to it belong those of 1823, 1859, 1880-81, 1887, 1907, and 1919 (the Alika Flow). This type occurs as both the pahoehoe and the aa form, and chemical study shows that there is very little difference between them.

This type of lava is typically basaltic. The color is very dark gray to black, the structure is either dense and compact, or vesicular according to the pahoehoe or aa type, depending on the part of the flow from which the specimen was collected. The groundmass is very dense and quite aphanitic, and in most specimens there are no phenocrysts.

The thin sections show rather numerous thin tables of slightly twinned andesine, the ends of which are often fringed, with fewer small prismatic microphenocrysts of augite, in addition to which there appears to be a little hypersthene in specimens from the 1880-81 flow collected near Hilo. There is rarely a small olivine grain here and there. The microgroundmass in which these lie is very fine-grained and almost opaque, but is resolvable under high powers into a mass of very minute augite and magnetite grains with some minute andesine laths and considerable interstitial feldspar substance.

Analyses were made of four specimens of this type; one from the long north flow of 1859, where it crosses the Kona-Waimea road, the pahoehoe form being selected; another from the 1880-81 flow, in Ponahawai, a few miles southwest of Hilo, the pahoehoe form of this being also selected; one from the 1887 flow; and one from the Alika Flow of 1919, where they cross the Kilauea-Kona road, the compact portion of the aa form of these two, beneath the upper rough surface, being taken for analysis. The analyses are shown in Table IV.

TABLE IV.

	1	2	3	4
SiO_2	52.28	52.65	51.90	52.30
Al_2O_3	10.83	12.12	11.69	11.84
Fe_2O_3	1.90	2.19	2.24	2.06
FeO	9.30	8.87	8.84	9.03
MgO	7.69	7.43	7.37	7.15
CaO	10.03	10.12	9.87	10.60
Na_2O	2.29	2.25	2.07	2.47
K_2O	0.51	0.35	0.41	0.49
H_2O+	0.15	0.24	0.31	0.15
H_2O-	0.08	0.07	0.04	0.03
TiO_2	4.43	3.52	4.89	3.98
P_2O_5	0.32	0.25	0.28	0.28
MnO	0.12	0.11	0.11	0.10
	99.93	100.17	100.02	100.48
Sp.gr.	2.816*	2.955*	2.838*	2.874
at	21°	24°	21°	24°

Norms.

	1	2	3	4
Q	7.74	7.98	9.96	6.42
Or	2.78	2.22	2.22	2.78
Ab	19.39	18.86	17.82	20.96
An	17.79	21.96	18.63	19.74
Di	24.16	21.10	22.95	24.91
Hy	15.75	17.24	14.00	14.19
Mt	2.78	3.25	3.25	3.02
Il	8.36	6.69	9.27	7.60
Ap	0.67	0.67	0.67	0.67

1. Aphyric andesine basalt, III.4″.3(4).(4)5. Pahoehoe of 1859, Road on north slope, Mauna Loa. Washington analyst.
2. Aphyric andesine basalt, III.4″.″4.(4)5. Pahoehoe of 1880-81, near Hilo, Mauna Loa. Washington analyst.
3. Aphyric andesine basalt, III.4.″4.(4)5. Aa of 1887, Mauna Loa. Washington analyst.
4. Aphyric andesine basalt, III.4(5).3(4).(4)5. Aa of 1919, Alika flow, Mauna Loa. Washington analyst.

The Mauna Loa flows of 1859, 1880-81, 1887, and 1919 are remarkably similar in chemical composition, the differences between them being insignificant. They are all high in silica and thus show a notable amount of normative quartz (excess silica), so much indeed that they all fall in the fourth, quardofelic order. Any modal olivine that they may carry is, therefore, due to the Bowen-Andersen effect which was discussed in the introduction to the first paper of this series.[10] In their modal and chemical characters, and in the presence of notable normative quartz, they closely resemble the ophitic andesine basalt of Mauna Kea at the Waipio Pali.[11] The only marked difference is in the iron oxides, and here we find the relatively higher ferrous oxide in the somewhat glassy Mauna Loa lavas, while it is lower in the holocrystalline Waipio rock, the total amounts being about the same.

As part of an investigation of the differences between pahoehoe and aa separate determinations were made of ferrous oxide in two of these lavas. For the aa of 1859 the value $FeO = 8.99$ was obtained, contrasting with the value $FeO = 9.30$ for the pahoehoe form of the same flow, as given above. The ferrous oxide was determined also in the very rough exterior crust of the 1919 aa, with the result $FeO = 8.24$, while in the compact rock below $FeO = 9.03$. These results will be discussed in connection with the lavas of Kilauea.

Chrysophyric oligoclase basalt.—I collected only one specimen that belongs definitely to this type, from the flow on which is built the "City of Refuge," at Honaunau, Kona District, at the foot of the west slope of Mauna Loa. The date of this building is uncertain; although it is commonly attributed to the 12th century or earlier, Thrumm[12] states that it may have been built about 1570. It appears from the descriptions of Cross that other recent flows of Mauna Loa are olivine basalt, possibly of this type, as he speaks of olivine being rather abundant in them but not so much so as in the picrite-basalt.

The specimen from Honaunau is a dense black basalt,

[10] H. S. Washington, this Journal, 5, 469, 1923.
[11] H. S. Washington, this Journal, 5, 493, 1923.
[12] T. G. Thrumm, Hawaiian temple structures, Proc. 1st Pan-Pacific Cong., Spec. Pub. Bishop Mus., No. 7, 89, 1921.

finely vesicular of the pahoehoe type. It shows about 5 per cent of small phenocrysts of yellow olivine in a dense aphanitic groundmass. In thin section there are seen many thin tables of andesine or oligoclase-andesine, with somewhat ragged ends, simply twinned for the most part but with a peculiar undulatory extinction. Clear olivine phenocrysts, mostly of megascopic sizes, are rather common. Most of them are very well-shaped, some long and some almost equant, with sharp angles. The base is indeterminate, whitish and opaque under low powers, but under higher is resolved into a dense mass of extremely minute equant grains of augite, olivine, and magnetite, with very thin laths of feldspar and a little glass.

An analysis made of a specimen from the "City of Refuge" is given in Table V (No. 1), with two of the picrite-basalt to be described later.

TABLE V.

	1	2	3	4
SiO_2	48.48	48.57	49.27	48.51
Al_2O_3	8.47	10.51	9.38	9.86
Fe_2O_3	2.72	2.19	1.28	1.72
FeO	8.66	9.45	10.31	9.80
MgO	11.82	17.53	17.74	17.49
CaO	10.56	8.06	7.46	7.70
Na_2O	3.15	1.59	1.80	1.68
K_2O	0.54	0.34	0.42	0.38
H_2O+	11.9	0.37	0.12	0.24
H_2O-	0.24	0.10	0.06	0.08
TiO_2	3.77	1.48	2.58	2.02
P_2O_5	0.33	0.19	0.26	0.22
Cr_2O_3	n.d.	0.10	n.d.	0.10
MnO	0.11	0.16	0.09	0.12
NiO	n.d.	0.08	n.d.	0.08
	100.04	100.72	100.77	100.00
Sp.gr.	2.881*	3.065	3.094*	3.080
at	21°		24°	

Norms.

	1	2	3	4
Or	3.34	2.22	2.22	2.22
Ab	20.96	13.62	15.20	15.01
An	7.23	20.29	16.40	18.35
Ne	3.12	....	....	....
Di	41.14	15.14	14.89	14.42
Hy	....	22.88	27.67	26.34
Ol	12.66	20.35	16.74	17.16
Mt	3.94	3.25	1.86	2.55
Il	7.14	2.89	4.86	3.80
Ap	0.67	0.34	0.67	0.67

1. Olivine-oligoclase basalt, (III)IV."2.2.2.2. "City of Refuge," Honaunau, Kona, Mauna Loa. Washington analyst.
2. Picrite-basalt, (III)IV.1(2).2(3).1(2).2. Flow of 1852, Mauna Loa. Steiger analyst. Daly, Jour. Geol., 19, 296, 1911.
3. Picrite-basalt, (III)IV.;(2).2.1(2).2. Flow of 1868, Mauna Loa. Washington analyst.
4. Picrite-basalt, (III)IV.1(2).2.1(2).2. Average of flows of 1852 and 1868. Steiger and Washington analysts.

The Honaunau basalt is low in alumina but rather high in magnesia and soda. The norm shows a little nephelite and considerable olivine, while actually this nephelite has been converted to albite through the Bowen-Andersen effect, which has thus produced more modal than normative olivine. This lava resembles, both chemically and modally, the olivine basalt of Mauna Kea. The normative feldspar in both is oligoclase, in both there is a little nephelite, and in both the diopside molecule is much more abundant than that of olivine. Although they thus closely resemble each other, yet they fall into different places in the quantitative classification; No. 1 contains enough femic molecules to place it just in class IV, while the Kea lava is in class III, but this latter rock contains enough normative nephelite to put it in the sixth order. The difference is less marked if we consider the symbol of the salic portion of No. 1. This would be (III).5".2".(4)5, which is not far from the symbol of No. 4, Table I. The Honaunau basalt resembles chemically also rather closely, the picrite-basalt next to be described.

Picrite-basalt.—Basalts that contain very abundant olivine, mostly as phenocrysts but also in the groundmass, seem to be rather common at Mauna Loa. To this type I have given the name picrite-basalt in the preceding paper of the series. Dana speaks of them as being rather common among the recent flows, mentioning that of 1868 as particularly rich in olivine. The observations of Cross, however, with which my rather scanty ones agree, were to the effect that picrite-basalt is less common among the recent flows on the lower slopes than they are at the crater, most of those that show olivine megascopically carrying so little of it that they belong rather to the preceding type. Daly[13] found that the 1852 flow, between Loa and Kea, is of picrite-basalt. The only specimens that I collected at Mauna Loa which can surely be referred to this type are those of the flow of 1868. Daly's description of his specimen of the 1852 lava would fit them very well.

The more solid, interior parts of the aa blocks (that which was analysed) show many bright greenish yellow phenocrysts of olivine, in a dense aphanitic, dark gray groundmass. The olivines are mostly well-formed and very fresh, and make up about 25 per cent of the rock by volume. Olivine is the only phenocrystic mineral in the specimens from both the 1852[14] and 1868 flows. All my specimens are more or less vesicular, some being of the pahoehoe and others of the aa form.

In thin sections from the 1868 flow the olivine phenocrysts show a few small inclusions of magnetite, but present no features of special interest. There are no other phenocrysts. The groundmass, however, is peculiar. It varies considerably in size of grain, and the texture is best seen in the coarser portions. There are numerous small (up to 0.5 to 1.0 mm. long) laths of somewhat twinned labradorite scattered thickly and irregularly through a dense, dark, very glassy base. The laths of feldspar are crowded with minute (.01-.02 mm.) grains of colorless augite. These are mostly highly automorphic and their peculiar inclusion in the feldspar laths and clustering along their sides is quite unparalleled in my

[13] R. A. Daly, Jour. Geol., 19, 294, 1911.

[14] Daly (p. 295) gives an analysis by Steiger of the olivine of the 1852 flow. It will be discussed later.

experience. There are no olivine grains in the base, all of this mineral occurring as phenocrysts.

The two Mauna Loa picrite-basalts are almost identical chemically (Table V) and the differences between them may probably be ascribed in part to slight differences in the analytical technique. This is seen in the respective figures for ferric and ferrous oxides, alumina and titanium dioxide, and magnesia and lime. The respective sums of these pairs are each almost the same in both analyses, but they differ in that when one member of a pair is higher the other is lower. The mean of the two analyses, calculated to 100 per cent (shown in No. 4), should give a very fair idea of the chemical composition of this picrite-basalt at Mauna Loa, where the type seems to be very uniform. We have met with a variant of picrite-basalt containing rather more magnesia at Mauna Kea, and we shall see it also at Kilauea and elsewhere.

Ancient Lavas.

In 1920 Mr. W. O. Clark and Dr. L. F. Noble studied the underground water-supply of an area around Pahala, in southern Kau, on the southeast slope of the long southwest axis of Mauna Loa, between this and the sea. In the course of this investigation the areal geology was studied, as well as the structure of the region, and many specimens of the lavas were collected, which have been studied petrographically by Cross. Four analyses of representative specimens have been made in the U. S. Geological Survey Laboratory by R. K. Bailey. Reports on the geology of the area and the characters and occurrence of the lavas were made by Noble, and Cross made one on their microscopic petrographic characters.

Through the cordial and most generous coöperation of the gentlemen named above, as well as of Drs. W. C. Mendenhall and G. Steiger of the Geological Survey, I have been permitted to study the reports, to make use of such parts of them as I might desire to incorporate in this paper and to use the analyses. The results obtained by Clark and Noble are of great interest for the study of the petrology of Hawaii, as well as for our knowledge of the structure of the island. In the following pages I shall confine myself almost entirely to the petrological aspects of their results.

The lavas studied by Clark, Noble, and Cross are all older than the recent, historic lavas of the upper slopes of Mauna Loa. There has been considerable block faulting and much erosion which have aided in the study of the relations of the lavas. The whole complex of lava flows and ash beds is divided by Clark and Noble into three series.[15]

"I. The oldest series, which we call the pre-Pahala Series, consists chiefly of massive, rather uniformly bedded flows, most of which range in thickness from 6 to 25 feet. The series includes a few [thin] beds of stratified yellow ash. The prevailing color of the lavas is light bluish or pinkish gray. Most of the lavas contain rather moderate amounts of olivine and some of them contain no visible olivine. The exposed thickness of the pre-Pahala series in the area is at least 1,000 feet and may be much greater.

"II. The next younger series, which we call the Pahala Series, is separated from the pre-Pahala series by a profound angular and erosional unconformity. The Pahala series is characterized chiefly by [thick] beds of stratified yellow ash which are interbedded with the lava flows. The Pahala lavas are, in general, *medium* to rather light bluish gray rocks, lighter in color than most of the historic and recent flows, but much darker than most of the pre-Pahala lavas, and lacking the pinkish tints that many of the pre-Pahala rocks show. Practically all the Pahala rocks examined contain more olivine than the pre-Pahala lavas, but not nearly so much as most of the recent and historic flows contain. [The thickness of the Pahala series has not been ascertained, but is probably over 300 feet.]

"III. The post-Pahala series comprises all lava flows in the region that are demonstrably younger than the youngest bed of Pahala ash. They are prevailingly *dark,* vesicular rocks, most of which contain olivine in great abundance. The olivine occurs in large conspicuous phenocrysts all through the rock, and is the most striking megascopic feature. No ash is interbedded with the post-Pahala lavas. It is impossible to estimate, as yet, the average thickness of the post-Pahala series, but it is much thinner than the Pahala."

"The dips of the lavas of the pre-Pahala series are rather uniformly gentle. The prevailing direction of dip is southeasterly, varying from about S. 15° E. to S. to 70° E. Thus, the beds do not dip away from the summit of Mauna Loa, which lies

[15] I cite certain portions of Noble's reports (in quotation marks), with slight verbal changes or omissions.

almost due north of the area, but away from a point far down the axis of the southwest slope of the mountain.''

''No dikes or intrusive bodies of any sort have been found in the pre-Pahala series.''

''It appears probable that in the pre-Pahala series we may have lavas much older than any which are exposed on the slopes of Mauna Loa or in the walls of the summit crater. * * * * * Possibly the Pahala series is roughly equivalent in age to some of the rocks exposed in the crater wall of Mokuaweoweo. The post-Pahala flows obviously belong to the same general period as the recent flows (prehistoric and historic) of Mauna Loa.''

The quotations made above are from the preliminary and more general report by Noble, in which the rocks are described only megascopically. The broad petrographic differences between the three series thus indicated are substantiated in general by the megascopic and microscopic examination of the specimens which was made by Cross. Cross states that the feldspar has a composition of about labradorite for all cases tested. Cross found some hypersthene, along with augite, in a few specimens of the pre-Pahala lavas, including one of those analysed. In one or two of the post-Pahala picrite-basalts he observed the plumose bundles of augite that Dana describes from the Mokuaweoweo lavas, but none of which were found in any of my specimens of Mauna Loa lavas. Cross' observations are summarized in Noble's second, partly petrographic report, from which the following may be cited:

''*Pre-Pahala.* If our specimens fairly represent the pre-Pahala series we may describe it as a series of rocks which range from olivine-rich plagioclase-augite basalt[16] to augite-hypersthene andesite practically free from olivine. Thus, the pre-Pahala series displays a wider range in composition than either the Pahala or the post-Pahala series. * * * * * Much the greater number of the pre-Pahala rocks, however, belong to one general type, consisting mainly of plagioclase (labradorite?), augite, and subordinate magnetite, with olivine rather sparingly present. Probably many of the rocks of this type may be classed as olivine-poor basalt or as andesite.''

''*Pahala rocks.* In so far as our specimens represent the Pahala series the rocks range from plagioclase-augite basalt moderately rich in olivine to olivine-bearing augite andesite. The

[16] The one specimen that may be so called is doubtfully pre-Pahala (H. S. W.).

dominant type of rock is plagioclase-augite basalt moderately poor to moderately rich in olivine, so that, on the evidence thus far available, the series is intermediate in composition between the pre-Pahala and the post-Pahala. * * * * It is more closely related to the pre-Pahala than to the post-Pahala."

"*Post-Pahala rocks.* The post-Pahala rocks range from plagioclase-augite basalt very rich in olivine (50 per cent) to plagioclase-augite basalt moderately poor in olivine. They are, dominantly, olivine-rich basalts. None of the specimens approaches andesite in composition. The series displays about as wide a range in composition as the Pahala, but not nearly so wide a range as the pre-Pahala."

Noble makes several hypothetical suggestions, which are briefly summarized here. He thinks:

1. "that the old land mass under Mauna Loa represented by the pre-Pahala series underlies Kilauea and the Puna plateau; and that Kilauea and the Puna pit-craters are essentially volcanic sinks or pits fluxed in the land-mass rather than vents that have built it up. If this guess is correct, the section in the Uwekahuna cliff of the Kilauea crater wall may be pre-Pahala. * * * * Apparently the older Kilauea lavas resemble either the pre-Pahala or the Pahala lavas much more than they do the post-Pahala."

2. "The Pahala series is roughly equivalent in age to at least a part of the section in the crater walls of Mokuaweoweo. The character of the great unconformity between the Pahala and the pre-Pahala as revealed in the Pahala region is, to my [his] mind, evidence that the Mauna Loa dome is built up on an old pre-Pahala land."

3. "The above interpretation of the history leaves the post-Pahala flows, the modern Mauna Loa lava streams, the overflows of the Halemaumau pit, and the modern Halemaumau flows of the Kau desert to the most recent recorded period of geologic time."

Chemical composition. For study of the chemical composition of the older lavas of the Pahala region we have four analyses made of specimens selected by Cross as best representing the three series. These are given in Table VI.

TABLE VI.

	1	2	3	4
SiO_2	49.24	48.60	49.24	45.97
Al_2O_3	12.72	10.75	13.51	5.98
Fe_2O_3	4.27	3.92	3.86	5.86
FeO	8.44	9.38	8.88	7.39
MgO	7.10	9.80	5.90	23.55
CaO	9.74	10.38	10.44	6.47
Na_2O	1.87	2.54	2.40	1.50
K_2O	0.28	0.34	0.46	0.42
H_2O+	1.57	0.22	0.70	0.64
H_2O-	1.15	0.06	0.47	0.04
CO_2	none	none	none	none
TiO_2	3.40	3.37	3.70	1.75
P_2O_5	0.08	0.18	0.17	0.21
MnO	0.10	0.05	0.12	0.11
	99.96	99.59	99.85	99.89

Norms.

	1	2	3	4
Q	8.28	....	5.10	....
Or	1.67	2.22	2.78	2.78
Ab	15.72	21.48	21.68	12.58
An	25.58	16.96	24.46	8.34
Di	17.57	27.15	20.67	17.25
Hy	15.20	18.35	12.19	19.62
Ol	....	1.25	....	26.34
Mt	6.26	5.57	5.57	8.58
Il	6.54	6.38	6.99	3.34
Ap	0.34	0.34	0.67	0.67

1. Aphyric labradorite basalt, III.4″.4″.5. Clover Hill, near Naalehu, Kau, Mauna Loa. Pre-Pahala series, R. K. Bailey analyst.
2. Ophitic olivine basalt, III″.5.3.″5. Kamaikeohu Spring, Kau, Mauna Loa. Pre-Pahala(?) series. Bailey analyst.
3. Feldspar phyric basalt, III.(4)5.″4.(4)5. Naalehu, Kau, Mauna Loa. Pahala series. Bailey analyst.
4. Chrysophyric picrite-basalt, IV.(1)2.3.1(2).(1)2. Makanao Valley, Kau, Mauna Loa. Post-Pahala series. Bailey analyst.

Aphyric labradorite basalt. (*Pre-Pahala.*)—The specimen from Clover Hill represents, according to Noble, the predominant olivine-poor type of pre-Pahala basalt. It is a dense, aphyric, bluish gray, slightly vesicular lava. Microscopically, it is seen to be composed essentially of labradorite and augite, with ophitic texture. A little hypersthene is present "in aggregates," olivine is "not abundant," and there are the usual magnetite grains and some ferritic glass.

The analysis of it is given in No. 1 of Table VI. This greatly resembles the analyses of the modern flows of andesine basalt of Mauna Loa, given in Table IV, except that the Pahala rock is lower in silica and in soda, and higher in alumina, the last features determining the presence of labradorite rather than andesine. In this Pahala basalt, as in the modern ones, there is a very considerable excess of silica, so that the norm shows about 8 per cent of quartz. This proves that the small amount of olivine which is reported in this and similar rocks is not essential, but is adventitious and due to the Bowen-Andersen effect. Noble remarks on the uncertainty of using the presence or absence of olivine as a field diagnostic, unless there is so much that the lava becomes picritic. He mentions having thought in the field that a light gray rock was a trachyte, but that it proved to be an olivine-bearing basalt; a case analogous to my experience with the Kaala basalt at Kohala mentioned in the first paper of this series.

Ophitic olivine basalt. (*Pre-Pahala?*).—This specimen was chosen to represent the most olivinic basalt of the pre-Pahala series, and is the only supposedly pre-Pahala specimen of its kind that was collected. Noble states that its exact relations are uncertain and that its reference to the pre-Pahala is doubtful.

According to Cross, the fine-grained rock is distinctly ophitic megascopically and the hand lens shows some olivine. Under the microscope the texture is ophitic, "with plagioclase (andesine?), augite, olivine, and magnetite well developed." Olivine appears to be more abundant than augite, mostly in small grains, and there is some ferritic glass.

The analysis (No. 2, Table VI) is, in general, that of an ordinary basalt, although low in alumina. Of the modern Mauna Loa lavas it most resembles that of the Honaunau aphyric olivine basalt (Table V), but it is slightly higher in alumina and lower in magnesia. The normative feldspar of the Pahala basalt is, thus, andesine while that of the Honaunau rock is oligoclase. The Pahala rock is less femic than the other but the differences are not very great. It is obvious from the very small amount of normative olivine, that the modal great amount of this mineral is due to the usual cause.

Feldspar phyric basalt (*Pahala*).—The rock from Naalehu, which Cross and Noble call "olivine-bearing augite andesite," was selected to represent the Pahala series.

The rock is medium gray and slightly vesicular. It is distinctly phyric through the presence of white spots 3 mm. in diameter or less; these are of feldspar (labradorite) and are either a single crystal or mostly aggregates of crystals. Olivine is not mentioned as visible megascopically. In thin section are seen a few microphenocrysts of augite and fewer of olivine, besides the more abundant phenocrysts of labradorite. The groundmass is somewhat trachytic, through the fluidal arrangement of the many feldspar laths. Between these are many small grains of augite, although Cross thinks it possible that some of them may be of olivine. There are some large grains of magnetite, but no glass is present.

The analysis (No. 3, Table VII) presents in itself no feature of special interest except that the magnesia percentage is the lowest shown by all four of the Pahala rocks. The analysis of this lava, a feldspar porphyry, may be compared with those of the feldspar porphyries of Kohala, Mauna Kea, and Hualalai. On reference to them it will be seen that the Pahala lava resembles them in general, especially those of Mauna Kea, except that it is a little higher in silica and lower in alumina. The presence of about 5 per cent of normative quartz is, once more, an indication that the small amount of modal olivine is fortuitous, and that this mineral should not figure in the name of the rock.

Chrysophyric picrite-basalt (*Post-Pahala*).—The pahoehoe of the Makanao Valley was selected for analysis as being the richest in olivine of the post-Pahala olivine lavas.

The rock, megascopically, looks much like the lavas of the 1852 and 1868 flows. Large olivine phenocrysts are very abundant, constituting about one-half of the rock. The highly vesicular groundmass is dark gray and aphanitic. Thin sections show that the groundmass is ophitic and composed of plagioclase (andesine?) with less augite, some grains of magnetite, and a ferritic glass base.

The analysis (No. 4, Table VII) differs from those of the 1852 and 1868 flows in its lower silica and alumina, and higher magnesia; in other respects these lavas are much alike. Its nearest analogues are found in the analyses of three lavas of Kilauea, which we shall study in the next section of this paper. These are; the olivine gabbro of the Uwekahuna cliff, the Nanawale (1840) flow, and an older flow in the Kau desert that appears to belong to Kilauea; the two last are almost identical megascopically with that of the Pahala region. These three Kilauea lavas are a little lower in magnesia, but the differences are insignificant; they all fall in the same subrang as the Pahala rock and contain about the same amount of normative olivine. It will be observed that the norm of the post-Pahala picrite-basalt shows only about 26 per cent of olivine, whereas about 50 per cent is stated to be present; this is another excellent example of the Bowen-Andersen effect.

Résumé.

From the foregoing summary of the observations of Noble and Cross, with the chemical analyses available, it is fairly evident that Noble was correct in stating that in general the older lavas of Mauna Loa may be referred to three main and successive types: the pre-Pahala aphyric, olivine-free, labradorite basalt, of the general symbol III.4.4.5, that is, with excess silica; the Pahala aphyric or feldspar-phyric labradorite basalt, often with some modal but little or no normative olivine, and of the general symbol III.5.3.5; and the post-Pahala highly chrysophyric and femic picrite-basalt, with the general symbol IV.2.3.1.2.

The correspondence of these with the three main types to which we have referred the modern lavas is remarkable. The modern lava types are: aphyric, olivine-free, andesine basalt, of the general symbol III.4.3-4.5, that is, with considerable excess silica; aphyric, oligoclase-andesine basalt, olivine-bearing, most specimens of which are probably dosalic with the general symbol III.5.2.5;[17] and highly chrysophyric and femic picrite-basalt, with the general symbol IV.1.2.1.2.

The correspondences of the lavas of the crater walls of Mokuaweoweo are uncertain, because of the lack of exact, modern petrographic descriptions and chemical analyses. But, as we have seen, the descriptions of Dana indicate that here also we have the same or similar three main types, represented by his "clinkstone-like basalt," "lava with crystals of feldspar and augite," and "chrysolitic basalt." It will be recalled that Noble suggested that the lavas of the Mokuaweoweo crater walls may be equivalent, at least in part, to the Pahala series; the later flows from the crater might well correspond with the post-Pahala. We have no observations to determine these and other such points, and a study of the lavas of Mokuaweoweo, from the walls and those of the recent flows, is clearly desirable.

The succession of lavas at Mauna Loa is very remarkable. In the early stages of the volcano[18] there occurs a fairly well-defined succession in time of three main types, each extending over a considerable period. This is followed in the present period by the pouring out of lavas of all these three types, not in orderly succession but irregularly. Thus, prior to 1570 we find type 2, in 1823 type 1, in 1852 type 3, in 1859 type 1, in 1868 type 3, and in 1880-81, 1887, 1907, and 1919 type 1.

Geophysical Laboratory,
Carnegie Institution of Washington,
June, 1923.

[17] The only specimen of this type analysed falls, it is true, in dofemane, with the symbol (III)IV.2.2.2.2, but the type, in general, is probably dosalic.

[18] In the study of the Hawaiian and other oceanic volcanoes it must be kept in mind that the lavas of only the uppermost part of the mass are accessible to our observation; the main lower bulk remains inaccessible.