ART. XXVIII.—*Studies on the Etched Figures of Japanese Quartz*; by SHIMMATSU ICHIKAWA. With Plates II to VII.

Introduction.

IN 1910 I published in Japanese a paper with the title "Studies on the etched figures of Japanese Quartz." The present article may be regarded as an abridged translation of that work, with only slight changes. My memoir gives an outline of the studies carried on by me during the four years 1905 to 1908. These studies are being continued and a second report with further details will be published later. I am desirous of receiving any suggestions or criticisms from those who may read this paper in regard to any of the points discussed in it.

1. *Artificial Etching of Japanese Quartz* (with Plate II).

The artificial etching of quartz crystals by hydrofluoric acid has already been described by Dr. G. Molengraaff;* the transformations of the original form of the crystal, however, have not yet been discussed in detail. In 1910 I made similar experiments on Japanese rock crystal and observed an interesting new form of elevations (*Aetz-hügel*) produced by etching, and a few new varieties of pits or depressions (*Aetz-grübchen*). The results of this study are illustrated in the accompanying plate (Plate II).

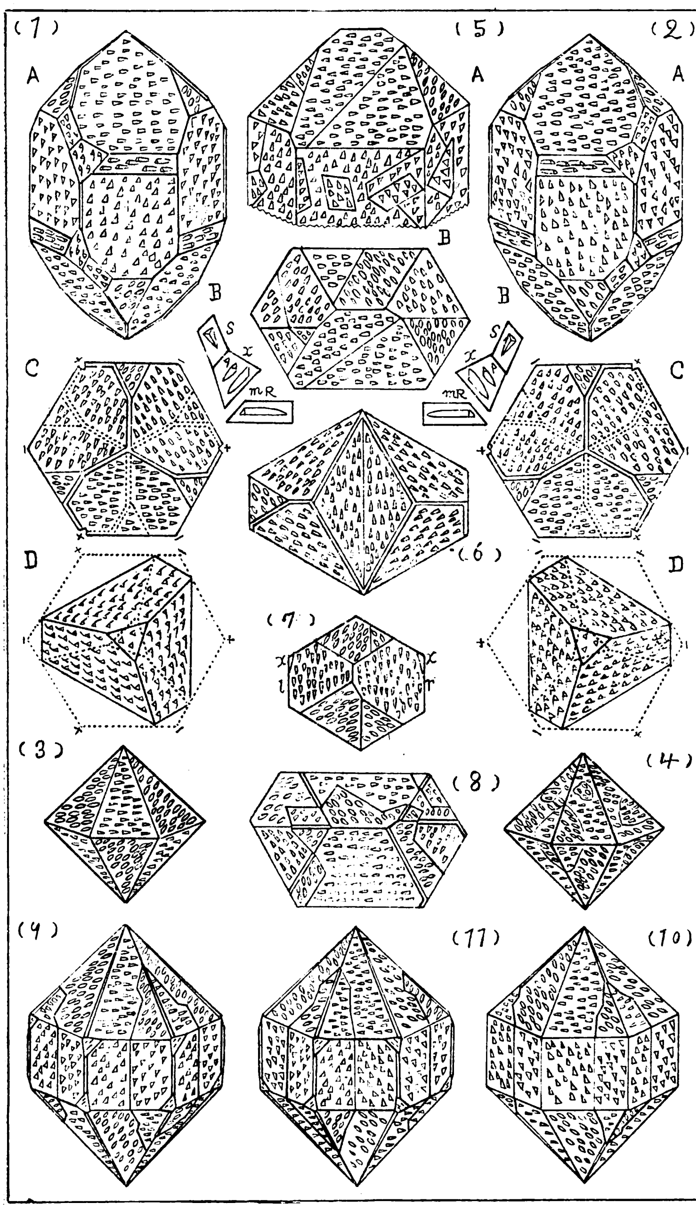
Plate II (*Concentration of hydrofluoric acid, 55 per cent*).

The grooves on the edges formed by etching can be barely observed by the naked eye, and the pits on the faces can only be investigated minutely under a magnification of 75 to 140 times.

Fig. 1, A, shows etched figures on a left-handed rock crystal from Takemori, Kai Province; the double lines on the edges indicate the grooves produced by etching. B shows the figures on the faces $s\left(\frac{2P2}{4}\right)$, $x\left(\frac{mPn}{4}\right)$ and mR, etc.; the pits on mR much resemble those formed by the combination of the two sets on R and ∞R. C is a horizontal projection on the vertical axis of fig. A; the dotted lines are the edges as seen from the opposite pole. D shows the form remaining after the crystal of fig. 1, A, had been etched for seven weeks, the dotted hexagon giving the position of the axes; the form much resembles the

* Zs. Kr., xiv, 173, 1888, etc.

PLATE II.



Artificial etching of Japanese Quartz. S. Ichikawa, del.

outline of a trigonal trapezohedron and has pits of 7-like shape on its faces. Fig. 2 is a right-handed crystal from the same locality, A, B, C, and D corresponding to A, B, C, and D of fig. 1.

Fig. 3 shows the etching of a left-handed quartz, forming phenocrysts in a quartz-prophyry from Otomezaka, Kai Province. Fig. 4 is on a Dauphiné twin of right-handed quartz from the same locality. Fig. 5, A, is a Brazilian twin of rock crystal from Takemori; B, a horizontal projection on the vertical axis of A.

Fig. 6 is a horizontal projection on the vertical axis of the parallel-growth of left-handed and right-handed rock crystals from Yusenji, Kaga Province. Fig. 7 shows the same for a rock crystal from Kinbuzan, Kai Province; the crystal appears like a simple crystal, but has a trigonal trapezohedron on its left and right sides.

Fig. 8 is an etched Dauphiné twin of right-handed rock crystal from Takemori, in horizontal projection on its vertical axis. Fig. 9 is a front view of a model-crystal of left-handed Dauphiné twin; fig. 10 one of a right-handed Dauphiné twin, and fig. 11 of a Brazilian twin.

The symmetry of the pits on the above crystal faces, and the position of the grooves on the edges, correspond to the trapezohedral symmetry. The pits on the rhombohedron, trigonal pyramid and trapezohedron, etc., can be formed by dilute acid, but those on the prism can be obtained distinctly only by pure acid. The trigonal pits and 7-like shaped depressions in fig. 1, D, etc., are formed by a more dilute acid than in the other two cases. The grooves on the edges of the prism can not be formed so regularly as those on the rhombohedral edges, etc.

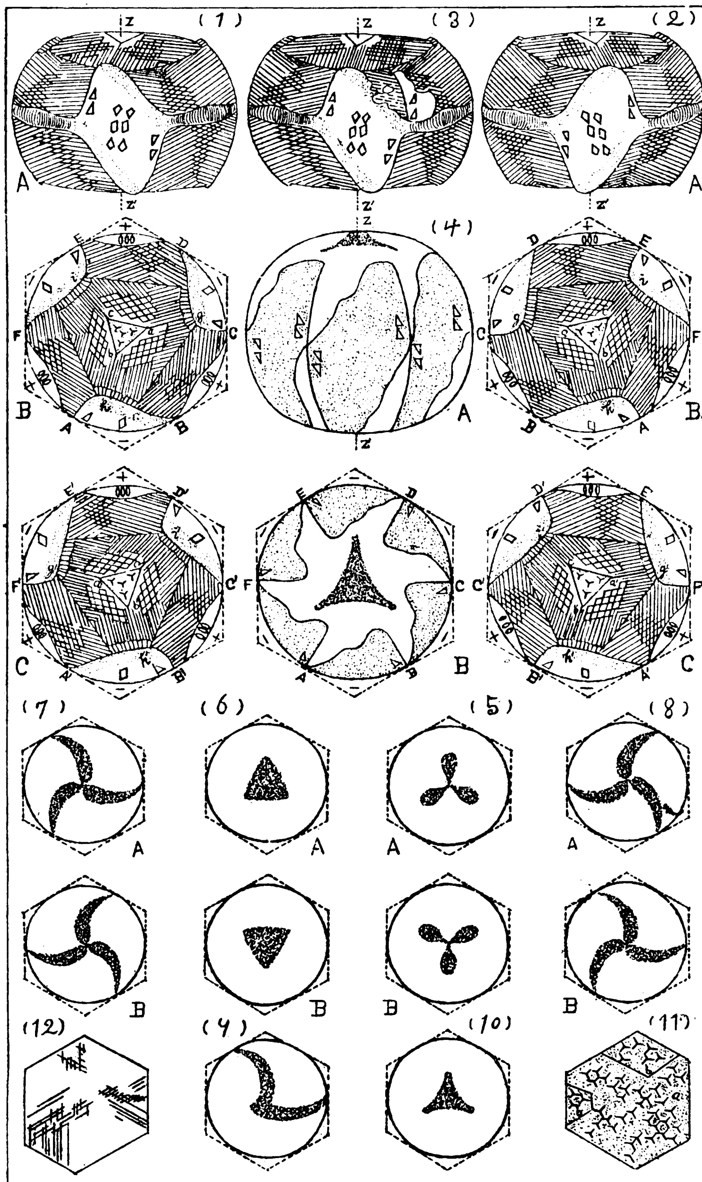
The extremities of the vertical axis are more quickly dissolved away than the lateral axes, and those of the positive lateral axes more quickly than those of the negative lateral axes; therefore, the resulting form in the etching proves to be a form resembling a trigonal trapezohedron.

2. *Artificial Etched Figures of some Spheres of Japanese Rock Crystal* (with Plates III and IV).

The artificial etching of a quartz sphere with hydrofluoric acid has already been described by Dr. Otto Meyer and Samuel L. Penfield.* In that paper, however, the order in which the modifications of the sphere occur, in the interval between the beginning and end of the corrosion, has not been

* Transactions of the Connecticut Academy of Arts and Sciences, vol. viii, pp. 158–165, 1889.

PLATE III.



Artificial etched figures of some spheres of Japanese rock crystal. S. Ichikawa, del.

described in detail. In 1909, I made similar experiments with rock crystal from Kinbuzan, and observed the dull figure formed on each pole of the vertical axis of the etched sphere at the beginning of the corrosion, which is modified as the etching is continued. I also observed a few interesting varieties of the elevations (*Aetz-hügel*), which may be called ridges or terraces; these are formed on each pole of the vertical axis in more advanced stages of the etching, and can be modified by the concentration of the acid, etc.* The results of the study of these etched spheres are illustrated in the accompanying plates (III and IV).

Plate III. (*Concentration of hydrofluoric acid*, 55 *per cent.*)

The dull figures, striations, etc., on the surface of the etched spheres can easily be observed by the naked eye, but the minute study of the ridges, pits, etc., on their surface require a magnification of 75 to 140 times.

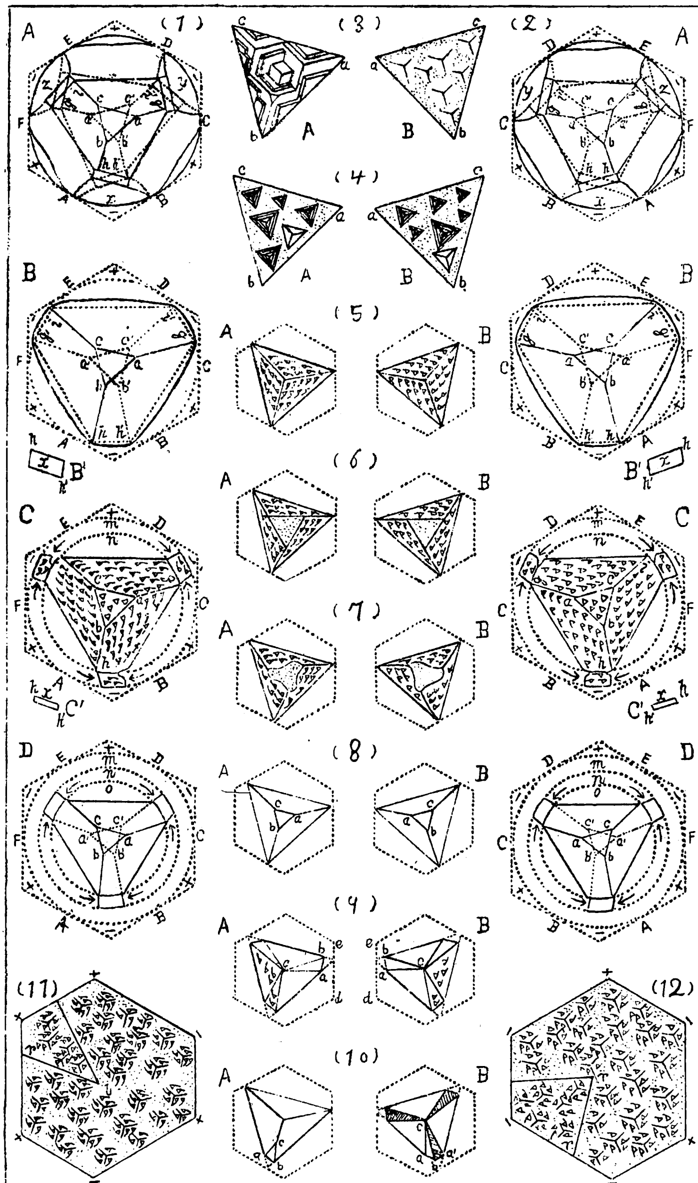
Fig. 1, A, shows a front view of a sphere of a left-handed rock crystal, the dotted line (z z') showing the direction of the vertical axis; B, is a basal view; C, that of a pole seen from the other pole. Fig. 2 is a sphere of a right-handed crystal; A, B, and C corresponding to A, B, and C of fig. 1. Fig. 3 is a sphere of an irregularly developed left-handed Dauphiné twin. Fig. 4 shows a sphere of a regularly developed right-handed Dauphiné twin; A, a front view; B, a basal view.

Fig. 5 shows the dull figures formed on each pole of a sphere of a right-handed Dauphiné twin at the beginning of corrosion; weak acid was employed. A, is a horizontal projection of a pole of the vertical axis of the sphere; B, that of a pole seen from the other pole; the figures do not reveal the direction of rotation. Fig. 6 is a sphere of a left-handed Dauphiné twin, A and B corresponding to A and B of fig. 5; here, also, the figures do not reveal the direction of rotation. Fig. 7 is a sphere of of a left-handed crystal more etched than those of figs. 5 and 6, thus revealing the direction of rotation; A and B correspond to A and B of fig. 5. Fig. 8 is a sphere of a right-handed crystal, corresponding to fig. 7.

Fig. 9 is a horizontal projection of a sphere of an irregularly developed left-handed Dauphiné twin. Fig. 10 is a dull figure on a sphere of a regularly developed Dauphiné twin; both poles of the vertical axis are observed horizontally, but when more etched, the direction of rotation is revealed as in fig. 4. Fig. 11 is a plate cut perpendicularly to the vertical axis of a right-handed Dauphiné twin, the plate shows the ridges observed

*See Journal of the Geological Society of Tōkyō, vol. xvi, p. 197, 1909; xvii, 320, 371, 1910.

PLATE IV.



Artificial etched figures of some spheres of Japanese rock crystal. S. Ichikawa, del.

on the pole of the etched sphere as in fig. 2 B, indicating a revolution of 60° about the vertical axis. Fig. 12 is the same as fig. 11, and the striations on its section show numerous regularly arranged ridges.

Plate IV.

Fig. 1, A, shows the outline of the sphere in fig. 1 of Plate III: A, observed horizontally through both poles of the vertical axis, the dotted hexagon showing the position of the axes. B, is the same as A, but it is more etched, and its outline resembles a trigonal trapezohedron as in Plate II, fig. 1, D; the dotted circle shows the original outline of the sphere. B′, is a front view on *h h′* of the negative end of the lateral axis (compare (*x*) in fig. A). C, is more etched than B, and shows that a part of the negative end of the lateral axes at the external part of the dotted circle (*n*) is just about separated from the direction of the intermediate axes; the structure in the internal part of the circle corresponds to the structure of Plate II, fig. 1, D. C′ is the same as B′. D, shows a sphere more etched than C; the part within the dotted circle (*n*) successively repeats the action as in fig. C, and gradually dissolves away. Fig. 2, A, those in Plate III, fig. 2, A, and B, B′, C, C′ and D correspond to B, B′, C, C′, and D of fig. 1.

Fig. 3 shows horizontal projections of the trapezohedral elevations formed on the base-like face of (*a b c*) at a pole of the etched sphere, A, left and B, right. Fig. 4 shows horizontal projections of these negative and positive trapezohedral elevations formed on base-like faces (*a b c*) at a pole of the etched sphere, A, left and B, right. Fig. 5 shows, magnified, the individual elevations of figs. 3 and 4, and has pits of 7-like shape on its faces; the dotted hexagon shows the position of the axes, A, left and B, right. Fig. 6 is more etched than fig. 5 and has a rough base-like face; the ridges are a little twisted to the left or right of the vertical axes. Fig. 7 is still more etched, the ridges being very much twisted like a left-handed or right-handed distorted quartz.

Fig. 8 shows the trapezohedral elevations with regularly developed base-like face. Fig. 9 shows the pole edges truncated by a trapezohedral face with different coefficient from itself. Fig. 10 shows forms of peculiar shape very rarely observed.

Fig. 11 shows the etching figures formed on a plate cut perpendicular to the vertical axis of a Brazilian twin, revealing the direction of rotation, and in the section, each area of the left (*l*) and right-handed (*r*) crystals is indicated as distinctly as in polarized light. Fig. 12 shows a Dauphiné twin as fig. 11.

The symmetry of the dull figures (except in Plate III, figs. 5 and 6) on the surface of these etched spheres exhibits the symmetry of the trapezohedral group to which they belong.

Both poles, in the vertical axis of the etched sphere, are more quickly dissolved away than the equator, and the positive ends of the lateral axes more quickly than the negative ends; the result is, therefore, a trapezohedral form as in those of the simple crystal of the quartz with bipyramid (Plate IV, fig. 1, B, compare Plate II, fig. 1, D.).

A sphere of a regularly developed Dauphiné twin reveals the twelve dodecants on its surface by etching, with the vertical axis and intermediate axes, and each dodecant is occupied by the positive and negative lateral axes; therefore when each dodecant belonging to the area of the positive or negative lateral axes of a simple quartz crystal is revolved 60° about the vertical axis, the quartz is supposed to make up the given regular Dauphiné twin.

The etching of basal sections cut perpendicular to the vertical axis of twin crystals reveals the revolved or interpenetrated areas and also the direction of the rotation: the etching of such sections is, therefore, an important method of the determination of a twin crystal.

When the acid is near concentration the section yields trapezohedral elevations (see Plate III, fig. 11), but if very weak the surface shows the negative crystal of the trapezohedral ridges (see Plate III, fig. 4); also if the section is kept in the very weak acid, depressions of 7-like shape are formed on the surfaces of the elevations (see Plate IV, figs. 11 and 12), and these are gradually twisted to the left or right of the vertical axis (see Plate IV, figs. 6 and 7.) Hence, the phenomena prove that the direction of the molecular dissociation in the etching corresponds to that of the circular polarization.

In etching hexagonal prisms or columnal seals, etc., of rock crystals it is found that they are attacked rapidly in the direction of the vertical axis, but barely at all in the direction of the lateral axes; the specimens are, therefore, gradually modified into thinner hexagonal or rounded forms, and at last are wholly dissolved away.

When etched basal sections, as Plate IV, figs. 11 and 12, etc., are again placed in the pure acid the sections are modified into a translucent, smooth plane by violent action of the acid, but after a day or two the ridges are again formed on the surface, and after three or four days 7-like depressions are formed, and after a week these are twisted in a direction to the left or right of the vertical axis.

The development of etching figures on the poles of the vertical axis of a sphere or a basal section, etc., of quartz crystal is closely connected with atmospheric pressure and temperature concentration of solvent, etc.; hence it is difficult to reproduce exactly results earlier obtained.

3. *Natural Etched Figures of Japanese Quartz* (with Pl. V).

The natural etching of quartz crystals has already been described by Dr. G. Molengraaff;* in these papers, however, the transformation of the edges has not yet been described in detail. In 1908 I first observed the natural etching of amethyst from Yusenji, Kaga Prov., with grooves on the edges; since then I have visited many quartz localities in Japan and collected some interesting new specimens of natural etching;† the results of the study of these are illustrated in the following plate:

Plate V.

The transformation of the edges and the depression of fig. 10, etc., can be observed by the naked eye, but the pits on the crystal faces of other specimens can not be investigated minutely unless under a magnification of 75 to 140 times.

Fig. 1 shows the natural etching of a left-handed amethyst from Yusenji, Kaga Prov. A is a front view, and the double lines on the edges of the rhombohedron and prism of the crystal show the grooves formed by etching. B is a horizontal projection on a rhombohedral face. C a horizontal projection of the section cut perpendicularly to the vertical axis. Fig. 2 shows the natural etching of a right-handed amethyst from the same locality, A, B, and C corresponding to A, B, and C of fig. 1. Fig. 3 is the natural etching of a Dauphiné twin of left-handed amethyst and fig. 4 a similar right-handed twinned amethyst, A, B, and C corresponding to A, B, and C of fig. 1 in each case.

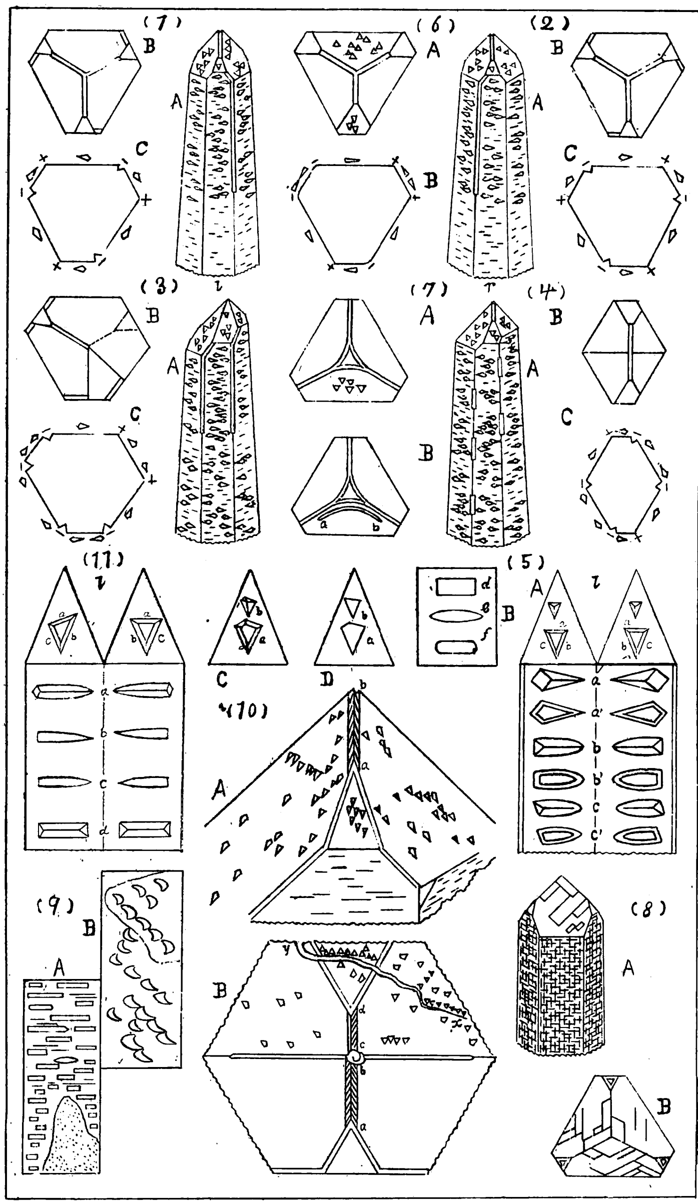
Fig. 5, A, shows varieties of natural pits on the rhombohedron and prism of fig. 1, A, but the pits on the former do not reveal the difference between positive and negative forms. B shows pits on the prism of the same crystal that are very rarely observed, but they do not reveal the direction of rotation.

Fig. 6 is the natural etching of an amethyst from Ozawa, Iwaki Prov. A is a horizontal projection on the rhombohedron of the same crystal, and the double lines on the edges show a new face formed by etching that looks like $-\frac{1}{2}R$. B is a horizontal projection on the section cut perpendicular

* See Zs. Kr., xiv, 173, 1888; xvii, 137, 1889.

† See Jour. Geogr. Tōkyō, vol. xv, 235 and 441, 1908; xvi, 129, 1909; xvii, 320, 1910.

PLATE V.



Natural etched figures of Japanese quartz. S. Ichikawa, del. (except fig. 11).

to the vertical axis of the crystal, and its negative edges are rounded by the etching.

Fig. 7 gives horizontal projections on the rhombohedron of rock crystals with natural etching from Yusenji; the double lines show rounded edges by etching, and a triangle on the center shows a pit that is produced in the direction of the vertical axis by etching. (*ab*) in fig. B shows a groove that is formed on the rhombohedron by etching. The direction of rotation is not shown.

Fig. 8 is the natural etching of rock crystals from Kamioka-mine, Hida Prov.; its rhombohedron has ridges suggesting the trapezohedral form found on the poles of the etched quartz sphere (see Pl. III, figs. 1 and 2, B, C, and Pl. IV, fig. 3, A, etc.), A is a front view, and B a horizontal projection on a rhombohedron. Fig. 9 is the natural etching on the prism of a rock crystal from Kinbuzan; the depressions in A much resemble those of fig. 5, B.

Fig. 10 is the natural etching of a smoky quartz from Kamikane, Kai Prov. A gives a front view, and B a horizontal projection on the vertical axis of A; the double line on each edge shows a new face formed by etching that resembles that of fig. 6, A. Both sides of the pole edges of (*ab*) and (*cd*) have striations formed by etching, and the angle is larger than the normal angle of quartz; (*xy*) shows a fissure with many depressions. C shows varieties of the natural pits on the rhombohedron. D shows the difference between the outlines of a natural depression of Molengraaff (*b*) and I(*a*) on a rhombohedron of quartz.

Fig. 11 shows varieties of the natural pits on the rhombohedron and prism of a foreign quartz which Molengraaff first observed (compare fig. 5, A). See also the results of Dr. K. Jimbo on the natural etching of a rhombohedron of Japanese quartz.*

The natural pits on the rhombohedron of fig. 5, A, do not reveal the distinction between the positive and negative forms as do those in fig. 11 taken from Molengraaff's work. Also while the natural depressions on the prism of fig. 5, A, and fig. 9, B, etc., reveal the direction of rotation, the symmetry of the natural pits on the prisms of fig. 5, B, and on the rhombohedron of fig. 5, A, do not correspond to the trapezohedral symmetry; therefore the method that determines the positive and negative rhombohedrons by Molengraaff's model figure (fig. 11) cannot be applied to natural etching of the above Japanese quartz.

The varieties of edges modified by etching are classified as follows: 1 has grooves (figs. 1, 2, etc.), 2 is rounded (fig.

* Jour. Geogr., Tōkyō, vol. iv, 172, 187, 1897.

6, B), 3 has a new face like $-\frac{1}{2}R$ (figs. 6, A, and 10, A, etc.), 4 has a larger angle than the normal angle (fig. 10, B). The position of grooves on the prismatic edges of natural etching is opposite to that of quartz crystal etched with hydrofluoric acid.

4. *Vicinal Faces of Japanese Quartz* (with Plate VI).

Artificial and natural etching of quartz crystal have already been described by mineralogists, but not the characteristics of the vicinal faces of the crystal, which are closely connected with these etching figures. In 1909, I first observed a smoky quartz from Tanokamiyama, Ōmi Province, with a different vicinal face on its positive and negative rhombohedral faces; since then I have collected a number of interesting quartz crystals with vicinal faces accompanied by natural etching on a rhombohedral face.* The results of the study of these vicinal faces are illustrated in the following plate:

Plate VI.

The size of the vicinal forms on the rhombohedral faces is larger than the natural pits on the same face, and they can usually be observed by the naked eye.

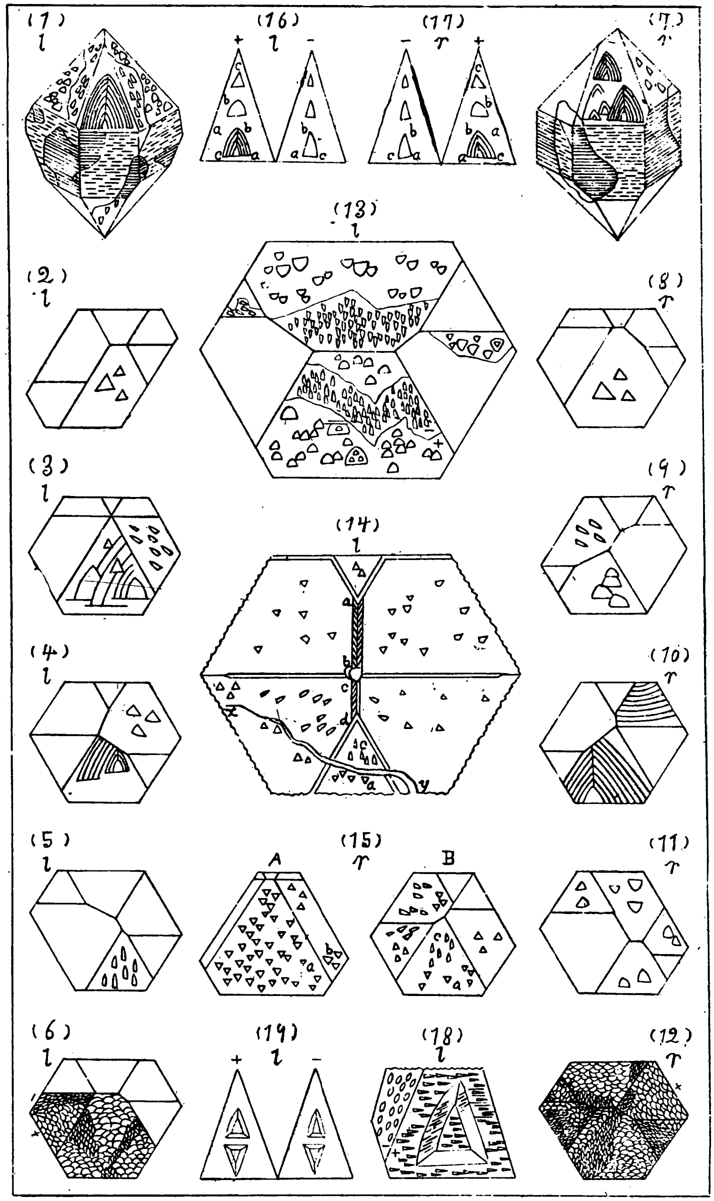
Fig. 1 shows vicinal faces on a Dauphiné twin of left-handed rock crystal from Kinbuzan. Fig. 2 is a horizontal projection on a pyramid of a left-handed cairngorm with vicinal faces from Naigi, Mino Province. Fig. 3 is a left-handed smoky quartz from the same locality as fig. 2. Fig. 4 is a left-handed rock crystal from Takemori. Figs. 5 and 6 are left-handed rock crystals from Kinbuzan; fig. 6 is a Dauphiné twin with numerous irregularly developed vicinal faces.

Figs. 7 and 8 are right-handed smoky quartz from Tanokamiyama, Ōmi Province; fig. 7 is a Dauphiné twin. Fig. 9 is a Dauphiné twin of right-handed smoky quartz from Naigi. Fig. 10 is a right-handed rock crystal from Takemori. Fig. 11 is a Dauphiné twin of right-handed smoky quartz from Tamokamiyama. Fig. 12 is a Dauphiné twin of right-handed rock crystal from Kinbuzan; the pyramid has innumerable irregularly developed vicinal faces.

Fig. 13 is a Dauphiné twin of left-handed smoky quartz from Tanokamiyama. Fig. 14 is a Dauphiné twin of left-handed smoky quartz from Kamikane, already shown in Plate V, fig. 10, B; the pyramid has many vicinal faces and natural depressions on its surface. Fig. 15 is a right-handed rock crystal from Kinbuzan, with a few vicinal faces and many natural pits; A and B show the pyramid on both ends of the prism.

*Jour. Geogr. Tōkyō, vol. xvi, 495, 1909; xvii, 239, 1910, and the correction in vol. xvii, 526, 1910; vol. xviii, 82, 1911.

PLATE VI.



Vicinal faces of Japanese quartz. S. Ichikawa, del.

Fig. 16 is a model figure showing varieties of the vicinal faces on the positive and negative rhombohedrons of left-handed quartz and the relation between their outlines to the edges on the positive and negative rhombohedral faces. Fig. 17 shows those on the rhombohedron of right-handed quartz.

Fig. 18 gives the vicinal faces on a rhombohedron of a Dauphiné twin of left-handed rock crystal from Takemori; the character of the rhombohedron is determined by hydrofluoric acid. Fig. 19 shows the relation between regular vicinal faces and natural depressions on a rhombohedron of left-handed quartz, and also the relation between their outline and the edges on the rhombohedron face.

In each of the above figures the symmetry of the vicinal face on the rhombohedron of the quartz crystals corresponds to the trapezohedral symmetry, and it also reveals the distinction between positive and negative forms and the difference between the left-handed and right-handed crystals; therefore, the vicinal faces are a profitable subject for investigation of quartz.

In figs. 14 and 15, the natural etched figures do not reveal the distinction between the positive and negative rhombohedrons, but the vicinal faces show this distinction. The vicinal faces of Japanese quartz are found in smoky quartz rather than in rock crystal, and the faces with them have a stronger luster than those without.

5. *Theoretical Figures showing the Molecular Structure of Rock Crystal* (with Plate VII).

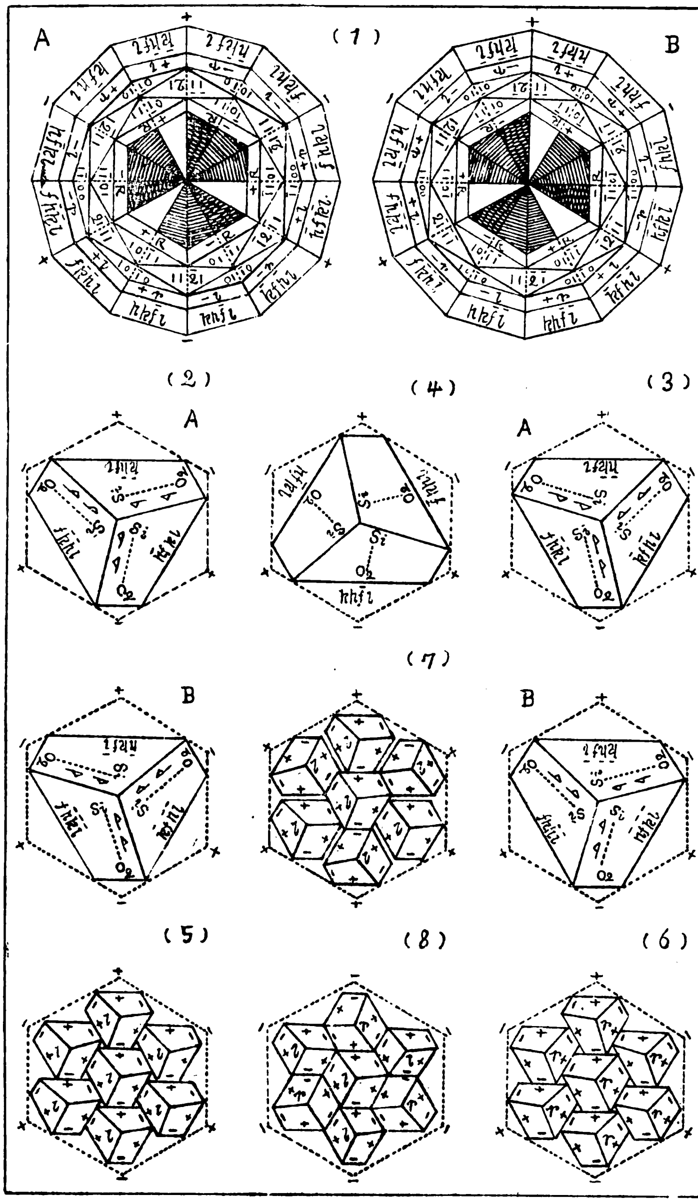
Theoretical figures, showing the molecular structure of rock crystal, have already been described by Lord Kelvin* and Dr. S. Nakamura.† In 1910, I also made a model of the crystal molecule corresponding to the trapezohedral form developed by hydrofluoric acid, and also investigated the molecular structure; the theory of this is illustrated in the following plate:

Plate VII.

Fig. 1 shows the various types of crystal faces occurring on rock crystal and the relation between them; the striations in the center of the figure give the position of the four trapezohedrals derived from the dihexagonal pyramid. The faces of these forms are commonly seen to the left or right of the prismatic edges, corresponding to the positive lateral axes, but the prismatic edges of the negative lateral axes do not have these faces (see Plate II, figs. 1 and 2, A). A gives the left-handed faces, and B the right-handed.

* Baltimore Lectures, pp. 602–642, 1893.
† Rigakukuwaishi, vol. iii, No. 13, p. 12, 1910.

PLATE VII.



Theoretical figures showing the molecular tactics of a rock crystal. S. Ichikawa, del.

Fig. 2 is a theoretical figure showing the structure of a crystal-molecule of left-handed quartz, in which it is assumed that six molecules of silica (SiO_2) go to form the six faces of the trapezohedral form produced by etching; the atom of silicon (Si) with the positive ion takes its place in the direction of the positive lateral axes, and the atom of oxygen (O) with the negative ion takes its place in the direction of the negative lateral axes. The dotted hexagon shows the position of the axes and its internal part represents the limit of area of the crystal-molecule ($6SiO_2$). A is a horizontal projection on a pole of the vertical axis of the crystal-molecule; B that on a pole seen from the other pole. Fig. 3 is a theoretical figure showing the structure of the crystal molecule of right-handed quartz crystal; A and B correspond to A and B of fig. 1. Fig. 4 shows a left-handed trapezohedron (in a position opposed to that of fig. 2), supposed to be formed by natural etching (K_2CO_3).

Fig. 5 is a theoretical figure showing the structure of the crystal-molecules of a simple left-handed crystal; seven crystal-molecules are grouped regularly in the direction of the intermediate axes, and they are combined with each other by the energy of the positive and negative ions. Fig. 6 shows the same on a right-handed quartz crystal.

Fig. 7 is a theoretical figure showing the molecular structure of a left-handed Dauphiné twin, in which it is assumed that the crystal-molecule at the end of each negative lateral axis is revolved 60° about the vertical axis. Fig. 8 is a similar figure of a Brazilian twin of rock crystal in which it is assumed that the crystal-molecule belonging to the area of the negative lateral axes of a right-handed quartz penetrates into the area of the positive lateral axes of a left-handed quartz.

The symmetry of the crystal-molecule (six molecules of silica (Si_2O) with geometric arrangement) in the above figs. 2 and 3 corresponds to the symmetry of the trapezohedron, and the crystal-molecule thus reveals the trigonal symmetry by the revolution about the vertical axis, and the binary symmetry by the revolution about the lateral axes, and it has neither center nor plane of symmetry.

In the above models the structures of simple crystals and twin crystals of the given quartz are readily understood, and there are also numerous cases where the physical and chemical reactions by which the molecules act upon other adjacent molecules can be well explained by the models; a few examples are mentioned in the following:

When a quartz crystal is kept in strong hydrofluoric acid, a groove will be found on each positive edge of its prism (see Plate II, figs. 1 and 2, etc.); if we assume that the prismatic positive edges with positive ion (Si), which belong to the territory of the positive lateral axes are attacked by the acid with negative ion (F), the phenomenon will be easily understood.

When quartz crystal is naturally etched, a groove will be found on each negative edge of its prism (see Plate V, figs. 1 and 2, etc.); this is understood if we assume that the prismatic negative edges with negative ion (O), which belongs to the area of the negative lateral axes, are attacked by a natural solvent (salt of K, Na, etc.) with positive ion.

Rhombohedral pole edges of the combination of $+R$ and $+R$ or $-R$ and $-R$ in a quartz crystal develop a groove in hydrofluoric acid, and the edges have also the same result through natural etching; this can be understood if we assume that the crystal-molecules of the edge to take its place in the direction of the intermediate axes keep the condition of neutrality with each other (see Plate I, fig. 1; Plate V, fig. 1, etc.).

The basal section of quartz crystal is attacked equally by hydrofluoric acid; this is clear if we assume that the crystal-molecules on the plane keep the condition of neutrality with each other (see Plate VII, figs. 5–8).

A quartz crystal is more easily cleaved in the direction of the intermediate axes than in other directions; which suggests that the crystal-molecules of quartz are regularly arranged in the direction of the intermediate axes as in the above models.

When two rock crystals are struck together with each other by their prismatic edges, the crystals will emit a phosphorescence (triboluminescence) on each individual; if we may assume that this is an electric light by which the negative and positive electricities of the crystal-molecules, developing as the reaction of striking together, neutralize each other with the electricities of the adjoining crystal-molecules in a moment, the phenomenon will easily be understood. Besides amethyst, milky quartz emits phosphorescence. but (cairngorm, smoky quartz, etc.), do not emit it, except after their color is lost by ignition.*

The phenomena of pyro-electricity and piezo-electricity, etc., can also be explained by the above models, but whether the quartz crystal has the simultaneous development of positive and negative charges of electricity on different edges of the crystal, as well by etching as by temperature or pressure, can not be determined, unless after an exact measurement.†

* See my note "On the relation between the colors and phosphorescence of quartz," (Tōyōgakugezatsushi No. 334, p. 355, 1909, and Jour. Geogr., Tōkyō, vol. xvi, p. 234, 1909).

† See my note "On the development of electricity on quartz crystal." Tōyōgakugezatsushi, No. 346, p. 338, 1910.

APPENDIX.

Quartz Work in Japan.

In 1906, I personally visited the quartz works at Kofu, Kai Prov.; since then, in 1909, I visited the quartz and agate-works at Onu, Wakasa Prov., and the amethyst and jasper-works at Matsue, Izumo Prov., and obtained some interesting knowledge of quartz-work. I give below a summary of the results:

The cleavage of quartz crystal is not distinctly observed, but it is proved by etching that the fracture surfaces are sometimes parallel with R, $\frac{mPn}{4}$, $\frac{2P2}{4}$, ∞R, etc.; besides this cleavage is also imperfect parallel with $\infty P2$, or the direction of the intermediate axes. This was proved by the experience of a sculptor at Kofu, many years ago; it is found that a crystal can easily be cleaved in two if a shallow groove be dug perpendicular to the oscillatory combination of the prismatic face and struck lightly with a wedge. In this case it emits a stronger phosphorescence (triboluminescence) than when it is cleaved in other directions.

The fracture of quartz crystal is conchoidal or subconchoidal, but the fracture perpendicular to the vertical axis of the crystal is more regularly conchoidal than in other directions. In quartz-work, the needless parts of the original quartz are broken away with a little hammer and a slender chopstick of steel; in this way, a skillful sculptor dexterously makes up the outlines of a sphere, seal or paper-weight, etc., with many conchoidal fractures perpendicular to the vertical axis of the original crystal, the direction in which cleavage is not found, and then these surfaces are polished by emery. In the production of tigers, lions, personages, etc., the needless parts of the original quartz are cut away with a wire of steel and emery.

The hardness of quartz crystal is 7, but it is not the same on all faces of the crystal, the prismatic faces are harder than others and the artificial basal section is much softer than the natural crystal faces. This is proved by the etching and polishing; therefore letters of quartz-seals in Japan are carved on the artificial basal section of the crystal.

Primary quartz is more brittle than secondary quartz, as shown by the fact that the sculptors of Kofu distinguish between the brittleness of rock crystal from the pegmatite of granite from Kinbuzan, and rock crystal from quartz vein of spotted clay slate formed by contact with granite from Takemori.*

* See my note "On the luster and brittleness of rock crystal" in Jour. Geogr. Tōkyō, vol. xvi, 541, 1909.

The luster of quartz crystal is vitreous, but primary quartz has a stronger luster than secondary quartz. Natural etching gives a stronger luster than artificial etching; in the latter case the strong acid yields a stronger luster than the weak acid. The diaphaneity of quartz crystal is from transparent to opaque, but secondary quartz is more transparent than primary quartz, and in secondary quartz, that from granite pegmatite is more transparent than quartz in metal-veins.

Smoky-quartz, amethyst, etc., lose color by ignition, but milky-quartz does not change in this way; ignited quartz has a stronger luster and is less brittle than before ignition.

The direction of the vertical axis of rock crystal is softer than that of the lateral axes; therefore in making hollow spheres, vases, etc., the hole must be dug in the direction of the vertical axis. In the direction of the vertical axis rock crystal has no double reflection; hence quartz lenses must be cut perpendicularly to this axis. A basal section of a crystal is dissolved by a strong hydrofluoric acid and its plane does not show etching figures in the direction of the vertical axis, like an isotropic body.

In the above studies it has been shown that the principles governing the methods of the crystal sculptors in Japan correspond to those developed by my etching. There are numerous other cases where etching and the principles revealed by it must be applied to the work in quartz.

Kitashinjo-mura, Imatate-gun, Fukui-ken, Japan, 1913.