Communications from the Oxford Mineralogical Laboratory. No. XXI.

An example of Quartz twinned on the primary rhombohedron.

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[Read March 21, 1911.]

EXAMPLES of quartz twinned on a face of the primary rhombohedron *R* are extremely rare. Only three isolated examples have so far been recorded. The first was observed by Q. Sella;[1] but as his crystal could not be measured, owing to its position on the matrix, it is of only slight importance as evidence of this mode of twinning of quartz.

The second example was found at Reichenstein in Silesia, and was described by G. Rose.[2] This specimen showed small rosettes of quartz, which were explained by Rose as being formed of four crystals, viz. a central one with the other three grouped symmetrically round it in twin-position, each with an *R*-face parallel to one of the *R*-faces of the central crystal, and the composition-plane perpendicular to this face. This description was questioned by several other crystallographers,[3] and C. Hintze[4] gives a résumé of this discussion. It will, therefore, suffice here to mention that the quartz was found to be regularly orientated on calcite, and that it was thought more probable that the apparent twin-relation of the side-individuals to the central portion was due to this orientating influence of the calcite, for, up to that time, no conclusive evidence of the occurrence of this mode of twinning of quartz had been given. Later, however, the discovery of a measurable specimen by

[1] Q. Sella, Mem. Accad. Sci. Torino, 1858, ser. 2, vol. xvii, p. 321.

[2] G. Rose, Ann. Phys. Chem. (Poggendorff), 1851, vol. lxxxiii, p. 461.

[3] F. Hessonberg, Neues Jahrb. Min., 1854, p. 806; H. Eck, Zeits. Deutsch. Geol. Ges., 1866, vol. xviii, p. 428; A. Frenzel and G. vom Rath, Ann. Phys. Chem. (Poggendorff), 1875, vol. clv, p. 17.

[4] C. Hintze, 'Handbuch der Mineralogie,' 1905, vol. i, p. 1857.

V. Goldschmidt[1] led him to reconsider the reasons adduced for and against this twinning in Rose's specimen and to accept it as sufficiently grounded. A theoretical consideration of the general principles of twinning, which is set forth in a second paper,[2] showed him that this mode of twinning should, in fact, be comparatively important among the modes of twinning of quartz.

Goldschmidt's specimen came from the Griesernthal, a side-valley of the Maderanerthal in Switzerland. It shows a small, much distorted crystal, tabular parallel to *R*, in close contact with an *R*-face of a much larger crystal, but the triangular etchings on the two have their apices *pointing in* opposite directions. They are in twin-position, the twinning being by rotation of 180° about the normal to their face of contact, *R*. Goldschmidt's measurements fully confirm this, and so establish the existence of the *R*-twinning of quartz. Here *R* is also the composition-plane, whilst in Rose's specimen the composition-plane is perpendicular to *R*.

The twinned crystal of quartz to be described in the present communication was found in the Esterel Mountains, near Cannes, in the south of France. The rock in which it occurred is a laccolitic quartz-diorite, whose large zoned andesine phenocrysts have been studied by several petrographers. Michel Lévy[3] has published a detailed study of this rock, and has named it 'esterellite'. The size of its porphyritic constituents, as well as their relative numbers, varies very much; some of the more acid portions are crowded with bipyramidal quartz phenocrysts averaging 12 mm. in diameter, but sometimes reaching 15 and even 20 mm. These are found scattered over the surface of the weathered rock in large numbers.

The twinned specimen is of average size, and consists of two nearly equal bipyramids joined parallel to an *R*-face. Above there is a re-entrant angle of $-27° 8'$, and below, in the same zone, a salient angle of $+27° 8'$. Both in mode of twinning and general development it is comparable with the so-called 'butterfly-twins' of calcite, as a glance at the accompanying text-figure will show. The measurements are only approximate, owing to the roughness of the faces, but so far as they go

[1] V. Goldschmidt, 'Quarzzwilling nach r = 10,' Min. Petr. Mitt. (Tschermak), 1905, vol. xxiv, pp. 157–166.

[2] V. Goldschmidt, 'Über die Zwillingsgesetze des Quarz,' tom. cit., pp. 167–182.

[3] A. Michel Lévy, 'Sur le porphyre bleu de l'Esterel,' C. R. Soc. Géol. France, 1896, pp. xlvii–xlix; and Bull. Serv. Carte Géol. France, 1897, vol. ix, no. 57, pp. 1–47, pls. I–VIII.

they confirm the truly symmetric position of the two individuals. In the first set of measurements (I) the crystal was coated with celluloid varnish and the readings taken at the positions of maximum illumination. In II and III different sets of cover-glasses were affixed to the faces. The results of the two latter sets of readings show that the cover-glass method is here unsatisfactory, owing to slight projections on the faces.

	I.	II.	III.	Calculated.
A	104°	103° 15′	104° 45′	103° 34′
B	−27	−25 50	−26 25	−27 8
C	103	103 10	102 0	103 34
D	77	76 55	77 40	76 26
E	26½	25 25	25 40	27 8
F	76½	77 5	76 20	76 26
A				
M	—	43° 5′	41° 35′	43° 27′
E				
N	—	43° 45	42° 0′	43° 27′
F				

It is quite impossible to determine whether the parallel *R*-faces are + *R* or − *R*. From a statement made by Friedel,[1] that above 600° C. quartz shows hexagonal-trapezohedral and not trigonal-trapezohedral symmetry, it may be suggested that in these quartz bipyramids, formed in a molten magma, the pyramid-faces were all of the same nature at the time of crystallization. Further experimental evidence is, however, necessary before this can be finally accepted.

Two other interesting features may be observed in the quartz bipyramids from this locality. Firstly, the frequent repetition of parallel growth in the larger specimens gives rise, very imperfectly it is true, to a rough basal plane formed by a number of apices packed closely together, an occurrence observed in a more perfect manner at some other localities.

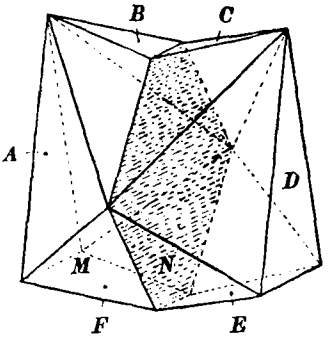
[1] G. Friedel, *Bull. Soc. franç. Min.*, 1902, vol. xxv, p. 112.

Secondly, many of the crystals, which otherwise show no trace of a prism-face, cleave well in this direction. Measurements from such a cleavage-face in the zone with the upper and lower pyramid-faces gave:—

	Measured.	Calculated.
$\bar{R}$ } ∞R	38° 0′	38° 13′
∞R } R	38 0	38 13

The cleaved face gave by far the best reflection of the three.

Up to the present, twinning of quartz parallel to R does not seem to have been generally accepted, the only twin with inclined axes that is mentioned in crystallographic works being that in which the twinning-plane is ξ $(11\bar{2}2) = (P2)$, which truncates the edge between two adjacent



Quartz twinned on R; from the Esterel Mts., France.

(With the exception of a slight overlapping along the edge between the faces E and F, which has been omitted, the figure gives an exact representation of the crystal, about three diameters the natural size.)

pyramid-faces. Goldschmidt has, however, shown that the former is theoretically well founded, and the addition of yet another example to those already known is in support of this. The author hopes to be able to find further examples at the same locality, so as to convince those who hesitate to accept an isolated specimen as sufficient evidence. He is himself, however, convinced, after closely examining this specimen, that it is a genuine twin and not merely a chance intergrowth closely simulating twinning. A further fact supports this: amongst over two hundred crystals from the same locality, he has never found a single case of irregular interpenetration of two individuals. The only irregularities of growth

are due to two or more crystals being joined in parallel position. These parallel growths, already mentioned above, are, in fact, extremely frequent and varied. Sometimes the second crystal only appears as a slightly raised portion on an R-face of the other; at other times the two may both be almost fully developed and attached in various ways, but always in strictly parallel position. Some crystals show a deep depression, with roughly hexagonal outline, on a pyramid-face; three alternate sides being parallel to the three sides of the triangular pyramid-face. These too, however, the author was able to prove to have been occupied by a second smaller crystal in parallel position to the first, for one specimen was found in which the parallel growth became detached, leaving a depression of exactly the same shape as those previously observed.

In concluding, the author would like to draw attention to Goldschmidt's papers on quartz-twinning, already mentioned above; and as the laws he establishes include some not generally recognized, a short résumé of them may be useful here, Goldschmidt's numbering and lettering of the classes and types being retained. His third group of 'hetero-twins' more closely approach in their nature the regular growths of two different substances than true twinning, and Goldschmidt only included them in a later paper [1] after he had had the opportunity of examining an actual example of the 'Zwickau' type.

Group I, the common modes of twinning with parallel axes:

A, without rotation (Brazil law).

B, with rotation about the principal axis (Dauphiné law).

Group II, true twins with inclined axes:

C, the well-known Japanese law with $\xi\,(11\bar{2}2) = P2$ as twin-plane, and the axes inclined at 84° 33′.

D, R-twins with $r\,(10\bar{1}1)$ as twin-plane, the axes being inclined at 76° 26′; two types are distinguished:

(i), the Griesernthal type, in which R is also the plane of composition. The Esterel example is of this type.

(ii), the Reichenstein type in which the plane of composition is perpendicular to R.

E, twin-plane $d\,(10\bar{1}2) = -\frac{1}{2}R$, the axes being inclined at 64° 50′. Only once observed [2] (Sardinian law).

[1] V. Goldschmidt, 'Über Quarz,' Zeits. Kryst. Min., 1908, vol. xliv, pp. 407–416.

[2] Q. Sella, Mem. Accad. Sci. Torino, 1858, vol. xvii, p. 323.

Group III contains two examples of hetero-twins, which are accepted by Goldschmidt as theoretically possible:

F, Zwickau law of Jenzsch[1]; the zones $[mr]$ and $[mz]$ coincide, and the principal axes are inclined at 47° 43′.

G, Zinnwald law of Jenzsch[1]; *m* and *r* coincide, and the principal axes are inclined at 38° 13′.

If these can all be accepted, and the theoretical considerations adduced by Goldschmidt make them highly probable, twinning parallel to *R* should be of comparatively frequent occurrence, and the discovery of still further examples should be merely a question of time.

The author wishes to thank Professor Bowman most heartily for allowing him the use of the laboratories at Oxford to carry out the practical work in connexion with this paper, and also for his valuable suggestions.

[1] G. Jenzsch, Ann. Phys. Chem. (Poggendorff), 1867, vol. cxxx, p. 597; 1868 vol. cxxxiv, p. 540.