A.b. III

REPORT No. 139
GEOLOGICAL SURVEY OF JAPAN
Tomofusa Mitsuchi, Director

An Orbicular Rock in Andesite from Akagi Volcano, Japan.

By

Haku KOIDE

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TOKYO 1951, MARCH

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Introduction.

In the course of my geological study of Akagi volcano in May 1948, I got a block of fine orbicular rock embedded in andesite found along Goroga-sawa, a small valley running north-west of Ara-yama (point B in Fig. 1).

Orbicular rock is generally found in acidic to intermediate plutonic rock. Although it is rather rare in occurrence, there are many descriptive and genetic studies on orbicular rock from the world.[1]

In Japan, the orbicular rocks are collected from several localities, some of which were studied by some petrologists.[2] They are all enclosed in granodioritic rocks, therefore they are called " ball-granite " or " ball-diorite ". But I have not had the opportunity of seeing the orbicular

1) J. J. Sederholm: On Orbicular Granites, spotted and nodular granites etc, and on the rapakivi texture. Bull. Comm. Geol. Finlande, No. 83, 1928, pp. 1-105.
S. R. Nockolds: On an Orbicular Diorite from the Island of Alderney. Geol. Mag. Vol. 68, 1931, pp. 499-506.
A. Johannsen: Orbicular Granite. A descriptive Petrography of Igneous Rocks II. 1932. pp. 248-258.
P. Eskola: On the Esboitic Crystallization of Orbicular Rocks. Jour. Geol. Vol. 46, 1948, pp. 448-485. (Suppl. no. in honour of Prof. A. Johannsen)
G. Berg: Kugelgranite im Riesengebirge. Jb. preuss. Geol. Landesanst. Vol. 58, 1938, pp. 677-690.
G. E. Goodspeed: Orbicular Rock from Buffalo Hump, Idaho. Amer. Min. Vol. 27, 1942, pp. 37-47.

2) B. Yoshiki: Petrographic properties of orbicular rock from Minedera-yama. Jour. Min. Pet. Econ. Geol. Vol. 10, 1933, pp. 109-115.
Y. Kawano: Preliminary note on the chemical studies of orbicular rock from Minedera-yama. Jour. min. Pet. Econ. Geol. Vol. 10, 1933, pp. 124-136.
Y. Kawano. Chemical studies of ball granite from Sanage-yama. Jour. Min. Pet. Ecom. Geol. Vol. 20, 1938. pp. 14-25. pp. 48-58.
H. Takeuti: Studies of the orbicular rock from Kenashi-yama. Jour. Min. Pet. Econ. Geol. Vol. 22, 1939, pp. 101-117.
Y. Kawano: Chemical studies of orbicular rock and its related rocks from Kenashi, Shinano Prov. Jour. Min. Pet. Econ. Geol. Vol. 22, 1939, pp. 118-129.

rock in volcanic ones. It is, however, of special notice that noritic or gabbroic inclusion in lavas are found and reported as "micro-allivalite, micro-eucrite and microgabbro" from Sakura-jima, Ōshima and others.[1] Some of these inclusions were treated as "ball-norite, ball-allivalite and ball-eucrite" by K. Yamaguchi[2] in his paper.

He studied petrologically these inclusions in detail and concluded them all as "cognate xenoliths", although they have quite similarity with the orbicular rock in questions in many petrographical characters.

The orbicular rock is treated not only as the peculiar rock, but also as the rock having important petrological meaning in special reference to granite petrology, as were already discussed by Sederholm and others. The discovery of orbicule in volcanic rock, that may hardly be expected by petrologists, will give us many important and foundamental problems with regard to the petrogenesis of volcanic rocks. I should like to give here a short petrological notes on the orbicular rock in questions with the expectation of development of these problems in the future.

Geological Outline

Akagi-san is a volcano based on the Chichibu Series, the Palaeozoic formation consisting mainly of shale and sandstone. The brief geological sketch of the crater wall and its neighbourhood is given in fig. 1.

It is geologically composed of tuff breccia, on which lava domes consisting of andesitic and dacitic rocks are developed in and around the crater wall. Kurohi-yama and Ara-yama are constructed of andesitic lavas. Many dykes develop in tuff breccia especially near Kurohi-yama and Ara-yama.

The andesitic rock carries often a good many of foreign materials as various xenoliths, which are probably derived from the members of Palaeozoic formation. Such andesitic blocks carrying xenoliths are abundantly found along Shira-kawa and Sakura-zawa. It is, however, not quite certain of the actual mode of occurrence of these xenoliths in the field.

1) B. KOTO: The Great Eruption of Sakura-jima in 1914. Jour. Col. Sci. Imp. Umiv. Tokyo, XXXVIII, Art. 3, 1916.
S. TSUBOI: Genetical study of micro-allivalite and micro-diorite from Ōshima volcano. Jour. Geol. Soc. Jap. Vol. XXV, No. 299, 1918, pp. 404-416.
Z. HARADA: On the Spheroidal Bomb of Volcano Hachijo-Fuji, Prov. Idzu. Jour. Geol. Soc. Jap. Vol. XXXI, Nos. 373, 374, 1924, pp. 357-364.

2) K. YAMAGUCHI: On the Noritic Inclusions in the lavas of Sakura-jima. Jour. Geol. Soc. Vol. XXXIV, No. 409, pp. 381-408, No. 410, pp. 461-472, No. 411. pp. 479-498, 1927.

The xenoliths are almost always in the advanced state of reaction with magma, so the original characters of them are not very certain in the field as well as in thin section. For this reason, I can only get the brief image on this respect based on the synthetic interpretation of many facts observed in thin sections.

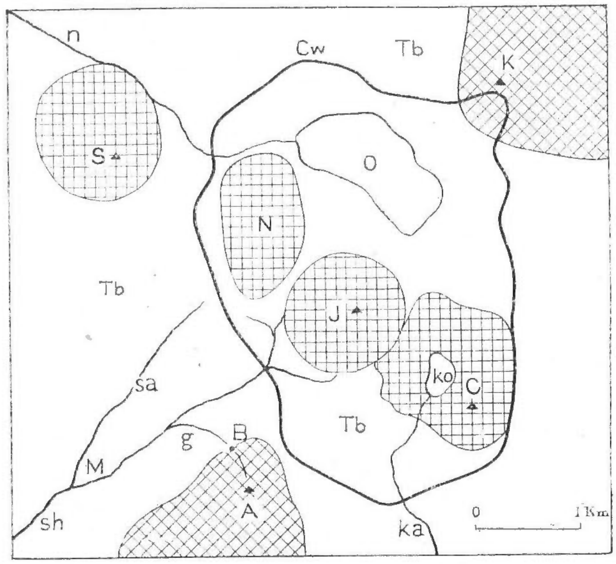

Fig. 1. Geological sketch of Akagi volcano.

J	Jizō-dake lava dome (地蔵岳)	B	The locality found the loose block of orbicular rock in andesite along Goroga-sawa (g).
N	Numano-taira lava dome (沼ノ平)	g	Goroga-sawa (ゴロガ澤)
C	Chōshichirō lava dome (長七郎)	sh	Shira-kawa (白川)
S	Suzuga-take lava dome (鈴ケ岳)	sa	Sakura-zawa (櫻澤)
K	Kurohi-dake lava (黒檜岳)	n	Numao-gawa (沼尾川)
A	Ara-yama lava (荒山)	ka	Kasu-kawa (粕川)
Tb	Tuff breccia	M	Minowa (箕輪)
Cw	Crater wall		
O	Ōno (大沼)		
Ko	Kono (小沼)		

Petrography

Macroscopic characters. The orbicule or the ball in andesite shows ovoidal structure with 6cm in longer axis and 4cm in shorter axis. It consists of four parts, which are concentric in the development (Plate I and Fig. 2).

The innermost part or the nucleus (1 in fig. 2) is black in colour and medium to fine in grain size, carrying some porphyroblastic feldspars or porphyroblastic aggregates of the minerals. This nucleus is surrounded by a leucocratic and coarse-grained ring with 0.3–0.5cm in width (2 in fig. 2). Weak radial structure is partially noticeable. This white ring is again surrounded by the other ring, which is wider measuring more or less 1.0cm in width (3 in fig. 2). This is much coarser in grain-size and less leucocratic. It is now very characteristic, owing to fine radial structure due to the radial growth of feldspars and the radial arrangement of mafic minerals, as will be described in the following pages. It gives a most characteristic feature to the orbicular rock. The outermost zone is medium to fine grained and greyish, varying from 0.5mm to 2.0mm width (4 in fig. 2). It is, however, coarser in grain size than the innermost part (nucleus).

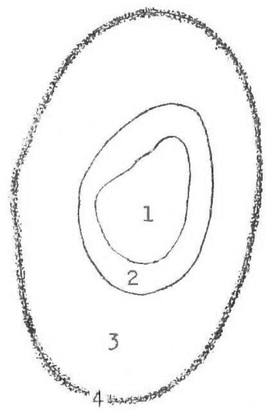

Fig. 2. Division of orbicular rock.
1...innermost part or nucleus
2...white ring
3...radial ring
4...outermost zone

These four parts above mentioned are, on the whole, sharply defined from each others and enclosed in a fine-grained porphyritic and greyish andesite with sharply defined boundary line, appearing as a characteristic orbicular rock.

Microscopic characters. For the sake of convenience, the orbicular rock is divided into four parts or zones, each of which is petrographically studied under the microscope as follows:

Innermost part or nucleus (1 in fig. 2). This consists of plagioclase, augite, hypersthene and magnetite as essential minerals, with a few quantity of glass as an accessory components. The rough estimation of volume percentages of them are given in table 1.

There are two kinds of plagioclase with regards to the sizes; fine-grained one usually less than 0.2mm and the coarse-grained porphyroblastic one measured up to 1mm in size. It seems to be easily divided into these two classes. The fine-grained crystal is granular and free from any twinning and zonal structure. It appears often as porphyroblastic aggregates, giving partially to the rock characteristic granoblastic texture. (Plate III. 1, 2).

TABLE 1.

	Plagioclase	Rhombic pyroxene	Monoclinic pyroxene	Magnetite	Olivine	Glass	Hornblende
1	43	18	28	11	—	Trace	—
2	94	3.9	—	2	0.1	Trace	—
3	88	9	Trace	3	Trace	Trace	—
4	80	14.3	0.2	5	—	0.5	Trace

1. Innermost part or nucleus (1 in fig. 2).
2. White ring (2 in fig. 2).
3. Radial ring (3 in fig. 2).
4. Outermost zone (4 in fig. 2).

But the coarse-grained plagioclase is hypidiomorphic or even idiomorphic in crystal outline, appearing as porphyroblasts (Plate III. 1, 2).

Twinning is rather rare in this case. Zonal structure is noticable in the porphyroblastic crystals, the calcic core being surrounded by narrow clear sodic rim with sharp boundary. Some of fhe porphyroblasts contain a good many of dusty inclusions and are turbid.

These two crystals seem in certain cases to be in genetic connection, suggesting that the larger well-formed prophyroblast is formed through "Sammelkrystallisation" of the fine-grained granular crystals.

Monoclinic pyroxene appears as ill-defined crystals, measuring up to 1.2mm in size. It shows weak pleochroism, changing from nearly colourless to pale greenish. Rhombic pyroxene is also xenomorphic. It is more or less 0.5mm in size measuring up to 0.8mm. Pleochroism changing from pale greenish to brownish is strong. Magnetite is quantitatively characteristic mineral, as is given in Table 1, occurring usually as well-formed crystals with 0.1–0.3mm in size. This is often one of the characteristic features of "eucrite, allivalite and micro-diorite" enclosed in lavas from Sakura-jima and Ōshima, suggesting that this may have an important meaning in the petrogenesis of these rocks, as will be briefly discussed latter. It alters often into brownish dusty material, which is probably limonitic iron ore. Small quantity of brown glass occurrs as interstices between other minerals.

The optical constants of some important minerals are given in Table II. It is noticed that the plagioclase is somewhat acidic and larger in composition range than the other parts of the orbicular rock. This is well represented by the development of zonal structure of the mineral in thin section.

From the facts above mentioned, it is least doubt that the nucleus is genetically in close connection with the metamorphism, suggesting the xenolithic origin enclosed in andesitic magma.

White ring (2 in fig. 2). This is coarse-grained rock, consisting mainly of calcic plagioclase with subordinate amount of rhombic pyroxene, magnetite and olivine, the rough estimation of volume percentages of these minerals being given in table 1. It is on the whole plutonic in textural feature.

Plagioclase is hypidiomorphic to idiomorphic in crystal outline with 0.1–4.0mm in size, showing strong tendency to develope with the longer axis perpendicular to the both sides 1 and 3 in fig. 2. There are some crystals having wedge-formed outlines which will be briefly described in the latter. Twinning after albite, carlsbad and pericline law are common. It is here of special notice to find that there are some crystals having interesting twinning which is probably imperfect pericline (Plate III. 3 Plate V. 4). The mineral is always weak in or rather free from zonal structure and is clear owing to the rarity or nearly absence of inclusion with a few exceptions. On the other hand, some crystals, especially the larger ones, show irregular block-wise extinction similar to strain shadow often observed in quartz under slight shearing stress (Plate III. 4). In these respects described above, the plagioclase differ considerably from the mineral in the foregoing rock, 1 in fig. 2. This seems to suggest that the feldspar in questions may crystallize rapidly in different physico-chemical condition, under which larger crystallization force is given to the mineral after the formation of mafic minerals, as will be briefly discussed later.

Rhombic pyroxene appears as fine-grained crystals usually less than 1.0mm in size. It tends to arrange around larger feldspars and surround the latter minerals. Mineralogically, it is quite similar to the rhombic pyroxene of the nucleus. Olivine is almost always in close association with rhombic pyroxene, being often perfectly enclosed in the latter. There is least doubt that the olivine is an earlier formed mineral, now an unstable relict, converting into rhombic pyroxene. Magnetite shows mineralogically quite similar characters to that of the nucleus.

Radial ring (3 in fig. 2). This is one of the most interesting zone of the orbicular rock, exhibiting radial structure due to the radial development of plagioclases surrounded by fine granular or elongated rhombic pyroxenes and magnetites, as are shown in Plate II and fig. 3.

The boundary between 2 and 3 is represented by the zonal arrange-

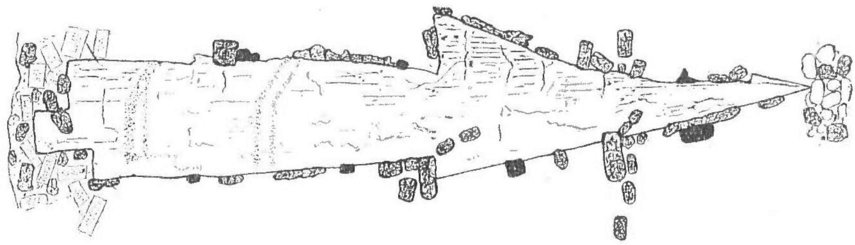

Fig. 3. Long wedge-formed crystal of plagioclase surrounded by pyroxenes and magnetites. 1 nucleus, 2 white ring, 3 radial ring, 4 outer most zone, 5 enclosing andesite.

ment of fine-grained granular rhombic pyroxenes and magnetites (Plate II). There is almost absent of plagioclase crystal, which develops over this boundary line from 2 to 3 in fig. 2, although there is an interesting exception described in the following.

Long wedge-formed crystals of plagioclase, measuring up to 1cm or more in length, are radially developed. The top of wedge is, in this case, always directed toward the core of the orbicular rock, as are shown in plate IV, plate V 1, 2 and fig. 3. One of such wedge-formed plagioclases has the top on the margin of nucleus and the bottom on the outer most zone (4 In fig. 2) of orbicules, cutting the boundary line between 2 and 3 in fig. 2 (Fig. 3). Such feature of plagioclase suggests us that the mineral crystallizes from the core toward the margin of the orbicular rock.

In certain part of the rock, plagioclase is on the whole hypidiomorphic to idiomorphic in crystal outline. It is, therefore, texturally rather similar to plutonic rock under the microscope (Plate V 3, 4).

Mineralogically, plagioclase is quite similar to the mineral of the foregoing rock, 2 in fig. 2. It is also usually fresh and weak in zonal structure, being calcic in composition and having smaller range, as is shown in table 2. Rhombic pyroxene is fine grained granular or stout prismatic, occurring usually around plagioclase (Plate IV 1, 3 Plate V 1, 3, and fig. 3). It gives therefore a characteristic radial structure to the orbicules, in special reference to the radial development of plagioclases. Magnetite is somewhat larger in size than the nucleus. It alters also into dusty limonitic iron ore.

TABLE 2

	Plagioclase An%	Rhombic Pyroxene		Monoclinic Pyroxene	
		α	β	α	β
1	62–80	1.697	1.705	1.689	1.700
2	88-94	1.695	1.704		
3	86-94	1.695	1.704		
4	65–79	1.700		1.695	

1. Innermost part or nucleus (1 in fig. 2).
2. White ring and radial ring (2 and 3 in fig. 2).
3. Outermost zone (4 in fig. 2).
4. Enclosing andseite.

Outer most zone (*4 in fig 2*). The outer most zone differs petrographically from the other three parts described in the foregoing pages in many respects. It varies from 0.5mm to 2mm in width, the mean value being about 1mm. The boundary between this and the radial ring (3 in fig. 2) is on the whole sharply defined, but it is always clearly defined against the enclosing andesite (Plate II, Plate V 1).

This zone is fine grained and micro-dioritic in textural feature (Plate VI 1, 2). It carries plagioclase, rhombic pyroxene and magnetite as main components with accompanied by glass, monoclinic pyroxene and brown hornblende in subordinate amounts (table 1).

Plagioclase is idiomorphic and appears always as tabular or lath-shaped crystals with more or less 0.5mm in size. Twinnings after albite, carlsbad and pericline law are common. But the mineral showing interesting twinning (Plate III 3, Plate V 4), which is characteristic to some minerals of 2 and 3 in fig. 2 is now perfectly absent. Zonal structure is somewhat noticeable. It is of special notice that plagioclase carries usually a good many dusty inclusions, which show almost always regular arrangement. Such plagioclase is commonly found as phenocrysts in andesite, as will be briefly described latter (Plate VI 3, 4).

Rhombic pyroxene is usually fine-grained or stout prismatic. It shows mineralogically similar characters to the mineral above mentioned. There are, however, some crystals grown up to larger size amounting to 1.5mm or more. On the other hand, it is of special interest to find that there are many fine long prismatic crystals and needles, which are paler in colour and weak in pleochrism. Such long prismatic or needle crystal of rhombic pyroxene is entirely absent in the other parts of orbicular rock and it is of special interest to notice that such crystal show strong tendency to appear in close association with or being embedded in the glass (Plate VI 1). This is an interesting fact in special connection with the formation of sanukite studied by Sugi.[1] He found that only rhombic pyroxene crystallized out easily in the glass derived through contamination of granitic rock by andesitic magma.

Magnetite is similar to that described in the foregoing pages. Glass occurs as interstices between other minerals. It is usually colourless and clear, but sometimes stained with dusty black material. Devitrification often takes place in such stained glass. To the present writer, there seems to be present of no evidence to suggest that the glassy material is introduced from the enclosing andesite.

Hornblende appears as prismatic fine crystals, showing strong pleochroism from yellow to reddish brown. Even the largest crystal amount to 0.3mm in size. It strongly tends to occur along the boundary with the enclosing andesite.

Enclosing andesite. The enclosing rock is augite-bearing hypersthene-andesite. It is greyish, somewhat porous and porphyritic.

Under the microscope, the rock is porphyritic in texture, many phenocrysts of plagioclase, pyroxene and magnetite being embedded in the glassy groundmass (Plate VI 3, 4).

Plagioclase phenocryst appears as larger tabular idiomorphic crystals, measuring up to 5mm in size at extreme case. It is often characterized by the presence of a good many of dusty inclusions usually shown regular arrengement. In certain case, several crystals with or without well-formed outlines gather to make a phenscryst, which seem to the present writer to be in genetical connection with xenolith (Plate VI 3, 4). Zoning and twinning are very common.

Hypersthene occurs as prismatic crystals with more or less 0.7–1.0mm in size. It is moderate pleochroic, changing from pale greenish to yellowish. Augite tends to be rather ill-defined crystals. Twinning on (100) is common. Magnetite alters also often to dusty limonitic substance.

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1) K. SUGI: On the Sanukites at the Evirons of Takamatu, Sikoku, with special Reference to the Xenocryst found in Rocks. Bull. Volc. Soc. Vol. 4, No. 1, 1938 pp. 17–33.

Groundmass consists mainly of glass, in which the tiny crystals of lath-shaped plagioclase and prismatic hypersthene are developed.

The table 2 brings out the facts that plagioclase is more acidic and larger in composition range, and mafic minerals are higher in refractive indices than those of the orbicular rock.

Petrochemical Characters. Owing to the absence of chemical analysis[1] of the orbicular rock in question, I calculated the chemical compositions of the four parts from the results of volumetry.

Firstly from table 1, weight percentages of the main component minerals are calculated, assuming the specific gravities of them as follows: anorthite 2.8, labradolite-bytownite 2.7, rhombic pyroxene 3.3, monoclinic pyroxene 3.3. The results are shown in table 3, from which the chemical compositions are presumably calculated in table 4.[2]

TABLE 3.

	Plagioclase	Rhombic Pyroxene	Monochinic Pyroxene	Magnetite
1	35	19	29	17
2	92	4		4
3	86	10		4
4	75	16		9

1. Innermost part or nucleus (1 in fig. 2).
2. White ring (2 in fig. 2).
3. Radial ring (3 in fig. 2).
4. Outer most zone (4 in fig. 2).

These values are, of course, artificial and represent merely rough estimation of the chemical compositions of four parts of the orbicular rock. But it gives us satisfaction to see that these four parts have petrochemically many interesting characters, on which I am able to discuss the genetical viewpoints of the orbicular rock.

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1) Materials for chemical analysis could not be prepared because of shortage of the orbicular rock.

2) Chemical compositions of the four main component minerals are here assumed as follows;
Anorthite.................... SiO_2 44, Al_2O_3 36, CaO 9, Na_2O 1.
Labradorite-bytownite ...SiO_2 51, Al_2O_3, CaO 15, Na_2O 4.
Rhombic pyroxene.........SiO_2 55, FeO. Fe_2O_3. MgO 42, CaO 3.
Monoclinic pyroxene......SiO_2 54, FeO. Fe_2O_3 MgO 21, CaO 25.
Magnetite ....FeO Fe_2O_3 100.

TABLE 4.

	1	2	3	4
SiO_2	43.9	42.6	43.3	41.8
Al_2O_3	10.5	33.1	31.0	27.0
CaO	13.1	17.6	16.6	14.7
Na_2O	1.4	1.0	0.9	0.8
FeO. Fe_2O_3. MgO ...	31.1	5.7	8.2	15.7

1. Innermost part or nucleus (1 in fig. 2).
2. White ring (2 in fig. 2).
3. Radial ring (3 in fig. 2).
4. Outer most zone (4 in fig. 2).

It is firstly noticed that these four parts are all lower in SiO_2 and higher in other oxides, especially in Al_2O_3 and CaO. This fact is due to the richness of calcic plagioclase. Higher contents of mafic components are partly caused by the presence of magnetite in fair amount.

TABLE 5.

	1	2
SiO_2	42.9	45.18
Al_2O_3	25.4	25.69
Fe_2O_3	} 15.2	0.38
FeO		5.37
MgO		6.70
CaO	15.5	14.63
Na_2O	1.0	1.31
K_2O		0.30
$H_2O(+)$		0.21
$H_2O(-)$		0.17
TiO_2		0.17
P_2O_5		0.08
MnO		0.09
Total	100.0	100.11

1. Average composition of the four parts of orbicular rock in table 4.
2. Spheroidal enclosure of eucrite in lava of Sakura-jima by K. Yamaguchi.

There is reason to believe that the average composition of the four parts of orbicular rock, which is given in table 5, represents the chemical composition of orbicular rock in substance.[1] In reference to this, the chemical composition of a spheroidal enclosure of eucrite in the lava of Sakura-jima volcano studied by K. Yamaguchi[2] is also shown in table 5. It is here of special interest to notice that the average composition of the four parts of orbicular rock in question bears on the whole quite resemblance to the eucrite enclosure in the lava of Sakura-jima volcano.

Genetical Discussion.

Here, I must take the origin and the genesis of orbicular rock in consideration.

Firstly, I have to discuss the problem that whether the orbicular rock now in questions is a "cognate xenolith" representing the aggregate of earlier crystallized minerals of lava or a "xenolith" representing a foreign material incorporated in and reacted with lava.

But the theory of "cognate xenolith" seems to me to be uncertain because of the facts; (1) the nucleus exhibits mosaic texture under the microscope, suggesting that it is undoubtedly in genetical connection with metamorphism, (2) plagioclase of the nucleus is more acidic in composition with larger range than the other parts of orbicular rock, (3) larger wedge-formed plagioclases are not believed to crystallize out from andesitic magma, (4) strain shadow of plagioclase may suggest that the crystal does not crystallize out from liquid.

The orbicular rock seems, therefore, undoubtedly to be a "xenolith", that is a foreign rock enclosed and metamorphosed in basic magma. What is the foreign rock, then? With regard to this problem, there are three possible cases, that are (1) orbicular rock in granite, (2) calcareous sediments and (3) pelitic sediments, these being expected to be derived from the rocks constructing the base of Akagi volcano.

Among these three cases, it seems to be not probable to assume that the first two cases are able to treat as the origin of orbicular rock in many respects, especially in view of the small probability of their occurrence as the base rocks of Akagi volcano. I am therefore of opinion

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1) Weight percentages of the nucleus and the leucocratic rings of orbicular rock (2 and 3 in fig. 2) are roughly estimated as 45 and 55.

2) K. YAMAGUCHI: op. cit. p. 393.

that the orbicular rock in questions is probably derived from pelitic sediments, belonging to Palaeozoic formation, enclosed and then metamorphosed in basic magma. This idea is theoretically supported by the following theory.

Being based on the petrogenetical study of norite by Read,[1] which is later theorized by Rowen[2], it has been well-known theory that norite is seen developed through contamination of pelitic sediments by gabbroic or rather by basic magma in general saying. Now being subject to this theory, I am going to discuss the problems of the origin of orbicular rock and of the chemical reactions through which the main component minerals of it are formed.

Basic magma, probably basaltic in this case, caught a block of pelitic sediments of Chichibu Palaeozoic series in the magma chamber and then chemical reaction between them took place there, after the manner of the formation of norite above mentioned. Lime was metasomatically added to the pelitic xenoliths or rather to alumina in chemical term, from basic magma, certain amount of silica being probably subtracted from the xenolith.[3] Pyroxenes, especially rhombic pyroxene and calcic plagioclase were thus formed through lime metasomatism to alumina, and olivine was resulted through desilication in the place of rhombic pyroxene at the early stage of the chemical reaction. Chemical and mineralogical characters of the orbicular rock were thus fundamentally caused through metasomatic metamorphism discussed now.

But the textural features of orbicular rock give us many important, but difficult problems, which I can hardly explain with sufficient satisfaction. With regards to these problems, I should like to give here a short discussion below.

In the first place, a question arises as to how to see the innermost part or nucleus. It seems to me to be most probable that the nucleus is a product of metamorphic differentiation, through which mafic components gather from the surroundings to make seggregation, especially from the white ring (2 in fig. 2), and alumina removes outward, resulting the leucocratic rings surrounding the nucleus. The metamorphic differentia-

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1) H. H. READ: Xenolith in the contaminated rocks of Huntly. Geol. Mag. 61, 433, 1924.
——: Corundum-spinel xenoliths in the gabbro of Haddo House. Geol. Mag. 68, 446, 1931.

2) N. L. BOWEN: Behavior of inclusions in igneous magmas. Jour. Geol. XXX, 550, 1922.

3) Desilication of xenolith is, in general, widely observed even in acidic igneous rocks. It should be regarded as a general phenomena taken place in xenolithic environment.

tion might work in the chemical environment of lime metasomatism.

This theory will be supported by the chemical compositions of the orbicular rock given on table 4 and 5. The average composition of the orbicular rock, which shows quite resemblance to that of the spheroidal enclosure of eucrite in the lava of Sakura-jima, is now of special impor tance, suggesting that it might be a homogeneous rock having similar composition to the eucrite enclosure from Sakura-jima, before metamorphic differentiation was in action on the rock.

The metasomatical diffusion of alumina outward and of lime inward takes, on the other hand, an important role for the development of characteristic features and mineral compositions of the orbicular rock. The ratio of alumina to lime is consequently smaller in nucleus, resulting the crystallization of monoclinic pyroxene and of more acid plagioclase. The ratio becomes larger outward, especially in the surrounding white rings (2 and 3 in fig. 2), in which plagioclases are as much basic as anorthite. Such movement of alumina and lime, as well as the higher concentration of the two oxides in the white rings, result the remarkable crystallization of anorthite from inside toward outside of the orbicular rock. The mineral now gotten unusual crystallization force in the physical and chemical environment pushes out the mafic minerals as it grows, appearing often as larger wedge-formed crystals. The strain shadow of the plagioclases suggests us that the minerals might crystallize out in a frictional environment, which was probably caused by plagioclases themselves having unusual crystallization force.

The outermost zone is petrographically, as well as petrochemically, somewhat different from the other parts of the orbicular rock. It is quite similar to the average composition of orbicular rock in petrochemical characters. This fact suggests us that the outermost zone is the part left out of the metamorphic differentiation disscussed now. In other words, this may be the rock representing the pelitic sediments metasomatised by lime in basic magma and the equivalent of the so-called "micro-eucrite and micro-diorite" enclosed in the lavas of Sakura-jima, etc. The other parts of the orbicular rock in question may probably be derived from originally homogeneous rock, in the place of such rock as "micro-eucrite or micro-diorite", through metamorphic differentiation.

Presence of glass, especially in the outermost zone of orbicular rock, may suggest that the original pelitic sediments was, partially at least, melted through fusion. The molten liquid was quenched in the effusive condition and appeared as interstitial glass,[1] in which fine crystals of rhombic pyroxene crystallized out as in the case of Sanukite.

Lastly, it is of special interest to notice that the orbicular rock is richer in magnetite. This is one of the most characteristic features of the rock in question and also often of the " spheroidal enclosure of eucrite, allivalite and micro-diorite" in the lavas from Sakura-jima, etc. This seems to me to be an important fact supporting the theory that the orbicular rock is originally a pelitic semiments enclosed in basic magma. The ratios of Fe_2O_3 to FeO and of total iron oxides to MgO are generally both higher in pelitic sediments, which contain also usually higher amount of H_2O as an active oxidizer of ferrous oxide to ferric oxide. The increase of ferric oxide must, as a matter of course, appear as higher content of magnetite in mineralogical term.

Concluding Remarks.

The orbicular rock in andesite now under consideration is originally a pelitic sediments of Palaeozoic series, which is enclosed and reacts in basic magma.

The mineralogical characters and the textural features of orbicular rock are resulted through lime metasomatism accompanied by metamorphic differentiation in orbicluar rock. Differential movement of alumina, magnesia and iron oxides takes place in the rock, resulting the characteristic zonal and radial structure.

21. 2. 1949.

1) Alkalis might be concentrated in the glass. This seems to me to be an important problem which I should like to study in the feature.

要　　約

赤城火山産安山岩中の球狀岩

小　出　　博

1948年5月，赤城火山の山崩れの調査中に，荒山の北西にあるゴロガ澤で安山岩の中に包まれた“球狀岩”或いは球顆岩を採取した。珍らしい岩石であるが，轉石として僅に一個を見つけ得たのみであつたので，その後8月に再びゴロガ澤の調査を行つた。然し豫期したように露頭としてみつけ出すことは勿論，轉石としても採取することはできなかつた。

この“球狀岩”は今これを，安山岩など，一般に火山岩類の混成現象に關連させて見ると，甚だ興味深い多くの問題を提供しているので，以下“球狀岩”一般の立場から簡單に述べて見よう。

“球狀岩”は花崗岩質岩石に包まれて產出するのが普通であつて，一般に“球狀花崗岩”とゆう名稱で漠然と呼ばれている。“球狀花崗岩”もその產出は甚だ稀であるが，それでも世界の各地から發見され，記載されたものは相當の數にのぼつている。我國でも數個所にその產出が知られてゐる。

然し“球狀岩”が火山岩類の中に包まれて產出する例は，まだ殆んど知られていない。たゞこゝで注意したいことは，櫻島火山，大島火山などから，安山岩の中に包まれた球狀の eucrite, allivalite, micro-norite, micro-diorite と呼ばれる岩石が記載されていることである。そして山口鎌次はこれを“Spheroidal enclosure”とゆう言葉であらわしている。これ等の記載を見ると，色々の點で今問題としている安山岩中の“球狀岩”に似ているのであるが，小藤・坪井・原田・山口らの研究者は，これを安山岩岩漿の早期固結塊，卽ち“cognate xenolith”又は“autolith”と結論している。そしてこのような岩石を，所謂“球狀花崗岩”との關連において眺めようとする試みは全くなされていない。

要するに從來の觀念によれば，“球狀岩”の產出は一般に酸性乃至中性の深成岩のなかに限られるとされており，Sederholm, Eskola その他の研究者の結論をまとめてみると，彼等の考えている成因・機構から“球狀岩”が火山岩のなかに產出する場合を豫期することは甚だ困難であるように思われる。從つて今問題の安山岩中の“球狀岩”の發見ーとゆうよりは寧ろ，この岩石に對するわたしの研究態度ーは，この意味からも重要であり，且つ多くの岩石學上の重要な問題に發展せしめ得る可能性の大きいことがわかるであろう。

さて然らば，“球狀岩”とゆうのは一體どのような岩石であるか，その著しい特徵は何んであるかとゆうと，たゞ球狀又は楕圓體狀の岩石であるとゆうだけではなく，主として構造・組織が甚だ特異であることである。卽ち多くの場合に，その斷面にあらわれた

構造が，同心圓構造と，放射狀構造の組合せからできているもので，このような構造・組織は一般の岩石には全く現われない。

今問題の安山岩中の“球狀岩”は，上述の構造・組織上の著しい特徴を見事に示している。卽ち中心より外部に向つて四つの帶からできた同心圓構造を示し，このうち一つの帶は放射狀構造をもつている。この四つの帶に就いて簡單に述べると次のとおりである。

1. 核心部，有色鑛物の多い中粒乃至細粒の黑色部。斜長石・斜方輝石・單斜輝石・磁鐵鑛が主でガラスを交える。

2. 核心部を取りまく白色の環で粗粒。灰長石が主で，斜方輝石・磁鐵鑛・ガラス・橄欖石を交える。

3. 更にその外側をとりまく白色の放射狀構造を示す帶で粗粒。最も廣い面積をもつ部分である。灰長石が主で斜方輝石・磁鐵鑛・ガラスを交える。

4. 最外帶，灰白色で細粒閃綠岩質の部分。亞灰長石・斜方輝石が主で，單斜輝石・磁鐵鑛・角閃石・ガラスを交える。

次に“球狀岩”のこのような鑛物組成並びに構造・組織が，どうしてできたかとゆうことに就いての結論だけを以下に述べる。

(1) 先づ第一に問題の安山岩中の“球狀岩”は，所謂“cognate xenolith”とか“autolith”と呼ばれる概念の岩石に屬するものとは考えられない。それは外來の岩片が鹽基性岩漿のなかに取りこまれ，相互反應を行つてできた岩石で，“xenolith”の概念に屬するものである。

(2) そこで次に，どのような外來の岩石がその起原であるかとゆう問題がおこる。この問題に對しては色々の事實から，赤城火山の基盤である古生層の頁岩又は粘板岩に，その起原を求めるのが，この場合最もたしからしく思われる。

(3) 鹽基性岩漿のなかに取りこまれた頁岩又は粘板岩質岩片に對し，交代作用が行われ，岩漿より CaO が岩片に加えられ，岩片からは恐らく Al_2O_3 及び SiO_2 の一部が岩漿のなかに移行したと考えられる。この交代作用が捕促岩片の岩石學的諸性質を變化させる最も基本的な役割をはたした。

(4) 岩漿と岩片との間のこの交代作用に伴つて，岩片自身のなかに變成分化作用が行われた。これは FeO, Fe_2O_3, MgO 等の成分が岩片の中心部に集合し，Al_2O_3 が中心部より次第に外部に向つて擴散するような分化作用であつた。

(5) この變成分化作用によつて“球狀岩”の各部分の鑛物成分・構造・組織が決定され，“球狀岩”としての基本的な特徴が形成された。卽ち Al_2O_3 が中心より外部へ，CaO が外部より中心に向つて擴散する結果，Al_2O_3 と CaO の比が中心部，卽ち核心部で小さくなり，そこにやゝ酸性の斜長石と單斜輝石の晶出をみ，その周圍の白色帶ではこの比が大きくなり，基性の斜長石の晶出が行われ，單斜輝石が成生されなかつた。更に白色帶では，基性斜長石のみが異常に成生され易い化學的環境にあつたため，大きな結晶力

を得て，中心より外部へ向つてくさび形に發達した。

(6) 變成分化作用は“球狀岩”の最外帶には殆んど行われなかつたと思われる。從つて最外帶の部分は，變成分化作用の行われる前の岩石—それは恐らく均質な，そして所謂“eucrite”又は“micro-diorite”に似た岩石であつたであろう—の狀態を我々に示すものであろう。

(7) “球狀岩”特にその最外帶にはガラス質物質が他の鑛物の間をうめて存在する。そしてその中に針狀の小さい斜方輝石が多數に晶出している。このようなガラス質物質は所謂 Sanukite を想起させるが，成因的にも關連性のあることを示している。これは捕捉された岩片の少くとも一部が熔融し，“球狀岩”の略々完成した後に，そして安山岩熔岩の噴出のときに急冷され，ガラス質の物質となつたものである。この部分には或いはアルカリーの濃縮が行われているかもしれない。

(8) “球狀岩”の一つの著しい特徴は磁鐵鑛の多いことで，それが更に酸化されて褐鐵鑛となつていることである。櫻島の熔岩のなかの“eucrite, allivalite, nuicro-diorite”などでも，矢張り磁鐵鑛の多い傾向があるが，これは“球狀岩”の起原を頁岩・粘板岩などにもとめて見た場合，甚だ興味の深い事實と思われる。

1949. 2. 21.

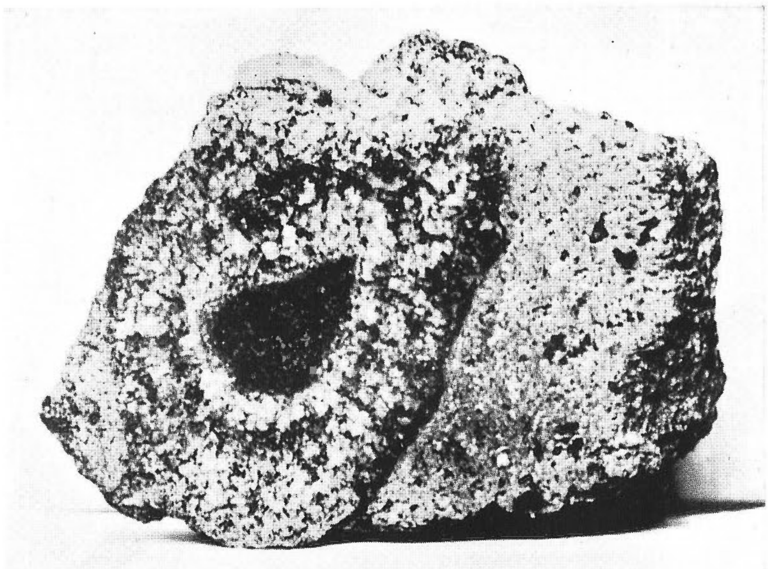
PLATES

AND

EXPLANATIONS

Plate I.

1. The orbicular rock in andesite from Akagi volcano.
2. Ditto.



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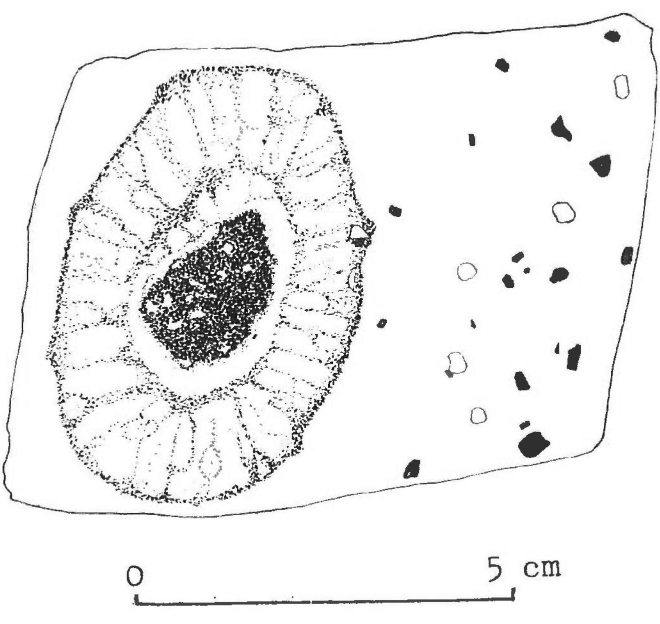

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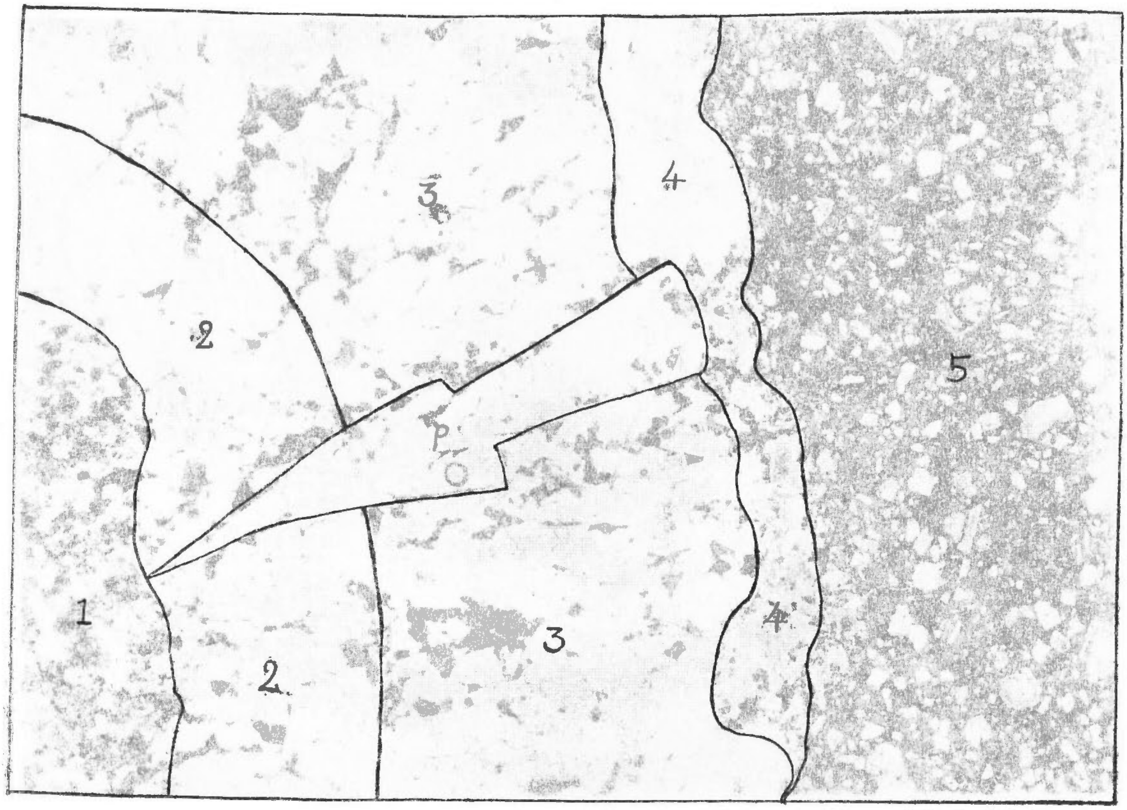
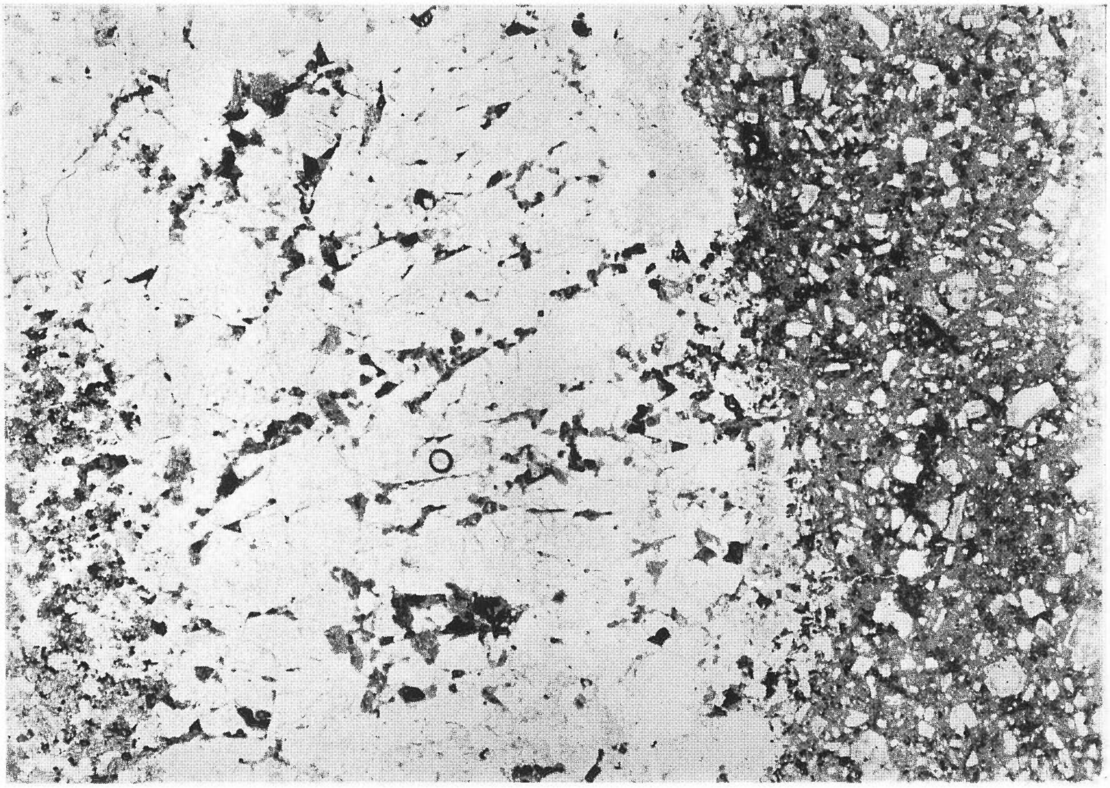


Plate II.

Enlarged photograph of the section of orbicular rock in andesite. × 7.

1……Innermost part or nucleus.
2……White ring.
3……Radial ring.
4……Outer most zone.
5……Enclosing andesite.
p……The wedge-formed plagioclase shown in fig. 3 and plate IV 1, 2.



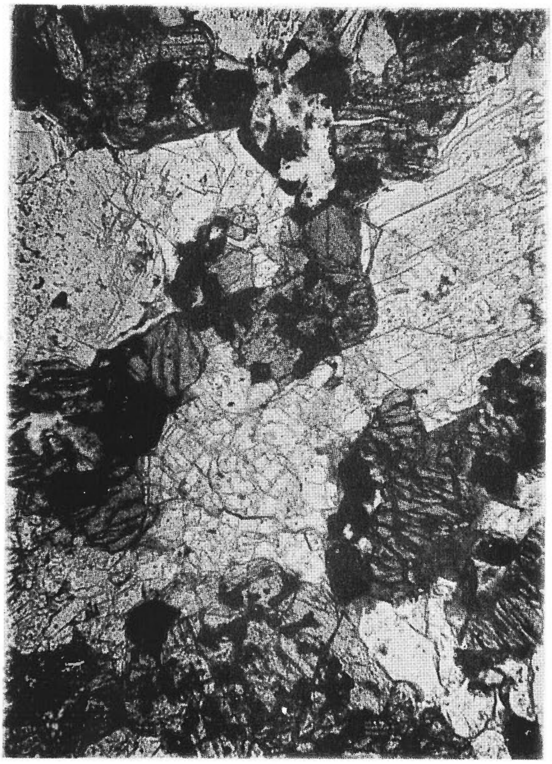


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Plate III.

1 Innermost part or nucleus consisting of plagioclase (white parts), pyroxenes (dark parts) and magnetite (block parts). Note the larger quantity of magnetite and turbidity of larger crystal of plagioctase. × 50. Open nicols.

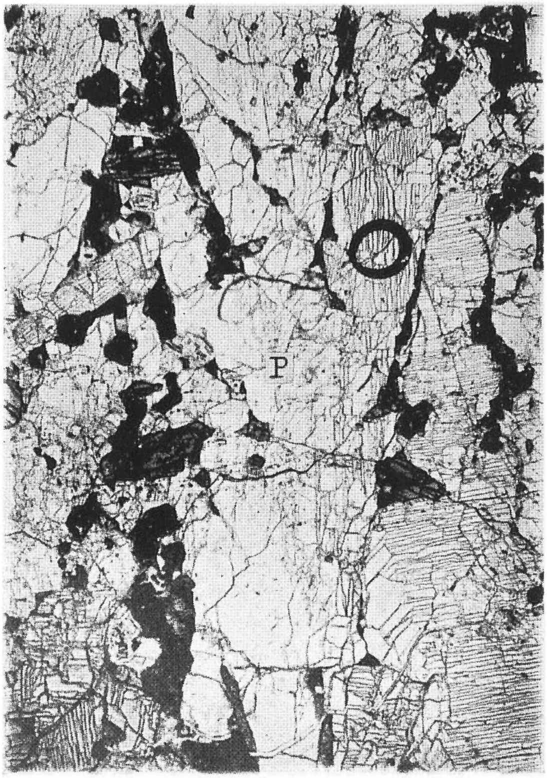
2. Ditto. The plagioclase in the central part of the figure form aggregate of fine-grained granular crystals. Crossed nicols.

3. Imperfect pericline twin of plagioclase in white ring. × 45. Crossed nicols.

4. Strain shadow or wavy extinction of plagioclase (dark part with distinct cleavages). × 50. Crossed nicols.

Plate IV.

1. A part of wedge-formed crystal (P) of plagioclase in fig. 3. Note the crystal surrounded by grains of hypersthene and magnetite. × 25. Open nicols.
2. Ditto. Crossed nicols.
3. Wedge-formed crystals (P) of plagioclase, which are also surrounded by grains of hypersthene and magnetite. × 16. Open nicols.
4. Ditto. Crossed nicols.



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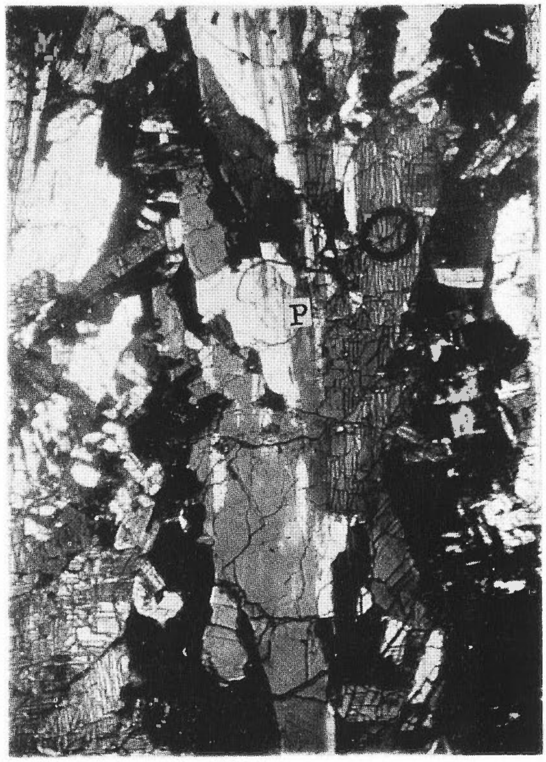

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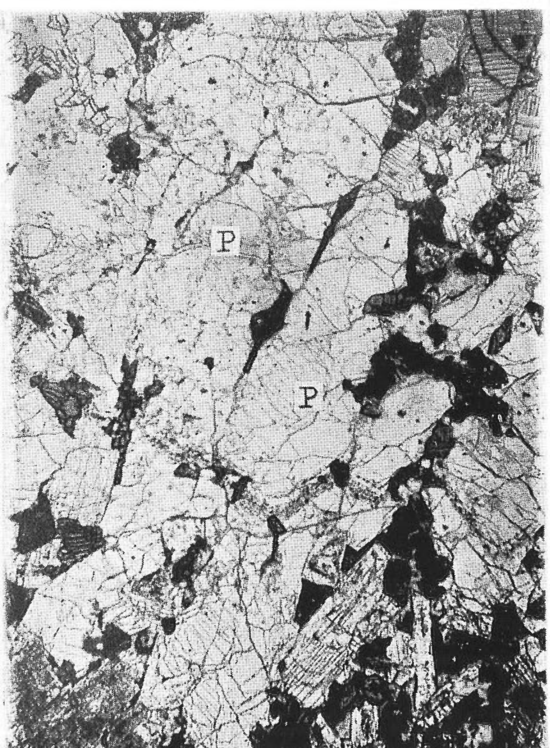

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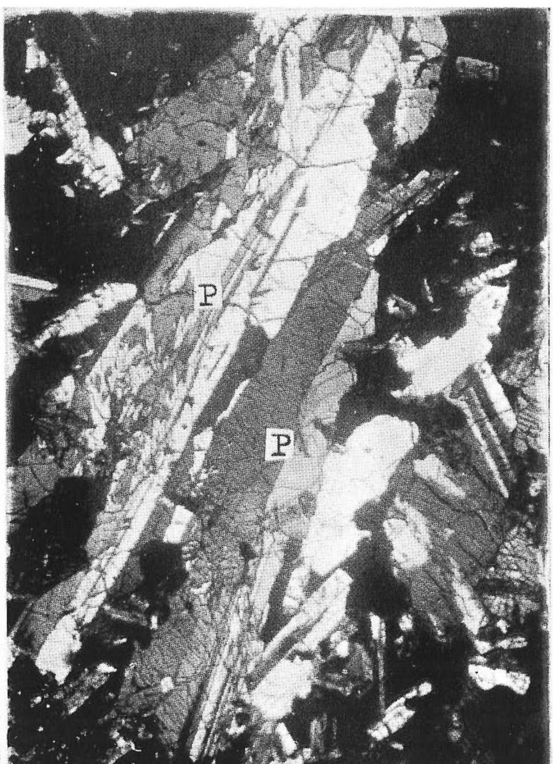

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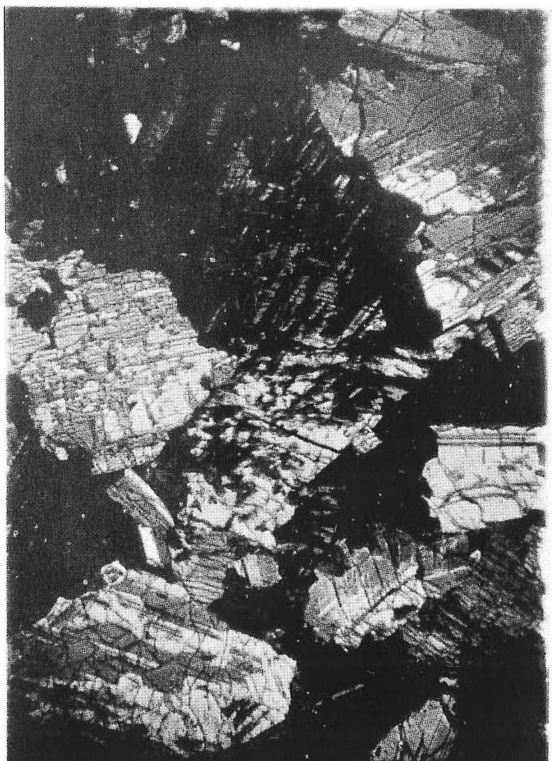

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Plate V.

1. Radial ring (R, the upper white part), outermost zone (O) characterised by turbid idiomorphic plagioclases and enclosing andesite (A, the lower dark part with porphyritic idiomorphic plagioclases). × 20. Open nicols.
2. Ditto. Note the wedge-formed crystals of plagioclases. Crossed nicols.
3. A part showing plutonic texture with tabular plagioclases in radial ring. Hypersthene and magnetite surround plagioclases. × 20. Open nicols.
4. Ditto. Note the twinning of plagioclases. Crossed nicols.

Plate VI.

1. Outermost zone of orbicular rock and the enclosing andesite (lower dark part of line AA). Note the plagioclase having regular inclusions. The spaces enclosed with black lines (G) are consisted of glass, in which a good many of stout prisms and needles of hypersthene are seen crystallized out. × 60. Open nicols.
2. Ditto. Crossed nicols.
3. Enclosing andesite. Note the phenocrysts of plagioclase characterised by the regular arrangement of inclusions. Several crystals of such plagioclase make a gathering (g). × 20. Open nicols.
4. Ditto. Crossed niclols.

1

2

3

4

The Geological Survey of Japan has published in the past several kinds of reports such as the Memoirs, the Bulletin, and the Reports of the Geological Survey.

Hereafter all reports will be published exclusively in the Reports of the Geological Survey of Japan. The currently published Report will be consecutive with the numbers of the Report of the Imperial Geological Survey of Japan hitherto published. As a general rule each issue of the Report will have one number, and for convenience's sake, the following classification according to the field of interest will be indicated on each Report.

A. Geology & allied sciences
- a. Geology.
- b. Petrotology and Mineralogy.
- c. Palaeontology.
- d. Volcanology and Hotspring.
- e. Geophysics.
- f. Geochemistry.

B. Applied geology
- a. Ore deposits.
- b. Coal.
- c. Petroleum and Natural Gas.
- d. Underground water.
- e. Agricultural geology.
  Engineering geology.
- f. Physical prospecting.
  Chemical prospecting & Boring.

C. Miscellaneous

D. Annual Report of Progress

Note: Besides the regularly printed Reports, the Geological Survey is newly going to circulate "Bulletin of the Geological Survey of Japan," which will be published monthly commencing in July 1950.

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A　地質及びその基礎科學に關するもの
- a. 地　質
- b. 岩石，鑛物
- c. 古生物
- d. 火山，溫泉
- e. 地球物理
- f. 地球化學

B　應用地質に關するもの
- a. 鑛　床
- b. 石　炭
- c. 石油，天然瓦斯
- d. 地下水
- e. 農林地質，土木地質
- f. 物理探鑛，化學探鑛及び試錐

C　其　他

D　事業報告

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