

## ALBITE, VARIETY CLEAVELANDITE, AND THE SIGNS OF ITS OPTIC DIRECTIONS

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## ABSTRACT

Type cleavelandite from Chesterfield, Massachusetts, is a relatively pure variety of albite characterized by its occurrence in granitic pegmatites (especially in hydrothermal units) in masses of *warped* or curved, generally coarse (010) lamellae, some of which form albite twins. Crystal faces and cleavages, except (010) are not commonly evident. Platy albite lacking these qualities should not be designated as cleavelandite. By assigning signs to the optic directions and using the values of the Köhler angles among these, one can differentiate readily between twinning types in the albites.

The variety of albite known as cleavelandite is very commonly present in granitic pegmatites, especially those which have so-called hydrothermal units. Brooke (1823) gave this name to albite while studying material from a pegmatite near Chesterfield, Massachusetts, which occurs with green and red tourmaline. He stated "as the albite is generally blue and sometimes red (in a sample received from M. Nordenskiöld) its name is consequently bad, and *siliceous spar* might be applied with equal propriety to other substances; I have therefore preferred adopting the term *cleavelandite* (after Dr. Parker Cleaveland) to denote the species. The specimen which first enabled me to determine the form is bright blue and it came from Labrador." He goes on to describe the form as having three cleavages which from the angles he gives we would now designate as (001), (010), and (110).

However, shortly after this time, agreement was reached that this material should be called albite (a name introduced by Gahn and Berzelius in 1815) and in Dana's System (1844, p. 353) is stated "cleavelandite is a white lamellar variety (of albite) occurring at Chesterfield, Mass., the lamellae of which are often so arranged as to form wedge-shaped masses." It is probable that Hedenberg (1806) had this sort of material on hand which he referred to as "krumtblätteriger Feldspath."

The loan of a sample of cleavelandite from Chesterfield, Massachusetts was obtained from the Leidy Collection of the U.S. National Museum (No. 82,274) through the courtesy of Mr. P. E. Desautels. This sample, about 9×5×4 cm, is mainly cleavelandite, but minor quartz and muscovite are present. One end of it is massive tourmaline (red and near black) making a very irregular contact with the cleavelandite, and small euhedrons (except for the ends of the crystals) of tourmaline of these colors (some bent and cracked) shoot through the cleavelandite. These near-

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euhedrons are subparallel to one another and to the elongation of the cleavelandite masses.

The cleavelandite is very light gray (nearly white, with perhaps a very faint bluish cast) and has a subpearly luster; the crystals consist of slightly curved lamellae parallel (010) as much as 5 to 6 cm long, 2 cm wide, and 1 to 2 mm in thickness. The material is very brittle and it was with difficulty that samples suitable for small thin-sections were cut from it approximately normal to its elongation. These samples show a V-shaped mass of coarse, polycrystalline quartz with sharp straight boundaries, against which are plastered the cleavelandite plates, which are parallel the plane surfaces of the quartz (Figs. 1, 2). The crystals are so thin that one sees the basal cleavage only with difficulty; for the same reason the (010) cleavage is not evident, the sample splitting along the (010) crystal faces or composition planes which appear warped and almost shreddy; no crystal faces except (010) were observed. The term cleavelandite should not be applied to platy crystals of albite which show nearly plane faces parallel (010) and which have additional crystal faces; it should be reserved for near-massive albite occurring in lamellae parallel (010) which are curved or warped and, in general, lack other well-defined crystal faces, and may be twinned on the albite law. The near-white color and the pearly luster on (010) are also striking in the Chesterfield cleavelandite. Billings (1941) has given a brief description of the pegmatites of the Chesterfield area (his "Western Belt" in Massachusetts); of the 20 deposits visited by him, one fourth contained cleavelandite.

Cleavelandite sometimes occurs in quite large masses. Fisher (1945) has described and pictured spherical to cylindrical masses ("pipes") of the material (with quartz and muscovite) up to 8 feet in diameter composed of radiating plumose crystals at the Old Mike pegmatite in the Black Hills. Shainin (1946) figured hemispherical masses from Branchville, Connecticut up to 3 feet through, the outer portions of which consist of radiating sheaves of cleavelandite. Wright (1948) described similar "bursts" up to 8 feet in diameter in the Petaca district of northern New Mexico.

However, the term *cleavelandite* has been applied in the literature to material that is very unlike the type cleavelandite. Thus Andersen (1928) tends to use it as synonymous with platy albite but his photographs (Plate V and p. 171) show masses of small crystals of platy albite very different from the Chesterfield cleavelandite. Following Andersen the writer (1942, 1945) made the same mistake, although some of the material I described is true cleavelandite; the error consisted in extending the term too broadly, covering other forms of platy albite. This mistake has been perpetuated in the recent volume of Tröger (1967, p. 689).

Lately I have been re-studying the poikilitic albites of the Black Hills pegmatites (Fisher, 1945) on the universal stage. For relatively pure albites such as these, and for cleavelandite, it is easy to be confused as regards the type of twinning involved, especially where the zonal technique does not yield a satisfactory distinction. Thus the angles between corresponding optic symmetry axes in the two units of an albite or Carlsbad twin, where the An percentage is 5 or less, are very close to one another. However these two twin laws are easily differentiated on the basis of the angles between the optic axes,  $A \wedge A'$  and  $B \wedge B'$ . All these values appear in Table 1, but in using this table, it is important to distinguish between (+) and (-) directions. These can be made clear on an upper

TABLE 1. KÜHLER ANGLES FOR (LOW) ALBITES

Name	Twin Axis	Comp. plane	% An	$X \wedge X'$	$Y \wedge Y'$	$Z \wedge Z'$	$2V_Z = \text{standard}$		$2V_Z = 4^\circ \text{ smaller}$	
							$A \wedge A'$	$B \wedge B'$	$A \wedge A'$	$B \wedge B'$
Normal (Plane or Reflection) Twins										
X (Doubtful)	$a^*$	(100)	0	12	169	175	107½	97½	111½	100½
			5	13½	168-	175	108	97	111½	99½
			10	22	158½	175	105	95	108	98
Albite	$b^*$	(010)	0	178½	147	33	82½	85	78½	82
			5	178+	149	31	82	85	78½	81
			10	179½	157	23	84	85	81	81
Manebach	$c^*$	(001)	0	138½	48½	155½	173½	134½	173½	134
			5	140	46½	157½	172½	137	174	136½
			10	149	35	165	171	148	172	146
Baveno-r	$\perp$ (021)	(021)	0	150½	69½	119	113½	152½	112	151
			5	151½	70	117	112-	152½	111-	151
			10	158½	75	109	112	143½	111	141+
Baveno-l	$\perp$ (02̄1)	(02̄1)	0	151½	125½	63½	119½	70	117½	68
			5	152+	123	64½	119½	75	116	71
			10	157+	113	72	122-	85+	119½	82
Unit-r	$\perp$ (111)	(111)	0	86	96	165	111½	138	114	140
			5	87	95	163½	111	136+	113	140
			10	95½	88	158	109	145	113	147½
Unit-l	$\perp$ (1̄1̄1)	(1̄1̄1)	0	85	118	127+	165½	72	170	74½
			5	86	116	128	166-	72+	169	74
			10	94-	104	132½	163	82	166½	84
Prism-r	$\perp$ (130)	(130)	0	118	146-	73	36	145+	35½	141½
			5	118	149-	72+	36	147½	35	144
			10	120	149½	68½	36+	146-	34½	142
Prism-l	$\perp$ (1̄30)	(1̄30)	0	121½	157+	63½	139	29+	135	27
			5	122-	160	62	138½	30	135	27½
			10	121-	171½	60-	141	24½	137½	21

TABLE 1. (Continued)

Name	Twin Axis	Comp. Name	% An	$X\Lambda X'$	$\Gamma\Lambda\Gamma'$	$Z\Lambda Z'$	$2V_Z = \text{standard}$		$2V_Z = 4^\circ \text{ smaller}$	
							$A\Lambda A'$	$B\Lambda B'$	$A\Lambda A'$	$B\Lambda B'$
Parallel (Axial or Edge) Twins										
Ala	a	A-(001) B-(010)	0	41	140	170	98	117	101½	121
			5	40	141	171	98	115	101½	118
			10	31½	150	174	96	107	99+	109+
Pericline	b	[010]	0	177	155½	26	78	85	74	81
			5	177	157½	21	78	87	74	83½
			10	177½	165	14½	80	86	77-	82
Carlsbad	c	A-(010) B-  [001]	0	168	35	147+	147	162½	146	161+
			5	167-	33½	149½	148-	165-	148	164
			10	158	31½	157½	148½	177½	148½	176+
Complex (Edge-Normal) Twins										
Albite-Ala	⊥[001] in	(010)	0	139	53	148½	178	128½	180	129½
			5	139½	50½	150-	178	130	180-	130½
			10	149	39	157½	176	142	177	142
Manebach-Ala	⊥[100] in	(001)	0	178	153	27	83½	81	79	77
			5	179½	155	25	83	83½	79	79
			10	178+	164-	16½	85	82	81-	78
X-Pericline	⊥[010] in	(100)	0	168	27	155	154	168	154-	165½
			5	167-	26	160-	154½	170½	154½	170
			10	158	26	166	155½	176½	155½	177½
Scopi	⊥[010] in	(001)	0	41+	139	174	101½	113	106	117
			5	40	140+	176	102	110	106	113½
			10	31½	148½	178	100	103+	103½	107+
X-Carlsbad	⊥[001] in	(100)	0	177	146½	33	82	86	77½	82
			5	177½	148½	31½	82-	88	78	84
			10	179½	157+	23-	84	85	80	81½
Roc Tourné	⊥[001] in	(010)	0	12	169	175	107	97	111	101
			5	13	168	175	107+	96	112-	99
			10	22	159	176	104	95	107½	99

Notes to Table 1. All angular values are between elements of like sign. Results were obtained graphically using an  $r = 20$  cm stereonet starting with the elements and optical indicatrix of Burri *et al.* (1967). "Standard"  $2V_Z$  values are those of Burri *et al.* ( $78.0^\circ$  for  $An_0$ ,  $78.4^\circ$  for  $An_2$ , and  $82.0^\circ$  for  $An_{10}$ ). See discussion in text. Plates 13-15 of Burri *et al.* graphically show the Köhler angles for albite, Carlsbad, and Roc Tourné twins. The numerical values appear in that work in Table 42 for albite ( $180^\circ - 2\varphi^*$ ), Carlsbad ( $2\rho$ ), and  $X(2F_2)$  twins; the latter are very close to the Roc Tourné values. The albite values are also given as  $2\epsilon$  in Table 433; the Manebach ones are  $2\eta$  of Table 434; and the Ala ones are  $2\nu$  of Table 435. What is commonly referred to as an X-twin (see above table) should be called an  $[a^*]$  twin; note that X is the twin axis of the Roc Tourné twin.

hemisphere stereogram normal to [001] with  $[b^*]$  running east-west such as Plate V of Burri *et al.* (1967), or Figure 170 of Winchell (Part II, 1951). Here for oligoclase ( $An_{25}$ ), which is optically negative, plus X is close to

the pole of  $[\bar{1}00]$ , *plus*  $Y$  is in the lower left quadrant not far from the pole of  $[001]$ , and *plus*  $Z$  is in the lower right quadrant near the pole of  $(010)$ ; also *plus*  $A$  is in the upper left quadrant, between *plus*  $X$  and *minus*  $Z$ ; and *plus*  $B$  is in the upper right quadrant, between *plus*  $X$  and *plus*  $Z$ . When such distinctions are made, it becomes clear that albite twins of this cleavelandite may be regarded as hemitropes on  $[b^*]$  or as reflection (normal) twins on  $(010)$ . Details of the technique for determining the signs of crystallographic vectors are explained by means of an example given in the appendix.

Studied on the U-stage, the Chesterfield cleavelandite yields the results shown in Table 2.

TABLE 2. U-STAGE RESULTS ON CHESTERFIELD CLEAVELANDITE

Element	Fig. 1 ( $R$ & $V$ )		Fig. 1 ( $S$ & $T$ )		Fig. 2 ( $X$ & $Y$ )	
	Angle	% An	Angle	% An	Angle	% An
$X \wedge X'$	177	ns	$176\frac{1}{2}$	ns	178	ns
$Y \wedge Y'$	148	3	150	6	148—	2
$Z \wedge Z'$	33	0	30	6	$32\frac{1}{2}$	2
$A \wedge A'$	82	ns	$81\frac{1}{2}$	ns	82	ns
$B \wedge B'$	86	ns	86	ns	86	ns
$2 V_z$	$78 \pm 2$	ns	$79\frac{1}{2} \pm 2$	ns	$80 \pm 2$	ns

*Notes.* The values given for the angles between optic axes are based on an assumed  $2V_z = 78^\circ$  for easy comparison with Table 1. ns = nonsensitive result. From the above Table  $Y \wedge [b^*] = (Y \wedge Y')/2 = 74\frac{1}{2}^\circ$ ; this corresponds to An<sub>1</sub> according to Burri *et al.* (1967, Plate XVI).

These values (omitting the nonsensitive results) show clearly that some of this material is twinned on the albite law and indicate 0 to 5 percent An.<sup>1</sup> This is in line with the old analysis by Stromeyer (in Laurent and Holms, 1835) which gives 10.5 percent soda and 0.2 percent lime. The two units marked  $R$  and  $V$  in Figure 1 are related by the albite law and constitute a single lamella. The next unit shown (marked  $G$ ) is simply in contact with unit  $V$  along  $(010)$ , but these two do not bear a twin relationship to one another; in fact here  $[c] \wedge [c']$  is very large (at least  $70^\circ$ ).

Similarly, in Figure 2 the units marked  $M$  and  $N$  are definitely not in twin relationship, but simply a random intergrowth, whereas units  $X$  and  $Y$  are related according to the albite law. In the case of  $X$  and  $Y$  the composition plane  $(010)$  is only  $3^\circ$  off vertical while  $[001]$  is only  $2^\circ$  off horizontal. For units  $R$  and  $V$  of Figure 1, plane  $(010)$  is  $4^\circ$  off vertical

<sup>1</sup> Microprobe analysis of the Chesterfield cleavelandite by C. R. Knowles (pers. comm., Aug. 25, 1967) showed 100% albite (only traces of Ca and K, not exceeding 0.1% each).

and [001] is  $11^\circ$  off horizontal. The V-shaped cross-section of quartz apparently represents later crystallization of that mineral between subhedral masses of cleavelandite which had consolidated earlier.

The data in Table 1 are of considerable value in determining the type of twin present in a given albite. But since the indicatrices for  $An_0$  and  $An_5$  are so close to each other (according to Burri *et al.*, 1967) these data will be of little help in determining the composition through this limited range. Certain twin laws yield results that are very close to one another:

- 1) X and Roc Tourné
- 2) Manebach and Albite-Ala
- 3) Ala and Scopi
- 4) Albite, Pericline, Manebach-Ala, and X-Carlsbad
- 5) Carlsbad and X-Pericline

In these cases identification of the composition plane may be of considerable help. Since the optic angles of the poikilitic albites so far studied by the writer are often smaller than the "standard" ones of Burri *et al.*, the last two columns of Table 1 can be of considerable help with a specimen in which the actual optic angle value has been determined.

#### APPENDIX

This is added for those who wonder how the signs of the various directions may be defined from the U-stage results. The explanation is given in terms of the values obtained for units  $R$  and  $V$  of Figure 1, shown in Table 3.

TABLE 3. U-STAGE READINGS ON UNITS  $R$  AND  $V$  OF FIGURE 1

	$A_1$	$A_2$	$A_4$	Sign <sup>a</sup>	$2V_z$	$A_1$	$A_2$	Sign
Composition plane	136	$4l^a$						
Unit $R$	64	$16\frac{1}{2} r$	320	(-)	80	$151\frac{1}{2}$	10 l	(+)
Unit $V$	30	17 r	50	(-)	76	120	2 r	(+)

<sup>a</sup> The sign shows whether addition or subtraction parallel  $A_4$ ;  $l$  and  $r$  mean reading on the left or right arc.

These are plotted on the stereograms of Figures 3 and 4 and explained in the legend for Figure 3.

It is clear that we are dealing with a reflection (normal) twin whose composition plane is (010). The upper hemisphere pole of this plane is either *plus* [ $b^*$ ] (assumed in Fig. 3) or *minus* [ $b^*$ ] (assumed in Fig. 4), but at the moment we do not know which.

Once the sign of [ $b^*$ ] is fixed, it is a fairly simple matter to define the

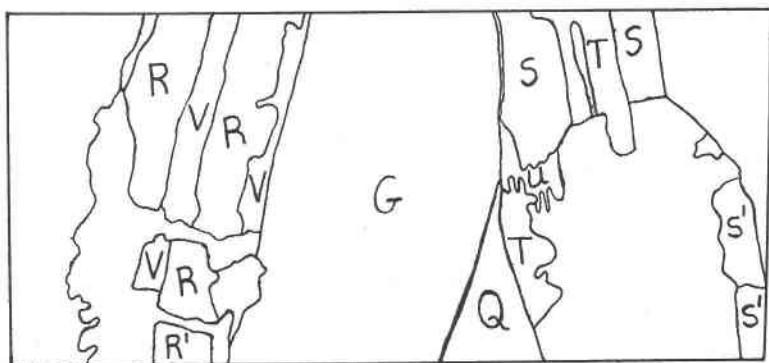
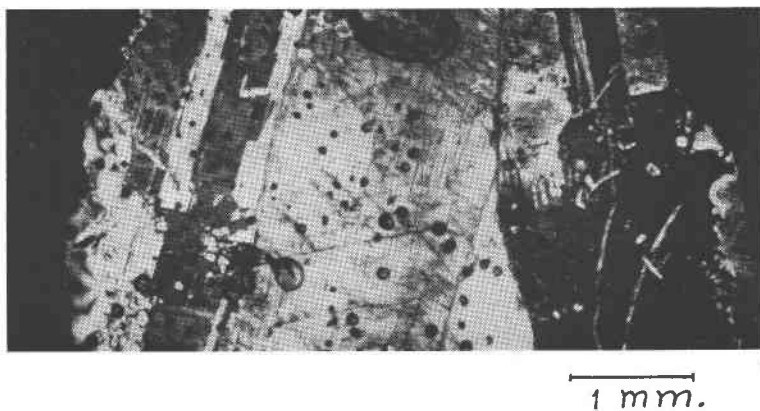
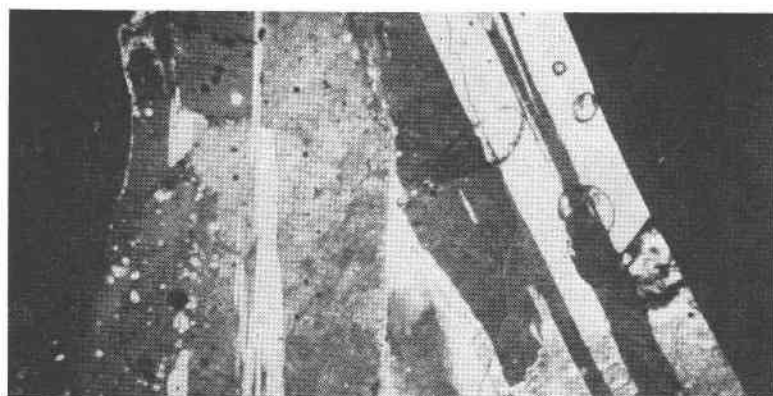


FIG. 1. Photomicrograph of Chesterfield cleavelandite (between crossed polars) taken nearly normal to the elongation of the cleavelandite lamellae. *Q* shows quartz; the other letters indicate cleavelandite units which may or may not form albite twins. A lamella may consist of an untwinned crystal (*G* in Fig. 1), of a random intergrowth (*MN*), or of albite twins (*RV*, *ST*, *XY*).

signs of *X*, *Y*, and *Z*. One way to do this is to have a rod model showing the directions and signs of the crystal axes and the optic symmetry axes in albite, and hold this above the stereogram. Another way is to rotate  $[b^*]$  and the optic symmetry axes so that *Y* lies at the center of the stereogram, and then place this above Plates IX or X (Burri *et al.*, 1967), since on these, the signs of the optic symmetry axes are shown. But here one important warning is necessary: If the stereogram is put *upside down* above one of these plates, this means that  $-Y$  (rather than  $+Y$ ) lies at the center of the stereogram. Under these conditions one must take the *opposite* sign from that shown on the plates for any and all points (poles)



1 mm.

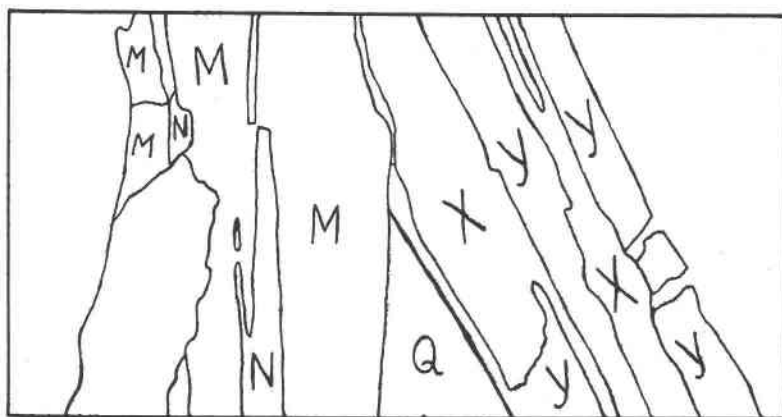


FIG. 2. Another view of the section shown in Fig. 1.

that are transferred to the upper side of the stereogram. Since  $(+)Z$  lies within  $11$  to  $17^\circ$  of  $(+) [b^*]$  in albite, there should never be any question about the sign of a particular  $Z$  direction in relation to the sign of  $[b^*]$ . One advantage of this technique is that the positions and signs of  $[a]$  and  $[c]$  may be taken from Burri, *et al.*, Plate X, and then these may be rotated back into the plane of the original stereogram; thus these have been added to both Figures 3 and 4.

It is now a simple matter to tell whether  $[b^*]$  is plus or minus. In Figure 3,  $A \wedge A' = 180 - 98 = 82^\circ$  and  $B \wedge B' = 180 - 95 = 85^\circ$ . In Figure 4 these values are reversed. But from Table 1, it is clear that the values of Figure



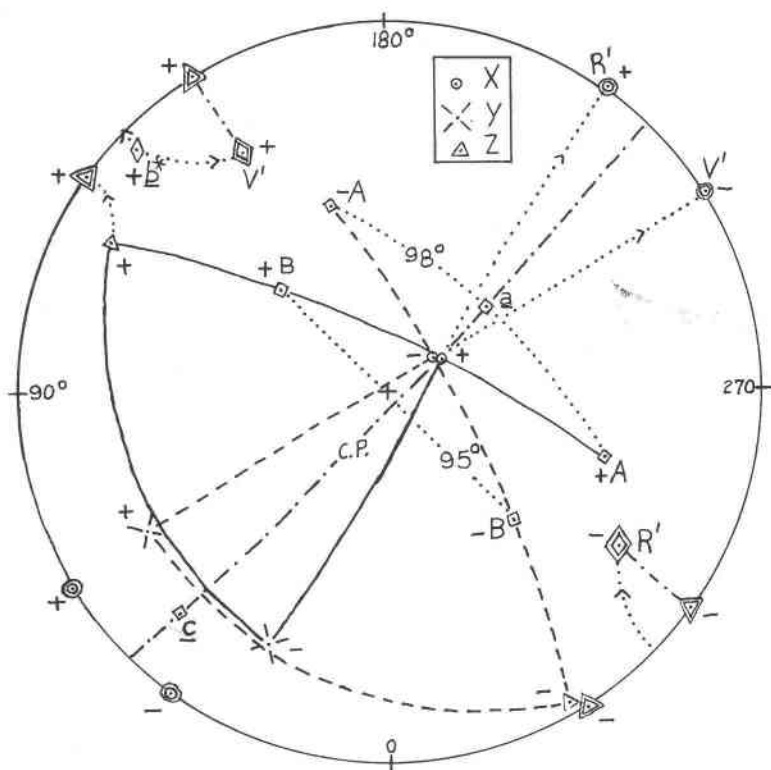


FIG. 3. Stereogram (projected to the upper hemisphere) showing  $R$  (continuous lines) and  $V$  (dashed lines) units of Figure 1. Here the upper hemisphere pole of the composition plane (C.P.) is taken to be *plus* [ $b^*$ ]. For unit  $R$  then  $X$  is (+) and  $[a]$  and  $[c]$  are (-), and for unit  $V$  the signs for these elements are opposite; i.e.,  $X$  is (-) and  $[a]$  and  $[c]$  are (+). The elements shown by double line symbols represent positions when  $Y$  is rotated to the center of the stereogram.  $2V_Z$  is taken as  $78^\circ$ . The rotated stereogram for the  $R$  unit is put on Plates IX-X (Burri *et al.*, 1967) upside down (i.e., with  $-Y$  at the center), but the  $V$  unit fits these right side up ( $+Y$  at the center).

3 are correct, those of Figure 4 are wrong. Thus it is evident that in this case the [ $b^*$ ] shown in Figure 3 is correct. Since there are but two possibilities, and one is shown to be correct, the other wrong, there can be no question as regards the signs of all the optic and morphologic directions; this is one of the virtues of dealing with a triclinic mineral. The differences between Figures 3 and 4 are that the signs of the directions not close to the central portion of the stereogram are reversed, as is the designation of the optic axes; also the positions of  $[a]$  and  $[c]$  are changed.

The preceding analysis seems reasonable as long as we consider ourselves

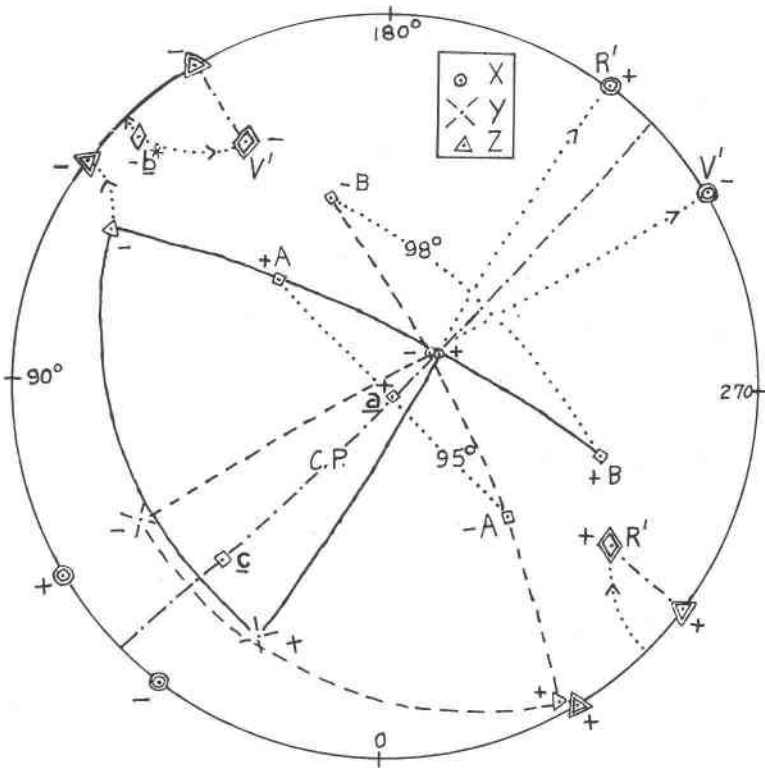


FIG. 4. Stereogram like Figure 3 except that the upper hemisphere pole of the composition plane is taken as *minus*  $[b^*]$ . Here for the  $R$  unit  $X$  and  $[c]$  are  $(+)$  while  $[a]$  is  $(-)$ , and for the  $V$  unit  $X$  and  $[c]$  are  $(-)$  while  $[a]$  is  $(+)$ . The rotated  $R$  unit fits Plates IX-X right side up ( $+Y$  at the center), but the rotated  $V$  unit is upside down (that is, with  $-Y$  at the center).

to be dealing with a  $[b^*]$  hemitrope of albite. In this case the sign of  $[b^*]$  must be the same in both units. But if the albite is a reflection (normal) twin on (010), then the sign of  $[b^*]$  is different in the two units. Under these circumstances there are two possibilities: (1) if in Figure 3 we leave the  $R$ -unit as it is, the new  $V$ -unit (obtained by reflection of the  $R$ -unit in the composition plane) would appear exactly as the present one in Figure 3 except that the signs of all six points (optic axes, optic symmetry axes, and  $[b^*]$ ) would be reversed; (2) if we start with Figure 4 and proceed in the same fashion, an exactly analogous new condition obtains for the new  $V$ -unit. In either of these cases the interoptic symmetry axis angular values become the supplements of the angles that appear in Table 2, whereas in the first case  $A \wedge A' = 98^\circ$  and  $B \wedge B' = 95^\circ$ , while in

the second case these values are reversed. The first case is thus a possibly correct one (since it fits the supplements of the interoptical angular values given in Table 1) whereas the second case is not.

It is thus confirmed that using purely optical data as herein employed, one cannot tell whether a given twin of albite is a  $[b^*]$  hemitrope or a (010) reflection twin.<sup>1</sup> It should be emphasized that the figures given in Table 1 assume the twin laws as stated therein, where all twins are taken to be hemitropes. As in the case of the albite law example just cited however, it seems that as far as this type of purely optical work is concerned, all these twins may be equally well considered as being of the reflection type. Thus the six complex twin laws of Table 1 could be taken as reflection twins in the following planes (in the order of Table 1):  $(b^*a)$ ,  $(c^*a)$ ,  $(a^*b)$ ,  $(c^*b)$ ,  $(a^*c)$ , and  $(b^*c)$ . Of course for this situation all the interoptical symmetry axes angles given in Table 1 would have to be the supplements of the values therein.

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<sup>1</sup> From this statement it should not be inferred that the writer thinks it possible to make this distinction on the basis of other properties not herein considered; both Professor J. D. H. Donnay and the Editor are adamant in this matter also.