A study on pseudo-hypersthene*

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(Received September 20, 1968)

Abstract

It should be reported here about the pseudo-hypersthene and honeycombed clinopyroxene found in the basalt lava from Saga Prefecture, northern Kyushu.

The results of the petrological study of these minrals are summarrized in the following studies, that is to say, both the relict orthopyroxene in the central part of pseudo-hypersthene and honeycombed clinopyroxene are as xenocryst. Namely, the orthopyroxene in this pseudo-hypersthene and honeycombed clinopyroxene may be considered to have been crystallized under the plutonic condition than the volcanic condition, and to have originally constituted gabbroic rock or basic nodule.

I. Introduction

Pseudo-hypersthene was proposed for such mineral determined as below by TOMITA (1931).

1. The central part of the mineral consists of orthopyroxene, and its surrounding part does of olivine and clinopyroxene (augite or pigeonite).
2. The mineral presenting intergrowth or aggregate of olivine and clinopyroxene in its surrounding part are due to the further progress of reaction, though there is no trace of orthopyroxene in the central part as pseudomorph after orthopyroxene.

The pseudo-hypersthene was first discovered by TOMITA (1931), in the lavas from Dôgo Island, one of the Oki Islands in the Japan Sea, and later at Hsuen-huashan Hill, Ching-hsing District, North China by him (TOMITA, 1933). Besides, the mineral is reported by MICHEL (1913), OGURA, SAWATARI and MURAYAMA (1939), and KUNO (1950), FUKUYAMA (1961), and MATSUMOTO (1961). TOMITA (1931) suggested on the origin of pseudo-hypersthene as follows. The orthopyroxene in the central part is the original phenocryst crystallized after olivine. And the pseudo-hypersthene, which consists of olivine and clinopyroxene, is a pseudomorph after the orthopyroxene and regarded as a product formed by reaction of magma with the orthopyroxene. If the

* A Lecture delivered before the general meeting held on the 15th, Oct., '61. in the Nishi-Nihon and the Kansai Branches of the Geological Society of Japan.

reaction is incomplete, the original orthopyroxene may remain as a core surrounded by reaction product. This fact attracted BOWEN-SCHAIRER'S notice (1935), as a matter of great interest, however, KUNO (1950) regarded the pseudo-hypersthene as xenocryst.

It should be reported here about the pseudo-hypersthene found in the basaltic lava in Saga Prefecture, northern Kyushu, that the orthopyroxene changed into this pseudo-hypersthene is hardly admitted as phenocryst since it is identified with a kind of xenocryst.

The author wishes to express his gratitude to Professor T. YAMASAKI at the Kyushu University, for his guidance and discussions. Thanks are also due to Dr. H. MATSUMOTO at the Kumamoto University for his chemical analysis.

II. General geology

Pseudo-hypersthene was newly found in the basaltic lava flow in the neighborhood

Table 1 Activities of the Matsura basalts from Kishima area, Saga Prefecture, Japan (MATSUMOTO, 1960, 1961)

Classification		rock type	rock series	
B_4	B_4b	hypersthene bearing augite-olivine basalt～andesite	Ⅴa	H
	B_4a	olivine basalt	Ⅲb—c	P
B_3	B_3	olivine basalt～(olivine trachybasalt)	Ⅲb	A
B_2	B_2d	augite bearing bronzite-olivine basalt	Ⅴb(Ⅴa)	A(H)
	B_2c	bronzite basalt～andesite	Ⅰd	H
	B_2b	olivine basalt～ (augite bearing bronzite basalt)	Ⅲb—c(Ⅴc)	P
	B_2a	augite-hypersthene-olivine basalt	Ⅴa	H
B_1	B_1d	bronzite bearing augite-olivine-acicular plagioclase basalt～trachybasalt	Ⅴb	A
	B_1c	augite-bronzite-olivine basalt	Ⅴd(Ⅴb)	A
	B_1b	aphanitic olivine basalt～basaltic andesite	Ⅴa	H
	B_1a	olivine basalt～(olivine trachybasalt)	Ⅲb	A

A: alkali rock series P: pigeonitic rock series H: hypersthenic rock series of Yanase, Minami Taku, Taku City, Saga Prefecture, Japan. The lava is a member of the Matsura basalts (MATSUMOTO and YAMASAKI, 1960; MATSUMOTO, 1960, 1961) that forms extensive plateau in Saga and Nagasaki Prefectures. The activities of Matsura basalts are divided roughly into four periods and the characteristics of these basalts are shown in Table 1. As will be clear from the table, the pseudo-hypersthene is found in the lowest lava flow (B_2a) of the second activities of the Matsura basalts assigned to the upper Pliocene age.

III. Petrology

A. Megascopic characters

The basalt containing pseudo-hypersthene generally looks grayish white, sometimes intermingled irregularly with black patches, and is porphyritic rich in phenocryst of olivine which is altered to iddingsite, and of pyroxene. There is comparatively many cavities, in which fine crystals of chabazite accompanied with white clay and pale green clay (each of them is montmorillonite) are found.

B. Microscopic characters

Under the microscope, the main phenocrysts or microphenocrysts, arranging in order of abundance, are olivine, orthopyroxene, clinopyroxene, and a small amount of plagioclase. Besides, magnetite and ilmenite occur as a microphenocrysts scattered throughout the rock. The groundmass are almost holocrystalline showing intergranular texture, and consist of plagioclase, potash-plagioclase, anorthoclase, olivine, orthopyroxene, clinopyropene, phlogopite, magnetite and ilmenite. In cavities are found orthopyroxene, phlogopite, clay mineral (montmorillonite), and chabazite. Besides, as will be referred to later, the pseudo-hypersthene in question and honeycombed clinopyroxene are present as xenocrysts. Important optical characters of them are shown in Table 2 and comparison of the chemical composition of pyroxene is illustrated in Fig. 1. Here, in order to estimate the chemical composition (Mol. %) of plagioclase, olivine, orthopyroxene and clinopyroxene from their optical properties, each diagram of CHAYES (1952), FOLDERVAART (1950), KUNO (1954), and HESS (1952), were used.

Olivine: Phenocrystic olivine is 1mm–0.2mm in length, generally from subhedral to unhedral due to magmatic corrosion, and sometimes altered entirely to iddingsite. Olivine in the groundmass is from euhedral to subhedral, short prism or granular, less than 0.2mm in diameter, 0.05mm in average, often altered to iddingsite and occasionally to serpentine. In many cases, olivine forming pseudo-hypersthene is mostly short prism or granular, occurring paragenetically with clinopyroxene. Chemical composition of this mineral determined by its refractive indices and optic axial angle is shown in Table 2; phenocrysts or microphenocrysts is inferred to be Fo83-Fo70, the groundmass component Fo72–Fo68, and that forming pseudo-hypersthene Fo83-Fo68.

Table 2 Constituent minerals and their optical properties of pseudo-hypersthene bearing, basaltic rock from Saga Prefecture

	Honeycombed	Pseudo-hypersthene	Phenocryst and micro-phenocryst	Groundmass	Cavity
Olivine	—	$-2V=88°, 84°, 83°, 81°$ α min $=1.679$ $\beta=1.699-1.741$ Fo83 — Fo68	$-2V=88°, 86°, 86°, 85°, 84°, 82°$ α min $=1.662$ $\beta=1.690-1.738$ Fo83 — Fo70	$-2V=83°, 82°, 81$ α min $=1.708$ $\beta=1.738-1.741$ Fo72 — Fo68	—
Rhombic pyroxene	—	$-2V=76°\rightarrow67°, 75°\rightarrow66°, 73°, 66°$ $\alpha=1.677$ $\beta=1.682-1.689$ $\gamma=1.700$ En78 — En70	$-2V=63°, 61°, 59°, 58°, 55°, 55°$ $\alpha=1.688$ $\beta=1.693-1.701$ $\gamma=1.711$ En68 — En58	$-2V=57°, 56°, 55°, 53$ $\alpha=1.694$ $\beta=1.699-1.705$ $\gamma=1.715$ En60 — En55	$-2V=59°, 56°, 55°, 54°, 53°$ $\alpha=1.692$ $\beta=1.698-1.705$ $\gamma=1.715$ En63 — En55
Monoclinic pyroxene	$+2V=49°, 49°, 48°, 47°, 46°, 45°, 45°, 44°$ $\alpha=1.675$ $\beta=1.688-1.692$ $\gamma=1.705$ Wo39En51Fs10	$+2V=49°, 48°, 48°, 48°, 47°, 47°, 46°, 45°$ $\alpha=1.682$ $\beta=1.687-1.700$ $\gamma=1.715$ Wo39En45Fs16	$+2V=47°, 46°, 44°$ $\alpha=1.682$ $\beta=1.688-1.694$ $\gamma=1.718$ Wo38En44Fs18	$+2V=45°, 44°, 43°$ $\alpha=1.690$ $\beta=1.694-1.702$ $\gamma=1.724$ Wo36En39Fs25	—
Phlogopite	—	—	—	$-2V=8°, 13°$ $\alpha=1.538$ $\beta=1.565$ $\gamma=1.569$ x:colorless y:reddish brown z:yellowish brown b=Y	$-2V=6°, 9°, 12°, 19°$ $\alpha=1.538$ $\beta=1.563$ $\gamma=1.567$ x:colorless y:reddish brown z:yellorish brown b=Y
Feldspar	—	Plagioclase 2V= +81° max.ext.Angle 34° An60	Plagioclase $\beta=1.565-1.559$ max.ext.angle 37° — 30° An64 — An53	Plagioclase $\beta=1.561-1.556$ max.ext.angle 32° — 25° An57 — An45 Potash-plagioclase Anorthoclase	—
Other minerals	—	—	Magnetite Ilmenite	Magnetite Ilmenite Apatite	Chabazite Montmorillonite

Orthopyroxene: Microphenocrystic orthopyroxene is 0.5mm-0.2mm in length, generally euhedral to subhedral and long or short prism. Orthopyroxene in the groundmass, less than 0.2mm in length, from euhedral to subhedral, occurring as long prism. Orthopyroxene associated with chabazite in cavity, less than 0.4mm in length, is long and euhedral prism (Plate I, Nos. 1 and 2), showing strong pleochloism. Beside, these orthopyroxene forming pseudo-hypersthene, the largest one being 5mm in length, is surrounded both by olivine and clinopyroxene. It shows weak pleochloism. The chemical composition of these orthopyroxenes determined by optic axial angle and refractive indices is inferred as follows: microphenocryst is Fo68-Fo58, groundmass components Fo60-Fo55, that in cavity Fo63-Fo55, and that in pseudo-hypersthene Fo78-Fo70.

Clinopyroxene: Microphenocrystic clinopyroxene, occurring from euhedral to subhedral, is less than 0.5mm in length and short prism. Clinopyroxene in the groundmass is granular and short prism, less than 0.1mm in diameter. Clinopyroxene froming pseudo-hypersthene is mostly in granular forms, having intergrown with olivine. Besides, clinopyroxene showing honeycombed structure are found. They are generally 3mm in diameter, reaching 7mm in maximum, and sometimes an aggregate of them, reaching 8mm in maximum. As for the average inferred composition of these clinopyroxenes determined by optic axial angle and refractive indices, microphenocryst is Wo38En44Fs18, groundmass constituents Wo36En39Fs25, honeycombed one Wo39-En51Fs10, and the one forming pseudo-hypersthene Wo39En45Fs16.

Phlogopite: Phlogopite occurs chiefly in cavity, generally less than 0.2mm in diameter and shows the tabular from (Plate I, Nos. 3 and 4). In addition to occurance in the groundmass, this mineral occurs as inclosure in the pseudo-hypersthene associated both with olivine and clinopyroxene.

Plagioclase: Microphenocrystic plagioclase occurs as euhedral and long prismatic crystal, less than 0.6mm in length. Albite twinning is common, but carlsbad and pericline twinnings are less common. Plagioclase in the groundmass, less than 0.2mm in length, about 0.1mm in common is euhedral and prismatic shape. The inferred chemical composition of plagioclase are as follows; phenocryst is An64-An53 (labradolite), constituent of the groundmass An57-An45 (labradolite-andesine).

Potash-plagioclase: Intersertal potash-plagioclase occurs in the groundmass. Positive optical axial angle is small, about 50° when observed with conoscope.

Anorthoclase: It occurs, similarly as potash-plagioclase, in the groundmass, showing intersertal texture.

Chabazite and **montmorillonite**: Chabazite occurs rarely as crystal, 3mm in diameter, besides as euhedral crystsl in cavity, commonly about 1 mm in diameter. Chabazite intergrown commonly with white caly and pale green clay (each of them montmorillonite).

Other minerals: Granular magnetite and tabular ilmenite are dotted over.

IV. Pseudo-hypersthene

A. The degree of reaction on pseudo-hypersthene

Pseudo-hypersthene, as already mentioned, commonly consists of two parts; the central part of orthopyroxene, and the surrounding part olivine and clinopyroxene. The latter is regarded as a reaction products between magma and the former. So it may be classified into three types according to the degree of reaction, i. e., the rate of orthopyroxene remains.

1) the pseudo-hypersthene in which orthopyroxene is completely relicted in the central part as a kernel and its surrounding parts consists of olivine and clinopyroxene (Plate II, Nos. 5 and 6)

2) the one in which orthopyroxene is slightly relicted in the central part with greater part changed into olivine and clinopyroxene (Plate II, Nos. 7 and 8)

3) the one in which no orthopyroxene is remained at all, having entirely turned to olivine and clinopyroxene (Plate III, Nos. 9, 10, 11, and 12)

B. Constituent minerals in pseudo-hypersthene

Pseudo-hypersthene characterized by the occurrences of olivine and chinopyroxene, may by considered to be occured under the unstable condition of the original orthopyroxene, by the reaction of magma with it. But no regularity about the occurrence of olivine and clinopyroxene is noticeable, whereas some of olivine shows slightly radial texture (Plate III, Nos. 11 and 12), and sometimes it shows slender prism filling the cleavage or crack of original orthopyroxene (Plate II, Nos. 5 and 6). Clinopyroxene is irregular and indefinite in shape.

Beside the above, though rarely, plagioclase or phlogopite are dotted over in pseudo-hypersthene, intermingled with olivine and clinopyroxene. It is not clear whether the plagioclase occured in the process of reaction forming pseudo-hypersthene or not. Phlogopite seems to have been filled the cleavage of olivine and clinopyroxene (Plate II, Nos. 7 and 8). It is also presumed that the stage of the crystallization of this phlogopite almost corresponds to that of phlogopite in the cavity.

C. Mineral components of pseudo-hypersthene

As shown in Table 2, the orthopyroxene in the central part of pseudo-hypersthene is inferred to be En78–En70 and bronzite, which is earlier stage in crystallization than such minerals as the microphenocrystic orthopyroxene (En68–En58), the orthopyroxene in the groundmass (En60–En55), the orthopyroxene in cavity (En63–En55). Furthermore zonal structure due to chemical difference is marked in the orthopyroxene in the central part of pseudo-hypersthene, showing the variation of inferred composition from the inner part to the outside, i. e., En78→En71, En77→En70. The olivine forming pseudo-hypersthene is inferred to be Fo83-Fo68 and shows no great difference compared with those of phenocryst or microphenocryst (Fo83–Fo70) and of the groundmass (Fo72–Fo68). And the inferred composition of clinopyroxene forming pseudo-hypersthene is Wo39En45Fs16 in average, showing no great difference compared with that of clinopyroxene of microphenocryst Wo38En44Fs18, but it is far later stage in crystallization than the honeycombed clinopyroxene Wo39En51Fs10.

The chemical composition of plagioclase rarely associated with olivine and clinopyroxene of pseudo-hypersthene is inferred to be around An60, being medium component of microphenocrystic plagioclase (An64-An53).

It may be correct to conclude by these data as follows: relict orthopyroxene in the central part of pseudo-hypersthene may definitely show to be the earlier products in crystallization than the same mineral of microphenocryst, of groundmass or cavity, while both olivine and clinopyroxene forming the surrounding part of pseudo-hypersthene show almost the same crystallized stage, at least obviously not earlier, that of each minerals in this rock.

V. Honeycombed clinopyroxene

Honeycombed clinopyroxene, less than 3mm in average, reaching sometimes 7mm, is anhedral in common. It is characterized sometimes by the formation of granular olivine which is scattered in it (Plate IV, Nos. 13 and 14), or it occurs as an aggregate (so-called nodule), 8mm in diameter, which consists of clinopyroxene of 1-2mm (Plate V, Nos. 17, 18, 19 and 20). Some of them show conspicuous lamellar twin (Plate IV, Nos. 15 and 16). Average chemical composition of honeycombed clinopyroxene is inferred to be Wo39En51Fs10, which shows obviously an earlier stage in crystallization than the same mineral of microphenocryst Wo38En44Fs18, of groundmass Wo36En39-Fs25, and of forming the surrounding part of pseudo-hypersthene Wo39En45Fs16.

VI. Chemical compositions of pseudo-hypersthene bearing basaltic rocks

In Table 3 are shown the result of chemical analyses of pseudo-hypersthene bearing basaltic rocks, normative mineral compsitions and percentage of or–ab–an, wo–en–fs, wo–fo–Q, Q–fo-fa, MgO–($FeO+Fe_2O_3$)–(Na_2O+K_2O). No. 1 shows the bulk chemical composition of pseudo-hypersthene bearing basaltic rock of Saga Prefecture and No. 2 analytical values of the same rock from which pseudo-hypersthene and honeycombed clinopyroxene have been removed as much as possible. As will be plain from Table 3, they are all unsaturated rocks with little SiO_2. Comparing No.1 with No. 2, the latter shows more SiO_2 and less MgO and FeO.

Table 3 Chemical compositions of pseudo-hypersthene bearing basaltic rocks

	1	2	3	4	5	6	7
SiO_2	47.56	50.92	44.96	45.46	46.54	48.40	49.03
TiO_2	1.80	1.54	2.36	3.17	3.46	2.88	1.71
Al_2O_3	15.17	16.38	12.28	15.04	14.41	16.74	14.43
Fe_2O_3	6.16	2.71	2.24	3.17	7.07	0.52	1.29
FeO	7.61	6.87	11.47	6.39	4.49	8.87	9.40
MnO	0.21	0.22	0.20	0.16	0.15	0.15	tr
MgO	9.86	8.33	10.64	8.58	4.88	7.38	11.93
CaO	7.43	8.58	7.39	10.55	8.81	8.20	7.28
Na_2O	2.80	2.87	3.95	3.81	5.07	2.78	3.14
K_2O	0.82	1.12	1.33	1.38	1.18	2.88	1.24
P_2O_5	0.24	0.32	0.91	1.08	1.88	0.92	0.44
H_2O+	0.36	0.30	1.41	0.74	0.96	0.07	0.73
H_2O-	0.17	0.11	0.79	0.16	1.18	0.10	—
Total	100.19	100.27	99.93	99.69	100.08	99.89	100.62
or	5.00	6.67	7.78	8.34	7.23	17.24	7.23
ab	23.58	24.63	20.44	18.86	36.68	21.22	26.72
an	26.41	28.36	11.95	19.74	12.79	24.46	21.41
ne	—	—	7.10	7.10	3.41	1.28	—
wo	3.94	5.22	8.00	10.56	7.89	4.41	4.99
en	16.50	17.00	4.80	8.00	6.80	2.60	5.40
fs	4.09	6.73	2.77	1.45	—	1.58	2.38
fo	5.74	2.66	15.26	9.45	3.78	11.13	17.08
fa	1.63	1.22	10.00	2.04	—	7.55	8.57
mt	9.05	3.94	3.25	4.64	4.87	0.70	1.86
hm	—	—	—	—	3.68	—	—
il	3.50	2.89	4.56	6.08	6.69	5.47	3.19
ap	0.34	0.67	2.02	2.69	4.37	2.02	1.01
or	9	11	19	18	13	27	13
ab	43	41	51	40	65	34	48
an	48	48	30	42	22	39	39
wo	16	18	51	53	54	51	39
en	67	59	31	40	46	30	42
fs	17	23	18	7	0	19	19
wo	15	21	29	38	43	24	18
fo	66	59	66	54	46	72	76
Q	19	20	5	8	11	4	6
Q	21	26	6	13	19	5	7
fo	62	56	57	72	81	57	62
fa	17	18	37	15	0	38	31
MgO	37	38	36	37	21	33	45
$FeO+Fe_2O_3$	49	43	46	40	52	42	39
Na_2O+K_2O	41	19	18	23	27	25	16

1 Matsura Basalts B_2a
Pseudo-hypersthene-bearing augite-hypersthene-olivine basalt, Yanase, Minami Taku, Taku City, Saga Pref., Japan, bulk composition. Analyst: H. MATSUMOTO

2 Same No. 1
Pseudo-hypersthene and honeycombed clinopyroxene have been removed as much as possible. Analyst: H. MATSUMOTO

3 Po li san lava
Pseudo-hypersthene bearing titanaugite-olivine trachybasalt, Po li san, Chi Hsing Shan Volcano, Manchuria. Analyst: Geological Survey of Japan. (OGURA et. al., 1939)

4 Augite-bearing titanaugite-olivine basalt, Suzume-zima, Dōgo, Oki-Islands, Shimane Pref., Japan. Analyst: M. Teshima (TOMITA, 1935)

5 Pseudo-hypersthene bearing olivine trachybasalt, Hseuh-hua-shan Hill, Ching-hsing District, North China. Analyst: H. Teshima. (TOMITA, 1933)

6 Hypersthene and augite bearing-olivine-labradorite trachybasalt, East of Hatta, Dōgo, Oki Islands, Shimane Pref., Japan. Analyst: M. Teshima (TOMITA, 1935)

7 Hypersthene-bearing olivine trachybasalt, Nakamura, Dōgo, Oki Islands, Shimane Pref., Japan. Analyst: K. Yokoyama (TOMITA, 1935)

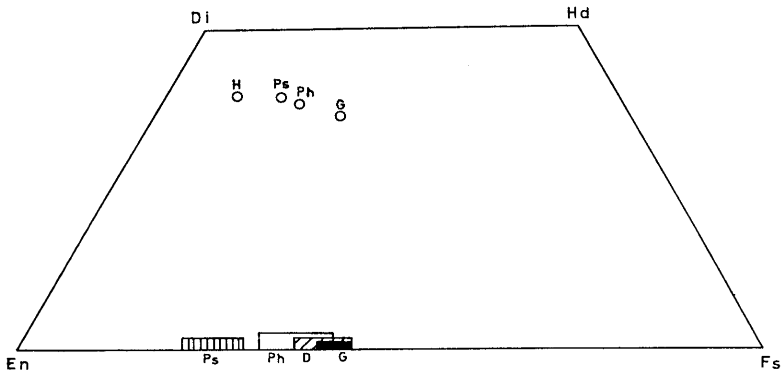

Fig. 1 Co-existing pyroxenes in pseudo-hypersthene bearing basalt from Yanase, Minami Taku, Taku City, Saga Prefecture, Japan

○ clinopyroxene
H : honeycombed clinopyroxene
Ps : clinopyroxene associated with olivine in pseudo-hypersthene
Ph : microphenocrystic clinopyroxene
G : groundmass clinopyroxene

▭ orthopyroxene
Ps : orthopyroxene in the central part of pseudo-hypersthene
Ph : microphenocrystic orthopyroxene
G : groundmass orthopyroxene
D : drusy orthopyroxene

VII. Origin of pseudo-hypersthene and honeycombed clinopyroxene

As already mentioned, it may be concluded that both the relict orthopyroxene in the central part of pseudo-hypersthene and honeycombed clinopyroxene are regarded as xenocryst for the following reasons:

(1) These minerals are obviously earlier in the crystallized stage than that of each minerals occured as phenocryst, microphenocryst and groundmass component.

(2) Honeycombed clinopyroxene is remarkably honeycombed, and shows marked lamellar twin. It occurs sometimes as aggregate or the so-called basic nodule (YAMAGUCHI, 1964).

KUNO (1950) reported previously the same conclusion on the pseudo-hypersthene in basic basalt from Hakone volcano which had been considered to be xenocryst by him. Furthermore, as shown in Fig. 1, the orthopyroxene in this pseudo-hypersthene and honeycombed clinopyroxene may be considered to have crystallized from magma under the plutonic condition than volcanic condition, though the basic nodule which is similar to the peridotite nodule occurring as xenolith in the pseudo-hypersthene bearing basaltic rock from Chi-Hsing Shan volcano, Manchuria (OGURA, SAWATARI and MURAYAMA, 1939), or from Simoganya, Nakamura, Dôgo Island, Japan (YAMAGUCHI, 1962; UCHIMAZU, 1966), has not yet been found in the existing rock in Saga Prefecture.

Namely, the orthopyroxene in this pseudo-hypersthene and honeycombed clinopyroxene may be considered to have been crystallized under the plutonic condition than the condition of basaltic rock, or to have originally constituted gabbroic rock or basic nodule. Since these minerals may be considered to have been enclosed into the basaltic magma, it caused not only the instability of the crystals themselves but the reaction of magma with them. Thus, there occured the crystallization of olivine and clinopyroxene, while clinopyroxene honeycombed.

Discovery of the pseudo-hypersthene in Japan and its adjacent districts is restricted in the area of the so-called alkari rock regions or near, except Hakone volcano (KUNO, 1950). The reason for this is not known yet, but it will be an important problem for future study.

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Explanation of Plate I

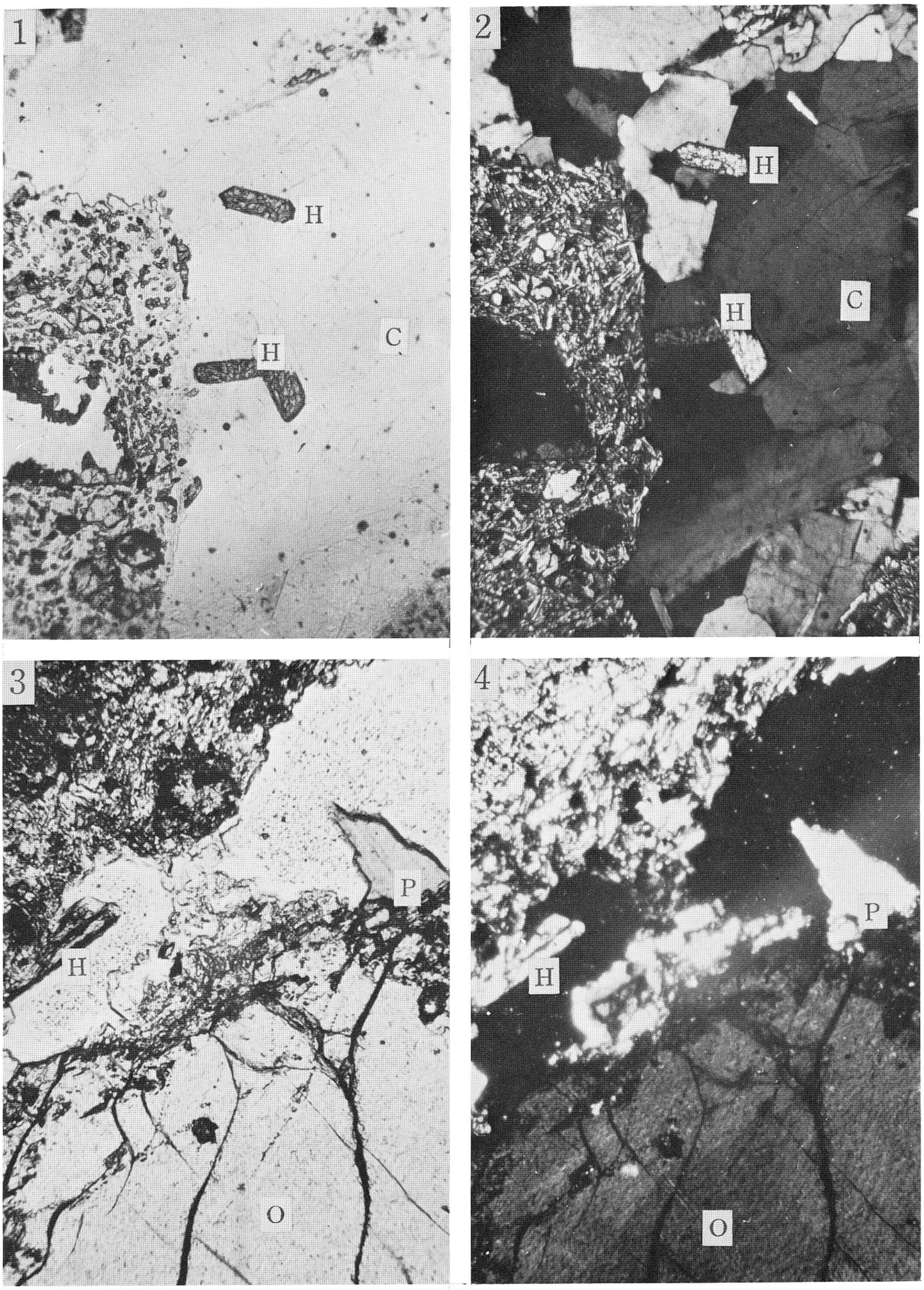
No. 1 Drusy hypersthene (H) and chabazite (C). open Nicols, ×35.

No. 2 Same No. 1. crossed Nicols, ×35.

No. 3 Drusy phlogopite (P) and hypersthene (H), large crystal is phenocrystic olivine (O). open Nicols, ×70.

No. 4 Same No. 3. crossed Nicols, ×70.

Plate I



Explanation of Plate II

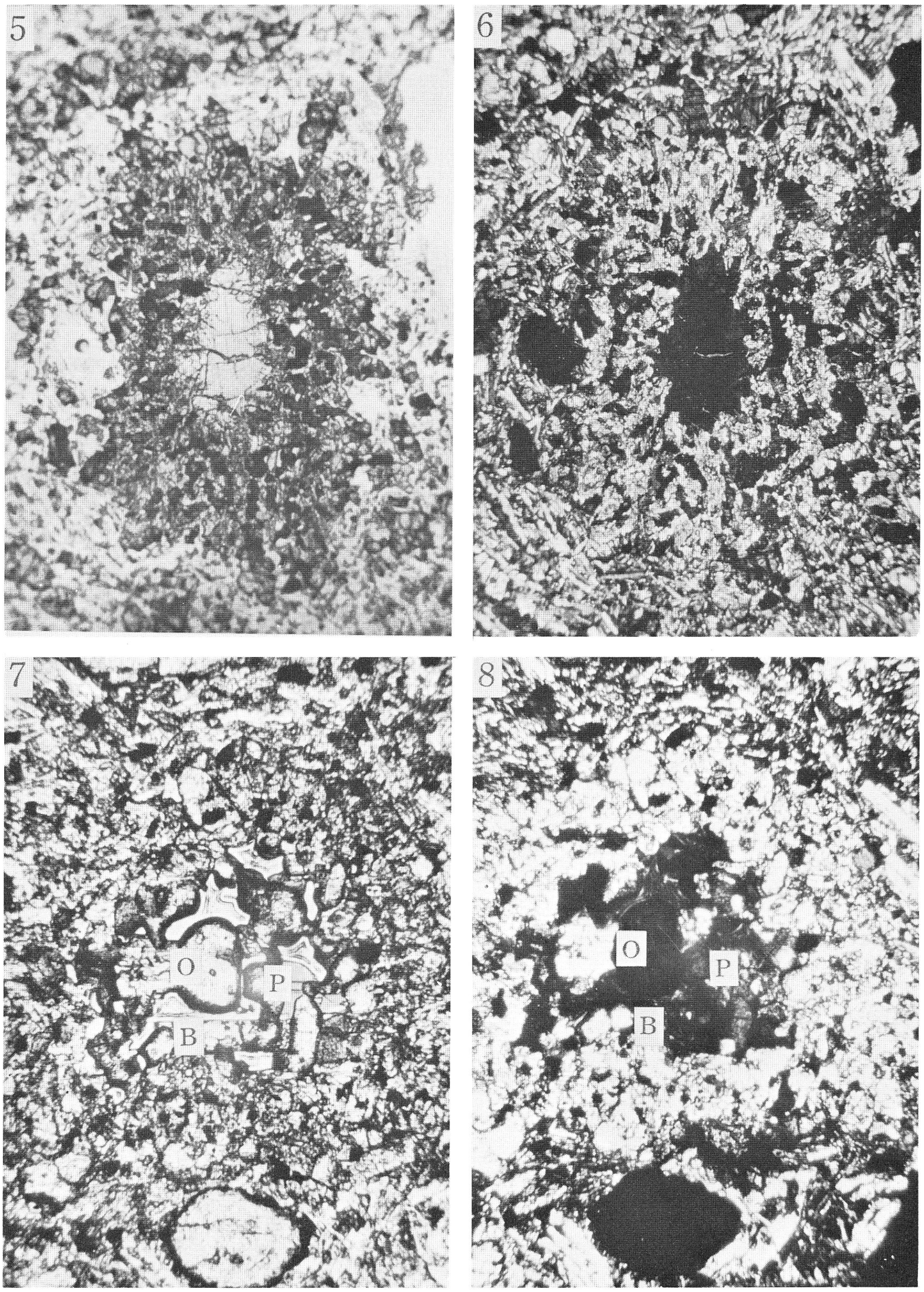
No. 5 Pseudo-hypersthene; in which orthopyroxene is completely relicted in the central part as a kernel and its surrounding part is consists of olivine, which are altered to iddingsite and clinopyroxene. open Nicols, ×35.

No. 6 Same No. 5. crossed Nicols, ×35.

No. 7 Pseudo-hypersthene; in which orthopyroxene (B) is slightly relicted in the central part with greater part changed into olivine (O) and clinopyroxene, furthermore development of phlogopite (P) in cavity of pseudo-hypersthene. open Nicols, ×70.

No. 8 Same No. 7. crossed Nicols, ×70.

Plate II



Explanation of Plate III

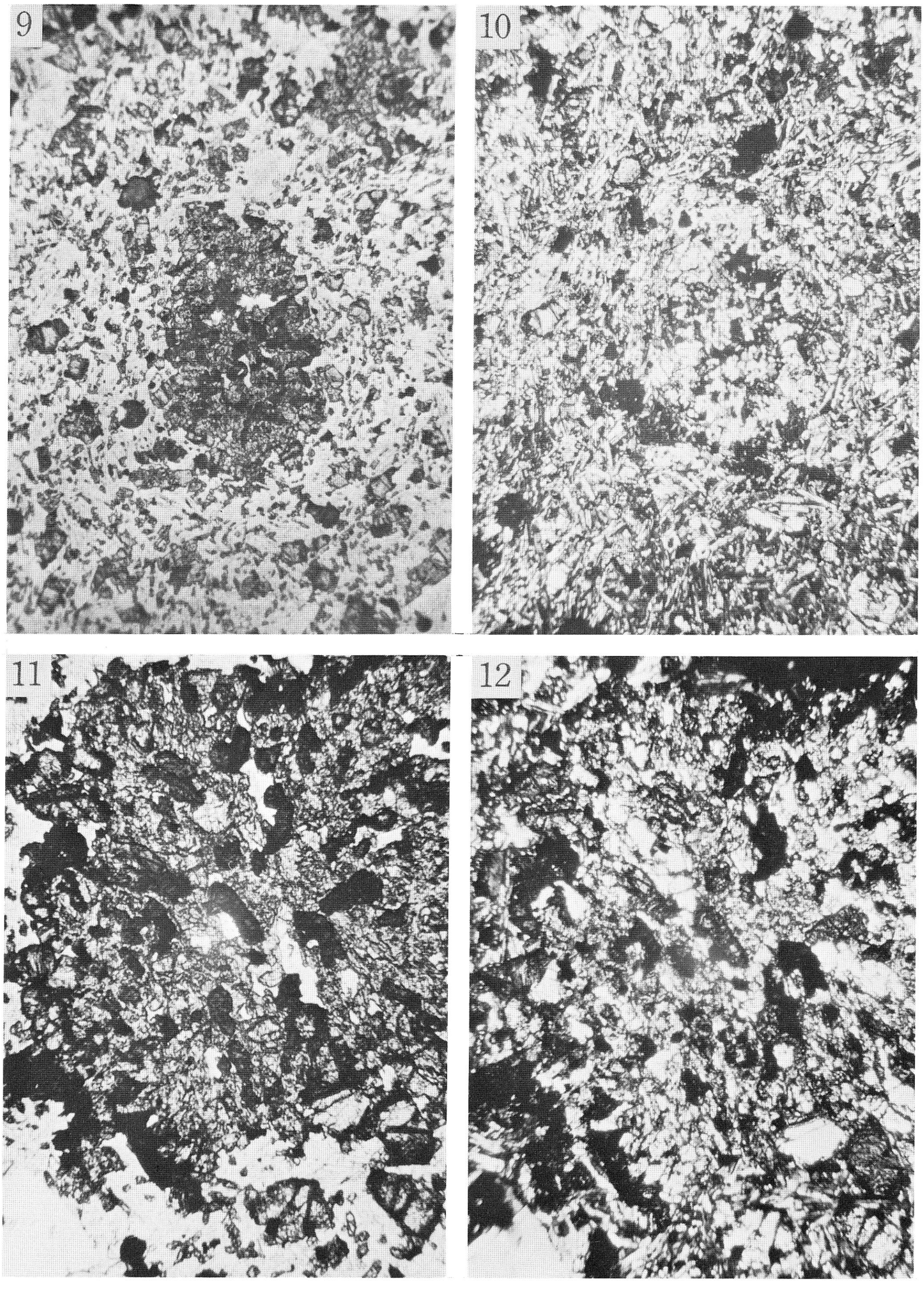
No. 9 Pseudo-hypersthene ; in which no orthopyroxene is remained at all, having entirely turned to olivine and clinopyroxene, the former is altered to iddingsite. open Nicols, ×35.

No. 10 Same No. 9. crossed Nicols, ×35.

No. 11 Pseudo-hypersthene; in which no orthopyroxene is remained at all, having entirely turned to olivine and clinopyroxene, the former is altered to iddingsite. open Nicols, ×70.

No. 12 Same No. 11. crossed Nicols, ×70.

Plate III



Explanation of Plate IV

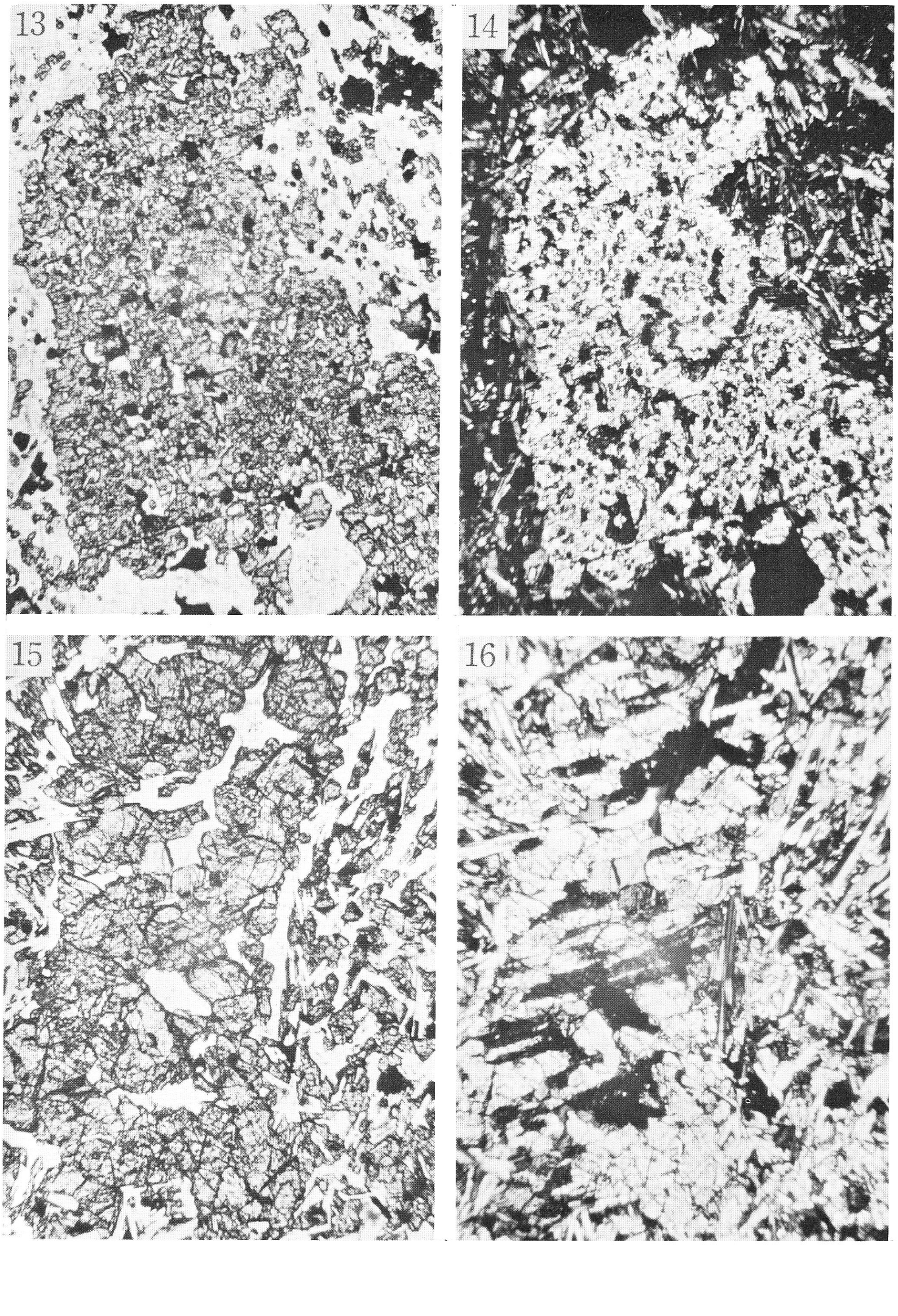
No. 13 Honeycombed clinopyroxene; is anhedral and characterized by the formation of granular olivine which is altered to iddingsite, and scattered in it. open Nicols, ×35.

No. 14 Same No. 13. crossed Nicols, ×35.

No. 15 Honeycombed clinopyroxene; is anhedral and show conspicuous lamella twin. open Nicols, ×70.

No. 16 Same No. 15. crossed Nicols, ×70.

Plate Ⅳ



Explanation of Plate V

No. 17 Honeycombed clinopyroxene; it occurs as an aggregate (so-called nodule). open Nicols, ×35.

No. 18 Same No. 17. crossed Nicols, ×35.

No. 19 Honeycombed clinopyroxene; it occurs as an aggregate (so-called nodule). open Nicols, ×35.

No. 20 Same No. 19. crossed Nicols, ×35.

Plate V