Optical, Chemical and Thermal Properties of Anorthite from Three Localities in Japan

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Optical, Chemical and Thermal Properties of Anorthite from Three Localities in Japan.

BY

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With 10 Text-figures.

Contents.

INTRODUCTORY NOTES.

1. The first of the anorthite crystals to be treated in the present paper was obtained in Miyakejima, one of the smaller isles of Izu Shichi-To or the Seven Izu Islands, lying about 180 km. to the south of Tokyo, and the best known locality of the mineral in Japan. With regard to the occurrence and morphological characters of the mineral, a detailed description was prepared by the late Dr. Y. KIKUCHI[1]) and published in the Journal of the College of Science, Imperial University, Tokyo, Japan; but with the exception of the extinction angles and optical orientation, its optical properties were not treated in that work and form the subject of the present research.

1) Y. KIKUCHI: On Anorthite from Miyakejima. Journal of College of Science, Imperial University, Tokyo, Japan. Vol. II, Part I, 1888.

As described by Dr. Y. KIKUCHI, the occurrence of the mineral is noteworthy in the fact that what may be termed "crystal bombs" are abundantly scattered over the lava-field formed by the eruption on the third of July, 1875.

The crystals of the mineral are well formed and quite large, being commonly 3 cm. in length, and 18 crystal faces have been identified by Mr. KIKUCHI.[1] The surface of the crystals is usually coated with a thin black crust of glassy lava which prevents measurement on the reflection-goniometer. Twinning according to three different laws, Albite, Pericline and Carlsbad, is generally present, and owing to its polysynthetic character considerable difficulty is experienced in measuring the optical properties even though we have quite fresh crystals of adequate size.

2. The second anorthite occurs in Mitaki, situated at about 2 km. north of Sendai, which is the largest city in the northern part of Japan, about 300 km. to the north of Tokyo, and now site of our Tôhoku Imperial University.

The geological formations developed in the environs of Sendai are later Tertiary (?) deposits consisting of volcanic tuff, sand and clay, in which abundant fossils, shells and plants, are contained. Professor H. YABE and his assistants are now making geological studies of the region, the results of which will be published in the near future.

Through these formations, volcanic rocks appear here and there in minor intrusions and extrusions. At Mitaki, an andesitic rock occurs, apparently as an extrusive sheet, though its true character is not yet certain. This volcanic rock contains large phenocrysts of anorthite, often reaching 5 cm. in length. The observations described below were made on crystals isolated from this rock. According to Mr. K. NAKAJIMA,[2] the anorthite crystals occur in two different relations, one as phenocrysts in the andesitic rock, and the other in the fragments of the same rock found in brecciated tuff, underlying the main sheet of the rock. He made a study of the crystal form of the mineral and found 17 different crystal faces.[3]

3. The third anorthite comes from the volcano Tarumae, Hokkaidô, which has lately attracted special attention because of the formation of a new lava-dome, which took place between the evening of the 17th and that of the 18th of April, 1909. Like the mineral from Miyakejima, it occurs as "crystal bombs," having been thrown out of the crater in the course of that eruption. This lava and the occurrence and features of the anorthite crystals have already been described by the writer in the Journal of Geology[4] published by the Chicago University Press; but the optical data on the mineral there given are not altogether eccurate, and should be superseded by those of the present paper.

The crystal habit of this anorthite is again almost the same as that of the mineral from Miyakejima. The size, however, is generally smaller being 1.5 cm. in length. The surface of the crystals is free from lava coating, though still not smooth enough for the measurement of interfacial angles by the reflection goniometer. Twinning according to Albite, Pericline and Carlsbad laws in polysynthetic relation is common. The principal crystal faces observed by the writer are also cited in the foot-note[5] for comparison with those from the other two localities.

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1) $P=0P\,(001)$, $M=\infty\breve{P}\infty\,(010)$, $T=\infty/P\,(1\bar{1}0)$, $l=\infty/P\,(110)$, $z=\infty/\breve{P}3\,(1\bar{3}0)$, $f=\infty P'/\breve{3}\,(130)$,
$t={}_2'P'\bar{\infty}\,(20\bar{1})$, $y={}_2{,}P{,}\bar{\infty}\,(201)$, $x={,}P{,}\bar{\infty}\,(10\bar{1})$, $e={}_2P'\breve{\infty}\,(021)$, $n={}_2'P'\bar{\infty}\,(02\bar{1})$, $m=P'\,(111)$,
$o=P{,}\,(11\bar{1})$, $p={,}P\,(1\bar{1}\bar{1})$, $b={}_4'P\breve{2}\,(2\bar{4}1)$, $v={}_4P\breve{2}\,(24\bar{1})$, $w={}_4{,}P\breve{2}\,(2\bar{4}\bar{1})$, $u(?)={}_2P{,}\,(22\bar{1})$.

2) K. NAKAJIMA: Anorthite from Mitaki near Sendai. Beitraege zur Mineralogie von Japan, N. 4, Juni, 1912, Tokyo.

3) $P=0P$, $M=\infty\breve{P}\infty$, $y={}_2{,}P{,}\bar{\infty}$, $n={}_2'P{,}\bar{\infty}$, $e={}_2{,}P\breve{\infty}$, $p={,}P$, $o=P{,}$, $T=\infty'P$, $l=\infty P'$,
$t={}_2'P'\bar{\infty}$, $a='P$, $m=P'$, $z=\infty'\breve{P}3$, $f=\infty P'\breve{3}$, $w={}_4{,}P\breve{2}$, $b={}_4'P{,}\breve{2}$, $v={}_4P{,}\breve{2}$.

4) S. KÔZU: Preliminary Notes on Some Igenous Rocks of Japan. IV. On Lava and Anorthite-crystals erupted from the Tarumae Volcano in 1909. Journel of Geology, Chicago, Vol. XIX, No. 7, 1911.

5) P (001), M (010), T $(1\bar{1}0)$, l (110), t $(20\bar{1})$, y $(20\bar{1})$, e (021), n $(0\bar{2}1)$, m (111), o $(11\bar{1})$,
p $(1\bar{1}\bar{1})$, v $(2\bar{4}1)$.

Optical Characters.

Of the anorthite crystals described above, I have made optical measurements of the three principal indices of refraction, the birefringence, the axial angle, and the dispersion. These were determined for five rays, namely, red (686 $\mu\mu$ and 671 $\mu\mu$), yellow (589 $\mu\mu$), green (535 $\mu\mu$), blue (486 $\mu\mu$) and violet (450 $\mu\mu$). Among the results obtained, the most noteworthy as well as interesting phenomenon is the peculiar dispersion of the optic axes.

1. Index of Refraction and Birefringence.

In order that the refractive indices of the mineral might be measured, the crystals were polished until their surfaces were practically plane and bright. The three principal indices for the sodium ray were obtained by using the ABBE-PULFRICH total-refractometer.

Table I.

	I	II	III
α	1.5738	1.5738	1.5736
β	1.5818	1.5819	1.5818
γ	1.5872	1.5873	1.5872
Birefringence.			
$\gamma-\alpha$	0.0134	0.0135	0.0136
$\gamma-\beta$	0.0054	0.0054	0.0054
$\beta-\alpha$	0.0080	0.0081	0.0082

I The anorthite from Miyake-jima.
II The anorthite from Mitaki.
III The anorthite from Tarumae.

Further experiments on the refractive indices for the four different rays, obtained by spectrometer, were made with the anorthites from Miyakejima and Tarumae.

Table II (a).
The anorthite from Miyakejima.

	α	β	γ	$\gamma-\alpha$	$\gamma-\beta$	$\beta-\alpha$
Red (686 $\mu\mu$)	1.5697	1.5783	1.5828	0.0131	0.0045	0.0086
Red (671 $\mu\mu$)	1.5702	1.5787	1.5834	0.0132	0.0047	0.0085
Yellow (Na)	1.5738	1.5818	1.5872	0.0134	0.0054	0.0080
Green (535 $\mu\mu$)	1.5770	1.5851	1.5906	0.0136	0.0055	0.0081
Blue (486 $\mu\mu$)	1.5807	1.5888	1.5947	0.0140	0.0059	0.0081

Table II (b).
The anorthite from Tarumae.

	α	β	γ	$\gamma-\alpha$	$\gamma-\beta$	$\beta-\alpha$
Red (686 $\mu\mu$)	1.5705	1.5785	1.5835	0.0130	0.0050	0.0080
Red (671 $\mu\mu$)	1.5709	1.5789	1.5839	0.0130	0.0050	0.0080
Yellow (Na)	1.5736	1.5818	1.5872	0.0136	0.0054	0.0082
Green (535 $\mu\mu$)	1.5768	1.5849	1.5905	0.0137	0.0056	0.0081
Blue (486 $\mu\mu$)	1.5810	1.5889	1.5947	0.0137	0.0058	0.0079

The mutual relations of those indices of refraction are shown in figure 1.

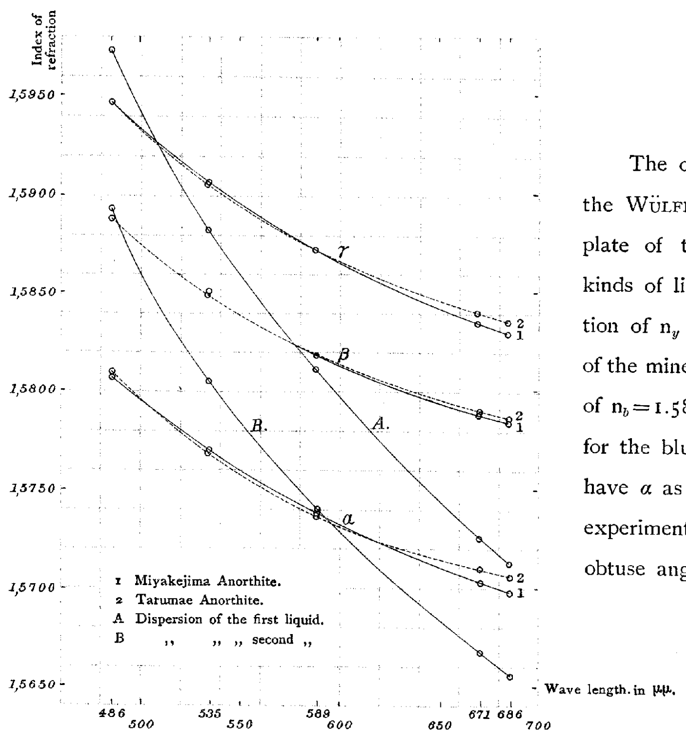

Fig. 1. The variation curves of the dispersion of the three principal indices of refraction of the anorthite from Miyakejima and Tarumae, and of the dispersion of two kinds of liquid in which the axial angles of the mineral were measured. The indices of refraction for the different rays of the mineral are taken as ordinate and the wave-lengths as abscissa.

2. Optic Axial Angle.

The optic axial angles were measured with the WÜLFING's axial angle apparatus, the thin plate of the mineral being immersed in two kinds of liquid, one having the index of refraction of $n_y = 1.5811$ which is almost equal to β of the mineral for the sodium ray, and the other of $n_b = 1.5893$ which is close to β of the mineral for the blue ray. The axial angles given below have α as the acute bisectrix, although in the experiment the first two were measured in the obtuse angle and the third in the acute.

Table III (a).

Axial angles measured in the first liquid ($n_y = 1.5811$).

	I	II	III
Red (671 μμ)	76° 29′	76° 28.5′	77° 54′
Yellow (589 μμ)	77° 12.5′	77° 10′	78° 6′
Green (535 μμ)	77° 54′	77° 55′	78° 19′
Blue (486 μμ)	78° 43.5′	78° 47.5′	78° 28′
Violet (450 μμ)	89° 41′	79° 47′	78° 33.5′
Yellow (2 V calc)	78° 17′ 10″	76° 21′ 26″	77° 45′ 34″

I 2Hα of the anorthite from Miyakejima.
II 2Hα of the anorthite from Mitaki.
III 2Hα of the anorthite from Tarumae.

The last values given in the above table are 2V for the sodium ray, obtained by calculation[1] based on their indices of refraction, using the formula

$$\tan^2 V_\gamma = \frac{\frac{1}{\alpha^2} - \frac{1}{\beta^2}}{\frac{1}{\beta^2} - \frac{1}{\gamma^2}}$$

1) F. E. WRIGHT.—Graphical Methods in Microscopical Petrography. Am. Jour. Sci., Vol. XXXVI, Nov., 1913.

The real (calculated) axial angles for the four rays are shown in table III (b). The dispersion of the liquid which enables us to calculate the real axial angles (2V) for the different rays was measured, and is also given in the same table.

Table III (b).

	I	II	III	IV
Red (686 $\mu\mu$)...........	...	...	...	1.5712
Red (671 $\mu\mu$)...........	76° 7′ 44″	76° 3′ 50″	77° 32′ 30″	1.5725
Yellow (589 $\mu\mu$)	77° 9′ 14″	77° 6′ 32″	78° 3′ 15″	1.5811
Green (535 $\mu\mu$)........	78° 4′ 52″	78° 6′ 14″	78° 30′ 40″	1.5882
Blue (486 $\mu\mu$)	79° 14′ 14″	79° 17′ 20″	78° 57′ 52″	1.5973

I 2Vα of the anorthite from Miyakejima.
II 2Vα of the anorthite from Mitaki.
III 2Vα of the anorthite from Tarumae.
IV Dispersion of the first liquid.

Table IV (a)[1]

Axial angles measured in the second liquid (n_b=1.5893).

	I	II
Red (686 $\mu\mu$)	76° 34′	78° 14′
Red (671 $\mu\mu$)	76° 42′	78° 20′
Yellow (589 $\mu\mu$)	77° 28′	78° 32′
Green (535 $\mu\mu$)	78° 14′	78° 44′
Blue (486 $\mu\mu$)	79° 12′	78° 56′
Violet (450 $\mu\mu$)....................	80° 4′	79° 10′

I 2Hα of the anorthite from Miyakejima.
II 2Hα of the anorthite from Tarumae.

Table IV (b) also shows the values of 2V for the different rays and the dispersion of the second liquid (column III), used in this experiment.

Table IV (b).

	I	II	III
Red (686 $\mu\mu$)	75° 50′ 6″	77° 28′ 6″	1.5655
Red (671 $\mu\mu$)	76° 1′ 20″	77° 36′ 50″	1.5667
Yellow (Na)	77° 0′ 52″	78° 4′ 20″	1.5740
Green (535 $\mu\mu$)	77° 57′ 56″	78° 27′ 40″	1.5805
Blue (486 $\mu\mu$)	79° 13′ 36″	78° 57′ 26″	1.5893

Table V.

	I	II	III	I a	II a
Red (686 $\mu\mu$)...	75° 50.1′	77° 28.1′	−1° 38′	71° 26′ 44″	76° 19′ 8″
Red (671 $\mu\mu$)...	87° 4.5′	77° 34.75′	−1° 30.25′	72° 55′ 6″	76° 17′ 20″

1) The axial angles given in table IV (a) were measured hastily with the object of finding out whether or not the dispersion of the anorthite from Tarumae, which is remarkably different from that of the mineral from other two localities, was influenced by some accidental condition.

Yellow (Na)...	77° 5.2′	78° 3.8′	−0° 58.6′	78° 17′ 10″	77° 45′ 34″
Green (535 μμ)	78° 2.8′	78° 29.15′	−0° 26.35′	78° 38′ 12″	78° 30′ 36″
Blue (486 μμ)..	79° 17.2′	78° 57.65′	+0° 19.55′	80° 35′ 20″	81° 31′ 32″

I The mean values of 2Vα of the anorthite from Miyakejima.

II The mean values of 2Vα of the anorthite from Tarumae.

III The difference between 2V of the anorthite from Miyakejima and from Tarumae.

I a 2Vα of the anorthite from Miyakejima, obtained by calculation based upon the refractive indices.

II a 2Vα of the anorthite from Tarumae, obtained by calculation based upon the refractive indices.

In comparing 2Vα of these two kinds of the anorthite, an interesting feature will be seen in the difference of the corresponding values for the different rays. As will be seen in column III of the above table; for each of the rays from red to green, the axial angle of the mineral from Miyakejima is less than that of the anorthite from Tarumae, decreasing toward the red, while for the blue and violet rays, the former is greater than the latter, increasing toward the violet. It is clear that, from figures 2 and 3, the crystals have equal axial angles for the wave length 500 in μμ.

With a view of showing the mutual relation of the figures given in tables III, IV and V, the accompanying diagrams (Figs. 2 and 3) were drawn, taking axial angles as ordinate and wave lengths in μμ as abscissa.

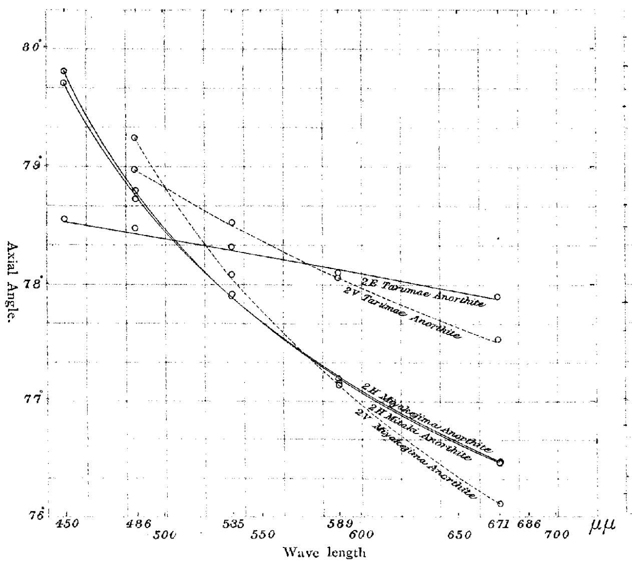

Fig. 2.
The variation curves of the observed axial angles for the different rays of the anorthite from Miyakejima, Mitaki and Tarumae, the mineral being immersed in the first liquid.

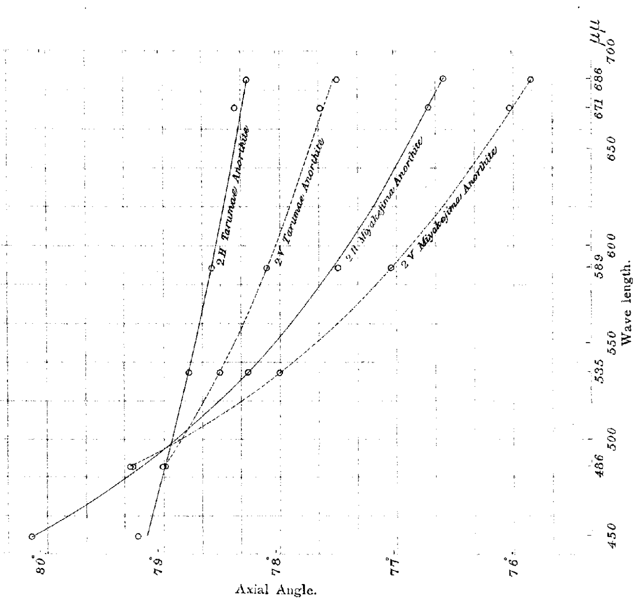

Fig. 3.
The variation curves of the observed axial angles for the different rays of the anorthite from Miyakejima and Tarumae, the mineral being immersed in the second liquid.

As will be seen in the figures, the axial angles of the anorthite from Miyakejima and Mitaki are practically identical, but they differ from those of the mineral from Tarumae. A noteworthy difference is also seen in the character of the dispersion of the optic axes.

3. Dispersion.

The dispersion of the optic axes was observed in the same thin sections immersed in the first liquid (n_y= 1.5811) by using the WÜLFING's axial angle apparatus. In the following tables, the optic axes A and B are employed in the same sense in ROSENBUSCH's "Mikroscopische Physiographie." The values denoted by H are the observed angular horizontal component of the dispersion, measured along the optic plane for the sodium ray, and those by V are the vertical angular component, perpendicular to the former direction.

Table VI (a).
Miyakejima.

	A		B	
Red (671 μμ)	+24.5′	H	−19.0′	H
Yellow (589 μμ)	0.0′	H	0.0′	H
Green (535 μμ)	−23.5′	H	+17.0′	H
Blue (486 μμ)	−53.0′	H	+38.0′	H
Violet (450 μμ)	−90.0′	H	+58.5′	H
Red (671 μμ)	+5.5′	V	−2.75′	V
Yellow (589 μμ)	0.0′	V	0.0′	V
Green (535 μμ)	−5.5′	V	+2.75′	V
Blue (486 μμ)	−11.0′	V	+5.5′	V
Violet (450 μμ)	−13.7′	V	+8.25′	V

Table VI (b).
Mitaki.

	A		B	
Red (671 μμ)	+30.0′	H	−11.5′	H
Yellow (589 μμ)	0.0′	H	0.0′	H
Green (535 μμ)	−27.5′	H	+18.0′	H
Blue (486 μμ)	−61.5′	H	+35.5′	H
Violet (450 μμ)	−97.0′	H	+59.0′	H
Red (671 μμ)	+7.5′	V	−2.7′	V
Yellow (589 μμ)	0.0′	V	0.0′	V
Green (535 μμ)	−7.5′	V	0.0′	V
Blue (486 μμ)	−10.2′	V	+2.7′	V
Violet (450 μμ)	−12.9′	V	+5.5′	V

Table VI (c).
Tarumae.

	A		B	
Red (671 μμ)	+9.0′	H	−3.0′	H
Yellow (589 μμ)	0.0′	H	0.0′	H
Green (535 μμ)	−8.5′	H	+5.0′	H
Blue (486 μμ)	−15.5′	H	+7.0′	H
Violet (450 μμ)	−24.5′	H	+13.0′	H
Red (671 μμ)	−5.5′	V	−9.25′	V
Yellow (589 μμ)	0.0′	V	0.0′	V
Green (535 μμ)	+5.5′	V	+5.5′	V
Blue (486 μμ)	+11.0′	V	+11.0′	V
Violet (450 μμ)	+16.5′	V	+16.5′	V

The above relations are schematically shown in the accompanying diagrams (Fig. 4).

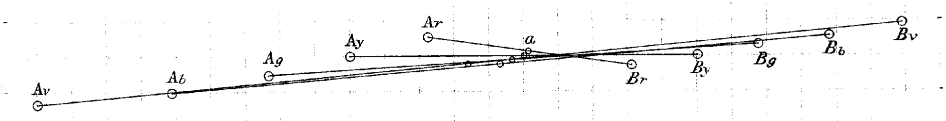

Fig. 4a. Apparent dispersion of the anorthite from Miyakejima.

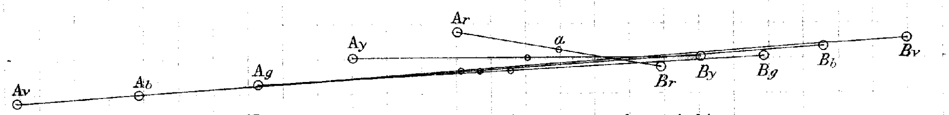

Fig. 4b. Apparent dispersion of the anorthite from Mitaki.

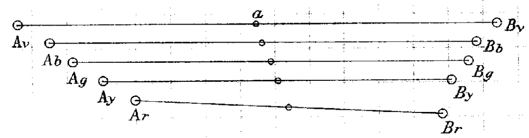

Fig. 4c. Apparent dispersion of the anorthite from Tarumaé.

Fig. 4a–4c.

Schematic diagrams of the observed dispersion of the optic axes. In these diagrams, the optic axes for the sodium ray are placed arbitrarily along the abscissa and the deviation of the optic axes for other rays is plotted with these points as origins, one division both ordinate and abscissa corresponding to one minute of the observed angular distance.

The apparent dispersion given in the above tables may be corrected to the real values[1] by the indices of refraction of the liquid for the different rays (table III (b)) and the values of β of the mineral for the corresponding ray (table II). These results are given below:

Table VII (a).

Miyakejima.

	A			B		
Red (671 $\mu\mu$)	+24′ 26″	H	A	−18′ 57″	H	B
Yellow (589 $\mu\mu$)	0′ 0″	H	A	0′ 0″	H	B
Green (535 $\mu\mu$)	−23′ 33″	H	A	+17′ 24″	H	B
Blue (486 $\mu\mu$)	−53′ 19″	H	A	+38′ 17″	H	B
Violet (450 $\mu\mu$)	......	H	A	......	H	B
Red (671 $\mu\mu$)	+3′ 30″	V	A	−1′ 45″	V	B
Yellow (589 $\mu\mu$)	0′ 0″	V	A	0′ 0″	V	B
Green (535 $\mu\mu$)	−3′ 30″	V	A	+1′ 23″	V	B
Blue (486 $\mu\mu$)	−7′ 37″	V	A	+3′ 26″	V	B
Violet (450 $\mu\mu$)	......	V	A	......	V	B

1) The real angular horizontal component of the dispersion will be found by the equation $\sin H(r) = \frac{n}{\beta} \sin H(o)$, and the real angular vertical component of the dispersion by

$$\sin V(r) = \frac{1}{n} \sin \left\{ \sin^{-1} \left(\frac{n}{\beta} \sin V(o) \right) \right\}$$

In the above two equations,

H (r) = the real angular horizontal component of the dispersion.
H (o) = the apparent horizontal component of the dispersion.
V (r) = the real angular vertical component of the dispersion.
V (o) = the apparent angular vertical component of the dispersion.
n = the index of refraction of the liquid.
β = the mean index of refraction.

The corrections assume that the crystal plate is cut perpendicular to the optic axis which is used as reference—the axis for the yellow ray in this case. However, the corrections are so small that, if the plate is considerably inclined and the inclination known approximately, satisfactory corrections can be made. In the case of the anorthite from Miyakejima and Mitaki, the sections were very nearly—within 5°—perpendicular to the bisectrix: in case of the mineral from Tarumae the trace of the section on the optic plane was nearly perpendicular to the bisectrix, and the section inclined about 50° to the bisectrix.

Table VII (b).

Mitaki.

		A	B
H	Red (671 $\mu\mu$)	$+29' 55''$	$-11' 30''$
H	Yellow (589 $\mu\mu$)	$0' 0''$	$0' 0''$
H	Green (535 $\mu\mu$)	$-27' 33''$	$+18' 0''$
H	Blue (486 $\mu\mu$)	$-61' 52''$	$+35' 43''$
H	Violet (450 $\mu\mu$)	......	......
V	Red (671 $\mu\mu$)	$+4' 46''$	$-1' 43''$
V	Yellow (589 $\mu\mu$)	$0' 0''$	$0' 0''$
V	Green (535 $\mu\mu$)	$-4' 43''$	$0' 0''$
V	Blue (486 $\mu\mu$)	$-6' 26''$	$+1' 42''$
V	Violet (450 $\mu\mu$)	......	......

Table VII (c).

Tarumae.

		A	B
H	Red (671 $\mu\mu$)	$+9' 0''$	$-3' 0''$
H	Yellow (589 $\mu\mu$)	$0' 0''$	$0' 0''$
H	Green (535 $\mu\mu$)	$-8' 30''$	$+5' 0''$
H	Blue (486 $\mu\mu$)	$-15' 36''$	$+6' 56''$
H	Violet (450 $\mu\mu$)	......	......
V	Red (671 $\mu\mu$)	$-3' 30''$	$-5' 50''$
V	Yellow (589 $\mu\mu$)	$0' 0''$	$0' 0''$
V	Green (535 $\mu\mu$)	$+3' 28''$	$+3' 30''$
V	Blue (486 $\mu\mu$)	$+6' 56''$	$+7' 3''$
V	Violet (450 $\mu\mu$)	......	......

From the above figures, we can calculate φ and λ of the optic axes for the different rays, if we know the inclination of the optic plane (O.P) of a ray to any crystallographic face. In my calculation,[1] the

1) The calculation was made by the following process: In the orthographic projection (Fig. 5), projected on the plane perpendicular to an optic axis for the sodium ray, P is the optic axis for another ray.

Then $\theta = \tan^{-1} \frac{\sin \delta}{\sin \varepsilon}$

In which, $\sin \delta$ or PA=the corrected vertical component of the dispersion of the optic axis, and $\sin \varepsilon$ or PB=the corrected horizontal component of the dispersion of the optic axis.

In the same figure,

$$OP = \sin \rho = \frac{\sin \delta}{\sin \theta}$$

In the stereographic projection (Fig. 6), projected on the plane perpendicular to the optic axis for the sodium ray, we already know from the above calculation ρ and $(\theta-\alpha)$ of P referring to the co-ordinates φ'' and λ''. Therefore we can calculate φ'' and λ'' by the following formulae:

$$\varphi'' = \tan^{-1} \frac{\cos(\theta-\alpha)}{\cot \rho}$$

$$\lambda'' = \sin^{-1} (\sin(\theta-\alpha) \sin \rho).$$

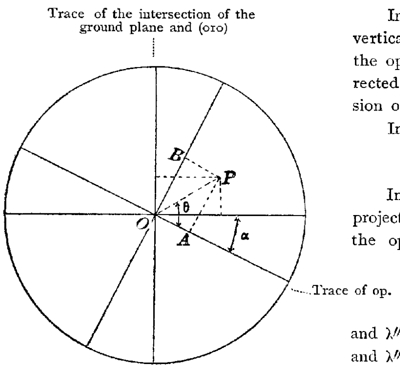

Fig. 5.

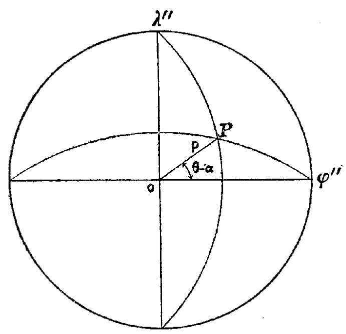

Fig. 6.

In which, α is the inclination of the optic plane for the sodium ray to the side pinacoid$=26° 52' 45''$ by calcultion given by BECKE.

inclination (O.P $\wedge$ 010) for the sodium ray was taken as $63° 7' 15''$, which was obtained from the data given by Professor BECKE,[1] that is, $\varphi = -63° 12'$ and $\lambda = 57° 54'$ for the A axis, and $\varphi = -2° 36'$ and $\lambda = -6° 12'$ for the B axis. The following figures refer to co-ordinates, whose origins are the optic axes for the sodium ray.

Table VIII (a).

Miyakejima.

Axis		φ''	λ''
A	R	$+23' 10''$	$-7' 55''$
A	Y	$0' 0''$	$0' 0''$
A	G	$-22' 36''$	$+7' 30''$
A	B	$-50' 59''$	$+17' 22''$
B	R	$-17' 44''$	$+6' 55''$
B	Y	$0' 0''$	$0' 0''$
B	G	$+16' 41''$	$-6' 54''$
B	B	$+35' 42''$	$-14' 15''$

Table VIII (b).

Mitaki.

Axis		φ''	λ''
A	R	$+32' 1''$	$-10' 53''$
A	Y	$0' 0''$	$0' 0''$
A	G	$-26' 42''$	$+8' 15''$
A	B	$-57' 54''$	$+22' 10''$
B	R	$-11' 3''$	$+3' 41''$
B	Y	$0' 0''$	$0' 0''$
B	G	$+16' 3''$	$-8' 8''$
B	B	$+32' 41''$	$-14' 40''$

Table VIII (c).

Tarumae.

Axis		φ''	λ''
A	R	$+6' 52''$	$-5' 49''$
A	Y	$0' 0''$	$0' 0''$
A	G	$-3' 21''$	$+5' 36''$
A	B	$-10' 45''$	$+13' 12''$
B	R	$-5' 19''$	$-3' 51''$
B	Y	$0' 0''$	$0' 0''$
B	G	$+6' 2''$	$+0' 52''$
B	B	$+9' 16''$	$+3' 4''$

On the condition that the inclination of the optic plane for the sodium ray to the side pinacoid is $63° 7' 15''$, the stereographic co-ordinates of the optic axis A for the sodium ray are given below, in which the axis B is taken as the origin in the center of the projection, those values being shown with the signs φ' and λ' in the following table.

Table IX.[2]

	φ'	λ'
Anorthite, Miyakejima	$-60° 23' 30''$	$+63° 6' 32''$
Anorthite, Mitaki	$-60° 23' 53''$	$+63° 9' 2''$

1) F. BECKE.—Zur Physiographie der Gemengteile der krystallinen Schiefer. p. 151, 1906.

2) The values of φ' and λ' given in the table were calculated from 2V and the inclination of O.P. to 010 ($63° 7' 15''$). For the first three crystals, the mean values given in tables III (b) and IV (b) were taken as 2V; and for the crystal from Vesuvius, $76° 18'$ given by BECKE was considered as its value. In the last case, the result of the calculation is somewhat different from $\varphi' = -60° 36'$ and $\lambda' = +64° 6'$, which were given by BECKE. 2V which corresponds to the values $-60° 36'$ and $64° 6'$ is $77° 37' 5''$ in the acute angle.

Anorthite, Tarumaé	$\varphi' = -60^\circ\ 46'\ 14''$	$\lambda' = +64^\circ\ 56'\ 2''$
Anorthite, Vesuvius	$\varphi' = -60^\circ\ 3'\ 52''$	$\lambda' = +61^\circ\ 40'\ 1''$

If we assume that the orientation of the optic axis B in the anorthite from Vesuvius, that is, $\varphi = -2^\circ\ 36'$ and $\lambda = -6^\circ\ 12'$, may be applicable to the case of the anorthite crystals which are now considering the orientations (φ and λ) of the optic axes A and B for the different rays will be obtained from the figures given in tables VII and VIII.

Table X (a).

Miyakejima.

	A: φ	A: λ	B: φ	B: λ
R	$-62^\circ\ 36'\ 20''$	$+56^\circ\ 46'\ 37''$	$-2^\circ\ 53'\ 44''$	$-6^\circ\ 5'\ 5''$
Y	$-62^\circ\ 59'\ 30''$	$+56^\circ\ 54'\ 32''$	$-2^\circ\ 36'$	$-6^\circ\ 12'$
G	$-63^\circ\ 22'\ 6''$	$+57^\circ\ 2'\ 2''$	$-2^\circ\ 19'\ 19''$	$-6^\circ\ 18'\ 54''$
B	$-63^\circ\ 50'\ 29''$	$+57^\circ\ 11'\ 54''$	$-2^\circ\ 0'\ 18''$	$-6^\circ\ 26'\ 15''$

Table X (b).

Mitaki.

	A: φ	A: λ	B: φ	B: λ
R	$-62^\circ\ 27'\ 52''$	$+56^\circ\ 46'\ 9''$	$-2^\circ\ 47'\ 3''$	$-6^\circ\ 8'\ 19''$
Y	$-62^\circ\ 59'\ 53''$	$+56^\circ\ 57'\ 2''$	$-2^\circ\ 36'$	$-6^\circ\ 12'$
G	$-63^\circ\ 26'\ 35''$	$+57^\circ\ 5'\ 17''$	$-2^\circ\ 19'\ 57''$	$-6^\circ\ 20'\ 8''$
B	$-63^\circ\ 57'\ 47''$	$+57^\circ\ 19'\ 12''$	$-2^\circ\ 3'\ 19''$	$-6^\circ\ 26'\ 40''$

Table X (c).

Tarumaé.

	A: φ	A: λ	B: φ	B: λ
R	$-63^\circ\ 15'\ 22''$	$+58^\circ\ 38'\ 13''$	$-2^\circ\ 41'\ 19''$	$-6^\circ\ 15'\ 51''$
Y	$-63^\circ\ 22'\ 14''$	$+58^\circ\ 44'\ 2''$	$-2^\circ\ 36'$	$-6^\circ\ 12'$
G	$-63^\circ\ 25'\ 35''$	$+58^\circ\ 49'\ 38''$	$-2^\circ\ 29'\ 58''$	$-6^\circ\ 11'\ 8''$
B	$-63^\circ\ 32'\ 59''$	$+58^\circ\ 57'\ 14''$	$-2^\circ\ 26'\ 44''$	$-6^\circ\ 8'\ 56''$

4. The Inclinations of the Optic Planes and the Axial Angles, obtained by Calculation, using the Data of Dispersion.

The inclinations of the optic planes to the side pinacoid and the real axial angles, both in the succeeding table XI, were culculated from the values φ' and λ' for the different rays, which are easily obtained from the figures in table IX. For comparison, the real axial angles obtained by the correction from the observed angles (table III) will be given in the same table.

Table XI (a).
Miyakejima.

	O.P. $\wedge$ 010	Δ (O.P. $\wedge$ 010)	2V (calc.)	2V (obs.)	Δ 2V
R (671 $\mu\mu$)	62° 32′ 2″	35′ 13″	76° 41′ 57″	76° 4.5′	+37.5′
Y (589 $\mu\mu$)	63° 7′ 15″	34′ 7″	77° 1′ 37″	77° 5.2′	−3.6′
G (535 $\mu\mu$)	63° 41′ 32″	40′ 38″	77° 27′ 53″	78° 2.8′	−34.9′
B (486 $\mu\mu$)	64° 22′ 0″		77° 54′ 5″	77° 17.2′	−1° 23.1′

Table XI (b).
Mitaki.

R (671 $\mu\mu$)	62° 29′ 27″	37′ 48″	76° 42′ 30″	76° 3.5′	+38.8′
Y (589 $\mu\mu$)	63° 7′ 15″	36′ 57″	77° 6′ 32″	77° 6.5′	0
G (535 $\mu\mu$)	63° 44′ 12″	40′ 43″	77° 48′ 12″	78° 6.25′	−18′
B (486 $\mu\mu$)	64° 24′ 55″		78° 14′ 26″	79° 17.3′	−1° 2.9′

Table XI (c).
Tarumaé.

R (671 $\mu\mu$)	62° 56′ 8″	11′ 7″	77° 59′ 8″	77° 34.75′	+24.4′
Y (589 $\mu\mu$)	63° 7′ 15″	12′ 2″	78° 3′ 48″	78° 3.8′	0
G (535 $\mu\mu$)	63° 15′ 17″	9′ 3″	78° 9′ 18″	78° 29.15′	−19.85′
B (486 $\mu\mu$)	63° 24′ 28″		78° 15′ 45″	78° 57.65′	−41.9′

As will be seen, the axial angles in the anorthite from Tarumaé, which were obtained by calculation, agree comparatively well with those observed; whereas, those in the mineral from Miyakejima and Mitaki show poorer agreement, in other words, the inclination of the optic plane for the sodium ray to the side pinacoid of the anorthite from Tarumaé is closer to that of the anorthite from Vesuvius given by Professor Becke.

For comparing with the real values of φ', λ', φ'', λ'', O.P. $\wedge$ 010 and axial angles for the different rays, their apparent values were calculated from the apparent dispersion. In the succeeding tables, these values are given in parallel columns. The comparison of these results with their corresponding real values would enable us in other instances to obtain an approximate idea of the real values when we know the apparent values.

Table XII.

φ'' and λ''						
			A axis		B axis	
			Real	Apparent	Real	Apparent
Miyakejima.	Red (671 $\mu\mu$)	φ''......	+23′ 10″	+24′ 30″	−17′ 44″	−18′ 12″
		λ''......	−7′ 55″	−6′ 10″	+6′ 55″	+6′ 0″
	Yellow (589 $\mu\mu$)	φ''......	0 0	0 0	0 0	0 0
		λ''......	0 0	0 0	0 0	0 0
	Green (535 $\mu\mu$)	φ''......	−22′ 36″	−23′ 33″	+16′ 41″	+15′ 50″
		λ''......	+7′ 30″	+5′ 44″	−6′ 54″	−5′ 4″
	Blue (486 $\mu\mu$)	φ''......	−50′ 59″	−52′ 14″	+35′ 42″	−36′ 20″
		λ''......	+17′ 22″	+14′ 6″	−14′ 15″	−12′ 4″
	Violet (450 $\mu\mu$)	φ''......	......	−1° 26′ 50″	......	+55′ 24″
		λ''......	......	+28′ 30″	......	−18′ 54″
Mitaki.	Red (671 $\mu\mu$)	φ''......	+32′ 1″	+30′ 9″	−11′ 3″	−11′ 20″
		λ''......	−10′ 53″	−6′ 50″	+3′ 41″	+2′ 45″
	Yellow (589 $\mu\mu$)	φ''......	0 0	0 0	0 0	0 0
		λ''......	0 0	0 0	0 0	0 0
	Green (535 $\mu\mu$)	φ''......	−26′ 42″	−27′ 52″	+16′ 3″	+16′ 4″
		λ''......	+8′ 15″	+5′ 43″	−8′ 8″	−8′ 7″
	Blue (486 $\mu\mu$)	φ''......	−57′ 54″	−59′ 30″	+32′ 41″	+32′ 54″
		λ''......	+22′ 10″	+18′ 40″	−14′ 40″	−13′ 30″
	Violet (450 $\mu\mu$)	φ''......	......	−1° 32′ 48″	......	+55′ 13″
		λ''......	......	+30′ 30″	......	−21′ 46″
Tarumaé.	Red (671 $\mu\mu$)	φ''......	+6′ 52″	+8′ 59″	−5′ 19″	−6′ 51″
		λ''......	−5′ 49″	−5′ 29″	−3′ 51″	−6′ 53″
	Yellow (589 $\mu\mu$)	φ''......	0 0	0 0	0 0	0 0
		λ''......	0 0	0 0	0 0	0 0
	Green (535 $\mu\mu$)	φ''......	−3′ 21″	−5′ 6″	+6′ 2″	+7′ 10″
		λ''......	+5′ 36″	+2′ 45″	+0′ 52″	+2′ 0″
	Blue (486 $\mu\mu$)	φ''......	−10′ 45″	−8′ 52″	+9′ 16″	+11′ 12″
		λ''......	+13′ 12″	+16′ 48″	+3′ 4″	+6′ 39″
	Violet (450 $\mu\mu$)	φ''......	......	−11′ 57″	......	+19′ 2″
		λ''......	......	+21′ 20″	......	+8′ 51″

Table XIII.

φ' and λ'							
		Miyakejima		Mitaki		Tarumaé	
		Real	Apparent	Real	Apparent	Real	Apparent
Red (671 $\mu\mu$)	φ'	$-59° 42' 36''$	$-59° 45' 0''$	$-59° 40' 49''$	$-59° 44' 55''$	$-60° 34' 3''$	$-60° 32' 51''$
	λ'	$+62° 51' 42''$	$+63° 0' 34''$	$+62° 54' 28''$	$+62° 7' 13''$	$+64° 54' 4''$	$+64° 55' 25''$
Yellow (589 $\mu\mu$)	φ'	$-60° 23' 30''$	$-60° 27' 42''$	$-60° 23' 53''$	$-60° 26' 24''$	$-60° 46' 14''$	$-60° 48' 41''$
	λ'	$+63° 6' 32''$	$+63° 12' 44''$	$+63° 9' 2''$	$+63° 6' 48''$	$+64° 56' 2''$	$+64° 54' 0''$
Green (535 $\mu\mu$)	φ'	$-61° 2' 47''$	$-61° 7' 5''$	$-61° 6' 38''$	$-61° 10' 20''$	$-60° 55' 37''$	$-61° 0' 57''$
	λ'	$+63° 20' 56''$	$+63° 23' 32''$	$+63° 25' 25''$	$+63° 20' 38''$	$+65° 0' 46''$	$+64° 54' 45''$
Blue (486 $\mu\mu$)	φ'	$-61° 50' 11''$	$-61° 56' 16''$	$-61° 54' 28''$	$-61° 58' 48''$	$-61° 6' 15''$	$-61° 8' 45''$
	λ'	$+63° 38' 9''$	$+63° 38' 54''$	$+63° 45' 52''$	$+63° 38' 58''$	$+65° 6' 10''$	$+65° 4' 19''$
Violet (450 $\mu\mu$)	φ'	......	$-62° 49' 56''$	......	$-62° 54' 25''$	......	$-61° 19' 40''$
	λ'	......	$+64° 0' 8''$	......	$+63° 59' 4''$	......	$+65° 6' 29''$

Table XIV.

O.P. $\wedge$ 010						
	Miyakejima		Mitaki		Tarumaé	
	I	I (a)	I	I (a)	I	I (a)
Red	$62° 32' 2''$	$62° 32' 26''$	$62° 29' 27''$	$62° 43' 40''$	$62° 56' 8''$	$62° 54' 44''$
Yellow	$63° 7' 15''$	$63° 10' 4''$	$63° 7' 15''$	$63° 10' 4''$	$63° 7' 15''$	$63° 10' 4''$
Green...............	$63° 41' 22''$	$63° 44' 51''$	$63° 44' 12''$	$63° 49' 6''$	$63° 15' 17''$	$63° 20' 46''$
Blue	$64° 22' 0''$	$64° 27' 57''$	$60° 28' 55''$	$64° 30' 19''$	$63° 24' 20''$	$63° 27' 3''$
Violet	......	$65° 14' 10''$	......	$65° 18' 58''$	......	$63° 36' 58''$

I O.P. $\wedge$ 010 obtained from the real dispersion.
I (a) O.P. $\wedge$ 010 obtained from the apparent dispersion.

Table XV.

Axial angles					
		I	II	III	IV
Miyakejima	Red	76° 41′ 57″	76° 4.5′	76° 47′ 0″	76° 29′
	Yellow	77° 1′ 37″	77° 5.2′	77° 9′ 44″	77° 12.5′
	Green	77° 27′ 52″	77° 2.8′	77° 47′ 53″	77° 54′
	Blue	77° 54′ 5″	79° 17.2′	77° 56′ 50″	78° 43.5′
	Violet	......	......	78° 27′ 26″	70° 41′
Mitaki	Red	76° 42′ 30″	76° 3.8′	76° 22′ 26″	76° 28.5′
	Yellow	77° 6′ 32″	77° 7.2′	77° 6′ 32″	77° 10′
	Green	77° 48′ 12″	78° 6.25′	77° 47′ 44″	77° 55.5′
	Blue	78° 14′ 26″	79° 17.35′	77° 57′ 52″	78° 47.5′
	Violet	......	......	78° 28′ 46″	77° 47′
Tarumaé	Red	77° 59′ 8″	77° 34.75′	77° 58′ 18″	77° 54′
	Yellow	78° 3′ 48″	78° 3.8′	78° 3′ 40″	78° 6′
	Green	78° 9′ 18″	78° 29.15′	78° 8′ 44″	78° 19′
	Blue	78° 15′ 45″	78° 57.65′	78° 15′ 51″	78° 28′
	Violet	......	......	78° 20′ 56″	78° 33.5′

I $2V\alpha$ obtained by calculation based upon the true dispersion.
II $2V\alpha$ obtained by correction of the observed 2H.
III $2H\alpha$ obtained by calculation based upon the apparent dispersion.
IV $2H\alpha$ obtained by observation.

5. Summary.

A summary of what is set forth in the foregoing pages is as follows:

1. The anorthite crystals from the three different localities which were taken for the present study are phenocrystic minerals of andesitic lavas,[1)] which have not yet been worked out petrologically in detail.

2. The three principal indices of refraction for the sodium ray were determined for the three crystals from Miyakejima, Mitaki and Tarumaé; and the indices for the other four rays were also measured for the mineral from Miyakejima and Tarumaé. These results are practically the same for all these crystals

1) The petrographical character of the lava from Miyakejima was described by the late V. KIKUCHI (Journal of College of Science, Tokyo, 1888) and by J. PETERSEN (Beiträge zur Petrographie von Sulphur Island, Peel Island, Hachijō and Miyakejima); and the lava from Tarumaé by the present writer (Journal of Geology, Vol. xix, No. 7, 1911). These descriptions, however, are not sufficient for the purpose of showing the details of the physical and chemical characters of the mineral ingredients occurring in association with the anorthite.

During the printing of this paper, the writer has had an opportunity to read, through the courtesy of Professor L. V. PIRSSON, a quite recent publication "Ueber die Laven der Kleineren Izu-Inseln," by CARL BACHER (Munich, 1914, p. 38). In his paper the Miyakejima lava erupted in 1875, in which were formed the anorthite crystals treated in the present study, is described, with a chemical analysis and they correspond to those of an anorthite whose chemical composition is Ab_2 An_{98}, according to the diagrams of WRIGHT and BECKE; and Ab_0 An_{91}, according to IDDINGS.[1]

3. The axial angles for the different rays of the anorthite from Miyakejima and Mitaki are practically equal, but those of the mineral from Tarumaé are very different. The angles of the mineral from Tarumaé vary lsss for the different rays than those of the former type; and the value of the angle, which is the same in both kinds for the same light, can be obtained when they are measured with the ray having a wave length of 500 $\mu\mu$.

4. The difference in the dispersion of the optic axes between these two kinds of anorthite is remarkable, and appears not only in the relative values of the axial angles, but in the position of the crossing of the optic plane for the different rays. The cross-dispersion is seen in the obtuse axial angle in the mineral from Tarumaé, while it is seen in the acute angle in that from Miyakejima and Mitaki.

5. Under the assumption that the optic plane of the mineral for the sodium ray lies in the known direction with the inclination 63° 7′ 15″ to the side pinacoid, the inclinations of the optic planes for the other rays were calculated by using the data of the dispersion. These results are not quite exact, due to the lack of knowledge of the exact optic orientation of the present anorthites, but they may enable us to obtain an approximate idea of the property of these minerals, which has never been described before, so far as known to the writer.

6. As seen in tables XII and XIII, the axial angles obtained by calculation from the dispersion (2V calc.) differ from those obtained by observation (2V obs.). This difference must be due essentially to the assumption that O.P. $\wedge$ 010=63° 7′ 15″ and to the possible experimental errors for the determination of the dispersion, and, since the former factor must from its nature exercise greater influence upon the calculated results, we are led to conclude that it has been the main cause of such difference between the sets of axial angles. This conclusion is further strengthened by the smaller difference of inclination of the optic plane in the Tarumaé anorthite when compared with the type from Miyakejima and Mitaki to the inclination of the optic plane of the anorthite from Vesuvius. From this fact it is also proven that the inclination of the optic plane of the Tarumaé anorthite is very near to that of the mineral from Vesuvius.

7. φ and λ for the sodium ray, which were obtained by calculation under the condition stated on a previous page are as follows:

	A		B	
	φ	λ	φ	λ
Miyakejima	−62° 59.5′	+56° 54.5′	−2° 36′	−6° 12′
Mitaki.....................	−62° 59.9′	+56° 57′	−2° 36′	−6° 12′
Tarumaé..................	−63° 22.25′	+58° 44′	−2° 36′	−6° 12′
Vesuvius..................	−63° 12′	+57° 54′	−2° 36′	−6° 12′

made by DITTRICH. For the sake of giving some idea concerning the chemical relation between the lava and the anorthite, the analysis of the lava, (op. cit. p. 21) is cited here and the norm calculated from it by the writer is also given with its classification.

		Norm.		Ratios.
SiO_2	53.35			
Al_2O_3	15.62	Quartz	9.7	$\frac{Sal}{Fem} = \frac{63.3}{36.0} = 1.76$
Fe_2O_3	4.21	Orthoclase	5.0	
FeO	8.12	Albite	18.3	$\frac{Q}{F} = \frac{9.7}{53.6} = 0.18$
MgO	4.44	Anorthite	30.3	
CaO	9.68	Diopside	14.6	$\frac{K_2O'+Na_2O'}{CaO'} = \frac{44}{109} = 0.40$
Na_2O	2.48	Hypersthene	14.1	
K_2O	0.84	Magnetite	6.0	$\frac{K_2O'}{Na_2O'} = \frac{9}{35} = 0.26$
H_2O+	0.34	Ilmenite	2.3	
H_2O-	0.06			
TiO_2	1.18			
CO_2	trace			

According to the Quantative System the lava is classified as bandose (II, 4, 4, 3) and thus agrees in its chemico-mineralogical character with the recent pyroxene-andesites and andesitic basalts so widely spread through the Japanese archipelago and which generally fall in this sub-rang.

1) J. P. IDDINGS:—Rock Minerals. 2nd Edition, p. 217, 1911.

8. Generally speaking, according to the dispersion of the optic axes, the anorthite crystals which were studied can be classified into two types; but this distinction is hardly recognizable in the refractive indices, which are obtainable by the usual total refractometor with a glass hemisphere.

Chemical Characters.

Chemical analyses of the anorthite from Miyakejima and Tarumaé have already been published by KIKUCHI[1] and by the writer[2] respectively, but in these analyses those rare elements, whose presence in the mineral is usually believed to cause a remarkable difference on the optical characters of the mineral, were not looked for. As described in the foregoing pages, the anorthite crystals from Miyakejima and Tarumaé show so remarkable a difference in the dispersion of the optic axes, as to be beyond the limit of a possible experimental error. With the view of finding out what chemical difference exists between them, careful analyses of these two kinds of anorthite were undertaken by Dr. H. S. WASHINGTON, in the Geophysical Laboratory of the Carnegie Institution, to whom the writer is greatly indebted. These new results in parallel with the old anylyses made in Japan are given below:

Table XVI.

	Miyakejima		Tarumaé	
	I	II	III	IV
SiO_2	44.49	44.03	44.03	43.51
Al_2O_3	36.00	36.80	35.93	35.75
Fe_2O_3	0.08	...	0.10	trace
MgO	0.04	0.20	trace	1.11
CaO	19.49	19.29	18.66	19.48
Na_2O	0.59	0.23	1.00	0.61
K_2O	0.03	...	0.07	0.05
BaO	none	n.d.	none	n.d.
SrO	none	n.d.	none	n.d.
total	100.72	100.67	100.24	100.53

I Miyakejima anorthite, H. S. WASHINGTON analyst.
II Miyakejima anorthite, T. KITAMURA analyst.
III Tarumaé anorthite, H. S. WASHINGTON analyst.
IV Tarumaé anorthite, Y. OGAWA analyst.

As will be seen above, all analyses agree well, especially in the case of the Miyakejima anorthite. It will be seen that neither of these anorthites contains strontium or barium. The chemical difference between them will be better illustrated by the norms given below, which are obtained by calculation from the chemical analyses made by WASHINGTON.

	Miyakejima	Tarumaé
Orthoclase	......	0.56
Albite	3.93	4.72

1) Loc. cit.
2) Loc. cit.

Anorthite	95.35	92.57
Nephelite	0.71	1.99
Diopside	0.22	......
Wollastonite	0.46	......
Hematite	0.08	0.10
	100.53	99.84

Assuming these most probable mineral molecules to be present in the minerals, the Miyakejima anorthite may be indicated by the formula $Ab_{3.9}\ An_{95.4}\ Cg_{0.7}$, containing a negligible amount of wollastonite and diopside; and the Tarumaé mineral by the formula $Or_{0.6}\ Ab_{4.7}\ An_{92.6}\ Cg_{2.0}$. If, for convenience of comparing with the normal plagioclase series, we reckon the small amount of potash and extra soda as orthoclase and carnegieite with the albite molecules, they will correspond to $Ab_{4.6}\ An_{95.4}$ and $Ab_{6.4}\ An_{93.6}$ of the pure albite-anorthite series respectively.

Fusion Phenomena and Fused Material.

Experiments of fusion and fused material were made with the anorthite from Miyakejima and Tarumaé, but the mineral from Mitaki was not thus examined, as the former two were quite fresh and we were able to obtain material almost free from enclosures of olivine and magnetite, while the latter contained abundant impurities enclosed intimately.

The Miyakejima anorthite is well known as the Izu or Japanese anorthite, as it was taken as the sample for the determination of the melting point of anorthite by DOELTER[1] and by BRUN,[2] respectively. The melting point of the mineral given by DOELTER is considerably lower than that given by BRUN, which agrees fairly well with the melting point of the artificial pure anorthite determined by DAY and SOSMAN.[3] Any difference in the determination of the melting point of a mineral must have its main cause in the accuracy of the methods employed. In this connection a generalization was briefly mentioned by Clarke in his work "Data of Geochemistry."[4] The last named author also said in the same place, that "other discordances are due to the difference between the substances examined, for natural minerals are rarely pure." With the view of observing what differences exist between artificial and natural anorthites, an anorthite whose chemical composition is close to the natural one was prepared artificially and studied.

1. Fusion.

The fusion test was made by two methods of "heating curve" and "quenching," in an electrically heated furnace, called the platinum-alundum furnace, which is now being used for "quenching" in the Geophysical Laboratory of the Carnegie Institution. The temperature was measured by means of a thermoelement and potentiometer.

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1) C. DOELTER: Die Silikatschmelzen. Sitzungsb. Akad. Wien, Vol. 115, 1906, p. 743.
The melting points of the anorthites from Miyakejima and Vesuvius, determined by the author are:

	Beginning of Fusion	Liquid and Solid	No. solid face.
Anorthite, Miyakejima	1260°	1310°	1340°
Anorthite, Vesuvius	1255°	1290°	1330°

2) BRUN: Arch. Sci. phs. et nat. (4), XVIII, 537, 1904.
The melting point of the Miyakejima anorthite, determined by the author is 1490°–1520° C.
DOUGLAS obtained 1505° C. as the fusion-point of the glass formed by the melting anorthite from Monte Somma, using a meldometer. Q. J. G. S., 1907, p. 157.

3) A. L. DAY and R. B. SOSMAN: the Melting Point of Minerals in the Light of Recent Investigations on the Gas Thermometer. Am. Jour. Sci, Vol. 31, 1911, p. 341.

4) F. W. CLARKE: Bulletin 491 (second edition) U. S. G. S., 1911.

Table XVII.

Artificial pure anorthite.		Miyakejima anorthite.				Tarumaé anorthite.			
M.V.	V.	M.V.	V.	M.V.	V.	M.V.	V.	M.V.	V.
15869	21	15827	26	15825	19	15809	28	15821	18
890	18	853	27	846	18	837	26	839	16
908	19	880	24	864	19	863	23	855	15
927	18	904	25	883	15	886	23	870	14
945	18	929	20	898	15	909	21	884	12
963	16	949	20	913	14	930	17	896	12
989	14	969	17	927	12	947	16	908	12
993	16	986	14	939	13	963	13	920	12
16009	13	16000	15	952	11	976	16	932	12
022	13	015	14	963	11	992	15	944	11
035	11	029	15	974	11	16007	22	955	11
046	11	044	10	985	10	029	26	966	12
057	9	064	29	995	13	057	38	978	12
066	9	093		16008	13	095	41	990	13
075	7	...	197	021	19	136	44	16003	16
082	8	280	37	040	43	180	36	019	16
090	7	313	24	083	90	215	36	035	19
097	7	337	25	173	37	251	30	054	20
104	5	362		210	20	281	31	074	21
109	6			230	16	312	26	095	26
115	5			246	16	338		121	21
120	6			262	14			142	19
126	5			276	14			161	
131	4			290	12				
135	6			302	12				
141	5			314	12				
146	4								
150	5								
155	5								
160	5								
165	6								
171	4								
175	5								
180	7								
187	8								
195	10								
205	11								
216	14								
230	13								
243									

Artificial pure anorthite, melting point observed 16180 microvolts, value by standard element 16150 microvolts, correction −30 microvolts. Melting temperature in degrees 1550°C.

Miyakejima anorthite, melting point between 16020 M.V. and 16044 M.V. Correction −30 M.V. Melting temperature in microvolts about 16002, and the temperature in degrees 1538±2°.

Tarumaé anorthite, melting point 16007–16027. Correction −30 M.V. Melting temperature in microvolts about 15988, and the temperature in degress 1536±2°.

Heating curve:—It will be seen from table XVII, that the break on the heating curve, which corresponds to the melting point, is distinct in each case. Under column I, the heating curve of the artificial pure anorthite is given, from which the thermoelement employed can be corrected by the table, calibrated by the standard thermoelement. The correction is −30 microvolts, so the temperature in degrees of the melting point of the anorthites from Miyakejima and Tarumaé can be indicated as 1538°±2°C. and 1536°±2°C. respectively.

In December, 1912, the melting points of the anorthites from Miyakejima and Tarumaé were measured in the Physical Laboratory of Tôhoku Imperial University, Japan, by Y. YAMASHITA, S. MASHIMA and the writer under Dr. K. HONDA, Professor of Physics, as practice work in high temperature measurements. The minerals were heated in a Tamman's furnace and the temperatures were measured both by a thermoelement connected with a Siemens' galvanometer and an optical pyrometer. Their results are:

	Miyakejima	Tarumaé
Optical pyrometer........................	1528°C	1533°C
,, ,, ...	1533	
,, ,, ...	1528	
,, ,, ...	1533	
Thermoelement	1528	

In these experiments, the purifying of the samples was not careful enough, hence the melting points observed are probably somewhat different from the true values. However these results agree fairly well with those which the writer obtained in the Geophysical Laboratory of the Carnegie Institution.

Quenching method:—By this method, the melting intervals (temperatures between solidus and liquidus) of the minerals were measured. The method used is the same as that described by BOWEN[1] in his paper dealing with the melting phenomena of plagioclase feldspars. The time, during which a definite temperature was kept, was 15 minutes in each case. The results are tabulated below. The first two experiments (the two natural anorthites) in the following table were made by a thermoelement which was employed for the determination of the heating curves given above. So the correction of the observed temperature in microvolts is the same as in the previous case (−30 M.V.). But as the artificial $Ab_5\,An_{95}$ was treated by another thermoelement at a later time, the temperature correction was made by means of the quenching charge of pure anorthite, which can be expressed in terms of the standard element. The results are given in the accompanying table (XVIII).

In order to compare these values with the data given by BOWEN,[2] calculations were made to obtain mol fractions corresponding to the temperatures 1500°C, 1530°C, 1540°C and 1545°C, using two simultaneous equations,[3]—which were derived by BOWEN from RAOULT's law[4] of vapor pressure lowering and the CLAUSIUS equation[5] for the change of vapor pressure with temperature, that is,

$$\frac{1-x}{1-x_1} = e^{\frac{L_1}{R}\left(\frac{1}{T_1}-\frac{1}{T}\right)}, \qquad \frac{x}{x_1} = e^{\frac{L_2}{R}\left(\frac{1}{T_2}-\frac{1}{T}\right)},$$

1) N. L. BOWEN: The Melting Phenomena of the Plagioclase Feldspars. Am. Jour. Sci., Vol. XXXV. June, 1913.

2) Loc. cit., p. 591.

3) In the two simultaneous equations, x and x_1 = the mol franction of albite on the liquidus and solidus respectively, L_1 and L_2 = latent heat of melting (molar) of anorthite and albite at T. respectively, R=gas constant, T_1=melting point of anorthite, T_2=melting point of albite.

4) $p=p_o\,(l-x)$, where p_o=vapor pressure of the pure solvent at any temperature, and p=partial pressure of the solvent at the same temperature, from a solution in which the mol fraction of solvent is $(l-x)$.

5) $\frac{dP}{dT} = \frac{l}{(v_1-v_2)\,T}$, where dp is the change of vapor pressure of liquid (or solid) corresponding with a change of temperature dT at absolute temperature T, l=latent heat of vaporization of one gram of the liquid (or solid) at T, v_1=the volume of one gram of the gass at T, and v_2=the volume of one gram of liquid (or solid) at T.

Table XVIII.

Temperature observed (microvolts).	Temperature corrected (microvolts).	Temperature (degrees).	Remarks.
MIYAKEJIMA ANORTHITE.			
15900	15870	1527°C	Crystals.
15925	15895	1529	Crystals.
15950	15920	1531	Crystals and glass.
16000	15970	1535	Mostly glass with a few crystals.
16050	16026	1539	Glass with a trace of crystals.
	Solidus 1530° ± 2°		Liquidus 1539° ± 2°
TARUMAË ANORTHITE.			
15850	15820	1523°C	Crystals.
15875	15845	1525	Crystals and glass.
15900	15890	1527	Crystals and glass.
15950	15920	1531	Glass with a few crystals.
15975	15945	1534	Glass with a trace of crystals.
16000	15970	1535	Glass.
	Solidus 1524° ± 2°		Liquidus 1553° ± 2°
ARTIFICIAL ANORTHITE (Ab_5 An_{95}).			
15830	15930	1532°C	Crystals.
15840	15940	1533	Crystals.
15870	15970	1535	Crystals and glass.
15900	16000	1538	Crystals and glass.
15950	16050	1542	Glass with a trace of crystals.
15970	16070	1543	Glass.
16000	16100	1546	Glass.
	Solidus 1534° ± 2°		Liquidus 1542° ± 2°
PURE ANORTHITE (ARTIFICIAL).			
16020	16120	1547°C	Crystals.
16050	16150	1550	Crystals and glass.
16100	16200	1554	Glass.
		Melting point 1550° ± 1°	

—the values 29000 and 12740 calories as the molar latent heats of melting of anorthite and albite and the temperatures 1550°C and 1100°C as their melting points. The results are given below.

Table XIX.

Temperature. (T−273)	x	x_1
1545	0.031	0.010
1540	0.077	0.025
1530	0.121	0.040
1500	0.279	0.098

The melting intervals of the artificial anorthite varieties, their chemical composition being near the anorthites under consideration, can be obtained graphically from the above figures.

Table XX.

Composition.	Solidus.	Liquidus.	Melting interval.
$Ab_2\ An_{98}$	1541°	1547°	6°
$Ab_5\ An_{95}$	1527°	1543°	16°
$Ab_7\ An_{93}$	1516°	1540°	24°
$Ab_{10}\ An_{90}$	1499°	1535°	36°

If we compare these calculated values with those obtained experimentally from the artificial $Ab_5\ An_{95}$ and the other two natural anorthites, it will be seen that the liquidus of $Ab_5\ An_{95}$ agrees well with the calculated one, but the solidus of the former is higher than that of the latter. As shown by BOWEN in table V of his paper, if we assume the latent heat L_{An} equal to the above value (29000) and the latent heat L_{Ab} slightly less (within the limit of experimental error 8 percent) than 12740, the calculated solidus will approach the experimental one. In the case of the natural anorthite, the liquidus is somewhat lower than the calculated one (5° in both cases), when they are plotted on the chart (Fig. 7) at the position of $Ab_{4.6}\ An_{95.4}$ and $Ab_{6.4}An_{93.6}$ respectively, and the melting intervals are also smaller as in the case of $Ab_5\ An_{95}$. Generally, however, those deviations are small and it may be concluded that the melting phenomena of the anorthite from Miyakejima and Tarumaé agree well with results obtained by BOWEN.

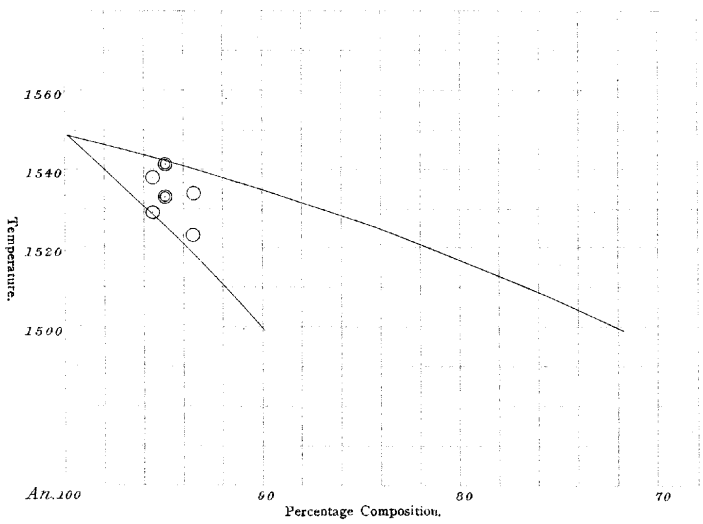

Fig. 7. The diagram shows the relation between the melting intervals observed by the writer and those given by BOWEN. The curves of liquidus and solidus were drawn by the figures given in table XIX. Double circles show the liquidus and solidus points of the Artificial $Ab_5\ An_{95}$ and the two sets of single circles show those of the anorthites from Miyakejima and Tarumaé.

2. Index of Refraction of the Anorthite Glass.

The refractive indices of the anorthite glasses were measured by the total reflectometer for the red (671 $\mu\mu$), yellow (589 $\mu\mu$), green (535 $\mu\mu$) and Blue (486 $\mu\mu$), rays, obtained by a spectrometer. In order to obtain more accurate data and to enable us to find out the accuracy of the former results, the refractive indices for the sodium ray were determined again by the method of minimum deviation on a goniometer with standardized circles. The results are given in the accompanying table.

Table XXI.

Anorthite glass.					
	Miyakejima.		Tarumaé.		$Ab_5 An_{95}$.
	Total reflectometer.	Goniometer.	Total reflectometer.	Goniometer.	Goniometer.
Red (671 $\mu\mu$)	1.5688		1.5679		
Yellow (589 $\mu\mu$)	1.5717	1.5721	1.5713	1.5716	1.5707
Green (535 $\mu\mu$)	1.5748		1.5741		
Blue (486 $\mu\mu$)	1.5796		1.5791		
Mean index[1] of refraction of the anorthite crystals.					
Red (671 $\mu\mu$)	1.5774		1.5778		
Yellow (589 $\mu\mu$)	1.5809		1.5809		1.580[2]
Green (535 $\mu\mu$)	1.5842		1.5841		
Blue (486 $\mu\mu$)	1.5881		1.5882		

1 The mean index of refraction was obtained by $\frac{\alpha+\beta+\gamma}{3}$.

2 This value was obtained by the immersion method.

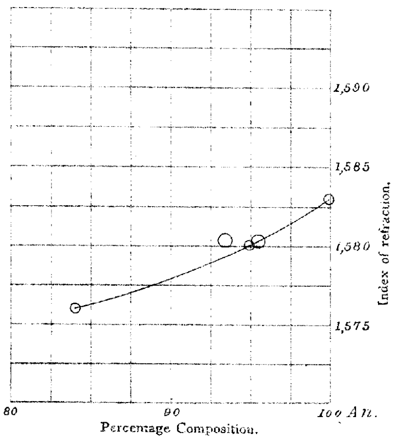

Fig. 9. The diagram shows the mutual relation between the mean indices of refraction of the artificial and natural anorthites. Smaller circles indicate the mean refractive indices of the artificial minerals and larger circles those of the natural anorthites.

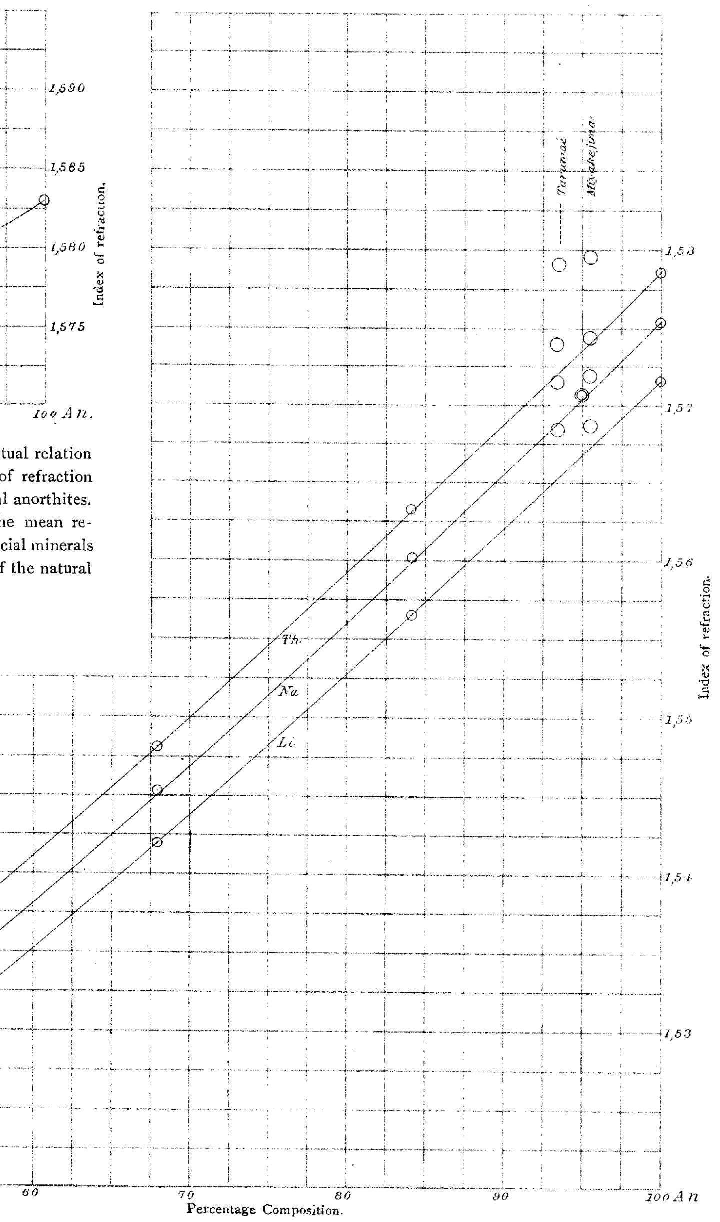

Fig. 8. The diagram shows the relation between the refractive indices of the glasses of the artificial and natural anorthites.

Smaller circles show the refractive indices of the glasses of the artificial An, Ab_1An_2, Ab_1An_5 and Ab_1An_1, for the Li, Na and Th rays, given by LARSEN.

Larger circles show the refractive indices of the natural anorthite glasses for the four rays with the wave lengths of 671 μμ, 589 μμ, 535 μμ and 486 μμ.

Double circle shows the refractive index of the glass of the artificial Ab_5An_{95} for the sodium ray.

3. Specific Gravity.

The specific gravity of the anorthite crystals and their glasses were determined by means of a WESTPHAL'S balance, using THOULET'S solution, and by MERWIN'S method,[1] at room temperature, ranging from 20° to 22° C.

Table XXII.

	Miyakejima.		Tarumaé.		$Ab_5 An_{95}$.	
	Crystal.	Glass.	Crystal.	Glass.	Crystal.	Glass.
I	2.758	2.682	2.756	2.681	...	...
II	2.758	2.684	2.757	2.683	2.755*	2.682*
Mean	2.758	2.683	2.757	2.682		

I MERWIN'S method.
II WESTPHAL'S balance.

Those marked with an asterisk are the values obtained graphically, using the specific gravites of the chemically synthesized feldspars and their glasses determined by DAY and ALLEN.[2]

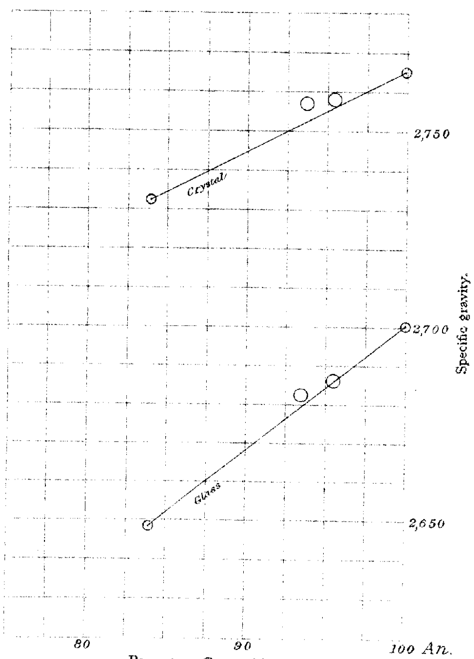

Fig. 10. The diagram shows the relations between the specific gravities of the artificial and natural anorthites and their glasses.

4. Specific Volume and Specific Refractive Energy.

Specific volumes and specific refractive energies of the anorthites and their glasses under consideration can be easily obtained from the figures in the two previous tables. The specific refractivity was tested by the two different equations given by GLADSTONE and DALE and by LORENTZ and LORENTZ. These results are tabulated as follows:

1) H. F. MERWIN: A Method of Determining the Density of Minerals by Means of Rohrbach's Solution having a Standard Refractive Index. Am. Jour. Sci. Vol. XXXII, Dec., 1911.

2) A. L. DAY and E. T. ALLEN: The Isomorphism and Thermal Properties of the Feldspars. Carnegie Institution of Washington publication, 1905, p. 58.

Table XXIII.

	Miyakejima. Crystal.	Miyakejima. Glass.	Tarumaé. Crystal.	Tarumaé. Glass.	$Ab_5\,An_{95}$. Crystal.	$Ab_5\,An_{95}$. Glass.
$\frac{1}{D}$	.3626	.3727	.3627	.3729	.3630	.3729
$\frac{n-1}{D}$	.2106	.2132	.2107	.2131	.2105	.2128
	.0026		.0024		.0023	
$\frac{n^2-1}{n^2+2}\cdot\frac{1}{D}$ ...	.12082	.12265	.12086	.12261	.12080	.12245
	.00183		.00175		.00165	

The specific volumes of the three kinds of anorthite agree well, within the limits of experimental errors, with the data given by DAY and ALLEN[1] (see the chart in their paper), especially in the case of the glasses.

The specific refractive energies of the glasses agree fairly well when we compare them with the corresponding values given by LARSEN,[2] though the values of the natural anorthite glasses are slightly higher, while those of the crystals show poorer agreement and are fairly lower than those of the glasses. The differences between them, as seen in table XXIII, are usually greater for the values computed by the equation of GLADSTONE and DALE.

General Summary.

The optical properties which were summarized in the foregoing pages are not needed to be repeated here, but it is specially noticeable that the Miyakejima and Mitaki anorthites are considerably different from the Tarumaé mineral on the character of dispersion of the optic axes. In order to examine other characters corresponding to the above difference; chemical analyses, fusion phenomena, densities and refractive indices of the fused materials of the anorthites were tested. These experiments were undertaken in parallel with the artificial anorthite ($Ab_5\,An_{95}$), which is close, chemically, to the natural anorthite under consideration. The chemical analyses of the anorthite crystals from Miyakejima and Tarumaé were made by Dr. WASHINGTON. According to the results, these minerals may be indicated by the notations $Ab_{3.9}An_{95.4}Cg_{0.7}$ and $Or_{0.6}Ab_{4.7}An_{92.6}\,Cg_{2.0}$. The melting points determined by heating curve are 1538°C±2° for the Miyakejima anorthite and 1536° C±2° for the Tarumaé anorthite; and solidus and liquidus determined by the quenching method are:

	Ab_5An_{95}	Miyakejima.	Tarumaé.
Solidus	1534°C±2°	1530°±2°	1524°±2°
Liquidus	1542°C±2°	1539°±2°	1535°±2°

The refractive indices and specific gravities of the natural anorthite glasses were determined, as seen in tables XXI and XXII. For convenience of comparing these physical properties of the natural mineral with the artificial one on charts, the chemical formulae of the anorthites from Miyakejima and Tarumaé were taken as $Ab_{4.6}\,An_{95.4}$ and $Ab_{6.4}\,An_{93.6}$ respectively, these being obtained by reckoning the small quantities of potash and soda as orthoclase and carnegieite with the albite molecule. If, under this condition, we compare the physical properties of the natural anorthites with those of the chemically corresponding artificial ones, it will be seen, as shown in the figures given previously, that all the properties of the former accord fairly well with those of the latter. The differences, in the case of the Miyakejima

1) Loc. cit., p. 72.

2) E. S. LARSEN: The Relation between the Refractive Index and the Density of Some Crystallized Silicates and Their Glasses Am. Jour. Sci., Vol. XXVIII, September, 1909.

anorthite, are so small that they can be taken as experimental errors; while in the case of the Tarumaé mineral, they are larger and usually higher than those of the corresponding artificial mineral, except with the values of liquidus and solidus. Whether such difference is essentially based upon the presence of the carnegieite molecules in the mineral is uncertain, because the relations between optical and chemical properties are reverse to those of the Linosa feldspar, described by WASHINGTON and WRIGHT.[1]

Summarizing more briefly: the anorthite from Miyakejima agrees well with the corresponding artificial anorthite ($Ab_3 An_{97} - Ab_5 An_{95}$) in all the properties given above; while the Tarumaé mineral shows physically and chemically somewhat larger deviation from the corresponding artificial one. Whether this deviation of the physical properties mentioned above depends essentially upon the chemical character shown by the analysis still remains a question.

My sincere thanks are due to Dr. E. F. WRIGHT and Dr. H. E. MERWIN in the Geophysical Laboratory of the Carnegie Institution of Washington, under whose guidance I made these optical experiments in the Laboratory. I am also greatly indebted to Dr. H. S. WASHINGTON for the chemical analyses of the anorthites from Miyakejima and Tarumaé, and to Dr. OLAF ANDERSEN and Dr. N. L. BOWEN for assistance in using the electric furnace.

1) WASHINGTON and WRIGHT: A Feldspar from Linosa and the Existence of Soda Anorthite (Carnegieite). Am. Jour. Sci., Vol. XXIX, January, 1910.