Notes on brown hornblende and biotite from Shabō-zan, of the Daiton volcanoes, Taiwan, Japan.

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Introduction.

THE Daiton volcanoes include all the volcanic groups which rise up at the north-western end of Taiwan (Formosa). They are old extinct volcanoes underlain by highly disturbed Tertiary sediments. Among them Shichisei-zan is the highest and the most prominent, rising up to 1108·7 metres above sea-level. It is mostly made up of hornblende-andesite, hypersthene-hornblende-andesite, and agglomerates. On the western slope of this partly dissected volcano there is a very characteristic cone called Shabō-zan. Its elevation is 643 metres above sea-level, and it is mostly made up of hypersthene-hornblende-andesite poured out through the thick accumulation of agglomerates. The andesite here has usually a grey colour, but often passes into a light reddish-brown variety, being sometimes associated with a noritic segregation mass. It is noteworthy that some of the andesites abundantly contain brown hornblende. This mineral also frequently appears, together with brown biotite, in the segregation mass. The writer first collected these minerals from its northern slope in the summer of 1929, and his attention has been attracted to their very characteristic pleochroism. The subject has already briefly been dealt with in his recent paper.[1] The brown hornblende here is easily mistaken for barkevikite, while the brown biotite somewhat resembles that in alkali-rocks. The minerals are, however, the alteration products from original varieties, and many specimens collected from various places show the different stages of transition between them. Hence, it is very interesting to compare the mode of occur-

[1] T. Ichimura, On the segregation masses contained in the hypersthene-hornblende-andesite from Shabō-zan Taiwan. [Japanese.] Trans. Nat. Hist. Soc. Formosa, 1929, vol. 19, pp. 406–409.

rence with that of basaltic hornblende associated with anomitic biotite in the quartz-andesite of the volcano Sambé.

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Andesite and its noritic inclusions.

It is necessary to give here a short description of the andesite and its noritic inclusion from Shabō-zan before the writer goes on to discuss the brown hornblende and biotite. The andesite under consideration is composed of plagioclase, hornblende, hypersthene, augite, magnetite, and haematite. It is a rough and porphyritic rock with abundant phenocrysts of plagioclase, hornblende, and hypersthene. The plagioclase ranges from andesine to labradorite, both grading into each other toward the interior of the crystal. Although they are often alternately arranged, the outer portion of the crystal is usually more acidic than the interior. A general feature in this case is the presence of a turbid zone. Besides hornblende, the predominant ferromagnesian mineral is hypersthene, which is intimately associated with it, showing a stout or long prismatic habit. It is always characterized by straight extinction and the following pleochroic scheme: α and β light brown, γ light greenish-grey. Absorption is $\gamma < \beta = \alpha$. Optically it is negative. This mineral is also found as minute crystals in the groundmass. Augite is, on the other hand, a minute ingredient of the groundmass and takes a slender prismatic or granular form. Octahedral or granular magnetite is also a common constituent associated often with hornblende and hypersthene. The groundmass shows an orthophyric or pilotaxitic texture, consisting of the above-mentioned minerals. Plagioclase in the groundmass takes a rectangular habit in the orthophyric variety, whereas it is of slender lath form in the pilotaxitic one.

The noritic mass consists of granular aggregates of plagioclase, hornblende, hypersthene, augite, apatite, magnetite, biotite, and haematite. The plagioclase is of a more basic variety than that of the hypersthene-hornblende-andesite. The index of refraction is as follows: $n_1 = 1{\cdot}5745$–$1{\cdot}5755$, $n_2 = 1{\cdot}5790$–$1{\cdot}5812$ on (010). Hence the mineral belongs to the variety ranging from bytownite to anorthite. It is also remarkable that such plagioclases are not so distinctly zoned as usually shown in the andesite. Other points of difference are the occurrence of apatite and biotite in this rock and the weak resistance to weathering. Both rocks occasionally show a gradual transition into one another, but commonly a well-bordered outline is seen between them.

The brown hornblende.

Crystal form and optical properties.—The brown hornblende usually takes a prismatic habit. It often shows very good crystal form in the andesite. When it is euhedral, the following faces are observed: $a(100)$, $b(010)$, $m(110)$, $p(\bar{1}01)$, and $r(011)$. In the andesite it occurs as phenocrysts and also as minute ingredients of the groundmass. The largest crystal is 2 cm. in length. In thin section it has a characteristic pleochroism : viz., α amber-yellow, β yellowish-brown, γ reddish-brown. The absorption is $\gamma > \beta > \alpha$. It is quite different from common basaltic hornblende, in which the pleochroism is α light yellow, β brownish-yellow, γ dark yellowish-brown; absorption is $\gamma > \beta > \alpha$. The extinction-angle of the brown hornblende is very small, viz., $\gamma : c = 0°–2°$; while in the basaltic hornblende $\gamma : c = 2°–10°$. It is optically negative. Indices of refraction in the type specimen are α 1·685, β 1·711, γ 1·731. Birefringence, $\gamma - \alpha$ 0·046, 2V 82° 20′. The plane of the optic axis is parallel to (010) and the acute bisectrix coincides with α. Some of the crystals show a twinning on (100). Most of them contain such inclusions as plagioclase, hypersthene, and magnetite. In the noritic mass the hornblende includes minute crystals of apatite and biotite together with the above-mentioned minerals. Plagioclase here is mostly found as patches and is the most prominent inclusion in hornblende. Moreover, the hornblende is generally subjected to magmatic resorption, and the crystals are partly or wholly changed into the minute aggregates of augite, magnetite, and haematite. Besides the characteristic pleochroic scheme, the brown hornblende is optically different from basaltic hornblende in its higher index of refraction and birefringence. However, various intermediate stages between brown hornblende and basaltic hornblende may be noted, and these gradually change in their optical properties in the same specimens.

Chemical composition.—A chemical investigation of the brown hornblende has recently been carried out by T. Kōno on the type specimen from the southern slope of Shabō-zan. According to his study the mineral is characterized by an exceedingly small percentage of ferrous oxide. The percentage of FeO reaches 8·21 in the basaltic hornblende from the same locality which was also chemically analysed by T. Kōno. The colour of this mineral seems to be partly due to the lack of ferrous oxide. The percentage of Na_2O is, of course, much lower than that of barkevikite. It is also interesting to compare them with the chemical composition of the basaltic hornblende from Germany as shown in (3), (4), and (5).

The results of chemical analyses of brown hornblende and basaltic hornblende are as follows:

	(1).	(2).	(3).	(4).	(5).
SiO_2	40·69	39·48	40·82	40·62	41·38
TiO_2	2·98	3·10	4·06	4·07	2·93
Al_2O_3	12·09	10·97	14·21	14·74	13·44
Fe_2O_3	11·83	11·23	7·36	8·29	8·97
FeO	0·21	8·21	4·97	5·21	5·06
MnO	0·70	0·53	—	—	—
MgO	14·34	10·30	11·99	12·41	12·36
CaO	11·85	13·65	12·27	11·37	11·70
Na_2O	2·45	0·99	2·13	2·20	2·48
K_2O	1·56	0·67	1·15	1·06	1·23
P_2O_5	0·10	0·24	0·83	0·67	0·87
H_2O	—	—	0·49	0·43	0·39
Ign. loss ...	1·24	1·49	—	—	—
Total ...	100·04	100·86	100·28	101·07	100·81
Sp. gr. ...	—	—	3·231	3·223	3·198

(1). Brown hornblende from the southern slope of Shabō-zan, Taiwan. Analysed by T. Kōno.
(2). Basaltic hornblende from the same locality. Analysed by T. Kōno.
(3). ,, ,, Todtenköpfchen, Gersfeld, } Rhön Mts., Germany.[1]
(4). ,, ,, Sparbrod,
(5). ,, ,, Kleiner Suchenberg,

Y. Deguchi[2] formerly reported the occurrence of barkevikite in the lavas of Shichisei-zan, but he did not say anything about its optical properties and chemical composition. It seems not to be different from the brown hornblende now under investigation by the writer. The hornblende here is also distinguishable from barkevikite in its optical properties.

The brown biotite.

The occurrence of biotite is restricted to the noritic inclusions in the andesite. It is found in minor quantity, and has a tabular

[1] X. Galkin, Chemische Untersuchung einiger Hornblenden und Augite aus Basalten der Rhön. Neues Jahrb. Min., 1910, Beil.-Bd. 29, pp. 689, 688, 694.

[2] Y. Deguchi, Geological report on the Daiton volcanoes. [Japanese.] P. 28.

habit which is characterized by the distinct cleavage parallel to the base. The mineral is usually associated with hornblende, and shows a remarkable pleochroism, α amber-yellow, β and γ bright reddish-brown with a yellowish shade. The absorption is $\beta = \gamma > \alpha$. The pleochroism of the brown biotite is thus quite different from the variety associated with basaltic hornblende. Absorption is sometimes variable along the basal cleavage. The birefringence is very high. Optically it is negative and 2V is very small. It often includes small patches of bytownite and anorthite together with magnetite. Sometimes it is included in hornblende and in this case there are frequently observed the minute aggregates of augite and magnetite along the contact. The index of refraction of the brown biotite has not yet been determined and the mineral has not yet been chemically investigated, for it is only accessory in the specimens collected by the writer.

Microscopical observations of various alteration stages in the andesite and its noritic inclusions.

The writer collected many specimens of andesite and its noritic inclusions from different parts of Shabō-zan to examine the alteration stages of the hornblende and biotite under the microscope. From those investigations it is evident that unaltered basaltic hornblende is almost restricted to the grey variety and its noritic inclusions. It is noteworthy that the hornblende here is mostly subjected to magmatic resorption and partly changes into minute aggregates of magnetite and augite. Such phenomena are more remarkable in the andesite than in its noritic inclusions. In a slightly altered specimen, the hornblende acquires a little different colour, a reddish-brown shade, showing more or less stronger pleochroism than before, viz., α light brownish-yellow, β dark yellowish-brown, γ dark brown with a reddish shade. Sometimes it exhibits different stages of alteration even in the same crystal : in this case a less-changed core of somewhat mottled colour is to be seen in thin section. The alteration usually begins from the outer side and gradually proceeds into the interior, until the mineral entirely attains such a typical pleochroic scheme as mentioned before : viz., α amber-yellow, β yellowish-brown, γ reddish-brown. In association with this alteration the opacitized margin of the crystal often passes into the dirty aggregates of haematite, and at the same time the crystal changes to haematite along its cracks or cleavages. Hypersthene and augite are more stable minerals than hornblende but they finally begin to segregate haematite along margins, cracks, and cleavages. Hypersthene under such conditions shows much stronger pleochroism. Some hypersthene and augite are entirely replaced by haematite, as can often be seen in the groundmass of specimens from the summit of the mountain. All the magnetite grains then similarly pass into haematite, giving a dusty appearance to the groundmass. This is also commonly the case with the hornblende in its final alteration stage. During alteration the index of refraction and birefringence gradually increase, but there is a decrease in the extinction-angle.

Origin of the brown hornblende and biotite.

So far as the investigation has gone at present the distribution of brown biotite seems to be restricted to a small area, whereas brown hornblende has been collected by the writer from various parts of Shabō-zan. The occurrence of this hornblende is particularly well shown along the road between Sōzan and Chōhokutō. It may also be expected in the same kind of lava poured out from Shichisei-zan and elsewhere. As will be understood from the gradual transition between the two kinds of andesite, such a brown hornblende-bearing variety is undoubtedly an alteration product from the grey one. It has, of course, not resulted from the alteration due to weathering, as there is no such evidence. It is more reasonable to attribute the reddish-brown colour of the andesite and the occurrence of brown hornblende to the predominance of ferric oxide.

S. Kōzu and his associates[1] have recently studied the relations between the grey andesite and the reddish variety from the volcano Sambé. According to them the volcano Sambé is composed of two similar types of rocks which differ in their hornblendes and biotites. In the first type the hornblende is the common brown variety and the biotite is meroxene; in the second type the hornblende is basaltic and the biotite is meroxene; and in the third type the hornblende is basaltic and the biotite is anomite. Kōzu[2] also concludes that the reddish andesite containing basaltic hornblende and anomitic mica may be produced by the reheating of the grey andesite containing common

[1] S. Kōzu, B. Yoshiki, and K. Kani, Sci. Rep. Tōhoku University, Ser. 3, 1927, vol. 3, p. 143 [Min. Abstr., vol. 3, p. 495].

[2] S. Kōzu, An interesting example of the mode of occurrence of basaltic hornblende associated with anomitic biotite in the quartz-andesite which forms the volcano Sambé, Japan. Proc. 4th Pan-Pacific Science Congress, Java, 1929, vol. 2, B, p. 721 [Min. Abstr., vol. 4, p. 287].

hornblende and meroxene mica at a temperature higher than 750° C. Howel Williams[1] carried out a similar experiment to convert the common hornblende to the brown variety under oxidizing or neutral conditions. He used specimens of the coarsely porphyritic, grey andesite from near the West Marysville Buttes in California and changed them into reddish varieties in which the common hornblende passed into the brown one with small extinction-angle, $\gamma : c = 2°$. He also tried to apply the results of these thermal experiments to the presence of the brown hornblende-bearing andesite from Shabō-zan. Further, many other experimental attempts to convert green hornblende to the brown variety or basaltic type have been made by Rosenbusch, Schneider, Belowsky, Graham, Kunitz, Barnes, and others.[2]

The brown hornblende from Shabō-zan is, however, found in a rather different condition. The writer has examined many specimens of the grey andesite and its noritic inclusions with a fresh appearance, but he has not yet found any trace of green hornblende from which the brown variety might be derived. The gradual transition is, on the other hand, always traceable between basaltic hornblende and the brown variety in slightly altered andesites. It is still more remarkable that the brown hornblende shows a high percentage of TiO_2, which cannot be expected in the green hornblende. Its chemical properties, thus, also seem to prove that it was altered from basaltic hornblende. Both microscopical and chemical evidence suggest that its formation may be the result of oxidation, probably due to reheating. The same explanation may be accepted for the formation of brown biotite.

Summary.

(1) So far as known at present the basaltic hornblende is mostly contained in the grey variety of andesite and its noritic inclusions.

(2) Brown hornblende, on the other hand, predominantly occurs in brown andesite.

(3) The occurrence of the brown biotite is not known in the andesite: it is restricted only to the noritic inclusions.

(4) There are various stages of alteration among these hornblendes, gradually changing the pleochroism.

[1] H. Williams, Geology of the Marysville Buttes, California. Univ. Calif. Publ. Bull. Dept. Geol. Sci., 1929, vol. 18, no. 5, p. 194.

[2] References given by V. E. Barnes, Changes in hornblende at about 800° C. Amer. Min., 1930, vol. 15, pp. 393–417 [Min. Abstr., vol. 4, p. 391].

(5) Both hornblende and biotite show a similar pleochroic scheme in their later stages: hypersthene, augite, and magnetite finally change into haematite during this process.

(6) The hornblende shows an increase in the index of refraction and birefringence, while the extinction-angle decreases gradually. Chemically, the brown hornblende shows a conspicuous decrease in FeO.

(7) Brown hornblende and biotite were derived from basaltic varieties, as shown by various transitions among them. It is evident that the brown hornblende here has not come from a green variety.

(8) The formation of brown hornblende and biotite may be due to the oxidation of basaltic varieties, probably under a certain condition of reheating where FeO passes into Fe_2O_3.