THE MINERALOGICAL MAGAZINE

AND

JOURNAL

OF THE

MINERALOGICAL SOCIETY.

No. 36.	MAY 1888.	Vol. VIII.

On the Development of a Lamellar Structure in Quartz-crystals by Mechanical means.

By Professor JOHN W. JUDD, F.R.S.

[Read January 10th, 1888.]

AS long ago as 1815, Brewster showed that many crystals have a lamellar structure developed in them by pressure,[1] and his observations became the starting point of a long series of very valuable researches. Reusch proposed that the planes along which such structures are developed by mechanical means should be called "Gleitflächen" (gliding-planes[2]), and he, Pfaff, and other mineralogists have investigated a number of curious cases of the kind. Baumhauer in 1879 showed that the lamellar structure could be brought into existence, in the case of calcite, by simply inserting a knife-blade in a definite direction into cleavage fragments of the mineral,[3] and his observations were confirmed in the following year by Brezina.

[1] *Phil. Trans.* 1816, pp. 156-178.
[2] *Pogg. Ann.* CXXXII. (1867), p. 441.
[3] *Zeitsch. Kryst.* III. (1879), p. 588.
[4] Ibid. IV. (1880), p. 518.

A

The investigations of many mineralogists, among whom may especially be mentioned Bauer and Mügge, have shown how universally such gliding-planes exist in all classes of minerals.

A few years ago it was shown that the lamellar structure so generally exhibited by the rock-forming felspars is really of secondary origin ; that it is developed in them as the result of internal strains produced by deformations of the crystal, arising either from unequal contraction or external stresses. This result was arrived at by J. Lehmann,[1] Van Werveke,[2] Foerstner,[3] and myself,[4] independently, and by different methods.

In a paper submitted to this Society in 1886 I have shown that the gliding-planes of crystals, after lamellar structure has been produced in them by mechanical means, become the planes along which chemical action most easily takes place ("solution planes" of von Ebner); and I have also pointed out the important bearings of the principle thus established in explaining the characters and modifications of many rock-forming minerals.[5]

Soon after Biot's discovery of the circular polarisation of quartz, Brewster showed that many amethysts exhibit a very remarkable lamellar structure, the alternate lamellæ consisting of right- and left-handed quartz.[6]

The structure of amethysts has been further investigated by Dove,[7] Haidinger[8] and Böklen,[9] who have confirmed and extended Brewster's early observations. On the ground of the peculiarity of its optical properties, Brewster proposed to divide the species amethyst from that of quartz, as had indeed been already suggested by Werner, but the subsequent discovery of equally complicated structures in almost all varieties of quartz-crystals has led mineralogists generally to refuse to acquiesce in this distinction.

Gustave Rose's memoir on the crystallisation of quartz[10] brought prominently before mineralogists the complicated effects produced by the

---

1 *Untersuchungen über die Enstehung der altkrystallinischen Schiefergesteine.* Bonn, 1884, p. 196.

2 *Neues Jahrb. für Min. &c.* 1883, II. p. 97.

3 *Zeitsch. Krystall.* ix. (1884), pp. 333-353.

4 *Quart. Journ. Geol. Soc.* Vol. XLI. (1885), pp. 354-358.

5 *Mineralogical Magazine*, Vol. VII. (1886), p. 81.

6 *Trans. Roy. Soc. Edin.* Vol. IX. p. 159. This paper was read Nov. 15th, 1819, but the observations on which it is based are said to have been made in 1817.

7 *Darstellung der Farbenlehre* (1853), p. 251.

8 *Sitzungsb. der Wiener Akad.* (1854), p. 401.

9 *Neues Jahrb für Min.* &c. (1883), Vol. I. p. 62.

10 *Abhandlungen der Akad. der Wissenschaften, Berlin*, 1844, p. 217.

curious intergrowth of two individuals in parallel but opposite positions;—phenomena having such curious analogies with some of the appearances usually grouped under the name of twinning, but which are so difficult to bring under any definition of a law of twinning that can be suggested.

In the year 1855, two investigators, working independently and by different methods, showed how complicated is the lamellar structure often exhibited by different quartz-crystals derived from widely distant localities. Des Cloizeaux examined basal sections of quartz by the aid of polarised light, and obtained permanent records of their structure by photographic means.[1] Leydolt exposed similar sections to the action of hydrofluoric acid, and showed that the patterns developed on the sections indicate the molecular structure of the different parts of the crystal.[2] Des Cloizeaux further showed that the lamellæ of right- and left-handed quartz are parallel to certain definite planes of the crystals, and that by their overlapping they give rise to the interesting phenomena of Airy's spirals, when the sections are examined between crossed nicols in convergent light.[3] The principal planes parallel to which these lamellæ were found were those of R (100) and $-$R ($\bar{1}$22). Of this interesting phenomenon Des Cloizeaux was able to give a complete theoretical explanation.

In several recent papers Vom Rath has shown how the existence of lamellæ parallel to the planes R (100) and $-$R ($\bar{1}$22) are made obvious in some quartz crystals, like those from Zöptau in Moravia,[4] and those from Burke County in North Carolina,[5] by striations on the prism faces of the crystals, and also on some of the exceptional rhombohedral faces which are developed in those crystals.

Into the difficult and somewhat vexed question of the theoretical interpretation of the lamellar and other structures in quartz I do not propose to enter. The general analogy of these lamellæ which are composed of right- and left-handed quartz arranged alternately, to the so-called twin-lamellæ of the plagioclastic felspars, of calcite, and of many other minerals, must be obvious to every one; and there is a wonderful similarity in the partial and irregular manner in which both are developed. In order to avoid prejudging the theoretical question however, I avoid the use of the term twinning with respect to the structures in quartz.

Up to the present time, so far as I have been able to ascertain, the

---

1 *Ann. Chim. et Phys.* XIV. (1855), p. 129.

2 *Ber. Akad. der Wissenschaften zu Wien.* XV. (1855), p. 59.

3 *Loc. cit.* p. 286.

4 *Zeits. fur Kryst.* V. (1881), p. 1.

5 *Ibid.* X. (1885), p. 475.

lamellar structure in quartz-crystals has always been regarded as an original one, due to the peculiarities in the original growth of the mass. Without for one moment asserting that such structures may not be original in some quartz-crystals, I propose to describe a case in which it is possible to show that these lamellæ of right-handed and left-handed quartz are as clearly of secondary origin, and as certainly due to the action of mechanical forces upon the crystals, as are the analogous structures found in the felspars and in calcite.

A fine crystal of smoky-quartz from an old collection was found to exhibit upon its exterior surface peculiarities which seemed to indicate that it was deserving of further investigation. The label indicating the original locality of the crystal was unfortunately lost, but it so greatly resembles the smoky-quartz from Miask in the Urals, that I have little doubt that it came from that locality. The crystal is a large one, a circle circumscribing the hexagonal equatorial section having a diameter of 7·4 centimetres, and the length of the crystal from its apex to the irregular fracture forming its base is 12 centimetres. The surface of the crystal indicated that it had undergone a considerable amount of bruising and other mechanical injury, probably from movements in the rock-mass in which it had been enclosed.

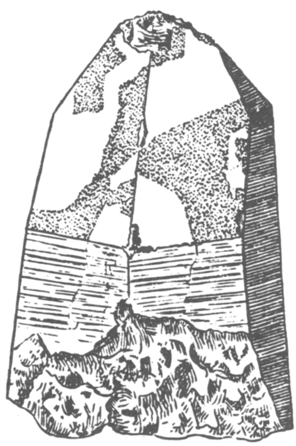


FIG. 1.—Crystal of Smoky-quartz exhibiting natural etchings on its rhombohedral faces. (One-half natural size.)

The rhombohedral faces of the crystal are very unequally developed, one of the R (100) faces and a $-$ R ($\bar{1}22$) face lying side by side attaining large dimensions, and the other faces being proportionately reduced. The crystal was at first seen to be covered by a deposit of carbonates and hydrous ferric oxides, and it was only upon the removal of these by the action of hydrochloric acid that the very beautiful surface characters of the crystal were fully revealed. (See Fig. 1.)

It was then seen that the faces had undergone a most beautiful process of natural etching, whereby the limits and mode of penetration of the two individuals of which it was composed became clearly manifested. The portions of the two individuals in the R and − R faces respectively showed the most striking differences in lustre; and on examining the surfaces with a lens, it was seen that this difference of lustre was due to diversities in the pattern of rhomboids developed upon the portions of the two individuals in the two rhombohedra. The portion which was dull on one rhombohedral face became bright in passing into the rhombohedral face by its side, and *vice versâ.* This is an appearance which has frequently been described as occurring in quartz-crystals, but the present example is finer than any that has before come under my notice.

In order to determine the nature of the individuals composing this quartz-crystal, a section was cut from it at right-angles to the principal axis, and examined in a polariscope with convergent light. By this means it was shown that the two individuals combined in the crystal both consisted of *left-handed* quartz, but here and there the section was found to exhibit the interesting phenomenon of Airy's spirals.

The next step in the investigation of the crystal consisted in etching a section cut at right angles to the principal axis, and the results which were thus obtained were of the very highest interest.

The distinction between the two individuals of which the crystal was built up came out in the strongest relief, the etching-figures produced by the action of the acid being in opposite positions, so that when one set reflected light and became bright, the other set were dull, and *vice versâ.* It was then seen how complicated was the intergrowth of the two individuals, small hexagons of the one individual appearing actually enclosed in the other. In spite of the irregularities, however, there was clearly seen to be a tendency to parallelism between the planes dividing the two individuals and the bounding faces of the crystal. (See Plate I., fig. 1.)

But in addition to the division of the section of the crystal between two individuals, it was found that, in certain parts of the section, alternating lamellæ made their appearance, these lamellæ having a wonderful resemblance to those found in plagioclastic felspars. They were seen to be sometimes broad, sometimes narrow. They were found to run irregularly into the crystal and stop suddenly short; and it was moreover seen that there were two sets of these lamellæ intersecting one another at angles of 60° and 120°. In photographs of these sections which were kindly prepared for me by Mr. Chapman Jones and Mr. A. E. Tatton, of the Normal School of Science, these peculiarities come out in a very striking manner.

Further examination of the section proved two very important facts.

First.—The portions of the section *a* and *b*, where these lamellæ make their appearance are just those in which, under convergent light, the Airy's spirals are seen. The lamellæ are thus proved, as Des Cloizeaux has shown, to consist alternately of right-handed and of left-handed quartz which overlap one another.

Secondly.—The lamellæ are only developed where the crystal has suffered injuries, and in many cases the lamellæ can be seen running up to and stopping short at a crack which traverses the crystal.

On examining one of the prism-faces of the crystal (Plate I., fig. 2) the evidence derived from the study of the section at right angles to the principal axis received remarkable confirmation. In its natural state, this face only exhibited the usual striations parallel to the basal plane, interrupted by the irregular line which marked the junction of the two individuals of left-handed quartz. In addition to this the crystal was seen to have undergone a certain amount of mechanical injury, a number of irregular cracks intersected some parts of the crystal, while here and there a number of curved cracks marked the incipient development of the conchoidal fracture.

When this prism-face was carefully etched with hydrofluoric acid, however, a most interesting series of phenomena was displayed. Two sets of lamellæ, very irregularly developed, were seen intersecting one another nearly at right angles. Upon making a drawing with the camera lucida and measuring the angle carefully with a protractor, the position of the planes and their angle of intersection were found to be parallel to those of R (100) and −R ($\bar{1}22$) in the crystal.

The parts of the crystal which had not suffered injury were found to be free from these lamellæ; but where injury had taken place these lamellæ were developed in a most striking manner. Moreover, it was clearly manifest upon a careful examination of the specimen that *the lamellæ in many cases ran up to and stopped short at an accidental crack*, in just the same manner as I have shown to be the case in the plagioclastic felspars.[1] These facts are very strikingly seen in the etched surface of which a drawing is given in Plate I., Fig. 2.

---

[1] *Quart. Journ. Geol. Soc.* Vol. XLI. (1885), p. 365, Pl. X., Fig. 1.

The very important conclusions which may be deduced from these observations are as follows:—

1. Quartz must be added to the list of minerals in which a lamellar structure can be developed by mechanical means.

2. The gliding-planes of quartz-crystals are those of R (100) and −R ($\bar{1}22$).

3. In quartz, as in calcite, the felspars and other minerals, in which a lamellar structure has been developed by mechanical means, the gliding-planes become the planes along which easiest chemical action takes place ("solution-planes").

The curious and very interesting circumstance in the case of quartz-crystals is that the lamellæ developed in them by mechanical action are not distinguished as in the case of calcite or felspar by exhibiting an opposite polarity in the molecules composing the alternating lamellæ, but by a *reversal of the direction of their circular polarisation.* That this reversal of the direction in circular polarisation can thus be effected by mechanical means is certainly a very startling fact. The analogy between the lamellæ of right and left-handed quartz and of the lamellæ of calcite or felspar with opposite polarity is a very striking one, and the fact that the definite planes in the crystal, along which the change takes place become planes of easy solution is also very remarkable. The claim of these lamellar structures, now shown to be of secondary origin, to be regarded as *twinning*, is one to be settled by crystallographers.

It is the circumstance that the gliding-planes of a crystal, after the lamellar structure has been set up in it by the action of a mechanical force, become the "solution planes," that enables us to trace the remarkable change which takes place in quartz-crystals.

The interesting observations recently made by Prof. J. Lehmann upon "Contractions-risse,"[1] taken in conjunction with my own results, suggest that the so-called "cleavage" of quartz, produced by heating crystals and plunging them into cold water, is really due to a yielding of the crystals along the *gliding* planes, and not to any true cleavage along the rhombohedral planes. Prof. Lehmann's observations show that the "Contractions-risse" are sometimes produced along cleavage-planes, and at other times along gliding-planes. This being the case, and my own demonstration of the fact that quartz has gliding-planes parallel to R (100) and −R ($\bar{1}22$) being taken into consideration, it is fair to

[1] *Zeitschr. fur Kryst.* &c. Vol. II. (1886), p. 608.

conclude that the supposed cleavage of quartz is not really such, but is due to the yielding along the now demonstrated gliding-planes.

The brittle and intractable character of quartz has hitherto foiled my efforts to produce these lamellar structures at will, either by crushing or percussion, or by alternate heating and cooling; methods which have yielded such very interesting results in the case of calcite, the felspars and many other minerals. I am, however, still continuing my experiments in this direction.

In studying a number of quartz-crystals I find that the irregular lamellæ are sometimes developed in certain parts of zoned-crystals in a manner strongly suggestive of the structure having been originated by irregular contraction in the crystal. The further consideration of this and many other very interesting questions must be postponed to a future occasion.

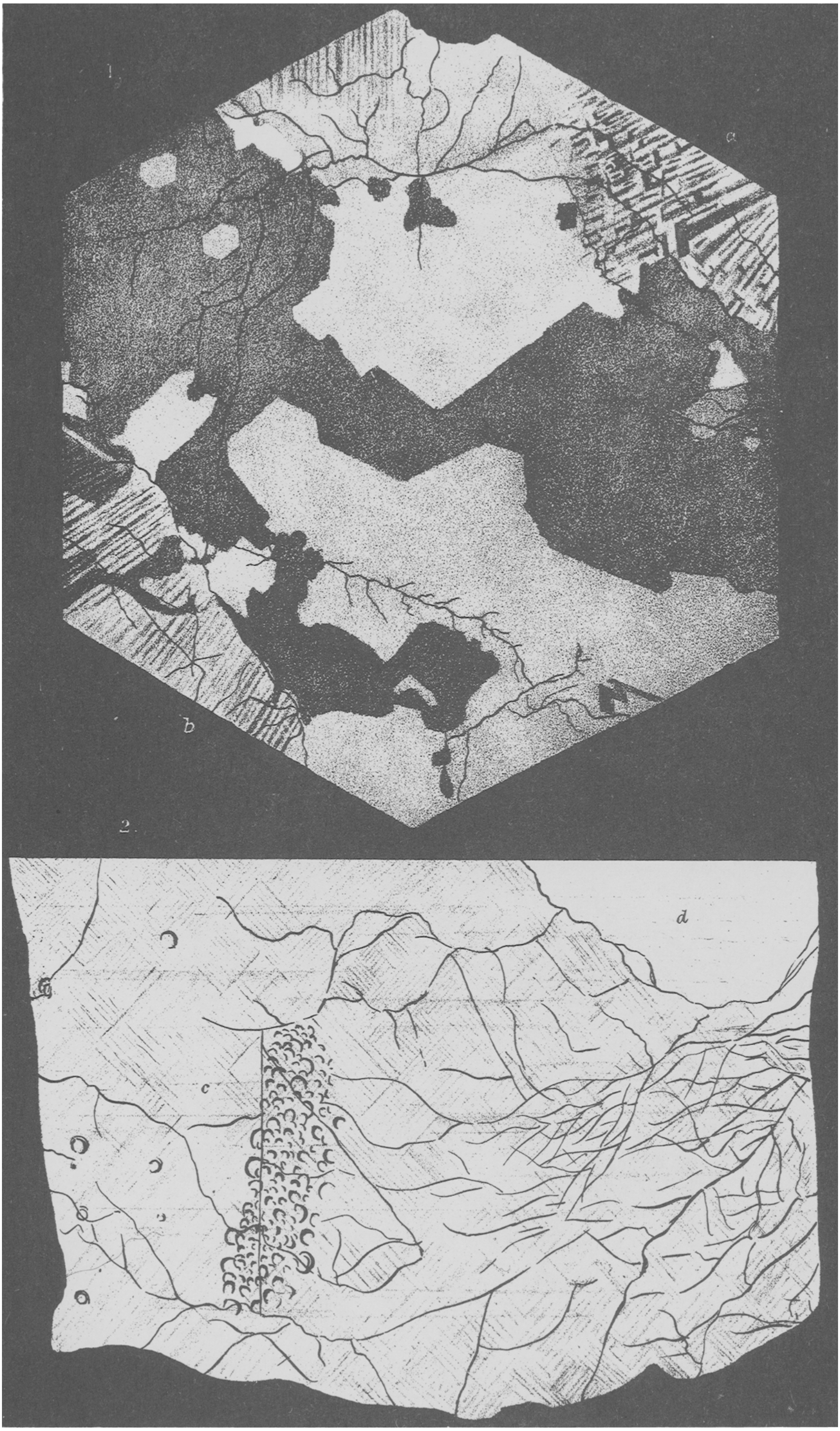
A very interesting question which suggests itself to petrologists in connection with this question is that of the existence of lamellar structure in the quartz of various rocks, and how far such a structure, if it exists, may be regarded as the result of the mechanical stresses to which the rocks have undoubtedly been subjected. In order to determine this problem, I have prepared sections of various rocks, especially those in which the felspar exhibited much complicated twinning in the case of plagioclastic felspar or of microcline structure in the orthoclase felspars, and have submitted them to etching. The results which I have yet obtained however, are of a negative character. The pressure which has produced the twin-striations in the felspars seems in most cases to have actually crushed the quartzes, so that a polysynthetic structure was the result.

In making the observations upon which this note is founded, I have been very greatly indebted for kind advice and assistance to our President, Mr. L. Fletcher, and to Mr. H. A. Miers.

DESCRIPTION OF PLATE I.

Fig. 1.—Section of smoky-quartz crystal at right angles to the principal axis, which has been etched with hydrofluoric acid, magnified 1½ times. The parts shaded light and dark respectively show the portions belonging to the two individuals (*both* of *left*-handed quartz) compounded in the crystal. The boundaries of the two portions, though often very irregular, exhibit a tendency to parallelism with definite planes in the crystal, small hexagonal patches of one individual lying within the limits of the other. At two points, *a* and *b*, groups of lamellæ are well seen, and that these consist of alternations of right- and left-handed quartz is shown by the fact that Airy's spirals are exhibited at those portions of the crystals. The general disposition of the cracks that traverse the crystal is shown by the sharp black lines.

Fig. 2.—Portion of a prismatic face of the same crystal also etched with hydrofluoric acid, and magnified 3 diameters. Where, as at *c*, the crystal has suffered a considerable amount of mechanical injury, indicated by the curved conchoidal cracks and the longer incipient fissures extending through it, the lamellar structure parallel to R (100) and −R ($\bar{1}22$) is admirably developed; but where, as at *d*, the crystal is uninjured, there is a total absence of the lamellar structure. The dependence of the lamellar structure on the mechanical forces which have produced cracks in the crystals is placed beyond doubt by the fact that some of the lamellæ stop short at artificial cracks, in just the same manner as is the case with the twin-lamellæ of felspars.



Parker & Coward del. et lith.

Mintern Bros. imp.

Secondary Lamellar Structure in Quartz.