An example of porphyry-quartz, from the Esterel Mtns., France, twinned on face (1012).

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IT is now well recognized that quartz undergoes a sudden change near 575° C., and Wright and Larsen (1) have shown that the characteristics of quartz formed above or below this point are so marked that they can be utilized to determine the temperature of formation of rocks containing quartz. Quartz formed above 575°, so-called β-quartz, is of distinctly hexagonal development, and occurs generally as regular hexagonal bipyramids with or without a subordinate prism-face. These external characteristics are of course preserved on cooling, and the bipyramids are converted into a pseudomorphous aggregate of α-quartz.

The examples of twinning in quartz that have most often been described are of low-temperature α-quartz. It seems desirable that twinning of high-temperature quartz should be treated apart from that of low-temperature varieties. Firstly, twinning with parallel C-axes, which is universal in low-temperature varieties, has no importance in high-temperature quartz. Secondly, the modes of twinning with inclined axes, or the relative importance of these, may be very different in the two cases. For instance, the relative importance of twinning on r $(10\bar{1}1)$ and on ξ $(11\bar{2}2)$ is very different. Only two cases of twinning on r $(10\bar{1}1)$ have so far been recorded for α-quartz, while numerous examples are known of β-quartz twinned on this law. For, since his communication to this Society (2) of an example of porphyry-quartz twinned on $(10\bar{1}1)$, the author has himself found (3) many new cases of the same law, and also of twinning on $(11\bar{2}2)$ in porphyry-β-quartzes. Dr. Balogh (4), of Kolozsvár, has described the same from the rhyolite of Verespatak in Transylvania. That these are not great rarities is also proved by the presence of twinned specimens in the limited quantities of porphyry-quartzes amongst the stocks of different dealers. Bipyramids of β-quartz from the Urals, from Cornwall, and from Auvergne also showed the same modes of twinning. One lot only, from

Java, externally very like the Esterel specimens of β-quartz, did not show any twinning at all.

Of all these occurrences of β-quartz, the Esterel one is the most suitable for the identification of less frequent twin-laws. While the crystals from other localities frequently show irregularities in development and interpenetrations, those from the Esterel are remarkably free from such imperfections. The faces in all cases being rough and unsuitable for goniometric measurement, one has to rely chiefly on the parallelism of certain zones and faces in determining the relative positions of the two individuals of a twin. Simplicity of development and absence of complications are therefore very desirable. For this reason, the careful

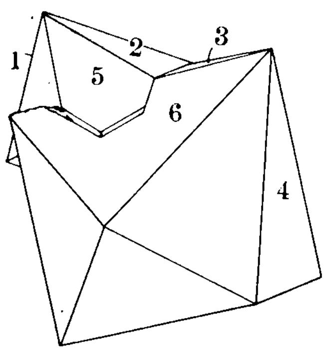

Fig. 1.

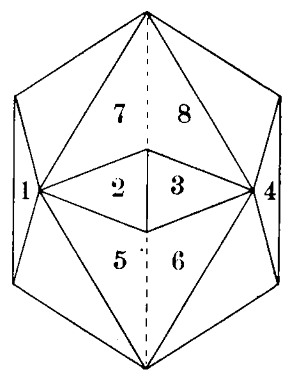

Fig. 2.

Quartz twinned on $(10\bar{1}2)$ from the Esterel Mtns., France.
Fig. 1.—Side-view, showing approximately the actual development.
Fig. 2.—Diagrammatic plan.

examination of any unusual interpenetration on an Esterel specimen usually leads to conclusive identification of the mode of association of its parts.

During a recent visit to the Esterel locality, the author picked up a specimen that looked at first sight like an Esterel-twin on $r\ (10\bar{1}1)$. The specimen is a typical β-quartz of hexagonal bipyramidal habit, about 10 mm. diameter, but the twinned portion, formed of two individuals of nearly the same size, is about 7×7 mm., and is partly embedded, in parallel position to one of its constituents, in a larger crystal (fig. 1). The re-entrant angle between the summits of the two twinned individuals is, however, quite free, and the parallelism of the edges between faces

1, 2, 3, 4 is quite obvious. The opposite pyramid faces 1 and 4 are, however, not parallel, as they should be in an Esterel-twin. The twin-plane is, then, other than $(10\bar{1}1)$. On closer examination, the faces 5 and 6 are found to be parallel, as also 7 and 8 (fig. 2). The twin-plane should be the face truncating the edge between 5–7 and between 6–8, i.e. a face of the form $\pi\,(10\bar{1}2)$. This is the mode of twinning described by Sella (5) in his 'Studii sulla Mineralogia Sarda', for a specimen of unknown origin. No other specimen has been found to confirm this law. The name 'Sardinian'-law was used by Jenzsch (6), from the title of Sella's paper. Owing to the doubtful origin of this specimen, it is a rather unfortunate designation, the more so as the true twin nature of the specimen is somewhat open to doubt. The crystal was not measurable, and Sella's description, though it might apply to porphyry-quartz, might apply equally well to the bipyramids of α-quartz containing carbonaceous inclusions from the Bologna district, which interpenetrate in every imaginable position. Chance simulation of twinning would here be very probable. The name 'Sardinian'-law has, however, become established, appearing in later papers on twins of quartz by V. Goldschmidt (7) and by F. Zyndel (8). It will therefore be retained here both for twinning on $\pm\frac{1}{2}R$ of α-quartz and on $\pi\,(10\bar{1}2)$ of β-quartz.

The theoretical angle between the vertical axes for this mode of twinning is 115° 10′ (or 64° 50′). The angle between the vertical axes of the Esterel specimen was found to be approximately 65° both by measurement with a contact-goniometer and by measurement on the rotating stage of a microscope under low magnification. In the Esterel-law the composition-plane is parallel to the twin-plane, while here it is roughly normal. Fig. 1 shows the crystal in the same position as the Esterel-twin in the former paper. The composition-plane, which bisects the acute angle between the C-axes, is vertical, and the twin-plane is horizontal.

Rough measurements were also carried out of the angles between faces 2–3 and 1–4, as also between 1–2 and 3–4. One set of measurements was carried out after coating the faces with gum-arabic and noting the position of maximum illumination; another after glueing small fragments of thin cover-glass on the faces. In the first set of measurements the variations in the different readings were appreciable; in the second they were sharp and the readings between the values of faces 2 and 3 showed approximately the same divergence from the theoretical angle as those between faces 1 and 2 of the same crystal. This showed that the divergence from the theoretical value was due to the difficulty of fixing the cover-glass perfectly true on the face 2. The extreme limits in the results are given below in whole degrees:

		Found.		Calculated.
Angle 1:4	...	11°– 18°	...	11° 38′
,, 2:3	...	33 – 40	...	38 44
,, 1:2 and 3:4	...	99 – 108	...	103 34
C-axes	...	65 (mean)	...	64 50

Though showing wide divergences, these measurements confirm sufficiently the true twin nature of the specimen. This law can, then, be taken as proved for β-quartz. It would be interesting to know definitely whether Sella's specimen was also of β-quartz. The existence of this law for α-quartz still awaits confirmation.

The following tabulation of the examples of twinning of β-quartz so far known may be of interest. The laws represented are still few and the nature of the material should make one cautious in admitting new cases without conclusive evidence. The careful study of high-temperature quartzes will, no doubt, bring other laws to light.

Dr. Zyndel (8), who was a keen investigator of twin-laws in quartz, systematically worked out according to Goldschmidt's principles all the possible laws of twinning (but practically all his work refers to low-temperature α-quartz). Most of the cases are of hetero-twinning, and of these he finds a very large number. He has also been able to find representatives of nearly all of them, and has published descriptions in a later paper (9). He never came across a case of $\frac{1}{2}R$ twinning for α-quartz —another argument against its existence for low-temperature quartz. He identified, however, a specimen of quartz from the Esterel, sent to him by the author, as an example of the hypothetical 'law A', which he explains on p. 36 of the paper just referred to. Dr. Zyndel was unfortunately drowned in the torpedoing of the *Laconia* in 1917, and the details of the law given in the table are taken from a letter received from him in 1913. See table opposite.

The author received from Dr. Balogh in 1914 a specimen from Verespatak, which was regarded to be a case of the Zinnwald-law. The specimen is minute and the faces very rough. The author's measurement of the angle between the *C*-axes approached 50°, while twinning on the Zinnwald-law requires 38° 13′. For this reason it is not entered below, although the specimen has the appearance of a true twin and not a chance conjunction. An accurate measure of the angle between the *C*-axes could be obtained by grinding a face parallel to the plane of the two axes and measuring the angle of optical extinction between them.

Dr. Balogh may have other specimens in support of this twin-law, but no publication respecting it is known to the author.

The Java specimens, on account of their great regularity, should furnish very symmetrical twinned examples, if only a sufficient number of specimens were searched through. The author would welcome any communication of the results of search through material from this or other occurrences of β-quartz.

The only deduction that can, so far, be drawn from the table is that in β-quartz the Esterel-law is the most frequent, followed closely by the Japanese-law (Verespatak-type) of twinning; while in α-quartz the Japanese-law is the only one well represented. Hetero-twinning can occur in both varieties.

Twin-laws for β-quartz.

Angle of C-axes.	Mode of twinning.	Name of law.	Locality.	Reference.
76° 26′	Twin-pl. $r\,(10\bar{1}1)$; comp.-pl. parallel to twin-pl.	Esterel-type of Reichenstein-Grieserthal-law	Esterel Verespatak Urals Cornwall Auvergne	(2), (3) (4)
84° 33′	Twin-pl. $\xi\,(11\bar{2}2)$; comp.-pl. parallel to twin-pl.	Verespatak-type of Gardette- or Japanese-law	Verespatak Esterel Urals Cornwall	(4) (3)
64° 50′	Twin-pl. $\pi\,(10\bar{1}2)$; comp.-pl. normal to twin-pl.	Sardinian-law	Esterel	Doubtful for α-quartz; may be new for β-quartz
'Hetero-twin'; one $(10\bar{1}1)$ face of each individual in a plane, and zone $[10\bar{1}1, 10\bar{1}0]$ of one parallel to zone $[10\bar{1}1, 01\bar{1}1]$ of the other.		Zyndel's law A of 1913	Esterel	New (9)

REFERENCES TO THE LITERATURE.

(1) F. E. WRIGHT and E. S. LARSEN, Amer. Journ. Sci., 1909, vol. 27, pp. 162, 421–447.

(2) J. DRUGMAN, An example of quartz twinned on the primary rhombohedron. Min. Mag., 1911, vol. 16, pp. 112–117; also Zeits. Kryst. Min., 1912, vol. 50, pp. 598–599.

(3) J. DRUGMAN, Zeits. Kryst. Min., 1913, vol. 53, pp. 271–272.

(4) E. BALOGH, Múzeumi Füzetek, Kolozsvár, 1913, vol. 2, no. 3.

(5) Q. SELLA, Studii sulla mineralogia Sarda. Mem. R. Accad. Sci. Torino, 1858, ser. 2, vol. 17, pp. 321–332, pl. V, figs. 48–50. (Separate copies, dated 1856, pp. 35–36); reprinted in Atti R. Accad. Lincei, Mem. Classe Sci. Fis. Mat. Nat., Roma, 1885, ser. 4, vol. 2, pp. 76–77, pl. V, figs. 48–50.

A mistake was made by the present author in his first paper (2) with reference to Sella's descriptions. He was misled by the close similarity of Sella's drawings of the Sardinian-law and by Sella's designation 'twin on edge [10$\bar{1}$1]', so that he quoted it as twinning 'on (10$\bar{1}$1)'. The first mention of r-twinning is, then, Rose's and not Sella's.

(6) G. JENZSCH, Ann. Phys. Chem. (Poggendorff), 1867, vol. 130, p. 597; 1868, vol. 131, p. 540.

(7) V. GOLDSCHMIDT, Tschermaks Min. Petr. Mitt., 1905, vol. 24, pp. 167–168; Zeits. Kryst. Min., 1908, vol. 44, pp. 408–416.

(8) F. ZYNDEL, Verhandl. Schweiz. Naturf. Gesell., 1910, Jahresvers. 93, vol. i, pp. 208–209.

(9) F. ZYNDEL, Zeits. Kryst. Min., 1913, vol. 53, pp. 15–52, 3 pls.