On Pyroxenic Components in certain Volcanic Rocks from Bonin Island

by

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With Plate XIV *bis.*

The following account of the Pyroxenic components in the rocks of Bonin Island is based upon the investigation of materials collected by myself, during a short visit to that island in November, 1887.

Ogasawarajima or Bonin Island is the name applied to an island-group of volcanic origin, apparently forming part of the chain of of volcanoes which extends from Central Japan through the *Shichitō Group* of the Prov. Izu. The most important of the Bonin Island-Group is that known as Chichijima (Peel Island, Lat. 27° 5′ N., Long. 142° 15′ E. Green.) It has a spacious harbour known as Futamikō (Port Lloyd) which without very good foundation has been regarded as the relic of a volcanic crater. The geological collections were principally made in this island, and also a few in Hahajima (Coffin Island) which is situated about 20 geogr. miles S.S.W. of Chichijima.

The volcanic activities seem to have subsided long since in these islands, and consequently their general features differ from those of such islands of the *Shichitō* or *Volcano Group* which have active volcanic cones. The interior is in some places covered with dense tropical forest, among which rise numerous pointed

pinnacles and ridges, due to the extrusion of the harder rock-masses by erosion. The most prominent of these ridges rises about 1100 ft. above sea-level.

The volcanic rocks are chiefly Andesite; sometimes in a massive state, occasionally showing prismatic joints; sometimes interstratified with tuffs. These tuffs usually contain fragments of volcanic rock, of various sizes, forming agglomerates. The volcanic rocks are generally much altered, and as the product of alteration, we find secretions of Chalcedony, Calcite, and Zeolite among the fissures. This is especially the case among the more basic glassy varieties, the characteristics of which will be given briefly in this place. They are also much decomposed at the surface into a peculiar reddish soil resembling Laterite.

In the first account relating to the geology of the island, found in the narrative of the famous American Expedition under Commodore Perry,* it is stated (Vol. I, p. 202) "The geological formation of the island is trappean, with its various configurations and mineralogical peculiarities; columnar basalt appears, and hornblende and chalcedony are found." The 'hornblende' mentioned in the above citation most probably refers to the crystallized *Rhombic Pyroxene* here to be described. This mineral therefore seems to have attracted the attention of early observers. Also in some Japanese book, treating of the products of the island, we find its crystal-form figured and mentioned as Olivine, and stated as also occurring in Kitajima, a small island to the north of Ototojima.

In the summer of 1884, Mr. T. Suzuki of the Geological Survey visited Chichijima, and made a collection of rocks, an account

* Narrative of the Expedition of an American Squadron to the China Seas and Japan performed in the years 1852, 1853, and 1854, under the command of Commodore Perry, compiled by F. L. Hawks. 3 vol. 1 Atlas. Washington 1856.

of which was given in the Bulletin* of the Geological Society of Japan. His collection besides contains specimens from the neighbouring island of Ototojima (Stapleton Island). A part of his collection he kindly placed at my disposal to supplement my own. The kinds of rocks from Chichijima and Ototojima, as enumerated by Mr. Suzuki are as follows :—1) Augite-andesite, 2) Augite-andesite glass, 3) Quartz Augite-andesite, and 4) Basalt. It may be noticed however, that the 'Augite-andesite glass' represents basic glasses, of the nature of Basalt-glass like Tachylyte. The absence of Olivine in these glasses is quite peculiar and noteworthy, its place being taken by the Rhombic Pyroxene and Augite.

In Chichijima, where I had the best opportunity for observing general geological features, volcanic rocks occur either in a massive state probably consolidated from lava-flows, or as agglomerates of volcanic pebbles, associated or almost cemented with tuffs. It is usual to find among the former class, a lighter coloured, porphyritic rock, the ground-mass of which is microcrystalline, usually with small quantities of glass ; the essential mineral constituents being Plagioclase, Augite, Rhombic Pyroxene and Magnetite. In fact, it resembles the Augite-andesite which is found in Honshiu. It seems to be especially well developed at Hahajima. Among the pebbles that compose the agglomerates however, we find various remarkable modifications. The peculiarity of these rocks is their basic character, with a dark coloured glass basis, in which the Pyroxenes are usually developed as Rhombic and Monoclinic forms. Their mode of occurrence suggests that they were formed as the accumulations of volcanic ejections, which were hurled away from a fluid lava, rapidly cooling on its way, and thus inducing an incipient state of crystallization. In some varieties however, the structure becomes porphyritic ; the crystals of Pyroxenes,

* Part. B. vol. I (Japanese).

and a comparatively few crystals of Plagioclase, being developed within a partly microcrystalline groundmass. The latter consists of a brown coloured basis, containing microcrystals of Plagioclase, filiform Augite, and Magnetite. These darker rocks are probably the rocks described above as Basalt. But they differ from the usual type of Basalt in the absence of Olivine. In the more glassy varieties, Plagioclase is absent except as 'Rhombic lamellæ.' These rocks are often dark pitch-coloured glass, with numerous round vesicular cavities filled with Zeolites. Under the microscope, they are always found to be of light greyish or brownish coloured glass, in which a light green coloured Augite is developed in slender filiform crystals in innumerable thick clusters. They are often found alternating with sheets of a peculiar greenish rock, resulting from the infiltration of Chalcedony and a green fibrous chloritic mineral through its mass, which thus has the appearance of a Jasper, and exhibiting microscopically a diabasic structure. This was especially well observed near Ōmura in Chichijima.

The glassy rock mentioned above often shows a most interesting modification, in which the basis becomes more glassy and contains very sharply defined crystals of Rhombic Pyroxene. In these varieties, the glass often exhibits pearlitic structure under the microscope, while the specimens from Ototojima are in spheroidal masses which have the tendency to separate in concentric layers like an onion. The microscopic porphyritic components are Rhombic Pyroxene, and sometimes monoclinic Augite of a light green colour, together with a microlithic form of the same mineral, Plagioclase and some Picotite. Olivine has not been hitherto recognised. Very characteristic microscopic objects in these glasses are the 'Rhombic lamellæ' already referred to. They have been found in basic glasses of other localities. A short account of these lamellæ may be given here. They are found making gradual transition to the porphyritic crystals

of Plagioclase. Thus there seems to be much probability that they are Plagioclase, as first suggested by Penck.* Kreutz † considers them as Anorthite. Doss ‡ also observed the gradual transition to typical Plagioclase in the Palagonitic tuffs of Haurân.

The 'Rhombic lamellæ' are especially well developed in the pearlitic glass of Susaki in Chichijima, and in the spheroidal glass of Ototojima. In the latter, the edges of these plates are sometimes so thickly covered with very delicate dark filaments of Augite, as to conceal the crystal almost entirely. They are extremely thin, and there is usually no action upon polarised light. Very sharply defined faces may often be recognised on the sides of the rhomb. The angles of the rhomb measures 52° and 128°, and may be considered to be formed of the faces P (001) and x ($10\bar{1}$), to which the face y ($20\bar{1}$) is sometimes added (fig. 22). In more perfect crystals, it has been observed that the one side of the rhomb is formed of two faces in place of the face x ($10\bar{1}$); in such cases the crystal would probably consist of faces P (001), M (010), y ($20\bar{1}$), o ($11\bar{1}$), p ($1\bar{1}\bar{1}$); the last two faces being in the same zone with x. Fine fissures parallel to P, probably the cleavage-fissures, are especially well developed in the specimen from Susaki. The lamellæ become broader in some cases, and the cross section exhibits twin-lamellæ of the Albite-type. The twin of the Carlsbad-type has also been observed, the most typical of which is copied in fig. 21.; the zone [P : M] running practically parallel to the zone [M : x], so that a rhombic modification sometimes results. This characteristic is peculiarly analogous to the rhombic modification of Anorthite-twin, e. g. that of Miyakejima described by the author.§

* Studien über lockere vulkanische Auswürflinge.—Zeitschft. d. d. geol. Gesellft. 1878 p. 99.

† Ueber Vesuvlaven von 1881 und 1883.—Tschermak's Min. u. Petro. Mitth. 1884. p. 139.

‡ Die basaltischen Laven und Tuffen der Provinz Haurân und vom Dîret et-Tulûl in Sirien—Tschermak's Min. u. Petro. Mitth. Bd. 7. 1886 p. 527.

§ On Anorthite from Miyakejima. This Journal, vol. II, p. 31.

The direction of extinction can be measured in thicker plates, in which there is a distinct effect upon the polarised ray. On the face *M*, the direction of extinction makes $-40°$ with the edge *P* : *M*. Thus there seems to be much probability that the 'Rhombic lamellæ' are Anorthite.

All of these glassy rocks contain more or less well-defined crystals of Rhombic Pyroxene, but it is in the more glassy modifications found in patches among these rocks that the well-defined crystals of this mineral are developed at the expense of the light-green coloured filiform Augite. Such modifications have been found so far on the coasts of Tatsumiura and Miyanoura in Chichijima. The specimen obtained from Tatsumiura presents a dirty brownish green colour, resulting from the alteration of the dark glass into a product resembling 'Palagonite,' in which green translucent crystals of Rhombic Pyroxene may be picked out. The specimen from Miyanoura also presents a similar character, but the degree of alteration is much less, the vesicular cavities being chiefly lined with Zeolites.* Microscopically examined, the glass transmits a faint greyish green colour. The glass would correspond to the 'Sideromelane' in Tachylyte. The fissures and cavities are filled up with a palagonitic matter, which transmit a sulphur-yellow colour in thin sections.

The palagonitic alteration-product above mentioned is of a dirty green colour, and is made up of fibrous microcrystalline aggregates, showing a weak double refraction. When it is found filling up round pores, the periphery is often radially fibrous, so that an aggregate polarization exhibiting a dark cross is observed between crossed Nicols. Before the blowpipe, the glassy portion swells up to a great bulk and easily fuses, due to the large amount of water it

* One of these Zeolites is *Stilbite*, in combination of the faces, o P (001), $\infty P\bar{\infty}$ (010), $\infty P\bar{\infty}$ (100), $P\bar{\infty}$ ($\bar{1}01$), 2 P ($\bar{2}21$) ; another is *Chabasite*, with characteristic striations on the rhombohedral face. There are also some fibrous crystals of an uncertain Zeolite.

contains ; but the altered portion almost resists fusion. It is found also that the latter is softer, and the specific gravity is less, than the glass. The glass and the alteration-product are scarcely attacked by hydrochloric acid.

The mineralogical composition of the rocks of Tatsumiura and of Miyanoura thus far indicated, would seem to be quite singular. It is probably to be classed as special rank among the glassy form of basaltic rocks. I am indebted to Mr. T. Suzuki, for the chemical analyses given below, of the glassy rocks of Ototojima and Miyanoura. The analyses were undertaken by Mr. R. Fukuda of the Geological Survey.

	I	II
$Si\,O_2$	53·18 %	54·44 %
$Al_2\,O_3$	16·18	12·90
$Fe_2\,O_3$	10·30	7·08
$Ca\,O$	10·12	5·12
$Mg\,O$	6·72	12·75
$K_2\,O$	·35	·35
$Na_2\,O$	1·85	2·06
loss by ignition	1·65	5·54
	100·35	100·24

I. is the dark spheroidal glass of Sp. G. 2·725, already mentioned, found at Kurose in Ototojima.

II. is the glassy portion of the rock from Miyanoura, comparatively free from the alteration-product. Sp. G. = 2·75.

The higher amount of lime in analysis I. probably points to the existence of basic Plagioclase, viz. in the form of the 'Rhombic lamellæ.' The high percentage of magnesia in II. is accounted for by the rich development of the Rhombic Pyroxene, the analysis of which is given in the sequel, while Augite is very scarce. The existence of a large quantity of water is also indicated by the large quantity of loss by ignition.

It has been pointed out by Judd and Cole * that the Basalt-glasses are of rather rare occurrence in Europe, and that when they occur, they are always found as selvage (Saalband) of dykes, or as small fragments thrown out of volcanic vents and cooled rapidly while passing through the air, whilst in some Pacific Islands (notably in the Sandwich Islands) Basalt-glasses are found as lava-streams. It has also been observed that the glasses from these islands are more transparent in thin sections than those found in Europe. Although it is not likely that the Basalt-glasses in the Bonin Islands have flowed as lava-streams, yet they seem to be nearer to those of the Sandwich Islands, &c., since they are always lightly coloured, transmitting a greenish grey or light brownish colour. Fragments of similar rocks probably derived from lapilli, have also been dreged from the bottom of the Pacific by the *Challenger*.†

Another peculiarity of the glasses of Miyanoura and Tatsumiura, is the almost total absence of Magnetite, which seems not to have separated from the magma. Olivine is also entirely wanting ; the recognisable mineral constituents being Rhombic Pyroxene and Augite, with some Picotite, which is however more generally found as enclosures within the Rhombic Pyroxene.

We shall now proceed to give the characteristics and the relation of the two Pyroxenes which are developed in these glassy rocks.

Rhombic Pyroxene.

Owing to the incoherent character of the glassy rocks, in consequence of alteration into a palagonitic substance, the crystals of the Rhombic Pyroxene which are unaffected by alteration, can be rather

* On the Basalt-glass (Tachylyte) of the Western Isles of Scotland—Quart. Jour. Geol. Soc. vol. XXXIX, 1883. p. 457.

† Report on the Scientific results of the Exploring Voyage of H. M. S. Challenger—Narrative of the Cruise—Vol. I, pt 2., 1885—p. 813. This occurrence is the more interesting as it seems to contain Rhombic Pyroxene.

easily obtained in a fresh state from the matrix. These crystals have a stout prismatic habitus, ·5—1 cm. in the direction of the vertical axis, usually flattened along the macropinacoidal face. They are somewhat brittle. The larger crystals are dark green in colour, the smaller ones transmitting a pistachio-green colour and in still smaller crystals a light olive-green colour. The observed faces,* when referred to the axial system of vom Rath† are as follows:

$$a = \infty P\bar{\infty} \quad (100)$$
$$b = \infty P\breve{\infty} \quad (010)$$
$$m = \infty P \quad (110)$$
$$e = P_{\bar{2}} \quad (212)$$
$$i = {}_2P_{\bar{2}} \quad (211)$$

The predominating faces are a, b, and e; the prism m truncating the edge of a : b as narrow bands. The face i is usually small (fig. 1), Thus the crystal is rather simple, being a stout prism with a very flat Pyramid e, and tabular along the Macropinacoid a. In this respect it resembles the crystal of Hypersthene (Amblystegite) from Laach volcanic bombs, described by v. Rath. (l. c.). The faces of the Pyramids e, i, are very dull and sometimes depressed a little, while the pinacoids and the prism-faces are brighter, but usually owing to surface irregularities, they do not give a very satisfactory reflection. The following goniometric measurements were performed with a small reflecting goniometer (Füss' Wollaston model). It may here suffice to show an agreement with the corresponding angles of Hypersthene given by v. Rath (l. c. p. 530):—

* In the position adopted by Tschermak (e. g. Lehrbuch der Mineralogie, 2te. Aufl. p. 436) the crystal is so placed that the *acute* prism-angle is turned forward, in order to bring it into analogy with monoclinic Pyroxene. In this position, the signatures and the symbols of the faces here mentioned are respectively, b (010), a (100), m (100), e (122), i (121). Fig. 9, represents a crystal formed of the faces a, b, m, and i figured in this position.

† Mineralogische Mittheilungen—Ueber ein neues Mineral aus Laach.—Poggendorf. Ann. d. Physk. u. Chem. Bd. CXXXVIII, 1869, p. 529.

		v. Rath (Amblystegite)
e : e (212 : $2\bar{1}2$)	= 153° 11′	152° 22 ½′
e : e (212 : $\bar{2}12$)	= 121° 12′	121° 8 ½′
i : m (211 : 110)	= 138° 35′	138° 55′
a : m (100 : 110)	= 136° 5′	135° 50′

From the last value the prism-angle of the Pyroxene would become 92° 10′.

The characteristic cleavage of the prism is distinctly developed, the cleaved face exhibiting a pearly lustre. Cleavage parallel to Brachypinacoid is scarcely observable, but it can sometimes be recognised as distinct fissures in microscopic slides cut at right angles to the Vertical axis. The crystal has the tendency to separate along the Macropinacoid a, the plane of separation presenting an uneven surface. This is however not due to any interposition, as is usual in the massive variety of this mineral.

The phenomenon of pleochroism is very marked. The axial colours examined along the three pinacoidal faces gave with a section of nearly ·5 mm. ; α = reddish-brown, β = greenish-yellow, γ = yellowish-green, with a weak absorption $\alpha > \beta > \gamma$. These characters agree with the observations of Hatch* on the Rhombic Pyroxene of Charchani. In still thinner sections the pleochroism becomes very faint.

The section parallel to the Base, when examined under a convergent polarised ray, shows the emergence of the positive bisectrix γ the plane of the optic axes lying parallel to Brachypinacoid b, while in the section parallel to the Macropinacoid a, the negative bisectrix α emerges perpendicularly.

The characteristics given above chiefly refer to the larger crystals which are found scattered within the glassy rocks, but the microscopic

* Vulkangruppe von Arequipa—Tschermak's Min. u. Petro. Mitth. Bd. 7. 1887. p. 339.

examination has revealed the fact that innumerable crystals of the Rhombic Pyroxene are also developed in the glass in smaller but sharply defined forms which, though on the whole closely allied to those already described, exhibit certain differences in habitus. They are more slender in form, being elongated along the vertical axis. The pleochroism is very feeble; in still smaller crystals being hardly noticeable, transmitting only a very faint greenish colour.

Most of the crystals are formed of the faces a = $\infty P\bar{\infty}$ (100), b = $\infty P\breve{\infty}$ (010), m = ∞P (110), and i = $_2P\bar{2}$ (211) as represented in fig, 2. The flatter pyramid e = $P\bar{2}$ (212) appears rather seldom so that the crystal appears sharper at the terminations. Sometimes a pseudo-monoclinic form results by the shifting of the pyramidal faces i as in fig. 7. The plane-angle formed by the edges of the pyramid i over the vertical axis, when measured along the brachypinacoidal face b, is 80 $^1/_2$°, while the corresponding angle when measured along the macropinacoidal face a, is always near 120 $^1/_2$° *

These crystals are found in all sizes usually ·05—1 mm. in length, gradually passing to the larger forms.

Twin.—Numerous stellate aggregates of crystals are often observed under the microscope. This is probably due to the union of the crystals according to several twin-laws. One of these is a cross-shaped penetration-twin (fig. 6), in which the two individuals have the faces of the Brachypinacoid parallel to or coinciding with each other, and the directions of the vertical axes make an angle of 60$^1/_2$°. This twin is therefore analogous to that described by F. Becke,† the twinning-plane being Macrodome P $\bar{\infty}$ (101).

* Rosenbusch gives the two values as 80° 52′, and 120° 38′ respectively—Mikroskop. Physiogr. 2te Aufl. Bd. I, p. 392.

† Ueber Zwillingsverwachsungen gesteinbildender Pyroxene u. Amphibole—Tschermak's Min. u. Petro. Mitth. Bd. 7. 1887. p. 95.

Parallel-intergrowth of the Rhombic Pyroxene with a green Augite.— On examining the microscopic crystals of the Rhombic Pyroxene under crossed Nicols, it is found, as might have been expected, that they extinguish the light parallel and at right angles to the direction of the vertical axis. But the crystal is sometimes bordered on both sides by very narrow bands, in which the direction of extinction is oblique. This phenomenon is observed only when the crystal is found lying horizontally upon the macropinacoidal face a. The narrow bands show a simultaneous extinction of 42°–45° with the prismatic direction as represented in fig. 3. It may be observed that in the crystal here figured, the terminal faces are formed by the flat Pyramid $e = P\bar{2}$, a case rarely seen in the smaller crystals. The breadths of these bands are not constant; sometimes they become so narrow as to be almost inappreciable except by a most careful scrutiny.

This is a phenomenon arising from the regular intergrowth of the Rhombic Pyroxene with a Monoclinic Pyroxene. We must consider that the Brachypinacoid $b = \infty P\breve{\infty}$ of the Rhombic Pyroxene is attached to the Orthopinacoid $a = \infty P\bar{\infty}$ of the monoclinic Augite, the vertical axes of both crystals being parallel. Thus the macropinacoidal face $a = \infty P\bar{\infty}$ of the former would become parallel to or coincide with the clinopinacoidal face $b = \infty P\grave{\infty}$ of the latter, which would extinguish the light obliquely. In this position, the characteristic prismatic angles of the two Pyroxenes would come to similar position. Such parallel-intergrowth of the Rhombic and Monoclinic Pyroxenes was first observed by Trippke* in a variety of Enstatite. It has also been recently observed in the Pyroxenes in some younger effusive rocks. Frederick H. Hatch† describes it as occurring in

* Ueber den Enstatit aus den Olivenknollen des Gröditzberges—Neues Jahrb. f. Min. Geol. u. Pal. 1878. p. 673.

† l. c. p. 327.

Andesite from Arequipa in Peru; and Judd,* as occurring in the lavas of Krakatoa.

The narrow band of Augite just described may be also recognised by the fact that it is traversed by fine fissures running parallel to the direction of the vertical axis, and at right angles to it. Under polarised light Augite shows a decidedly stronger interference-colour than the Rhombic Pyroxene, so that the marginal bands are in vivid contrast with the median portion.

With regard to the microscopic characters of these crystals, the longitudinal section shows traces of prismatic cleavage-fissures running parallel to the longer sides. The basal section is quadrate, formed by the traces of the faces, $\infty P\bar{\infty}$, $\infty P\breve{\infty}$, and ∞P at the corners, the cleavage-traces parallel to the last face being very distinct. The cleavage parallel to $\infty P\breve{\infty}$ is also occasionally observed as fine fissures. The basal section sometimes shows a peculiar zonal structure resulting from isomorphous layers. The central portion has, as shown in figure 12, a nucleus in its centre and is divided into two parts. It is distinctly pleochroic, being brownish $\|^{l}$ α axis, and greenish-brown $\|^{l}$ β axis. The outer zone is of a faint brownish colour, and pleochroism is almost inappreciable. The central portion, which is evidently more ferriferous than the outer, must have crystallized before the less ferriferous portion. The crystals in general do not show any sign of alteration whatever.

Enclosures.—The most frequent enclosures are gas-pores, and glass-enclosures with fixed bubbles. The symmetrical arrangement of these enclosures is very characteristic. Figures 4, 5, 7, 9 illustrate the typical forms of this arrangement. The most frequent form is that shown in fig. 7, 9, the enclosures being arranged at both ends of the crystal conforming to the faces of the pyramid $i = {}_2P\bar{2}$, i. e.,

* The lavas of Krakatoa,—Geol. Mag., Dec. III, vol. V, 1888. p. 1.

four at each end. Sometimes they are more numerous at one end, being arranged one upon the other (fig. 5) or, rarely, in rows diverging from the centre (fig. 4). These phenomena indicate the inclusion of extraneous matter during the successive growths of crystals. A similar kind of symmetrical arrangement of enclosures has been described by E. Cohen* in the Olivine entering into the composition of the lavas of Sandwich Island.

Sometimes we find very numerous glass enclosures of an elongated form running parallel to the direction of the vertical axis, such crystals presenting a hazy appearance in microscopic sections. They are shown magnified on the left hand side of fig. 4.

Very frequent mineral enclosures are certain small octahedra which are scattered within the crystal with no definite arrangement. They are often in very sharply defined forms, sometimes with their faces depressed in steps, and sometimes in twins, the twinning-plane being an octahedral face. The smaller crystals transmit a dark brownish colour, and are not affected by acids. They are most probably Picotite, an inference also supported by the presence of chromic oxide in the analysis given below.

The sample for the chemical analysis was obtained from specimens from Tatsumiura by separating with Thoulet's solution. The microscopic examination of the separated powder showed that there was much glass attached to the crystals. To remove this glass, the sample was lightly treated with hydrofluoric acid. A light green coloured residue was obtained, and the microscope showed that the glass was completely removed, and the smaller crystals came out in a very sharply defined form. The crystals were by this treatment scarcely attacked, but when the experiment was tried for a longer time, some of the crystals showed

* Ueber Laven von Hawaii und einigen andern Inseln des Grossen Oceans, nebst einigen Bemerkungen über glasige Gesteine im Allgemeinen.—Neues Jahrb. f. Min. Geol. u. Pal. 1880 II. p. 32

signs that they were beginning to be attacked. Peculiar transversal canal-like fissures were seen to traverse the crystal from both sides, on the pinacoidal faces, at right angles to the prismatic direction, as shown on the lower half of the crystal in fig. 5, probably corresponding to the line of chemical activity. The minute enclosures of Picotite could not be, in any way, removed. The sample thus obtained, was analyzed by Mr. T. Shimizu, to whom I here express my sincere thanks. The result of the analysis is as follows :—

SiO_2	55·04 %
Al_2O_3	·88
Cr_2O_3	·49
FeO	9·40
MnO	·18
CaO	1·55
MgO	32·65
H_2O	·45
	100·64

Rejecting the small quantities of alumina, lime &c. in the above result, and calculating the rest up to 100, we have :—

			Ox. ratio.
SiO_2	56·69 %	30·234	14·05
FeO	9·68	2·151	1
MgO	33·63	13·452	6·25
	100·00		

From this we see that the composition may be represented by $FeO.\ 6\ MgO.\ 7\ SiO_2$, which is equivalent to $FeSiO_3 + 6\ MgSiO_3$. This when calculated in percentage gives as follows :—

SiO_2	57·38 %
FeO	9·83
MgO	32·79
	100·00

Thus the Rhombic Pyroxene under consideration may be called *Bronzite*. The Rhombic Pyroxenes which have been recognised in Andesite and other effusive rocks, are so far usually of the more ferriferous kind known as Hypersthene. A well crystallized variety corresponding to the composition of Bronzite has hitherto been unknown to the writer. It ought to be remarked however, that the the ratio of the two silicates $Fe\,Si\,O_3$ and $Mg\,Si\,O_3$ seems to vary to a certain extent in the different varieties of rocks in which they occur. Thus it is found that the specimens found in the dark porphyritic rocks are probably more ferriferous, as shown by their stronger pleochroism. It has also been indicated on page 79 that in the rock of Miyanoura, the crystal sometimes occurs built up of isomorphous layers, (fig. 12) also indicating this variation in chemical composition.

The mean specific gravity was found to be 3·305

With regard to hardness, it was found that the sharp edge of the Pyroxene can scratch the Adularia Felspar with ease ; thus we may consider $H = 6$. The pyramidal face e, which is across the direc tions of the well-defined cleavage, is decidedly harder than faces lying in the prismatic zone ; the latter can be scratched with difficulty with a sharp edge of the Felspar, but we have never succeeded in scratching the former. Thus on this face $H = 6{\cdot}5$.

Thin pieces subjected to the tip of blow-pipe flame fuse at the edge, into a dark globule.

A Green Augite.

The occurrence of a light greyish green coloured Augite in parallel-intergrowth with the Rhombic Pyroxene has already been considered. In some specimens of the glassy rock, we find the former more abundantly than the latter. At first sight, these two minerals when found together seem to be almost indistinguishable from each

other. On closer examination however, it is found that the Augite shows a stronger interference-colour. Also a certain section shows an oblique angle of extinction making 40° with the direction of the vertical axis, such being a clinopinacoidal section generally formed of the traces of the faces $\infty P\bar{\infty}$, -P, o P.

The section at right angles to the vertical axis shows a trace of cleavage parallel to ∞P. Sometimes it is found that this section formed of $\infty P\bar{\infty}$, $\infty P\grave{\infty}$, and ∞P, is separated into two halves by a trace of a twin-boundary parallel to $\infty P\bar{\infty}$. As we cannot in general have the section falling exactly at right angles to the vertical axis, such a section generally shows a difference in the angular values of extinction, with respect to the line of boundary. This is in fact a common form of the Augite-twin, with $\infty P\bar{\infty}$ as a twinning face, which cannot of course be expected in the Rhombic system. In the ball-like masses of the glassy rock obtained from Ototojima this kind of Augite is specially well observed in association with the Rhombic Pyroxene, with Plagioclase both as well-defined crystals and as 'Rhombic lamellæ,' and with some Picotite.

More usually, however, the Augite is developed in the glassy rocks of Chichijima as very slender crystals, sometimes almost filling up the entire glass-mass in confused aggregates so as to make the glass resinous in lustre. The development of these crystals, as indicated on pag. 70, is always rudimentary, having the tendency to assume fern-like shapes somewhat simulating the Pitchstone of Arran in Scotland. The crystal always appears in elongated form along the vertical axis, the angle of extinction in clinopinacoidal section measuring nearly 40°. The cross section is always six sided formed by the prism-faces, and a pinacoid; the former presenting a peculiarly concave outline* (fig. 13c). The

* On account of the small size, and the curved character of the faces, the exact orientation of this section cannot be determined.

terminations of the crystal frequently end in fine filaments, which are often curved and branching into filiform threads (fig. 13a) shown magnified in fig. 14. Numerous longitudinal fissures as well as transversal clefts are also characteristically developed. The crystals are often found in irregular stellate aggregates, which are probably twin-groups. In some cases, the directions of the vertical axes differ by 60°. Sometimes a narrow median band is inserted, in which the extinction is straight (fig. 13b), showing that the Rhombic Pyroxene is in parallel-intergrowth with the Augite in the manner already described.

These rudimentary forms of the Augite-crystals are very characteristic in the glassy rocks of Bonin Island, especially of the rocks found near Ōmura and Kiyose in Chichijima. In the glasses of Miyanoura, and of Tatsumiura already mentioned as containing the crystals of the Rhombic Pyroxene, the monoclinic Pyroxene appears also in skeleton-forms, which, as may be seen from the accounts given below, must have had a close relation to the crystals of the Rhombic Pyroxene during their growth from the magma. A series of these micro-crystals are illustrated in fig. 15—20.* The most simple form is a rod-like body bifurcated at both ends, or sometimes X shaped with numerous delicate spiny processes proceeding from the branches (fig. 20). These are very delicate bodies measuring nearly ·025 mm. in length. The fine processes usually become more elongated in larger forms, which measure ·07—·09 mm. in length, and are so arranged that one set attached to one branch is always parallel to the other branches (fig. 15—18), these two sets being disposed nearly at right angle to

* These skeleton-crystals are strikingly analogous to those described by H. Vogelsang from a certain slag. (Die Krystalliten. p. 40. Taf. VI). The form assumed by these microlites also suggests an analogy with the so called "hour-glass shaped" structure found in some crystals of Augite. This structure is probably due to the unequal accretion of crystal-molecules in different directions as indicated by these rudimentary or so to say retarded crystals, combined with a certain chemical change during the growth of the crystal.

each other. These processes are not only peculiarly curved but somewhat rolled up along a certain axis, so that the entire shape often does not come out at once at one focal distance. However these bodies normally have their branches and processes extended along one plane. Their form usually assumes a rhomboidal outline as represented in fig. 15, I7, 18, or rarely disymmetric as in fig. 16. The form represented in fig. 18 reminds us of the clinopinacoidal section of Augite. Indeed it has been found that some of these well formed microlites extinguishes the light obliquely, the direction of extinction making 40° with the longer sides of the rhomboidal figure. It is to be noted that the smaller forms hardly exhibits an interference-colour.

A very interesting phenomenon which has been observed with regard to these skeleton-crystals is, that they are very frequently attached to the crystals of the Rhombic Pyroxene in a very regular manner. It is found that the crystals of the Rhombic Pyroxene, when looked at upon the macropinacoidal face $a = \infty P \bar{\infty}$, have the angles and edges of the terminal pyramidal faces (i or e) set with several curved spines arranged in a very symmetrical manner. Fig. 3, 7—9, show such crystals. It will be found that at the solid angles of the pyramidal faces these spines are much larger than elsewhere and sometimes branching. They are always disposed in such a way that they all lie parallel to the macropinacoidal face a. Thus when these crystals are looked at upon the brachypinacoidal face $b = \infty P \breve{\infty}$, these spiny processes appear all running in one direction as in fig. 6, 9. 11, i. e., parallel to the face a. There is no doubt as to the identity of these spines with skeleton-crystals of Augite already described, so that the regular attachment of the spines to the crystals of the Rhombic Pyroxene can be explained by the tendency which the Augite has to form parallel-intergrowth with the latter. The narrow bands of Augite attached to the crystale of the

Rhombic Pyroxene (described on pag. 78) sometimes run out into spiny processes at their terminations, and at the breaks formed by the transversal clefts (fig. 3). These Augite-bands however become very often exceedingly narrow, and then the spines appear as if they proceeded directly from the Rhombic Pyroxene crystals. From the appearances presented by the spines when looked at from the two pinacoidal faces, it is evident that they all run along a common plane, which would be parallel to the Macropinacoid a of the Rhombic Pyroxene. This fact shows that the micro-crystals of Augite are, as already indicated, flattened out along the clinopinacoid face, which, when they make parallel-intergrowth with the Rhombic Pyroxene, becomes parallel to or coincides with the Macropinacoid of the latter. Thus we see that this phenomenon represents a phase in the development of the two Pyroxenes, the molecules of which seem to have a marked tendency to unite themselves so as to come into similar positions. From their mode of growth it will be seen that the microlithic Augite has been attached to the Rhombic Pyroxene, after the latter has attained a perfect idiomorphic form, and hence the former must be in general younger than the latter. Various stages may, however, be observed under the microscope. Smaller crystals of the Rhombic Pyroxene have sometimes, on both ends, symmetrical pairs of simple processes as shown in fig. 19. Occasionally the rudimentary Augite-crystal is found having in its centre a band of the Rhombic Pyroxene as in fig. 15. These forms may again be traced to those in which a very narrow median band of the Rhombic Pyroxene is found between the slender form of Augite (fig. 13 b) which we have already considered.

Explanation of Plate XIV *bis*.

Fig. 1.—The crystal of the Rhombic Pyroxene frequently found at Tatsumiura as larger crystals, figured in the position of v. Rath (pag. 74–76).

Fig. 1 a.—The basal projection of the crystal shown in fig. 1.

Fig. 2.—The type of the microscopic crystals of the Rhombic Pyroxene, placed as in fig. 1. (pag. 77).

Fig. 3.—The crystal as in fig. 1, projected upon a plane parallel to Macropinacoid, the narrow bands of Augite on both sides making parallel-intergrowth with the crystal, as described on pag. 78, the direction of extinction in these bands being simultaneous and making 42° with the direction of the vertical axis, as shown by the oblique line. The spines proceeding from the Augite-bands explained on pag. 85.

Fig. 4.—The crystal, like that of fig. 2, projected as in fig. 3, to show the symmetrical arrangement of glass enclosures (pag. 79). On the left side are figured elongated enclosures which are sometimes arranged parallel to the direction of the vertical axis (pag. 80).

Fig. 5.—The crystal, as that of fig. 4, showing the succession of enclosures conforming to the pyramidal face i. In the lower part of the crystal are figured series of the canal-like figures produced when it is acted on for a long time by hydrofluoric acid (pag. 80).

Fig. 6.—The penetration-twin of the Rhombic Pyroxene projected as in fig. 3, 4, 5. The two individuals having their brachypinacoidal faces in common, and the directions of the vertical axes making ca. 60° (pag. 77). The spines of Augite attached at the angles are found to be running parallel with the face a (pag. 85).

Fig. 7.—The crystals, as in fig. 4, assuming a pseudo-monoclinic form, and showing the mode of attachment of Augite spines (pag. 85) and the symmetrical arrangement of enclosures at both ends of the crystal conforming to the Pyramid i. The black dots on the upper left-hand side, are the minute enclosures of Picotite.

Fig. 8.—The crystal, placed as in fig. 2, showing the symmetrical attachment of the branching skeleton-crystal of Augite (pag. 85).

Fig. 9.—The crystal, as in fig. 2, showing the appearance of symmetrical Augite-spines when looked at upon the face b. This is figured in the position adopted by Tschermak (pag. 75).

Fig. 10.—The same as in fig. 8, looked at upon the face a, with more thickly-set branching and curved spines.

Fig. 11.—The same as fig. 10, looked at upon the face b.

Fig. 12.—The cross section of the Rhombic Pyroxene showing characteristic cleavage-traces, and the difference in character between the inner and the outer portions (pag. 79, 82).

Fig. 13.—The crystals of Augite developed in glassy rocks. a.–A general habitus of the crystal with longitudinal and transversal striæ, and the terminations ending in threads. b.—The same in parallel-intergrowth with the Rhombic Pyroxene. c.—The cross section of the crystal like a.

Fig. 14.—One of the forked terminations of the crystal as in fig. 13 a, magnified.

Fig. 15.—The micro-crystals of Augite among the glass (pag. 83), having in its middle a small band of the Rhombic Pyroxene.

Fig. 16.—The same as fig. 15, but disymmetric in form.

Fig. 17.—The same, peculiarly curved.

Fig. 18.—The same, showing the typical outline assumed by these crystals.

Fig. 19.—The smaller crystals of the Rhombic Pyroxene, having at

their ends simple spines of Augite (pag. 84).

Fig. 20.—The smaller forms of the Augite microliths.

Fig. 21.—The 'Rhombic lamellæ'; the two individuals as a twin of the Carlsbad type (pag. 71). The upper individual shows an extinction-angles of 40° with the edge of P : M.

Fig. 22.—The same; with the development of the face y, and the pyramidal faces in the zone of M : x.

Fig. 23.—The same; the pyramidal faces being very distinctly seen in this crystal.

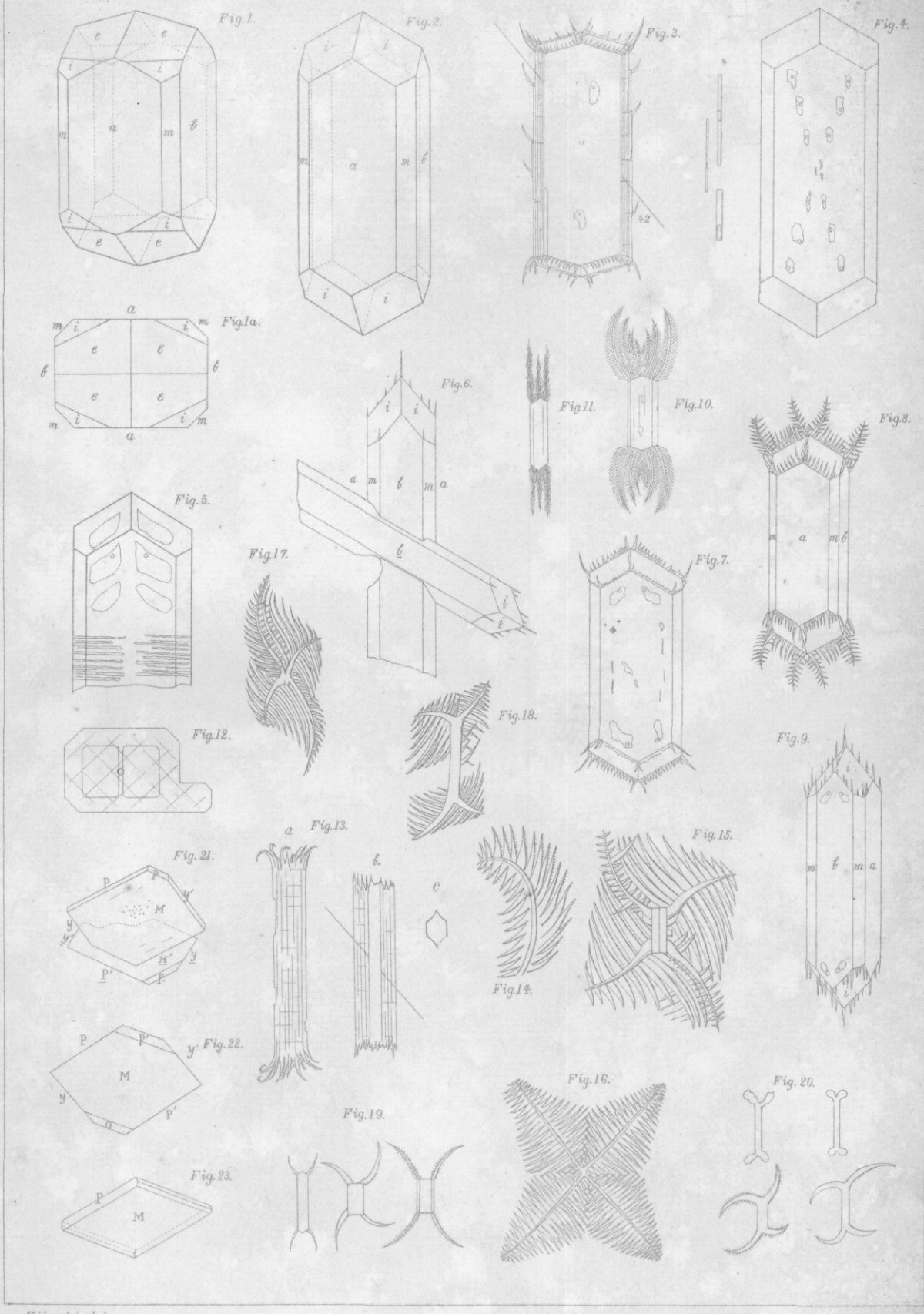
Fig. 1.
Fig. 2.
Fig. 3.
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Fig. 1a.
Fig. 5.
Fig. 6.
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Fig. 8.
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Fig. 10.
Fig. 11.
Fig. 12.
Fig. 13.
Fig. 14.
Fig. 15.
Fig. 16.
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