ART. XVIII.—*On Orthoclase Twins of Unusual Habit*; by
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THE orthoclase twins to be described in the following pages were collected by Prof. L. V. Pirsson during the summer of 1896, while engaged in work for the United States Geological Survey in Montana. They occurred as phenocrysts in an altered tinguaita porphyry which lay as an intruded sheet between black shales near the head of West Armell Creek in the Judith Mountains. The tinguaita sheet is described* as measuring "between ten or twelve feet in thickness with numerous immense feldspar phenocrysts, some of them being four by two by one inches across." The groundmass of the rock is fine-grained with a greenish gray color, the green tone being due to the presence of fine crystals of ægirite, while on the weathered surfaces it is spotted with numerous pits stained yellow with iron oxide. The writers desire to express to Prof. Pirsson their thanks for the opportunity to figure and describe these crystals.

The phenocrysts occur as well-developed crystals and, as has been said, are at times of considerable size. They are opaque and are frequently stained on the surface with iron oxide or colored green with a thin coating of ægirite. When broken, however, they present a glassy luster and fresh appearance. The crystal faces were too rough to admit of measurements other than those with the contact goniometer, but the forms present were easily identified in this way and by their zonal relations. They were all common forms comprising b (010), c (001), m (110), z (130), n (021) and o ($\bar{1}11$). A few crystals in the suite were untwinned and possessed a development as represented in figure 1, but for the most part the phenocrysts were twinned according to the Baveno law in which n (021) becomes the twinning plane. They differ markedly in habit, however, from the common form of Baveno twins in that instead of having the composition plane symmetrically placed in diagonal position through the square prism-like crystals, they are rather in the nature of contact twins having the two individuals more or less completely developed and grown together at right angles to each other without much interpenetration. Figures 2 and 3 illustrate this peculiarity of development. In these cases the division between the two individuals can be distinctly traced, and is practically a single plane. In the crystal illustrated in figure 2, the individual drawn in normal position is quite completely and symmetrically developed and the smaller

* Weed and Pirsson, U. S. G. S., Ann. Rep., 1896-7, iii, 524.

one, not so completely formed, is merely grown on to the side of the larger. The bottom plane of this twin is made up of the c ($00\bar{1}$) face of the first and the b' ($0\bar{1}0$) face of the second individual, the division between the two being clearly recognizable because in these crystals the clinopinacoid has always a somewhat brighter luster than the base. In this case the dividing line

between the two faces is almost straight. In the crystal represented in figure 3, the two individuals are more nearly equally developed, and here again the division between the two seems to be almost in the nature of a single plane. The composite face of this crystal is the one in back and to the left as the crystal is drawn and the distinction between the c and b faces is clearly

defined, as the former is coated with a thin film of green ægirite, while the latter is clean.

The crystal represented in figure 4, although in general of the same type, differs in that the individual shown in normal position is apparently set into the other, the latter in a measure surrounding the former. In order to ascertain the relations existing between the two individuals of this twin, a section was cut through the crystal along a plane at right angles to the *c* and *b* faces and close to the front of the crystal. Figure 5 shows the relationship between the two individuals along this plane as indicated by the section, the shaded portion of the figure representing that part of the crystal placed in twin position. Where the dividing line was straight and clean cut, there was a slight crack to be observed between the two parts of the twin, but elsewhere there was considerable kaolinization of the feldspar and this line became more irregular and indistinct.

The crystals were investigated both optically and chemically, in order to ascertain if they showed in these respects any unusual features which might be connected with their peculiar development. Sections were made parallel to the three pinacoids, *a* (100), *b* (010) and *c* (001). They showed that the mineral was slightly kaolinized, but not to any great extent. There was no evidence of microscopic twinning or of parallel growth of more than one feldspar. The optical orientation is that most common with orthoclase, the axial plane being perpendicular to *b* (010), *a* inclined to the *a* axis $+4^{\circ} 54'$, and $\rho > v$. The conformity in its optical properties to normal orthoclase is rather surprising when the large amount of soda shown to be present by the analysis is considered. The results of the analysis by Tillotson follow:

SiO ₂	64.01
Al ₂ O ₃	20.19
K ₂ O	10.48
Na ₂ O	5.37
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Total	100.05

This particular occurrence of the tinguaita rock was not analyzed because of the alteration it had undergone through weathering, but a closely similar and fresh rock from Cone Butte was analyzed by Pirsson* and the percentage of the alkalies found by him agree closely with those of the present analysis. In the Cone Butte tinguaita, however, the soda was considered to belong entirely to either albite or nephelite, but in the West

* This Journal, ii, 192, 1896.

Armell Creek occurrence, supposing that the two magmas were alike, it would all be accounted for by the orthoclase itself. In the present analysis the somewhat disproportionately low percentage of silica is probably due to the small amount of kaolinization which the feldspar showed in the thin sections.

Drawing of the Crystals.—The crystals were drawn from a stereographic projection of their forms. There was nothing new in the methods employed, but as concrete examples of the

use of the stereographic projection for the solution of such problems are seldom to be met with in the literature, a brief description of the manner of transposition of the poles of the faces from normal to twin position is here given.* According to the Baveno law of twinning the n (021) face becomes the twinning plane and as the angle $c \wedge n = 44^\circ 56' 1/2''$ the angle between c and c' (twin position) becomes $89^\circ 53'$. For the

* For a general discussion of the graphical use of the stereographic projection, see Penfield, this Journal, xi, 1, 1901.

purposes of drawing it is quite accurate enough to assume that this angle is exactly 90° and that accordingly the c face of the twin will occupy a position parallel to that of the b face of the normal individual.

Figure 6 shows the forms observed of the crystals both in normal and in twin positions, the faces in twin position being indicated by open circles and a prime mark (') after their respective letters, while the zones in twin position are drawn in dashed lines. Starting out with the forms in normal position, the first face to transpose is the base c . This form, from the law of the twinning, will be transposed to c' where it occupies the same position as b of the normal individual, and it necessarily follows that b itself in being transposed will come to b' at the point where the normal c is located.

In turning therefore the crystal to the left from normal to twin position, the faces c and b travel along the great circle I through an arc of 90° until they reach their respective twin positions. We have, in other words, revolved the crystal 90° to the left about an axis which is parallel to the faces of the zone I. The pole of this axis is located on the stereographic projection at 90° from the great circle I and falls on the straight line II, another great circle which intersects zone I at right angles. This pole P is readily located by the stereographic protractor on the great circle II at 90° from c . The problem then is to revolve the poles of the faces from their normal positions about the point P to the left and through an arc of 90° in each case.

During the revolution the poles of the n faces remain on the great circle I and as the angle $n \wedge n' = 90^\circ$, the location of their poles when in twin position is identical with that of the normal position and n' falls on top of n . We can now transpose the great circle II from its normal to its twin position, since P remains stationary during the revolution and we have determined the twin position of c . The dashed arc II' gives the twin position of the great circle II. The twin position of y must lie on arc II' and can be readily located at y' , the intersection of arc II' with a small circle about P having the radius $P \wedge y$. It is now possible to construct the arc of the zone III in its transposed position III', for we have two of the points, y' and n' of the latter, already located. By the aid of the Penfield transparent great circle protractor the position of the arc of the great circle on which these two points lie can be determined. On this arc, III', o' and m' must also lie. Their positions are most easily determined by drawing arcs of small circles about b' with the required radii, $b \wedge o = 63^\circ 8'$, $b \wedge m = 59^\circ 22 \frac{1}{2}'$ and the points at which they intersect arc III' locate the position of the poles o' and m' . At the same

time the corresponding points on IV' may be located, it being noted that IV' and III are the same arc. But one other form remains to be transposed, the prism z . We have already b' and m' located and it is a simple matter with the aid of the great circle protractor to determine the position of the great circle on which they lie. Then a small circle about b' with the proper radius, $b \wedge z = 29^\circ 24'$, determines at once by its intersections with this arc the position of the poles of the z faces.

The transposition of the faces from normal to twin position having been made, it is a simple matter to draw the crystal figures from the projection.* It may be pointed out that if it should be desired to make use of the methods of the gnomonic projection for the drawing of the figures the stereographic projection, as derived above, can be readily transformed into a gnomonic projection by doubling the angular distance from the center of the projection to each pole by the use of the stereographic protractor. But from whichever projection it is preferred to draw the figures, it is thought that the stereographic projection, with the aid of the Penfield protractors, offers the simplest method for the ready transposition of the poles of the faces from normal into twin positions.

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* See Penfield, this Journal, xxi, 206, 1906.