HOKKAIDO UNIVERSITY

Title	Pillow Lavas of Keflavik, Iceland and Their Genetic Significance
Author(s)	Yagi, Kenzo
Citation	Journal of the Faculty of Science, Hokkaido University. Series 4, Geology and mineralogy, 12(2), 171-183
Issue Date	1964-10
Doc URL	http://hdl.handle.net/2115/35939
Type	bulletin (article)
File Information	12(2)_171-184.pdf

Instructions for use

Hokkaido University Collection of Scholarly and Academic Papers : HUSCAP

PILLOW LAVAS OF KEFLAVIK, ICELAND AND THEIR GENETIC SIGNIFICANCE

By

Kenzo YAGI

Contribution from the Department of Geology and Mineralogy,
Faculty of Science, Hokkaido University, No. 935.

Abstract

Some of the pillow lavas at Stapafell quarry, near Keflavik, Iceland show remarkable concentration of olivine crystals in the lower parts of the pillows. The petrographic features of the pillows and the interpillow matrix of palagonite are described. From a series of thermal experiments on the specimens, the course of crystallization of the basalt was determined: olivine→plagioclase→monoclinic pyroxene. The temperature of the basaltic rocks at the time of formation of pillows is estimated at ca 1200°C or a little higher. Presumably the lava retained its fluidity even after the formation of the outermost margins of pillows, and the early crystallized olivine was settled toward lower parts. The validity of this possibility was examined in the light of the above experiments and some thermodynamic consideration. It is concluded that gravitational settling of olivine crystals through still fluidal interior of pillows could be possible in some rare cases, when the controlling factors were favorable to delay the cooling rate.

CONTENTS

§1. Introduction

In Iceland pillow lavas are well developed in various kinds of basaltic rocks of different geologic ages. During the field trip through Iceland, organized by the XXIst International Geological Congress in the summer of 1960, I had an opportunity to visit many localities of pillow lavas in this island. Later, after this pre-Congress trip was over, I had a chance to observe the pillow lavas at Stapafell quarry near Keflavik on the southwestern part of Iceland (Fig. 1).

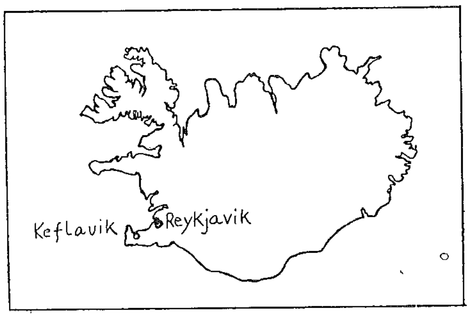


Fig. 1. Index map of Iceland

The pillow lavas well exposed at Stapafell quarry, about 5 km south of Keflavik, are probably the most beautiful example as such in Iceland. Here we noticed that olivine crystals were especially concentrated in the lower parts of the pillows exposed in one cliff. The mode of occurrence seems to substantiate the gravitational settling of the early formed olivine crystals within the still fluidal pillows. The petrographic description of these pillow lavas, with special reference to their genetic significance is now given in the present paper.

I was very much indebted to Drs. S. THORARINSSON and T. TRYGVASON of Iceland for their guide to the volcanic geology of Iceland. I was also benefited by the stimulating discussion in the field with Prof. W. H. MATHEWS of University of British Columbia and Dr. Y. BENTOR of Geological Survey of Israel, with whom I visited the locality. Prof. Y. SHIMAZU of Nagoya University and Dr. T. MURASE of Hokkaido Uni-

versity gave me valuable suggestions for the thermodynamic treatment of the problem. Dr. H. ONUKI of Tohoku University made chemical analyses of the rocks, and Dr. K. ONUMA of Hokkaido University helped me in the thermal experiments. My trip in Iceland was made possible through the kind financial help of the late Dr. K. SHIBUSAWA. My hearty gratitude is due to all of them.

§2. Mode of occurrence

In the southwestern peninsula of Iceland, so-called "grey basalts" of Pleistocene accompanied by palagonites are distributed over wide areas. The basaltic rocks which form pillow lavas typically exposed along the cliff at Stapafell quarry also belong to these basalts, which are generally grouped as "Móberg formation" (KJARTANSSON, 1960).

The pillows are mostly elliptical in cross section, and usually less than one meter in diameter, but sometimes attain as large as two meters, and some elongated tubes are even much longer. The pillows always have black aphyric tachylitic rims, carrying few olivine crystals. Radial, columnar joints, are always developed from the center, which remains not rarely vacant. Concentric structure is usually not distinct, though vesicules are sometimes concentrically distributed.

The interpillow matrix is always palagonite, which is composed of only yellow ocher-, or pale brown-colored earthy substance, or associated with numerous fragmental pitch black tachylitic substance.

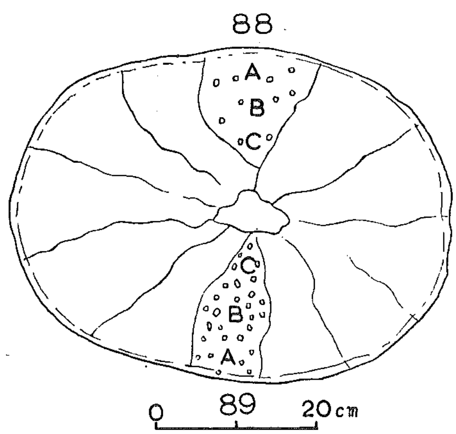


Fig. 2. Schematic sketch of the pillow described in this paper

It was noticed in an outcrop on a small cliff, about 5 m in height and tens of meters in width, that olivine crystals were distributed more concentrated in the lower part of the pillows than in the upper part, while they were in general much poorer in the marginal zones, as compared to the central main part. So far as we observed, this mode of concentration of olivine in the lower half of the pillows was found nearly in all pillows of this outcrop, but was not noticed in the pillows of other parts of this quarry.

One of the typical examples, treated in the present investigation, is drawn in a somewhat schematic way (Fig. 2). The photographs of the handspecimens of this pillow clearly indicate the concentration of olivine crystals in the lower part (89A, B, & C), as compared with the upper part (88A, B, & C) (Figs. 1 and 2, Plate I). Tachylitic rims, which are fragile and break off easily, are not shown in these photographs.

§3. Petrography

Macroscopically the rock is dark grey in color, and fine grained, olivine being the only crystals observed by naked eye. Vesicules, either rounded or ellipsoidal, are abundant, and sometimes are arranged concentrically. Under the microscope, olivine occurs both as phenocrysts and groundmass constituents, while plagioclase, monoclinic pyroxene and iron ores are confined to the groundmass. The rocks are very fresh, and no secondary minerals are found.

Minerals:

Olivine sometimes attains as large as 4 mm but usually 1~2 mm among phenocrysts and 0.1~0.3 mm among groundmass olivine. It is always euhedral, with well developed cleavages and irregular cracks. Serpentinization or other alteration is never observed. Characteristic skeletal crystals, which presumably show the various stages of growth, are common in groundmass olivine.

$\gamma=1.703$, $\alpha=1.672$

$2V(-)=85°$

Composition Fa 16~18 (mol%)

No appreciable difference in composition is found between phenocrystic olivine and groundmass one. Magnetite and picotite are included, commonly in larger crystals.

Plagioclase is always lath shaped, 0.1~0.6 mm in length and 0.1~0.05 mm in width. It is always twinned after Carlsbad or albite law, the termination often assuming swallow tail shapes. Skeletal crystals are rarely present. Zoned structure is almost absent, but is rarely observed in some larger crystals, and the margins are always more sodic.

n_2 (010) 1.568~1.574

composition An 68 ~ An 76

Rarely the marginal rims as sodic as An 58 are found in the larger crystals.

Pyroxene is either entirely absent or present only in poorly crystallized aggregates, dendritic forms or microlites. Euhedral crystals are never found. Only monoclinic pyroxene is present, and no rhombic pyroxene is found. Rarely it forms thin reaction rims around phenocrystic olivine. It is pale brown or slightly purplish brown in color, but is not pleochroic. Minute size made the accurate determination of its optic properties difficult, but it is probably slightly titaniferous augite, judging from color, and also the bulk composition of the rocks.

Iron Ores Both magnetite and picotite are present. Magnetite is usually square in shape and 0.01~0.05 mm in size. Picotite is present, often enclosed in olivine. It is deep brown in color, translucent, and square, hexagonal or sphenoid in shape, 0.03~0.1 mm in size. Neither apatite nor sphene is present.

Glass forms greater part of the palagonite, and nearly half of the groundmass of the pillows. It is generally pale brown in color. Index is 1.610~1.615. The glass in the palagonite is often clear, but that in the pillows is more or less devitrified, and is filled with minute microlites of either pyroxene or unidentified minerals. Such microlites are especially well developed around euhedral crystals of olivine or plagioclase, which are enclosed in the glassy base.

Texture

The inner parts (88C, 89C) are more crystalline and coarser grained than the marginal parts (88A, 89A) which grade into tachylitic rims. Palagonite is composed of aggregates of larger fragments of transparent glass and angular glass shards, 0.03~0.1 mm in size. Margins of such glass shards have minute, granular inclusions, and are also slightly hydrated, having higher indices than the clear inner parts (Figs. 1~6, Plate II).

Modal composition

The mode was determined by a point counter, and is given in Table 1. Since pyroxene forms often minute crystallites, it is practically not possible to discriminate them accurately from glass. Therefore pyroxene is included in glass in this table. Palagonite is formed mostly of glass with minor contents of olivine and plagioclase.

Table 1. Modal Composition of a Pillow Lava and Palagonite of Keflavik, Iceland. (Wt. %)

	87	88A	88B	89A	89B
Phenocryst					
Olivine	3.5	1.8	4.0	15.8	24.4
Groundmass					
Olivine	2.0	6.2	3.2	1.6	2.2
Plagioclase	5.8	31.3	31.1	24.0	26.6
Magnetite	1.6	3.8	5.3	0.6	3.1
Glass	87.1	56.9	56.4	58.0	43.7
Total	100.0	100.0	100.0	100.0	100.0

It is worthy of note that olivine is very much concentrated in the lower parts, especially in 89B, attaining as much as 26%, while it is very poor in the upper parts, especially in 88A, where its content is as low as 8%.

Chemical composition Two different parts of a pillow, the one richest and the other poorest in olivine crystals respectively, as well as a palagonite which form the interpillow matrix were chemically analysed as shown in Table 2.

Table 2. Chemical Composition and Norms of a Pillow Lava and Palagonite of Keflavik, Iceland.

	88A	89B	87		88A	89B	87
SiO_2	47.21	46.05	46.75	Or	1.67	1.11	2.78
TiO_2	1.95	1.89	1.82	Ab	16.24	13.62	19.39
Al_2O_3	13.86	12.17	14.02	An	28.36	25.58	26.69
Fe_2O_3	1.86	1.21	2.44				
				Wo	12.76	10.09	11.95
FeO	9.70	10.84	9.23	En	13.60	13.30	11.40
MnO	0.18	0.18	0.17	Fs	7.13	5.54	6.86
MgO	9.91	14.53	8.18	Fo	7.84	16.10	6.44
CaO	12.17	10.38	11.66	Fa	4.69	7.96	4.08
Na_2O	1.90	1.62	2.29	Mt	2.78	1.86	3.48
K_2O	0.25	0.21	0.42	Cm	0.22	0.22	
H_2O^+	0.43	0.46	0.95	Il	3.80	3.65	3.50
H_2O^-	0.02	0.02	1.21	Ap	0.67	0.67	1.01
P_2O_5	0.34	0.32	0.47				
Cr_2O_3	0.07	0.11	0.05				
Total	99.85	99.99	99.66				
Analyst	H. Onuki	H. Onuki	H. Onuki				

88A: Upper, outer part, poor in olivine crystals.
89B: Lower middle part, richest in olivine crystals.
87 : Palagonite

Contents of SiO_2 are low, and alkali contents, especially those of K_2O are very low, while the contents of FeO, MgO and CaO are high. The chemical composition is different from any pillow lavas described from Japan, for example, Nemuro (YAGI, 1958) or Ogi (CHIHARA, 1963). It is, however, very similar to that of the olivine basalt of the 1959 Eruption of Kilauea Iki (MACDONALD and KATSURA, 1961). The variation in chemical composition of different parts is also different from that observed in the pillow lavas from Nemuro. When MgO contents are plotted against SiO_2 contents, both recalculated water-free, a linear relation is observed (Fig. 3). This is similar to the trend found in Hawaiian lavas (MURATA 1960, MURATA and RICHTER 1961), and can be explained as the result of separation of olivine crystals. From the mineralogical as well as chemical composition, the pillow lavas belong to typical tholeiitic olivine basalt.

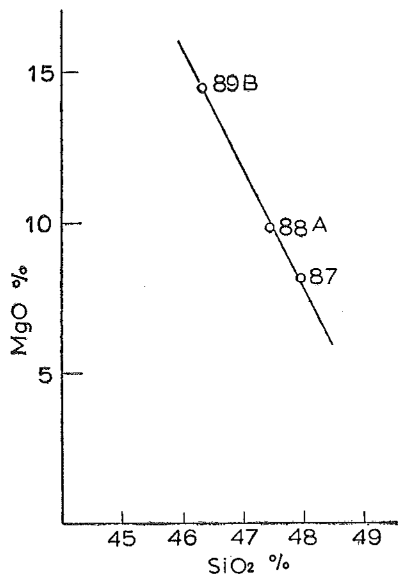


Fig. 3. Variation of MgO Contents

§4. Thermal experiments

In order to determine the course of crystallization, and the temperature at the time of pillow formation, a series of thermal experiments has been carried out on these specimens.

Experimental method 20~30 mg of analysed sample (<200 mesh) was put in a small Pt envelope and was heated at atmospheric pressure in an

Table 3. Thermal Experiments on Palagonite 87 under 1 atm Pressure.

Temp. °C	Time hrs	Results	Index of Glass
1300	1	All glass	1.626
1270	1	Rare *Mt* in glass	1.625
1250	8	Rare *Mt* in glass	1.626
1230	5	Rare *Mt* in glass	1.626
1220	1	Small amt. *Mt* in glass	1.626
1215	10	Trace of *Pl* & small amt. *Mt* in glass	1.627
1210	1	Rare *Pl* & mod. amt. *Mt* in glass	1.618
1205	24	Small amt. *Pl* & mod. amt. *Mt* in glass	1.628
1200	3	Small amt. *Pl* & mod. amt. *Mt* in glass	1.616
1195	10	Small amt. *Pl* & mod. amt. *Mt* in glass	1.616
1190	3	Small amt. *Pl*, small amt. *Ol* & mod. amt. *Mt* in glass	1.616
1185	16	Mod. amt. *Pl*, small amt. *Ol*, small amt. *Px* & mod. amt. *Mt* in glass	1.620
1180	10	Mod. amt. *Pl*, mod. amt. *Px*, small amt. *Ol* & mod. amt. *Mt* in glass.	1.616
1170	14	Mod. amt. *Pl*, mod. amt. *Ol*, mod. amt. *Px* & lots *Mt* in glass	1.612
1150	14	Mod. amt. *Pl*, lots *Ol*, mod. amt. *Px* & lots *Mt* in glass	1.610
1130	12	Well fritted. Lots small *Ol*, *Pl*, *Px*, & *Mt* in small amt. glass.	—

Table 4. Thermal Experiments on Pillow Lava 88A under 1 atm Pressure.

Temp. °C	Time hrs	Results	Index of Glass
1300	1	All glass	1.626
1270	1	Trace of *Mt* in glass	1.625
1250	1	Trace of *Mt* in glass	1.626
1230	1	Small amt. *Mt* in glass	1.627
1220	1	Small amt. *Mt* in glass	1.625
1215	10	Rare *Ol* & small amt. *Mt* in glass	1.625
1210	1	Rare *Ol*, rare *Pl* & small amt. *Mt* in glass	1.620
1205	16	Rare *Ol*, small amt. *Pl* & small amt. *Mt* in glass	1.620
1200	16	Rare *Ol*, small amt. *Pl* & mod. amt. *Mt* in glass	1.620
1195	10	Rare *Ol*, small amt. *Pl* & mod. amt. *Mt* in glass	1.625
1190	3	Small amt. *Ol*, mod. amt. *Pl* & mod. amt. *Mt* in glass	1.620
1180	10	Mod. amt. *Ol*, mod. amt. *Pl*. small amt. *Px*, & small amt. *Mt* in glass	1.614
1170	14	Mod. amt. *Ol*, mod. amt. *Pl*, mod. amt. *Px* & Small amt. *Mt* in glass.	1.612
1150	14	Lots *Ol*, *Pl*, *Px* & *Mt* in glass	—
1130	12	Well fritted. Lots *Ol*, *Pl*, *Px* & *Mt* in glass	1.610

Table 5. Thermal Experiments on Pillow Lava 89B under 1 atm Pressure

Temp. °C	Time hrs	Results	Index of Glass
1350	1	All glass	1.634
1340	1	Trace of *Mt* in glass	1.634
1335	5	Trace of *Ol* & trace of *Mt* in glass	1.634
1330	16	Trace of *Ol* & trace of *Mt* in glass	1.636
1320	1	Trace of *Ol* & rare *Mt* in glass	1.634
1300	1	Small amt. *Ol* & rare *Mt* in glass	1.634
1270	1	Mod. amt. *Ol* & small amt. *Mt* in glass	1.624
1250	1	Mod. amt. *Ol* & small amt. *Mt* in glass	1.627
1230	1	Mod. amt. *Ol* & small amt. *Mt* in glass	1.627
1210	1	Mod. amt. *Ol* & small amt. *Mt* in glass	1.626
1200	3	Lots *Ol* & mod. amt. *Mt* in glass	1.616
1195	10	Lots *Ol*, rare *Pl* & mod. amt. *Mt* in glass	1.625
1190	3	Lots *Ol*, small amt. *Pl*, rare *Px*, & mod. amt. *Mt* in glass	1.616
1180	10	Lots *Ol*, mod. amt. *Pl*, small amt. *Px* & mod. amt. *Mt* in glass	1.616
1170	14	Lots *Ol*, mod. amt. *Pl*. small amt. *Px* & mod. amt. *Mt*. in glass	1.610
1150	14	Lots *Ol*, *Pl*, *Px* & *Mt* in glass	—
1130	12	Well fritted. Lots *Ol*, *Pl*, *Px* & *Mt* in small amt. glass	—
1100	13	Fritted. Lots *Ol*, *Pl*, *Px* & *Mt* in small amt. glass	—

electric furnace for various length of time, ranging from 1 hr to 24 hrs, depending on the temperature of the runs. The charge was then quenched by dropping into water in a beaker and the products were examined under petrographic microscope, being immersed in oil. If warranted, powder X-ray diffraction patterns were made for identification of the phases present.

Results The results obtained are given in Tables 3 to 5.

In the case of palagonite it was noticed that the Pt-envelopes were expanded at the end of the runs, presumably owing to emission of the high water content enclosed in the glass. Hematite or magnetite is present in very small amounts even at very high temperature and their disappearance is rather indefinite. It is also noticed that the temperature of crystallization of olivine is different widely in different specimens:

87	1194°C	Olivine out
88A	1217°C	Olivine out
89B	1335°C	Olivine out

Apparently this difference is due to the content of olivine in the samples, and this fact also substantiate the effect of settling of olivine crystals from one part to another. Contrarily the temperature of crystallization of plagioclase and pyroxene shows more narrow ranges throughout the three samples as follows:

87	1215°	Plagioclase out
88A	1211°	Plagioclase out
89B	1196°	Plagioclase out
87	1187°	Pyroxene out
88A	1185°	Pyroxene out
89B	1191°	Pyroxene out

Course of crystallization Therefore the course of crystallization is olivine →plagioclase→pyroxene. This order is well coincident with the microscopic observation of the pillows.

If we take the case of 88A, the first silicate phase to crystallize in the liquid with decreasing temperature is olivine at 1217°C, and this is joined by plagoclase at 1211°C, and then by pyroxene at about 1185°C. Therefore these three major phases appear in the lava within a narrow temperature interval of only 32°. This value is smaller than the similar values obtained by YODER and TILLEY on various kinds of basaltic rocks (1962).

From the field and microscopic observations, it is estimated that the basalt was mostly liquid with only 10 to 15% of olivine crystals, when the basalt was extruded probably under glacier. Then plagioclase began its crystallization after the pillow lavas were formed. Therefore the liquid with about 10~15% of olivine is estimated to have had a temperature of ca 1200°C or a little higher at the time of extrusion.

§5. Thermodynamic consideration

From the above mentioned reasons it is considered that a basaltic liquid with about 15% olivine crystals at a temperature of ca 1200°C or a little higher was extruded to the earth surface, and formed pillow lavas by contact probably with glacial ice.

Cooling rate of the pillows

We should now calculate the rate of the decrease of temperature of this basaltic liquid within the pillows. We assume the temperature at a distance of one half of the radius from the center of a tube as the mean temperature. If the temperature of the pillow dropped from 1200° to 1100°C, then

$$\frac{T}{To} \gtrsim \frac{1100}{1200} \sim 0.9,$$

i.e. the mean temperature is 0.9.

Carslaw and Jaeger (1959, p. 55, Fig. 4b) have shown that the value of $\frac{Kt}{a^2}$ should be less than 0.05, when the mean temperature is 0.9 in an infinite tube with a radius a, and t is the time needed for cooling. Therefore,

$$\frac{Kt}{a^2} < 0.05.$$

K is a thermal diffusivity, which is of the order of 10^{-2} cm^2/sec in most lavas or magmas, and a is 20 cm in the present case. Then,

$$t < \frac{20^2 \times 5 \times 10^{-2}}{10^{-2}} \sim 2000 \text{ sec.}$$

Other factors which should be taken into consideration give either positive or negative effect to t, and the maximum value of t will be about 10^4 sec.

Rate of setting of olivine crystals

The settling of olivine crystals through the liquid will be governed by the viscosity of the liquid and the size of the crystals, as shown in the following equation: According to MURASE (1962) the viscosity of tholeiitic basalt from Oshima Volcano is about 10^3 at 1200°C, and is about $10^4 \sim 10^5$ at 1100°C. Now, assume the viscosity of the basaltic liquid under consideration be 10^4, then the velocity v will be given by,

$$v = \frac{\frac{2}{9} \times 980 \times (0.2)^2 \times (3.4 - 2.8)}{10^4}$$

$$= 5.2 \times 10^{-4}$$

Therefore the time required for settling of olivine for 40 cm will be

$$t = \frac{40}{5.2 \times 10^{-4}} \doteqdot 10^5 \text{ sec.}$$

This value of 10^5 sec. is much larger than the possible time of cooling 10^4 sec. However, if the basalt liquid was very fluid and if the viscosity was ca 10^3, then the time of settling would be 10^4 sec, which is of the same order as the time of cooling.

Therefore, in such cases the gravitational settling of olivine crystals within the still fluidal pillows could occur.

§6. Genetic significance

An alternative to the above mentioned explanation is as follows: the olivine crystals were already settled gravitationally in the magma reservoir and the heterogeneous parts were later mixed together within the pillows. This seems to be more probable at first, but it is difficult to explain the fact that olivine crystals are always concentrated only in the lower parts of the pillows. This fact seems to substantiate the possibility of separation of olivine crystals within the pillows after they were settled to their present position. It has been observed in the field that some pahoehoe lavas form globules of lava with tough glassy skins, while the interior parts are still fluid, and therefore the globules can be deformed by external force without breaking their outer skins (SNYDER & FRASER, 1963).

Consequently it is also possible that the pillows can maintain such fluidity, even after the outer rims are formed. If the rate of cooling of the interior and that of the settling of olivine are of the same order, gravitational separation of olivine will be possible within the pillows. Probably this condition can only be very rarely attained, otherwise we should have found many similar examples as those mentioned in this paper.

§7. Conclusion

From the field observation and the experimental research, it was concluded that the pillow lavas are typical tholeiitic olivine basalt, with olivine, plgioclase and poorly crystallized monoclinic pyroxene in the glassy matrix. The concentration of olivine crystals only in the lower parts of the pillows is explained by the gravitational settling of the early formed olivine crystals within the still fluidal pillows, even after their external shapes were completed. This phenomenon can occur only in very rare cases, when the cooling rate of pillows and settling rate of olivine crystals are of the same order.

References

CARSLAW, H. S. & JAEGER, J. C. (1959): Conduction of Heat in Solids. *Oxford pp. 510.*

CHIHARA, K. (1963): Basaltic Rocks of Ogi Peninsula, Sado. *Guide Book of Volcan. Soc. Japan Ann. Meet. 1963. pp. 13.*

KJARTANSSON, G. (1960): The Móberg Formation. *XXI Intern. Geol. Congr. Guide Book.* On the geology and geophysics of Iceland. *1960. pp. 21–28.*

MACDONALD, G. A. & KATSURA, T. (1961): Variations in the Lava of the 1959 Eruption in Kilauea Iki. *Pacific Sci.* **15**, *pp. 358–69.*

MURASE, T. (1962): Viscosity and Related Properties of Volcanic Rocks at 800° to 1400°C. *J. Fac. Sci. Hokkaido Univ. Ser. VII,* **1**, *487–584.*

MURATA, K. J. (1960): A New Method of Plotting Chemical Analyses of Basaltic Rocks. *Am.*

Jour. Sci. **258**-*A*, *247–52*.

MURATA, K. J. & RICHTER, D. H. (1961): Magmatic Differentiation in the Uwekahuna Laccolith, Kilauea Caldera, Hawaii. *Jour. Petr.* **2**, *424–37*.

SNYDER, G. L. & FRASER, G. D. (1963): Pillowed Lavas, I: Intrusive Layered Lava Pods and Pillowed Lavas, Unalaska Island, Alaska. *U. S. G. S. Prof. Pap.* **454**-*B*, *1–23*.

YAGI, K. (1958): Alkalic Rocks of Nemuro Peninsula, with Special Reference to the Pillow Lavas. *Comem. Vol. dedicated to Prof. Suzuki*, *287–97*.

YODER, H. S., Jr. & TILLEY, C. E. (1962): Origin of Basaltic Magmas: An Experimental Study of Natural and Synthetic Rock Systems. *Jour. Petr.* **3**, *342–532*.

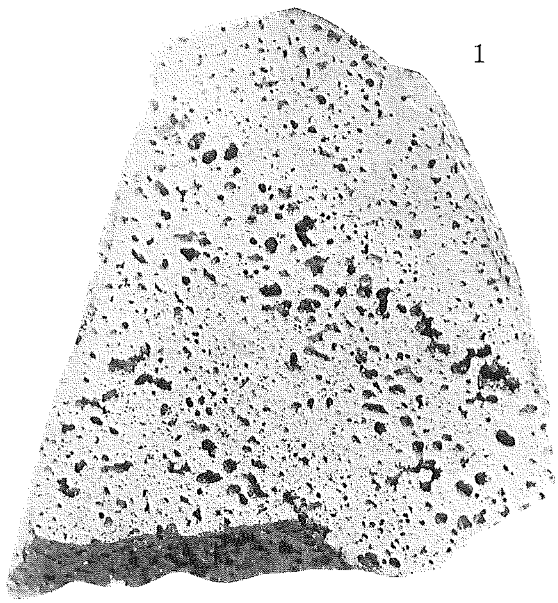
Explanation of
Plate I

Plate I

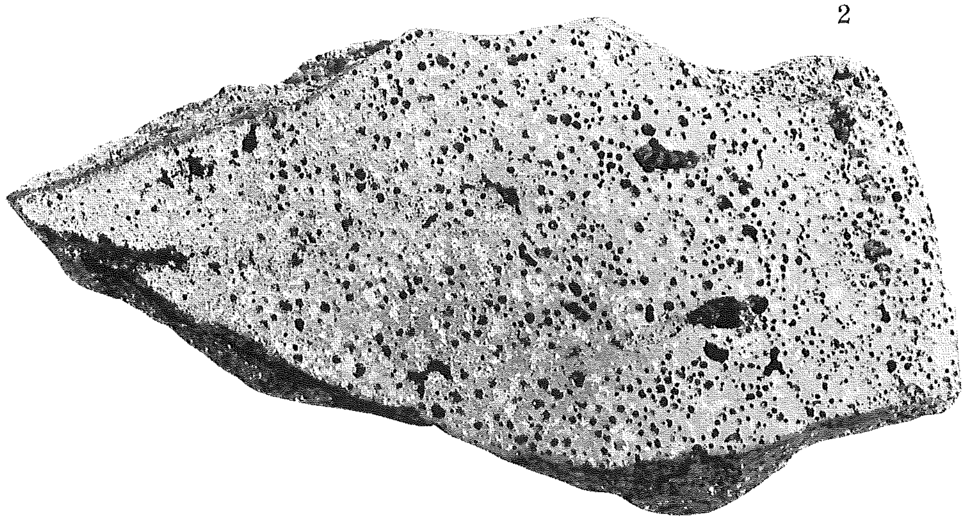
Fig. 1. Upper part (88A, 88B. & 88C) of a pillow.
Note that olivine crystals are very rare. Vesicules are concentrically arranged.

Fig. 2. Lower part (89A, 89B, & 89C) of a pillow. Note that olivine crystals are very abundant, especially in the central part of this slab. (4/5 of natural size)

1



2



K. YAGI: Pillow Lavas of Iceland

Explanation of
Plate II

Plate II

Fig. 1. Large olivine phenocrysts in the rather coarse grained groundmass. Olivine basalt 89B. (×20)

Fig. 2. ditto. (×50)

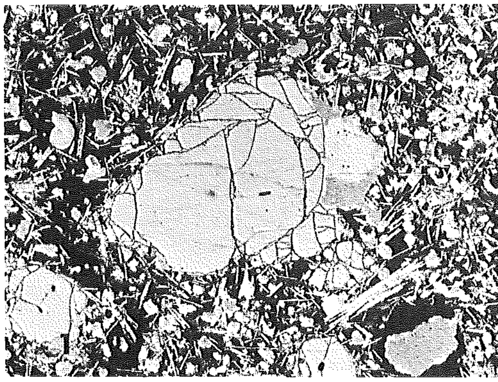
Fig. 3. Small olivine phenocrysts in the finer grained groundmass. Olivine basalt 88A (×20)

Fig. 4. ditto. (×50)

Fig. 5. Euhedral phenocrysts of olivine and plagioclase in clear glassy matrix. Palagonite 87. (×20)

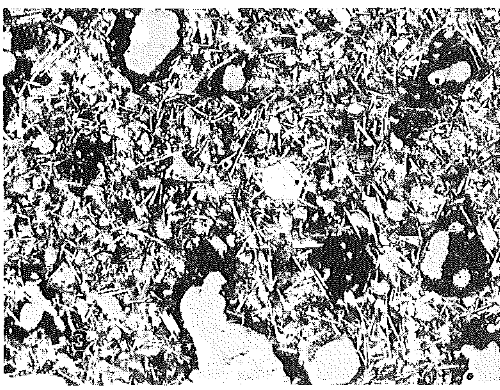
Fig. 6. Aggregates of glass shards. Palagonite 87. (×50)

1

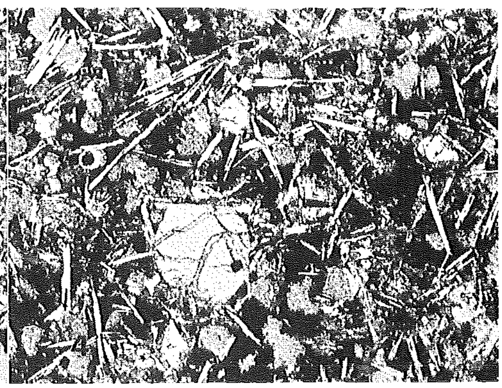


2

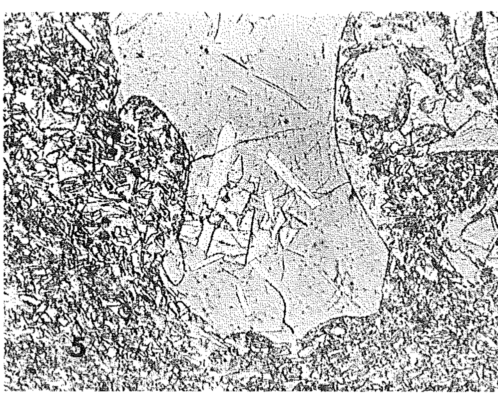
3



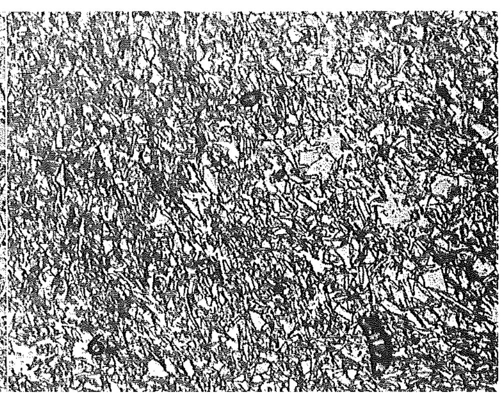
4



5



6



K. YAGI: Pillow Lavas of Iceland