13. Studies in Sodium-Poor Potash Feldspars

By

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Contents

Acknowledgments

Afforded with a scholarship from the Chinese Government, the author came to Sweden in the winter of 1948 in order to study the Scandinavian geology in general and do some specialized work in particular, but the work on Shansi alkaline rocks was not started until the early spring of 1950. Most of the measurements were made during the spring while still some others were carried out in the autumn after the summer excursions were ended.

The material put at the author's disposal out of the well-stocked Geological Museum of the Stockholm University is part of the comprehensive collection made by Prof. E. NORIN in 1920. It includes, however, also some specimens collected later by Prof. E. NYSTRÖM of the Shansi University and his students.

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Introduction

Tzuchinshan, the Golden Purple Mountain, from where the material comes, constitutes a small, isolated mountain group which rises above the extensive Mesozoic sandstone plateau in W. Shansi to a height of 200—450 m at a distance about 20 km N.N.W. of the town of Linhsien and 160 km W.N.W. of the provincial capital, Taiyuan Fu.

It is one of the three known occurrences of alkaline rocks in Shansi, the first detailed survey of which was carried out by NORIN in 1921. The rock types are known to comprise åkerite porphyry, augite syenite with associated alkali-lamprophyres and leucocratic dyke rocks as well as nepheline- and leucite-bearing tinguaites. Volcanic breccia is also reported containing, in addition to brecciated sedimentary country rocks, fragments of all the above-mentioned rock types except the latest introduced tinguaites, which cut the eccentrically situated volcanic neck in radial directions. A preliminary examination of the rock slides disclosed the interesting complexity furnished by the twin formation of the alkali feldspars. It is on this subject the present paper is contributed, attached with a general discussion on the disposition of alkali feldspars. For further information of the Tzuchinshan rocks, NORIN's preliminary paper (1921, pp. 45—70) is to be referred.

I. Alkali Feldspars in the Feldspathic Dyke ("Orthosite")

1. General Description of the Rock

The rock dealt with in this section is a medium-grained, equigranular, allotriomorphic dyke rock containing more than 99 % of alkali feldspar. Miarolitic cavities ranging from interstitial size up to 2 cm in its greatest width are not uncommon. They are in most cases filled up with scattered iron-ore grains or lined with such when the cavities are too large to be filled up. Such fillings and linings give the otherwise clear and clean rock a spotted appearance. A closer ocular examination of the hand specimen reveals also the presence of a few light-violet fluorite grains and clusters of biotite scales.

The ore grains are oxygenated and scarlet or deeply carmine-red in very thin section, appearing either with imperfect rectilinear sides in large cavities or irregular and lobate, sometimes also triangular with incurved sides filling the intergranular spaces between the feldspars. Biotite occurs only in very small amount, either independent or attached to ore grains. Occasionally also epidote is noticed. Calcite forms either triangular cavity-fillings or veinlets alongside the feldspar boundary, but may also be found as crack-fillings in the feldspars. The feldspars are anhedral and irregularly rounded or lobate in outline, though euhedral or partially idiomorphic crystals may occasionally be found, for instance as minute inclusions with (001) ($\bar{1}01$) and (100) perfectly developed or in sections perpendicular to the a-axis where (001) and (010) come to form the apparently pseudotetragonal symmetry of the Baveno twins, or, where the crystal is bound to miarolitic cavities even with (001), ($\bar{1}01$) and (110) faces well developed so that a rhomboidal form is simulated.

2. Cleavages and Partings

Two sets of cleavages are developed in the feldspar: the basal one is the most frequent and perfect while the clinopinacoidal, which is less persistent, is present only in the tetragonal or rectangular cross-sections of the Baveno twins. A third set, which is generally considered to have the character of partings, is as frequent and strongly marked as the basal cleavage. It consists of a number of independent parting planes variable in direction but go in the main roughly parallel to (100), (110) and $(\bar{1}10)$ faces. In one single crystal either of these parting planes may predominate, but there is tendency for the partings to pass from one direction into the other by following all possible vicinal and intermediate positions. In twins all the three sets of parting plane may be developed in equal strength, but it still holds that one set prevails over one unit of the twinned crystal. Careful investigation shows, however, that there are also frequent transitions from (100) to hemiorthodomic positions until it approaches to and beyond $(\bar{2}01)$. This fact is obvious not only from the angles between the parting planes and the (001) cleavage, being in the present case 60—90°, but is also evident from NIKITIN's diagram (1) against which the result of 11 measurements are plotted with reference to the optic indicatrix (Fig. 1). The partings are not persistent though as a rule sharp and distinct, crossing either several (001) cleavage planes in a short distance or simply confined by two successive (001) cleavage planes. Furthermore, when the parting planes pass from (100) through the murchisonite-parting zone to and beyond $(\bar{2}01)$ in the direction of hemiorthodomes, the frequency of occurrence is greatly reduced and it becomes at the same time less and less persistent.

The partings of potash feldspars has long been noted by petrographers and mineralogists. WINCHELL (1948, p. 361) reported the parting or poor cleavage in orthoclase. DANA (1932, p. 536) reported imperfect (110)-cleavage and (100)-parting as well as a hemiorthodomic parting inclined at a few degrees to (100), and that the (110)-cleavage is usually more distinct parallel to one face than to the other. MAGNUSSON (1923, p. 306) found (100) partings variable at 64—72° to (001) in alkali feldspars. USSING (1898, pp. 6, 44, 52, 61) recorded (100), (110) and $(1\bar{1}0)$ partings in soda-orthoclase, cryptoperthite and microcline and related that the angle between $(1\bar{1}0)$ and (001) varies between 65—70°; he also found that $(1\bar{1}0)$-parting is by far more frequent and perfect than (110) if both are present in one and the same individual. In the more or less weathered specimens the same author (USSING 1898, p. 53) found even partings roughly parallel to $(\bar{8}01)$. SPENCER (1930, pp. 308—309) found also such parting at an angle of 73° to (001) in the de-albitized moonstones from Ceylon. ROSENBUSCH (1905, pp. 301—302) related murchisonite partings corresponding to $(\overline{15}.0.2)$, $(\bar{7}01$, $(\bar{8}01)$ as well as occasional partings parallel to (100), (110)

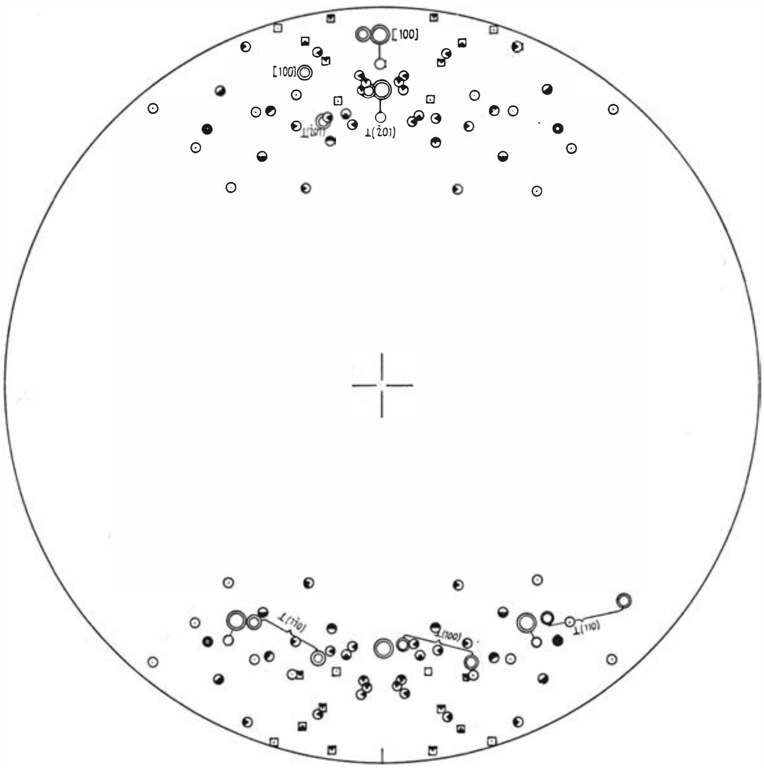


Fig. I. Poles for partings and cracks in potassic feldspars, plotted against NIKITIN's diagram 1936. (Rings for partings, squares for cracks.)

and ($\bar{2}01$) in orthoclase. DOLAR-MANTUANI (1931, p. 289) mentioned partings in anorthoclases parallel to (100), ($\bar{6}01$), ($\bar{5}01$) and ($\bar{4}01$).

The present investigation shows that in the treated alkali feldspars the partings are mainly parallel to (100), (110) and ($1\bar{1}0$), but there are also subordinate parting planes running parallel to hemiorthodomes which may be inclined at 20° to the orthopinacoid. They are not considered to be cleavages since they do not represent any definite structural plane, and faces of the same form do not present the same degree of development in one and the same individual. The true cleavages are the (001) and (010) ones which are regular and perfect in all crystallographically identical directions.

As to the irregularity and imperfectness of the partings, we may refer to TAYLOR, DARBYSHIRE & STRUNZ's joint work (1934, p. 490) in which the conclusion is reached that the (001) and (010) cleavages break only those bonds which link one chain of four (tetragonal) rings to adjacent chains while in any other direction it must break bonds within the four rings themselves.

Partings as a whole are commonly regarded as due to lamellar structure, secondary gliding or twinning. In feldspars perthitic lamellar growth has been noted on a number of occasions to be parallel to (100), (110), $(1\bar{1}1)$, $(40\bar{1})$, $(60\bar{1})$, $(70\bar{1})$, $(80\bar{1})$, $(13.0.\bar{2})$, $(15.0.\bar{2})$, $(30\bar{2})$, (350), $(1\bar{1}1)$, $(8\bar{6}1)$, $(8\bar{6}\bar{1})$, etc. (See REUSCH 1862—1863, WHITMAN CROSS 1885, BRÖGGER 1890, BÖGGILD 1924, USSING 1898, ANDERSEN 1929, SPENCER 1930, and ROSENQVIST 1950.) However, very prominent, sometimes almost micaceous partings are only noted in weathered specimens where chemical alteration has gone so far as to enhance the ease of the parting (USSING 1898, p. 53, SPENCER 1930, pp. 308—309). In our case the feldspars are very fresh and do not possess perthitic lamellar structure, neither are they polysynthetically twinned on such parting planes. Genetically it is believed therefore to be of a similar character as the (100), (110), (111) & (831) partings in some magnetites from N. Y. (GREIG, MERWIN & POSNJAK 1936, pp. 509—510), being developed without twinning or similar structure but by differential pressure during the crystal growth. The crystal structure must have exercised some control in the development of partings in general, but in the case of feldspars it seems to be that it can be developed over all in alkali feldspars regardless of its symmetry and composition.

3. Contraction Cracks

Cracks with uneven planes are not uncommon. They are associated with the perfectly even-planed partings in two major sets with some deviation and make only very small angles with each other. They come into confluence sometimes and bifurcate in other places just as LEHMANN (1886, p. 612) had observed in his experiment on adularias. They often, if not always, traverse the whole section of crystal and are oriented essentially parallel to (100), $(1\bar{1}0)$ & (110), sometimes also parallel to hemiorthodomes like $(\bar{2}01)$, etc., and making angles between 67—85° with (001)-cleavage just like the partings.

The existence of miarolitic cavities and the integrity as well as the random orientation of the composing grains of the rock show that the rock has not undergone any dynamic deformation, therefore the tectonic origin of the formation of the cracks is excluded. The effect of grinding during the slide preparation might have widened the cracks, which may in case be furthered by the pressure of the glass hemisphere on the universal stage, but they are evidently not the primary causes for the formation of cracks in question, since extremely fine calcite veinlets are sometimes seen to fill part of them for some length, emerging from the intergranular boundaries of the feldspar grains. Such fillings in the cracks are obviously introduced after the formation of the cracks in a later stage of the consolidation of the rock.

Table I.

Slide no.	Crystal no.	Partings/ (001)
6564	4	{ 73.° 86. 60. 70. 73. 86.[1]
»	8	69.5
»	9	60.
»	10	58.
»	11	75.
»	13	72.
»	14	67.
»	15	70. 70.
»	17	56. 75.
»	18	{ 67. 78.[1] 61. 68. 91.

Table II.

Slide no.	Crystal no.	Cracks/(001)	Cracks/partings	Intercrack-angle
6564	4	67.° 83.	{ 6.° 14; 4. 16. 26. 36. 44.	16°
»	14	82	{ 36. 50. 58.[1] 13	
»	15	75. 84. 83.	10. 17. 24. 31.	10

BLACKWELDER (1933, pp. 97—113) & GRIGGS (1936, pp. 783—796) came to the conclusion that the effect of insolation on crystal cracks was rather inconsiderable. KOZU & SAIKI's experiment (1925, pp. 203—238) on alkali feldspars also shows that the thermal expansion and contraction is practically negligible within the temperature range and gradient of the insolation. These arguments speak against the assumption that the cracks might be caused by insolation. On the other hand as we know, silicate minerals like feldspars have a relatively low heat conductivity, a fairly large coefficient of expansion especially in one direction and a tensile strength that is not extremely high. The tensile strength of the feldspar will thus easily be overcome by the tensile stress produced by differential expansion on its down-cooling after the crystallization. The consequence is the formation of the contraction cracks.

The present work confirms ANDERSEN's postulation (1929, pp. 140—141) that contraction cracks may also be formed in feldspars of equigranular rocks. What calls for more remarks is that the direction for maximum expansion and contraction of feldspars, according to FIZEAU (1886), BECKEN-

[1] Two or three sets of values are obtained from twinned crystals.

KAMP (1881), OFFRET (1890), KOZU & SAIKI (1925) and summarized later by ANDERSEN (1929, pp. 122—127), lies in (010) at angles about 18—20° to (001), in other words the contraction cracks make usually 70—72° with (001). In the present case, it shows also greater diversity, covering a range of 67—85° with 79° as its arithmetic mean.

That the contraction cracks do not follow the well-developed (001) & (010) planes may be explained by the existence of perfect interplanar cleavage spaces which act as buffers to stress. The fact that the cracks assume more or less the same crystallographic or crystallonomic positions as do the partings and that both show the same sort of diversity seems to indicate that they are controlled by the same structural essentials.

Angles made by the concerned partings and cracks with (001) are given above in Table I and II respectively.

4. Optic Axial Angle and Extinctions

18 measurements, one third in Baveno twins and two thirds in single crystals, were made for the determination for the axial angle and the angles $\perp\gamma:\alpha/(001)$ and $\perp\beta:\alpha/(010)$.[1] The readings will be seen in Table III.

Some anomalies exist in crystal nos. 5 and 16 so far as the extinction angles are concerned. This might well be caused by the distortion from twinning formation and will be discussed later. Taking all the values into account including the anomalies, the average of the angles $\perp\gamma:\alpha(001)$ is around 5°. ALLING (1921, p. 229) mentioned that this extinction for pure orthoclases can be much lower than 4.5—5°[2]; and according to WINCHELL (1948, p. 342) it corresponds to that of adularia and indicates a potash feldspar of low soda-content. However, if we take both the concerned extinction and the optic axial angle into consideration and compare it with SPENCER's investigation (1930, pp. 331, 342—343, 346; 1937, pp. 458—459, Tab. I, Pl. XVIII) the alkali feldspars in question are referable to "Burma Colourless" of SPENCER (1930, pp. 330 and 346) from the Mogok Ruby Mines in the N. Shan States of Burma. If we do not emphasize so

[1] Since the measurements are not made directly on cleavage flakes, angles measured from optic plane are chosen for the discernment of feldspar instead of extinction on (001) and (010). It is to be noted that both are not identical, since γ for the most cases is not normal to (001) and β is seldom exactly perpendicular to (010).

[2] Such low extinction angles may indicate the presence of some percent celsian molecules in the feldspar. According to the same author (ALLING 1921, p. 229), this angle increases to 12° as the amount of the soda-component increases to 25 %, but SPENCER (1937, Tab. I, Pl. XVIII) obtained much lower value, being 8° for the same composition. On the other hand, BRÖGGER (1890, pp. 536—537), USSING (1898, p. 59), SPENCER (1937, Tab. I, Pl. XVIII) and others obtained ca. 12 degrees' extinction on (010) for alkali feldspars containing around 50 % albite molecules. This seems to be very reasonable, since it represents the mean value of pure orthoclase and pure albite, the extinctions of which are respectively 5° and 20° on (010).

Table III.

Slide no.	Crystal no.	Twinning formation	Twinning unit	$\perp\gamma:\alpha/(001)$	$\perp\beta:\alpha/(010)$	$2V_\alpha$	cleavage	α/a
6564	1	2-ling	1	5°	—	42°	001	—
			2	—	1°	40	010	—
»	2	2-ling	1	—	—	46	—	—
			2	—	—	—	—	—
»	3	3-ling	1	—	0.5	42	010	—
			2	3	—	48	001	—
			3	—	2	35	010	—
»	4	3-ling	1	4.5	—	44	001	—
			2	—	0	—	010	—
			3	4.5	—	44	001	—
»	5	2-ling	1	7	6	44	001, 010	8°
			2	1	0.5	36	001, 010	1
»	6	1-ling	1	—	—	56	—	—
»	7	»	1	—	—	40	—	—
»	8	»	1	9	—	48	001	—
»	9	»	1	7	—	—	001	—
»	10	»	1	3	—	50	001	—
»	11	»	1	8	—	50	001	—
»	12	»	1	5.5	—	—	001	—
»	13	»	1	6	—	48	001	—
»	14	»	1	5.5	—	—	001	—
»	15	»	1	7	—	—	001	—
»	16	3-ling	1	8	3	40	001, 010	8.5
			2	3	0	45	001, 010	3
			3	1.5	3	46	001, 010	3
»	17	1-ling	1	5	—	—	001	—
»	18	»	1	4	—	—	001	—
			Average	5°.1	1°.8	44°.4		

much the optic axial angle, the adularia from St. Gotthard or the yellow orthoclase from Madagascar can be compared (SPENCER 1937, pp. 455 and 458—459, Tab. I, Pl. XVIII). All the three contain each of them less than 10% Ab and An in sum. If we confine alkali feldspars with more than 30% Ab molecules to anorthoclase as is usually done (ALLING 1921, pp. 233 and 293), the concerned feldspar falls without doubt in the range of orthoclase.[1] If we regard alkali feldspars with more than 30% Ab molecules as soda-orthoclase as suggested by WINCHELL (1948, pp. 262—263) or confine soda-orthoclase to the range $Or_{90}Ab_{10}$—$Or_{70}Ab_{30}$ as proposed by ALLING (1921, pp. 232—233), the present feldspar falls still in the range of normal orthoclase.

[1] ALLING gave two limitations for anorthoclase, namely $Or_{70}Ab_{30}$—$Or_{20}Ab_{80}$ and $Or_{70}Ab_{30}$—$Or_{35}Ab_{65}$, the latter must be a misprint. See also ALLING 1926, p. 600.

Concerning the extinction on (010), BARTH states (1930, p. 138) that, as a matter of fact, most of the so-called orthoclases from different types of rocks do not display perfect parallel extinction in the zone normal to (010), and according to his experience the deviation, though small, varies from 1—3°. ALLING (1921, p. 229) mentioned that the (010) extinction changes from 0—3° as the amount of soda-component increases to 25 %. SPENCER (1930, pp. 306, 331—332 and 338; 1937, p. 460) reported oblique extinctions in orthoclase phenocrysts (soda-orthoclase) from Colorado and moonstones from Ceylon and Burma, which sometimes amount to 2 or 4° and sometimes varies between 0—3° or 1—3°. Now the present investigation gives the same result. It seems that the tendency for oblique extinction on (001) raises, on the one hand, with the increment of soda-content which makes the orthoclase unable to keep strictly its monoclinic structure, but on the other hand such triclinic extinctions may well be caused also by merely structural, not at all compositional, differences in the alkali feldspars (CHAISSON 1950, p. 542). Here it seems evident that the twinning growth may have caused such structural distortions. The monoclinic structure of the orthoclase seems to be by no means a stable or resistant structure, a problem which will be treated more thoroughly in the second part of this paper.

5. Refractive Indices and Chemistry

The refractive indices of the alkali feldspars in question indicate also that they belong to the low-soda group. Two sets of measurements were made by using the double variation method on the LEITZ U-stage refractometer with ethylene bromide as medium.

The average 5 readings (a_4) at 22° C and 589 mμ (D-line) of these sets of measurements, checked against the Abbe total refractometer control ($\Delta a_4 = -0.05°$), resulted into the following refraction indices[1]:

N_α	readings	41°.21	41°.21		
	index	1.5177	1.5177		=1 5177
N_γ	readings	41°.00	40°.96	41°.00	
	index	1.5240	1.5241	1.5240	= 1.5241

Under the treatment many loose grains or broken cleavage pieces were tried, but since the optic axial plane in the alkali feldspar is nearly normal to (010), it fails to give any possibility for the determination of the index β. The required β value was calculated by using both the common equation and the simplified approximate formula (WAHLSTROM 1948, pp. 122—

[1] According to LEITZ, Tabelle 2. Zusammenhang zwischen Brechungsindex n und Ablesung am Messkreis der Achse A_4. U-Tisch-Refractometer für Messung von losen Körnchen. Beschreibung und Gebrauchsanleitung.

123). However, the difference lies only in the fifth decimal place, because the birefringence and the axial angle are both very small.[1] The complete data of refractive indices referred to air for 589 mμ or the D line at 20° C are as follows:

$$N_\alpha = 1.5177, \quad N_\beta = 1.5236, \quad N_\gamma = 1.5241$$

A check is made by means of the immersion method with α-chloro-naphthalene and butyl-diglycol as immersion media, the result referred to 589 mμ (D) at 20° is given below:

$$N_\alpha = 1.5184, \quad N_\gamma = 1.5262$$

Again the β value is calculated in like manner and the complete data of refractive indices referred to air for 589 mμ or the D line at 20° C are:

$$N_\alpha = 1.5184, \quad N_\beta = 1.5251, \quad N_\gamma = 1.5262$$ [2]

As pointed out before, the extinction angle of this feldspar corresponds to adularia from St. Gotthard, yellow orthoclase from Madagascar and "Burma Colourless" from Burma as given by SPENCER, but considering also the optic axial angle, it appears to be identical with the last-named "Burma Colourless", which like the other two contains less than 10 % soda-lime feldspar. However, considering further the refractive indices, we find that it corresponds to neither of the three but equals in its relatively higher indices the "Burma Blue II" of SPENCER which contains more than 20 % soda-lime feldspar (SPENCER 1930, p. 331; 1937, p. 457 and Table I, Pl. XVIII). Such deviation is obviously caused by the presence of the fourth component in the feldspar, namely the celsian molecule. The chemical analysis of the present feldspar is as follows[3]:

Table IV.

SiO_2	63.01
Al_2O_3	18.46
Fe_2O_3	0.44
FeO	—
MgO	< 0.02
BaO	1.08
CaO	0.52
K_2O	15.70
Na_2O	0.43
H_2O	0.26
Total	99.90

[1] The average of the optic axial angle being 44.4, the birefringence being 0.0074—0.0078.

[2] A check determination on sanidine of orthosite from Tzuchinshan by E. NORIN with Zeiss Opton Standard at $t = +21°$ gave:

$$N_{\alpha D} = 1.520(0), \quad N_{\gamma D} = 1.525(3), \quad \gamma - \alpha = 0.005.$$

[3] The chemical analysis being made by Dr. F. NYDAHL, Aug. 1950, Uppsala.

Table V.

Norm	Y. Orthoclase Madagascar	Adularia St. Gotthard	Burma Colourless	Alkali feld. Shansi	Burma Blue II
Orthoclase	96.0 (95.30)	90.43	90.9 (92.20)	91.6	78.8 (77.24)
Albite	4.0 (3.89)	7.78	6.6 (6.76)	3.8	19.0 (18.60)
Anorthite	tr.	0.55	2.5 (2.50)	2.7	2.2 (2.25)
Celsian	—	0.27		2.0	—
total	100.0 (99.28)	99.03	100.0 (101.46)	100.1	100.0 (98.09)
optic properties					
$2V_a$	34.8	68.4	43.6	44.4	52.9
extinction on (010)	5.0 (5.2)	5.25	5.3	5.1	7.0
extinction on (001)	—	—	0	1.8	0
N_a	1.5194	1.5192	1.5188	1.518 (1.5184)	1.5206
N_β	1.5237	1.5238	1.5230	1.525 (1.5251)	1.5249
N_γ	1.5241	1.5245	1.5236	1.526 (1.5262)	1.5260

The norm of the present feldspar is calculated[1] and given above together with its optic data, for comparison with SPENCER's investigation on related feldspars.[2]

According to the work of KOZU, ENDO and SETO (1916, p. 261; 1921, p. 3; 1923, pp. 220--221), it is known that in the potassic feldspars the albite molecule in the solid solution is more effective in changing the refractive indices than is the anorthite molecule — the higher the content of albite the higher the indices. Through the work of LACROIX, KOZU, SETO and FAUST (1922, pp. 557—562; 1916, p. 266; 1923, p. 221; 1936, pp. 756—757), it is learned that the ferric iron does replace aluminum in the tetrahedral structure of the feldspar and causes a noticeable raise of refractive indices if the resulting iron-orthoclase molecules amount to a certain percent. Now in three of SPENCER's samples referred to above, there is an excess of aluminum over alkalis and calcium, so the ferric iron exists most probably as impurities or inclusions, whereas in the fourth, the Burma Blue II, the ferric iron may have entered into the feldspar structure to form a few tenths of one percent iron-orthoclase, but there won't be much influence on the change of refractive indices. However, if we refer to LACROIX, KOZU and SETO's research, it will be seen that some 2 % celsian corresponds to 12 % iron-orthoclase in its effect on the raise of indices. Another correlative table is given below:

[1] MgO being added to CaO; SiO_2 and Al_2O_3 are deficient respectively for 0.0261 and 0.0093 mols. Since the rock contains iron ore and the feldspars are white or colorless, the ferric iron present in the analysis is not calculated into iron-orthoclase. In the norm-calculation, PHILIPSBORN's Tabellen zur Berechnung von Mineral- und Gesteinenanalysen (1933) is adopted for use.

[2] The correlative data are based on SPENCER's investigation in 1930 and 1937, values in parenthesis being his check value.

Table VI.[1]

Norm	Yellow Orthoclase, Madagascar I	II	III	Alkali feld. Shansi
Orthoclase	84.9 (84.2)	91.5 (85.44)	85.6 (82.6)	91.6
Albite	3.9 (3.72)	4.1 (3.55)	3.5 (2.87)	3.8
Anorthite	—	0.3 (0.35)	—	2.7
Fe-orthoclase	11.2 (12.53)	4.1 (4.81)	10.9 (11.85)	—
Celsian	—	—	—	2.0
total	100.0 (100.27)	100.0 (94.15)	100.0 (97.32)	100.1
N_α	1.5216	1.5185	1.5197	1.518
N_β	1.5259	1.5225	1.5248	1.525
N_γ	1.5261	1.5239	1.5253	1.526

According to STRANDMARK (1904, pp. 53—66), TAYLOR, DARBYSHIRE and STRUNZ (1934, pp. 354—355), celsian and orthoclase are isomorphous, and the replacement of potassium by barium may take place up to about 15 % barium in the hyalophane without causing any appreciable alteration in the stucture but there will be a continuous change in the physical and optic properties which responds to the replacement. Based on extrapolation on STRANDMARK's chart (1904, pp. 59, 61), 2 % celsian of replacement will give an extinction on (010) 1—2° and the refractive index γ will be 1.5265. If WINCHELL's chart (1948, p. 354) is used, the same composition, that is, $Or_{98}Ce_2$, will give again an extinction about 2°.5, an optic axial angle about 52° and a set of indices something like 1.520, 1.524 and 1.527. In both cases the results are rather consistent, this explains why we have so small extinctions like 1—3° on (010) on the one hand and why an alkali feldspar with less than 10 % soda-lime component may have refractive indices corresponding to a feldspar with more than 20 % soda-lime component. However, one must bear in mind that among the feldspars the relation between composition and refractive indices together with other optic properties is rather a complex one. On the one hand it is controlled by the temperature of formation of the feldspar (see ALLING 1926, p. 604, SPENCER 1930 and 1937, TUTTLE and BOWEN 1950, LAVES and CHAISSON 1950, LARSEN 1938;

[1] Norms I and II are calculated by SETO on his analyses I and II (SETO 1923, p. 221), values in parenthesis being a check made by FAUST (1936, p. 757) on the same chemical data. Indices I and II are KOZU's measurements (KOZU 1916, p. 266; SETO 1923, p. 223). Norm III is calculated from BOITEAUX's original analysis for LACROIX (LACROIX 1922, p. 560, analysis a); optic data being given by GAUBERT (LACROIX 1922, p. 561). These data are also cited by FAUST (1936, pp. 756—757), but 2 V_{Na} for LACROIX's type specimen is 36.4 instead of 34.4. BARTH (1931, p. 59) measured another yellow orthoclase from Madagascar which he considered to be corresponding to the type described by LACROIX, but the indices, $\alpha = 1.523$ and $\gamma = 1.529$, seem to be a little bit too high for a common yellow orthoclase.

BARTH and OFTEDAHL 1947, OFTEDAHL 1948, KÖHLER 1941, 1942 A and B etc.), on the other hand it depends upon the intricate relationship existing between different components which take part in the feldspar building (see also ALLING 1926, p. 592, footnote 2). As to the present case we are in fact dealing with a quaternary system.

6. **Barium-Feldspar Component**

Barium-bearing potassic feldspars are widely known. SPENCER (1937, pp. 457—458; Table I, Pl. XVIII) tabulated an adularia from St. Gotthard with 0.27 % celsian and a sanidine from Eifel of Rhineland with 3.2 % celsian. The former does not differ much from the normal barium-free samples of more or less the same composition but the latter shows refractive indices lower than normal. GOLDSCHMIDT, investigating the orthoclase from kamperite of the Fen region, got refractive indices $\alpha = 1.53$, $\gamma = 1.536$ and $2V = 60—70^{\circ}$ for a composition of $Or_{95.5}Ce_{4.5}$ (BRÖGGER 1921, pp. 100—103). Besides, BARTH (1927, pp. 34, 101—102) reported $Or_{97}Ce_{3}$ for the orthoclase lamellae in the antiperthite from canadite pegmatite of Seiland, SPENCER (1937, p. 474) mentioned another adularia from Zillerthal of Tirol with a composition of $Or_{84.5}Ab_{13}An_{0.5}Ce_{2}$, but indices are not stated. HÖGBOM (1895, pp. 40, 219) reported orthoclases in nepheline syenite from Alnö with 1.45 and 1.52 % of BaO while VON ECKERMANN (1948, p. 47) got 0.37 and 0.72 % BaO for soda-orthoclases in fenites and 1.62 and 1.20 % BaO for similar feldspars in the siliceous intrusive rocks. However, indices are not known.

Barium is found to be an element widely distributed and amounts to 0.048 % in the earth's crust whereas the amount of baryta varies between 0.055—0.10 % (WASHINGTON 1920, p. 773—777). WASHINGTON (1908, pp. 13, 20, 1920, 793—794, 1917) by a number of comprehensive analyses came to the conclusion that barium is specially prone to occur in potassic rocks, since barium and potassium frequently accompany each other in mineral constituents. Among the feldspar group, evidence for replacement of calcium by barium in plagioclase is little known except the example given by DES CLOIZEAUX (1877, pp. 99—100). In the orthoclase group barium feldspar is not seldom found to associate adularia, sanidine or common orthoclase as minor constituents, whereas in the case of perthites or antiperthites it is always found in the orthoclase lamellae (BARTH 1927, pp. 57—63, PENFIELD and SPERRY 1888, pp. 326—329). Now the present work comes to add another example to the known isomorphism of Ba- and K-compounds in the form of feldspars.

Since the feldspar concerned forms nearly the whole bulk of the rock, the Ba-content will amount to about 1 %, a figure approaching the maximum content of BaO in certain exceptionally high potassic rocks of Wyoming (WASHINGTON 1920, p. 767). As to strontium, it is absent in the present feldspar according to the chemical analysis. Since the ratio of BaO : SrO in percentages corresponds roughly to that of K_2O : CaO (ESKOLA 1922, pp. 365—366), not much strontium can be expected to be present in the present feldspars.

7. Perthitic Structure

Perthitic structure is seldom developed, if not entirely absent. Under low magnification almost all the feldspar grains show uniform extinction except some individuals appreciably affected by residual solution. Under medium magnification several grains show irregular patchy undulatory extinction under crossed nicols, indicating a tendency toward perthitic development, but no perthitic structure can be detected even under highest magnification.

Besides, some microperthitic veinlets and patches are occasionally found, either isolated or several in a set, curved and lobate, sometimes arborescent and anastomosing like the vein and patch perthites of ANDERSEN (1929, pp. 150—151, 166—169) but much thinner and smaller without assuming any fixed crystallographic position. The veinlets are in general less than 0.01 mm in width and a few tenths of mm long. They don't make use of any pre-existing cracks or interstices, but cross twinning planes and sometimes even crystal boundaries in its incidental course. Under crossed nicols it is observed that they always possess a central portion with slightly lower birefringence and therefore more potassic than the periphery. In this way it reminds of the microperthite interpositions that traverse the non-perthitic soda-orthoclase from S. Greenland (USSING 1898, p. 63, Pl. V, fig. I).

In conclusion it may be said that the feldspars in question are, as a whole, nonperthitic and homogeneous to polarized light. This is controlled by its chemical composition. The optic data indicate a composition with less than 10 % soda-lime component while the chemical analysis shows that there are about 2 % barium feldspar, 3 % lime-feldspar and 4 % soda-feldspar, together with perhaps 1.4 % iron orthoclase if the ferric iron be calculated into the orthoclase molecules. SPENCER (1930, p. 313) calculated the residual soda-feldspar in completely de-albitized moonstones from Ceylon and found that the approximate quantity of soda-feldspar capable of being retained in solid solution in orthoclase under normal conditions of equilibrium is about 9 %, a figure approaching to that deduced by WARREN (1930, pp. 142—143) for a number of examined perthitic feldspars. As to lime-feldspar, some few percent can always be held in solid solution without participating in the perthitic growth and therefore not affected by the later dealbitization. TAYLOR, DARBYSHIRE and STRUNZ (1934, pp. 476—477), STRANDMARK (1904, 53—67) and a number of others have proved the isomorphism between barium- and potassium-feldspar while LACROIX (1922), KOZU and SETO (1916 and 1923) and FAUST (1936) showed that iron-orthoclase does exist and is miscible with common orthoclase at least to the proportion about 12 % for the former in the latter. In the present case, feldspar components other than orthoclase enter with such low amount as to be held practically completely in solid solution under a condition of undersaturation. This explains why perthitic structure is absent in this rock.

By the way it can be added that BOWEN and TUTTLE (1950, pp. 499—501) succeeded to determine the solvus curve of alkali feldspars, a curve of positions of unmixing, by direct crystallization of glass at various temperatures, and by holding feldspars at a temperature where unmixing will take place. An attempt to extend their solvus curve (l. c. p. 497, fig. 3) on the potassic end will reach, by extrapolation, to a point representing more than 80 % potash-component or less than 20 % soda-component, most likely to a point with a composition like $Or_{90}Ab_{10}$ (l. c. p. 501, fig. 4). This conforms to SPENCER's work in 1930 and 1937. According to him (SPENCER 1930, p. 356; 1937, p. 485) the coarse "shadow perthite", that represents an early, high-temperature separation, might be absent altogether from feldspars with less than 20 % soda-component, whereas the fine, low-temperature separation of microperthite would be impossible in a feldspar with less than 10 % soda-component, though a nearness to this composition would also present exsolution.

8. Heat Treatment

The present feldspar and adularia from St. Gotthard have been subjected to differential thermal analysis. The thermal curve does not show any abrupt or conspicuous endothermal or exothermal heat reaction. There seems to be some heat absorption at the outset, but it is obviously caused by the evaporation of the moisture contained in the specimens. The differential thermal curves are represented in fig. II on next page and compared with that of Al_2O_3 (precalcined).

9. Generalities on Twinning Formation

In general, twin crystals are divided into two types, the contact or juxtaposition twins and the penetration or interpenetration twins. In some textbooks (e.g. KRAUS, HUNT and RAMSDELL 1936, pp. 90—91), the former are also designated as reflection twins and the latter as rotation twins, and both are described as due to hemitropy.

However, several points must be noticed concerning the twin formation.

(1) Not all twins can be described as due to hemitropy, since in crystals possessing no centro-symmetry the component individuals of the twin will neither form a simple crystal nor occupy the same position after a half-turn rotation. This is best illustrated by the twin formation of enantiomorphous crystals, for example, the right- and left-handed quartz crystals twinned together according to different laws (see GAULT 1949, p. 146), or by crystals with complementary forms like chalcopyrite which, twinned by reflection on

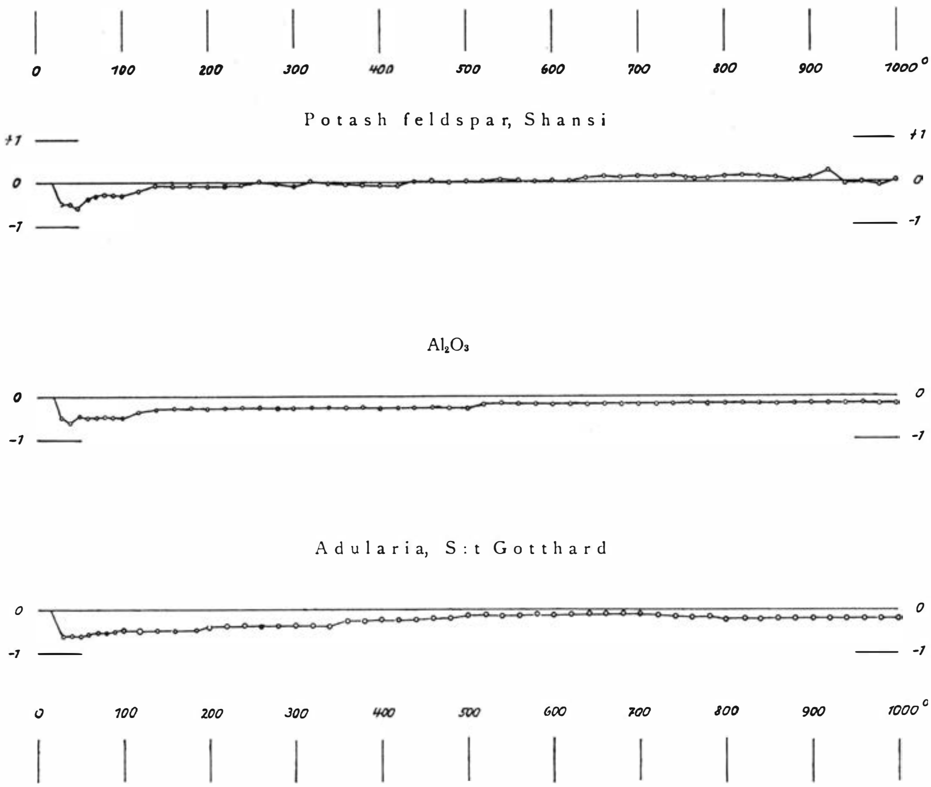


Fig. II.

(01$\bar{1}$) with tetrahedrons of the same sign, are opposing each other at the twin junction. This is nevertheless no problem for feldspars, since they are minerals with centrosymmetry.

(2) Not all normal twins are reflection twins, but all the reflection twins in crystals with centro-symmetry are normal twins. In crystals without center of symmetry the spinel type of twin in chalcopyrite and sphalerite may be mentioned, in which a half-turn rotation around [11$\bar{1}$] in (11$\bar{1}$) will bring tetrahedrons of different signs opposite to each other at the twin junction. In crystals with centro-symmetry the Baveno type of twin in feldspars may be taken as an example, the component individuals of which are brought into twinned position by a half-turn rotation around [021] in (021) which is structurally a glide plane (BRAGG 1937, pp. 246—248). As to reflection twins, which are meanwhile normal twins, the Manebach and albite twins of feldspar may be cited. In both cases the plane of twin junction is regarded as twinning plane whereas the term composition plane is reserved for twin junction which is neither a plane of reflection nor one of rotation. Both twinning and composition planes are contact planes, but a contact plane is not necessarily a twinning or composition plane.

(3) Normal twins and reflection twins are always contact twins, but parallel twins can either be juxtaposed or interpenetrant. The former ones are formed respectively by hemitropy and reflection in the twinning plane, therefore, theoretically, they must be contact twins. In the latter the twinning plane may altogether be absent and the twin formation results from rotation around a twinning axis; therefore either development is possible. Illustrative examples are penetration and contact twins on (100) in gypsum, hornblende and augite as well as Carlsbad twins on (010) in feldspars. As to complex twins both juxtaposed and interpenetrant types are rendered possible by the combined operation of a reflection and a rotation, or two rotations corresponding to that of a normal and a parallel twin on the same composition plane (EMMONS 1943, p. 104). However, such twins in feldspars are mostly repeated twins in juxtaposition, since they are either developed under stress late in crystal growth, or caused by special mechanism of secondary twin gliding after the completion of crystallization (BUERGER 1945, pp. 478 and 481; EMMONS and GATES 1943, pp. 288, 290—293; se also KÖHLER and RAAZ 1947, p. 169).

10. Baveno and Aveno — Normal and Parallel—(021) Twins

In the present rock only Baveno twins are found. Of 12 pieces 8 are twinnings[1] of the contact type, 4 are trillings of the penetration type (Fig. III). Sections of the twinned crystal, being 0.2—0.5 mm[2] in its apparent size, are cut mostly more or less normal to the *a*-axis in the [010] zone so that traces of the twinning and composition planes appear always diagonal to (001) and (010). Cross-sections in such orientation may be tetragonal, rectangular or irregularly lobate, depending on how much interference is imposed on the crystal growth from the neighbouring crystals and how the section is cut through the crystal (see Fig. XIV). However, in case there are rectilinear segments, they are always parallel to (001), (010) or (021) faces. Re-entrant angles may occur at the twin junction, but salient or plane-angled junctions are equally frequent. If the twin junction is marked by re-entrant angle, it seems that the faster crystal growth on the (001) face is the cause for such formation. The relative size of the composing individuals or units[2] differs too. In simple connate twinnings both halves are rather symmetrical as demanded by theory, but when both faces of *n* (021)[3] play equally important role, or (001) and (010) faces come to take part in twin-building at

[1] The term "twin" is used to denote all kinds of twinned crystal while the term "twinning" is reserved for twinned crystal with only 2 units or individuals.

[2] An individual in a twinned crystal may contain two units or more, therefore terms like individual and units are not always identical in usage. In the present paper the author prefers to use the term units, since they are easily distinguished under crossed nicols.

[3] The denotation of crystal faces of feldspars in this paper is according to GOLDSCHMIDT's Kristallographische Winkeltabellen (1897, pp. 143—144).

the junction, there is always prepondenance of one unit over the other in twin growth.

Genetically speaking there are three types of twins. Simple-paired twins like Baveno twins are considered to be growth twins from nuclei of supersaturation (BUERGER 1945, p. 476). By examining twinned crystals in thin sections under polarized light we find that the twinned units are not always simple connate but often inserted in each other or enclosing each other at the twin-junction in a very intricate way (see Fig. III). The twin-junction is very seldom a plane surface, but comprises a number of sharp bends and some curved parts. When it passes from (021) to (0$\bar{2}$1) or from (001) to (010), nearly right-angled bends are likely to be found, otherwise acute and obtuse angles of the magnitude circa 45° and 135° will be observed in case either face of *n* (021) passes into (001) or (010) or vice versa (cf. GONNARD 1910, pp. 253, 277; PARKER 1942, p. 278). Such sharp bends are also reflected at the edge of twinned crystals, which shows that the twinned crystals grow from a seed crystal or a compound nucleal molecule, under a growth condition which does not change much from the beginning to the end, and further that when a feldspar is once twinned, the later growth of feldspar on the same crystal is only a continued enlargement of the twinned structure (cf. EMMONS and GATES 1943, p. 294). Some local resorption and recrystallization may have taken place somewhere at the outset due to some local change of thermodynamic conditions so that some hooklike (Fig. III Crystal no. 2) or other kind of arched surface (Fig. III Crystal nos. 4, 16, 23 etc.) may be formed[1] but elsewhere the tendency for atoms or molecules to fall in twinned position according to a definite crystallographical orientation is so strong and overwhelming that such local anomalous growth is soon regulated. Similar redissolving effect, which takes place after the completion of the twin growth, may be observed elsewhere at crystal edges where the plane-surfaced crystal faces are replaced by irregularly warped surfaces.

It is further to be noticed that a continuation of cleavage from one unit into the other can always be found, indicating that the crystal structure is continuous in alternative twin junction. However, the crystal optics are different in different units and the crystallographical character of the cleavage changes at the twin junction, being parallel to (001) in one unit and to (010) in the other.

In simple twinning of the contact type, only one face of *n* (021) is developed while in trillings of the penetration type both faces are present. One of them functions as the twinning plane and the other as composition plane, the former being always more perfect than the latter. Crystal no. 4 is a typical example for penetration twin, possessing a common center which is mean-

[1] From its smoothness it may be considered as being composed of numerous imbricating vicinal faces as is the curved crystal surfaces of lenticular gypsum growth on (010 (see MIERS 1929, p. 306, fig. 445).

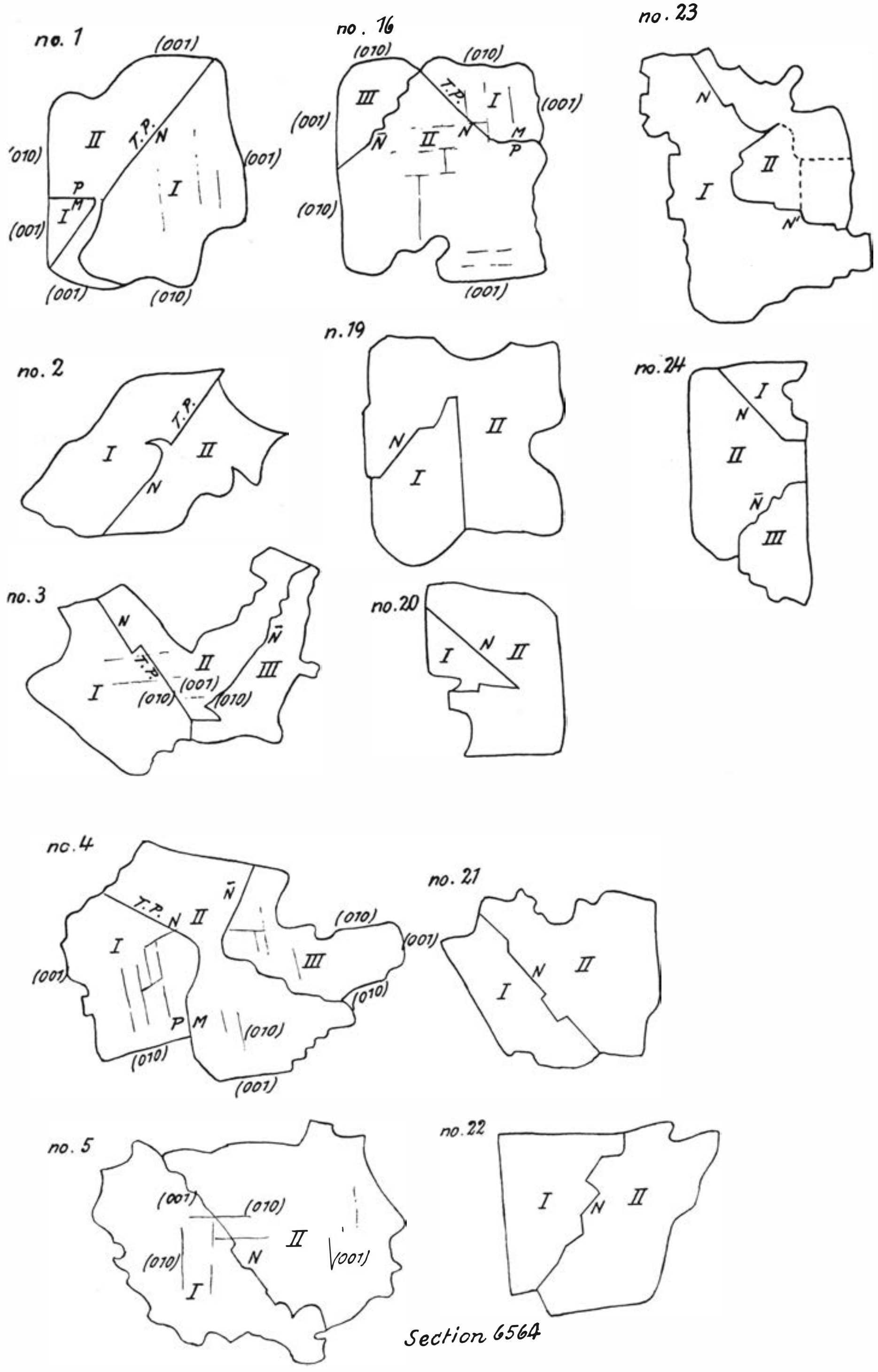
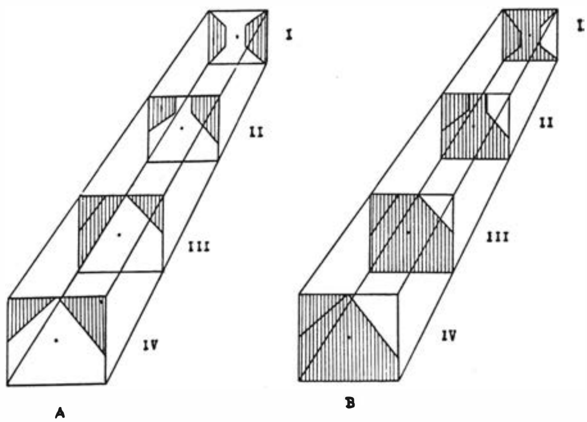


Fig. III. Twin Crystals in Orthosite Dyke.



Penetration twin   Contact twin

Fig. IV. *A* showing successive stages in the development of penetration twins. Stage I: crystal no. 4, II: crystal no. 24, III: not observed in the present rock of feldspars, IV: crystals no. 3 & 16.
B showing the corresponding development of contact twins in which the other face of *n*(021) exists no longer as contact plane, therefore no corresponding trillings of the contact type can be found.

while the center of the axial system for both individuals. However, if only half of it is developed, it will give rise to crystal no. 24. Again, if both faces of *n*(021) initiate simultaneously from the same initial position, crystals no. 3 and 16 will be formed. Therefore all these twins may theoretically be considered as half-developed or degenerated forms of crystal no. 4. Such forms are in reality nothing but milestones denoting different stages of development in twin growth as well as the growth of the crystal. All or some of them may be present in one and the same crystal, or a single crystal may represent only a single stage (see Fig. IV). As to crystal no. 1, it may well be considered as the outset of interpenetrant twin growth leading to the formation of a trilling, but its simple connate origin is very clear. In crystal nos. 19 and 20, unit II is enclosing unit I. It speaks for the postulation that there are two ways for the continuately arriving atoms or molecules to join the crystal nucleus in order to locate themselves in the edifice of the Baveno twin-structure: one way is to accumulate on *n*(021) faces and the other on (001) or (010) faces.

Concerning the optical properties, in crystal no. 4 the individual axial angle equals the average and the extinction on (001) in the central individual is straight (Tab. III). However, in other crystals both extinctions and sometimes even the axial angles may be quite different in different units and individuals and an oblique extinction on (001) is often met with. This means that the separate units of the twinned crystal can no longer keep strictly to the monoclinic structure and some kind of distortion or deformation of the indicatrices must have taken place during the twin growth. COLE, SÖRUM

Table VII.

Slide no. 6564						
Crystal no.	1	2	3	4	5	16
Twin type	Contact 2-ling	Contact 2-ling	Penetration 3-ling	Penetration 3-ling	Contact 2-ling	Penetration 3-ling
Diagonal contact pl.	N	N	$N+\overline{N}$	$N+\overline{N}$	N	$N+\overline{N}$
Twin units ...	I, II	I, II	I, II, III	I, II, III	I, II	I, II, III
Set of	1	—	1	1	2	2
(# 1)/(# 2)	—	—	—	—	89°	89°
N/(# 1)	45°	—	40°	44°	45.5	44
$\overline{N}$/(# 1)	—	—	59	45	—	47
N/(# 2)	—	—	—	—	45.5	47.5
$\overline{N}$/(# 2)	—	—	—	—	—	45.5
$N/\overline{N}$	—	—	82	89	—	87
$Z/[N]$	1	10°	4	3	0.5	16
$\overline{Z}/[N]$	—	—	4	4	—	12
$Z/[\overline{N}]$	—	—	77	88	—	93
$\overline{Z}/\overline{N}$	—	—	13	2	—	0
$Z/\overline{Z}$	—	—	2.5	4.5	—	5

and TAYLOR (1951, p. 21) reported that different fragments from the same sample of plagioclase may vary in composition by as far as 10 % in the molecular percentage of anorthite. EMMONS and GATES (1943, pp. 296—297) subjected adjacent plagioclase lamellae in albite twin habit to selective deuterical alterations and were convinced with the indication of different optic data on compositional difference. The same conclusion cannot be drawn in our case, since one unit should then contain perhaps 25—30 % soda-lime feldspar component whereas the other would be a rather soda-lime free potash-feldspar with some 10 % celsian modecule. Such compositional difference in different units of our twins is not to be expected, since the feldspar aggregates represent a simultaneous crystallization and the age of growth of different units, though may be not exactly synchronous, does not differ so much that a considerable difference in composition like this could be brought about by environmental changes. The author is therefore inclined to ascribe such optic differences to structural distortion caused by twinning growth. Recently CHAISSON (1950, p. 542) with the help of spectrographical analyses has proved that the mantle and the core of many adularia crystals which show respectively straight and inclined extinction to (010) are not different compositionally but structurally. Data for measured twins are given above (Table VII).

Instead of *n*, which denotes (021) faces, *N* and $\bar{N}$ are used to represent the two diagonal contact planes in trillings. [*N*] and [$\bar{N}$] are respectively the normal to *N* and $\bar{N}$, while *Z* and $\bar{Z}$ represent the respective twin axis for each of the twinned pairs I/II and II/III. As to the sign #, it represents either of the (001) and (010) cleavages (1 and 2).

It is seen from Tab. VII that in the majority of cases the diagonal contact planes do not deviate much from the *n* (021) faces and they form angles near to 90°. However, the angle *Z*/[*N*] for Baveno twins — the normal twins with *n* (021) as their twinning plane — is very seldom 0, being in our case 0.5—16°. This indicates that the twin axis for normal Baveno twins seldom coincides with the normal to the *n* (021) faces, which latter function therefore only as apparent twinning planes. Since the magnitude of this angle, which is called the angle of obliquity[1], is more variable and much larger than that of albite twins in plagioclases (DONNAY 1940, pp. 580—582), the application of the simple method suggested by EMMONS (1943, p. 111) for recognizing normal twins does not turn out successfully. Setting the junction plane N—S and vertical, the adjacent twin units of a normal twin will not remain equally illuminated on rotation on the outer E—W axis of the universal stage, provided that the angle of obliquity is large enough to have influence on interference.

This is further complicated through the existence of planes in parallel twinned position in the penetration twins, in which both faces of *n* (021) are equally developed, one as twinning plane and the other as composition plane. By comparing the stereographical projection of crystals no. 4 and 16 (Fig. V, a and b), it is seen that in both cases *N* represents the twinning plane and $\bar{N}$ the composition plane, and the twinned pairs I/II and II/III are twinned respectively in the way of a normal and a parallel twin. The twin axis for the first pair, *Z*, is near to the normal [*N*], while that for the second pair, $\bar{Z}$, is not near to the [$\bar{N}$] but lies in a plane near to $\bar{N}$. The angle between $\bar{Z}$ and $\bar{N}$ is the angle of obliquity for the parallelly twinned pair with the other face of *n* as its composition plane. With regard to the convention that the first way of twinning is called Baveno law, the second way of twinning is to be called Aveno law on the kind suggestion of Prof. HELGE G. BACKLUND. The word 'Aveno' is chosen as the name for this newly erected twin law, since it sounds like Baveno but is not identical with Baveno. There does exist some relation between the two, though radically they are different. The Aveno law is a parallel twin law, since the twin axis now lies in or nearly in the plane of operation, the diagonal contact plane or *n* (021), which is now the plane of composition, and a 180° turn around the twin

[1] Theoretically the obliquity of the twin in the case of a twin plane is the angle between the true normal to the twin plane and the lattice row quasinormal to it (DONNAY 1940, p. 579). Here this angle is measured between the apparent twinning and composition planes, and the twin axis.

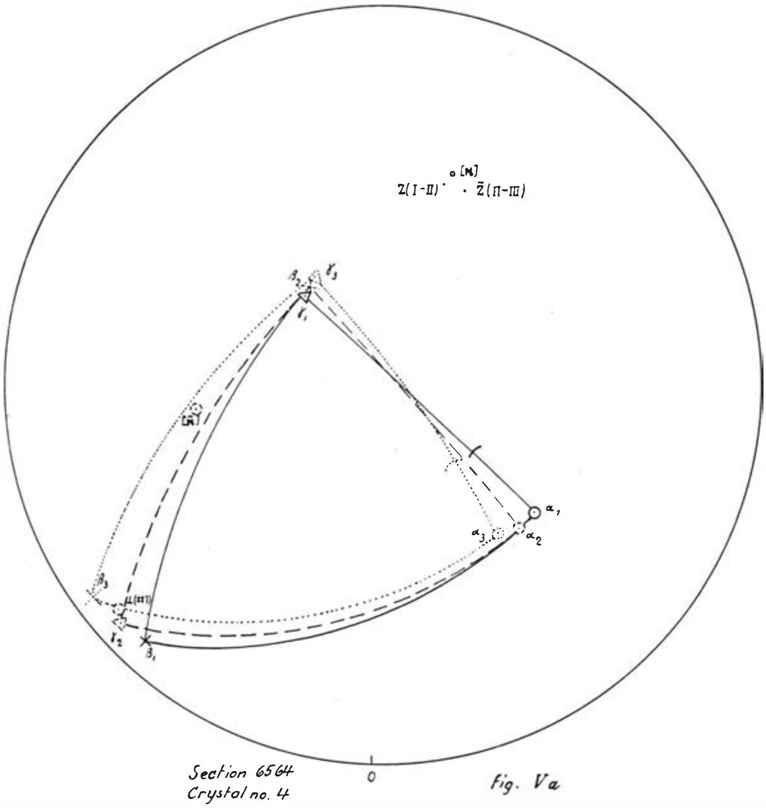


Fig. V a. Penetration trilling.

axis will bring the two units into the same position. Should it happen that the first twinned pair in the above-mentioned penetration trillings failed to develop, or the second pair developed independently as a single twin, the occurrence of parallel Aveno twins of the simple juxtaposed type is likely to be testified. By the way it can be pointed out that all the penetration Baveno twins in the old category are in reality combinations of Baveno and Aveno twins.

11. General Discussion of the Rock

The present rock is regarded as belonging to pegmatites which cut through the nepheline-syenite in dykes (NORIN 1921, p. 68). Its texture is almost aplitic but granulometrically it is not fine enough to be classified as aplite[1], though the grain size grades indeed down to less than 1 mm in diameter. On the other hand, by following the prevailing usage of the

[1] The line of division between pegmatite and aplite based on grain size is drawn arbitrarily at 2 mm by SUSSMILCH and JEVONS (1911, p. 535) but at 1 mm by GROUT (1932, p. 57).

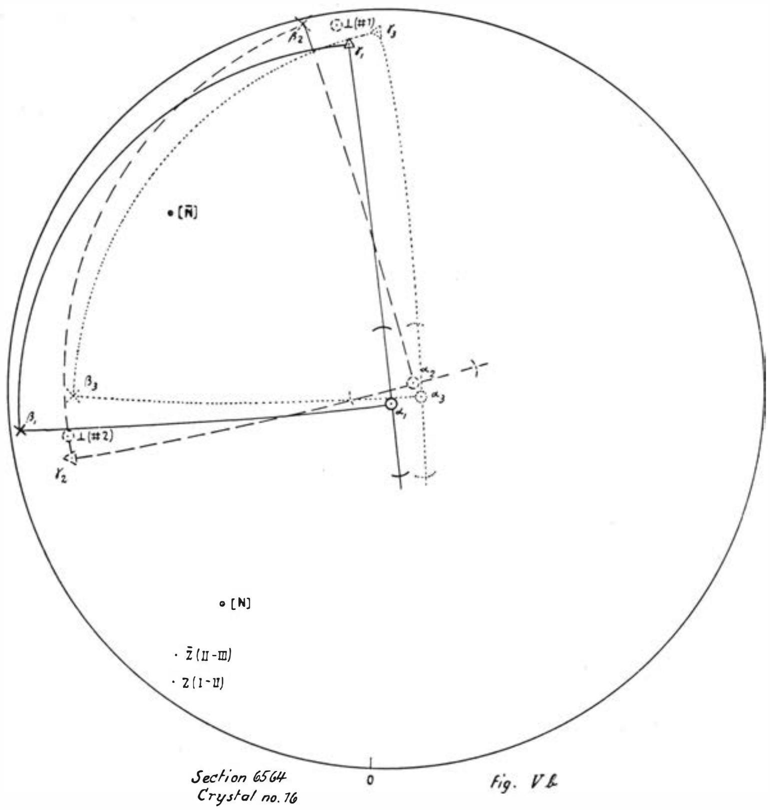


Fig. V b. Penetration trilling.

term pegmatite for coarse- to very coarse-grained rocks, which are hypidiomorphic if not panidiomorphic in texture, it can neither be denoted as true pegmatite. Such complicacy has obviously much to do with the abundance of miarolitic cavities present in this rock. The abundance of miarolitic cavities does not indicate that the crystallization initiated in a very dry condition but that the escape of volatiles must have greatly reduced the hydrothermal pressure. This explains why this rock has the composition and texture of aplite but the grain size of a granite or a very fine-grained pegmatite. Such examples are also found in the pegmatites of S. Norway (ANDERSEN 1931, p. 28). According to SPURR (1925, pp. 567—568) the escape of volatiles will take place within a depth of 800—1000 ft. It is difficult to say exactly in what depth this rock is formed, but the presence of the miarolitic cavities and the texture of the rock indicate a simultaneous crystallization near the surface at a rather low temperature. This argument is based on the nearly pure alkalic composition, the low optic axial angle, the variable extinctions and the refractive indices of the composing feldspars which have its β lying very near to γ, all being features characteristic partly of low-temperature pegmatitic feldspars and partly of hydrothermal adularias. In authigenic feldspars the two indices may be so near to each other that they practically make no difference at all in the fourth decimal place (FÜCHTBAUER 1950, p. 248). A further raise of β or reduction of γ along this line will accordingly convert the optic axial plane into the symmetry plane. So it is no wonder that the optic variation of adularias should occur in the direction of sanidine rather than microcline (see CHAISSON 1950, p. 546).

By the way it can be added that feldspar-rock is also found in association with elaeolite- and augite-syenite in Coimbatore District of Madras, India (BARTH 1927, p. 120). Such rocks may be called orthosite if they are composed entirely or almost entirely of orthoclase and it will be very interesting to see if the orthoclase grains show also triclinic optic properties like our dyke rock treated here.

II. Alkali Feldspars and their Twinning Formation in Epidote-"Orthosite" and Nepheline-Syenite

1. General Description of the Rocks

In the second part of this paper, special stress is laid on studies in development of Baveno and Aveno twins. Since nearly all possible stages or substages are present here, we can easily trace the transitions from one to the other. Two more rock types are treated for this purpose. One is a rock type which is very near to the orthosite dyke but marked by abundance of epidote, while the other is a nepheline-syenite.

The first one, which may be called epidote-orthosite, is greyish white in color, coarse-grained with miarolitic cavities up to 3 cm in width. In thin section it is allotriomorphic in texture, and found to contain feldspar, calcite, epidote, titanite, mica, and iron ore grains. The feldspars are mostly irregularly lobate, but when they are twinned in the habit of Baveno and Aveno law, they have often euhedral to subhedral outlines of a square or rectangle. They do not show any remarkable perthitic structure except where they are affected by later alteration. Their optic properties indicate that they are also alkali feldspars of high potash content just like those in the orthosite dyke. Calcite is present in large amount, and found not only corroding part of the feldspars and filling up their cracks and cleavage interspaces but also as large, independent anhedral to subhedral grains. Together with calcite occurs epidote, which is deep green in thin section but dark green to iron-black in hand specimen. It is this epidote which gives the rock a greyish sheen. They are mostly found as irregular intergranular fillings between the feldspars, sometimes also as euhedral prisms in miarolitic cavities. Together

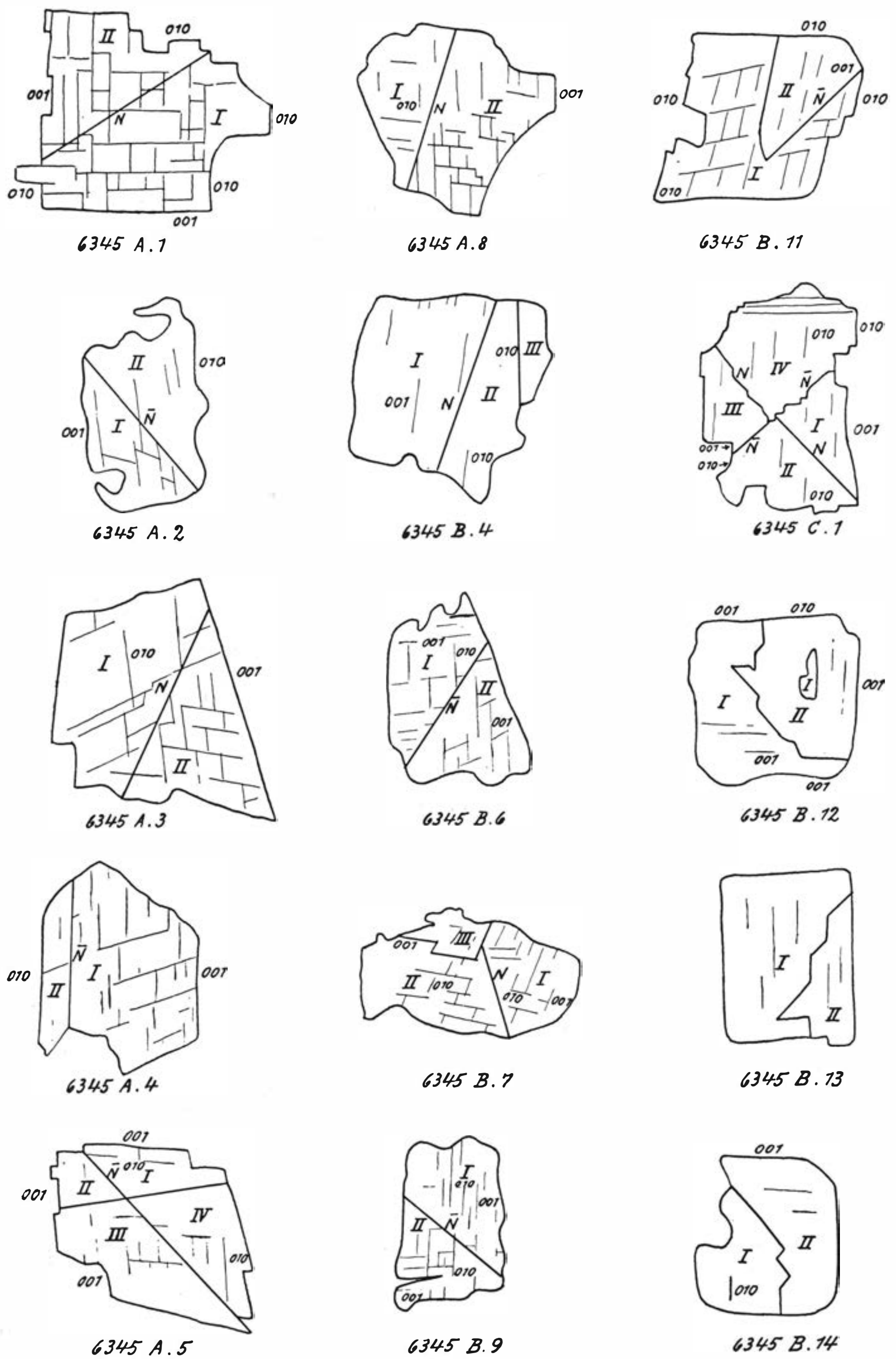


Fig. VI. Baveno & Aveno Twin-crystals in Epidote-orthosite & Nepheline-syenite.

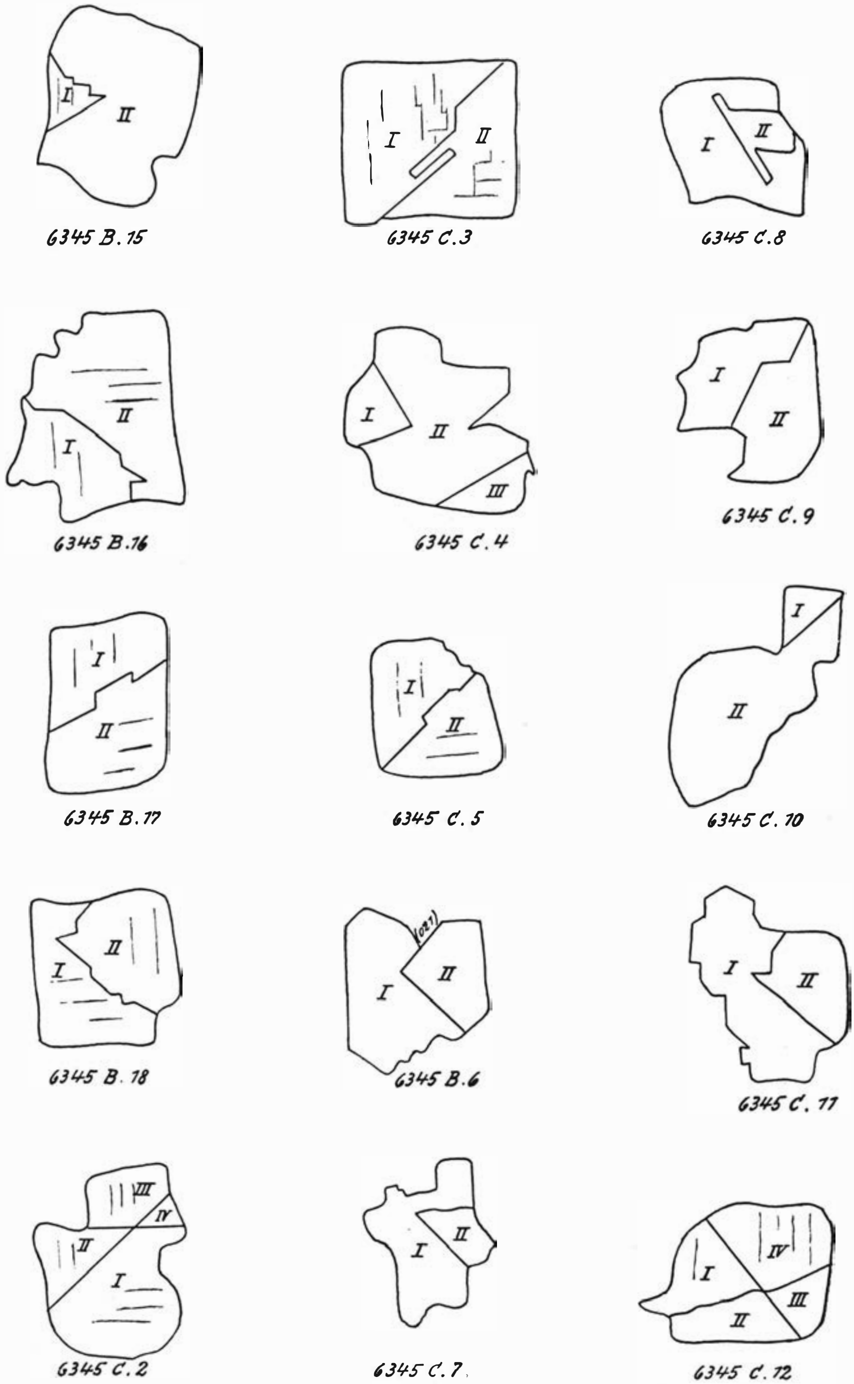

6345 B.15
6345 C.3
6345 C.8
6345 B.16
6345 C.4
6345 C.9
6345 B.17
6345 C.5
6345 C.10
6345 B.18
6345 B.6
6345 C.11
6345 C.2
6345 C.7
6345 C.12

Fig. VI.

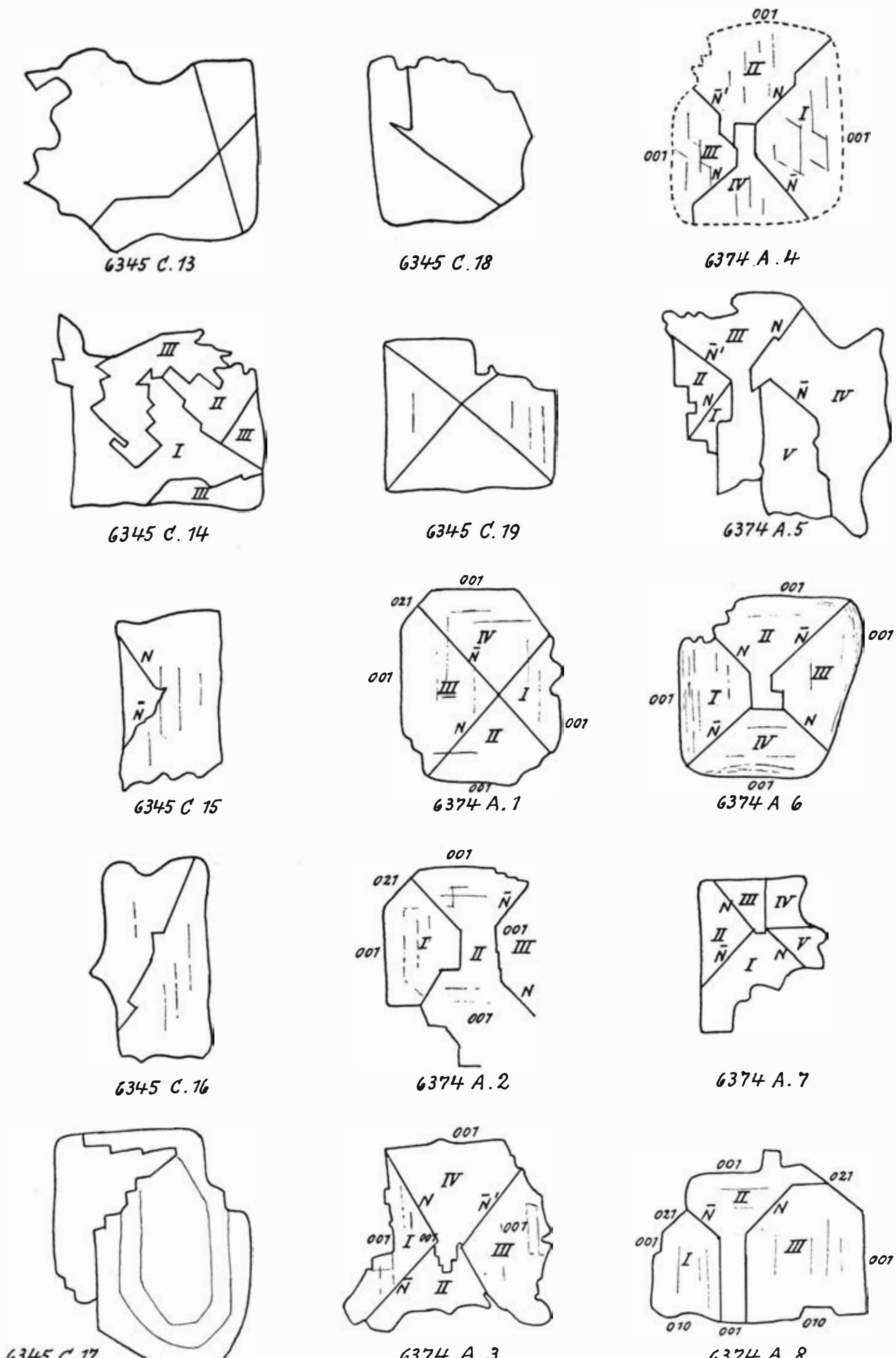

6345 C.13
6345 C.18
6374 A.4
6345 C.14
6345 C.19
6374 A.5
6345 C 15
6374 A.1
6374 A 6
6345 C.16
6374 A.2
6374 A.7
6345 C.17
6374 A.3
6374 A.8

Fig. VI.

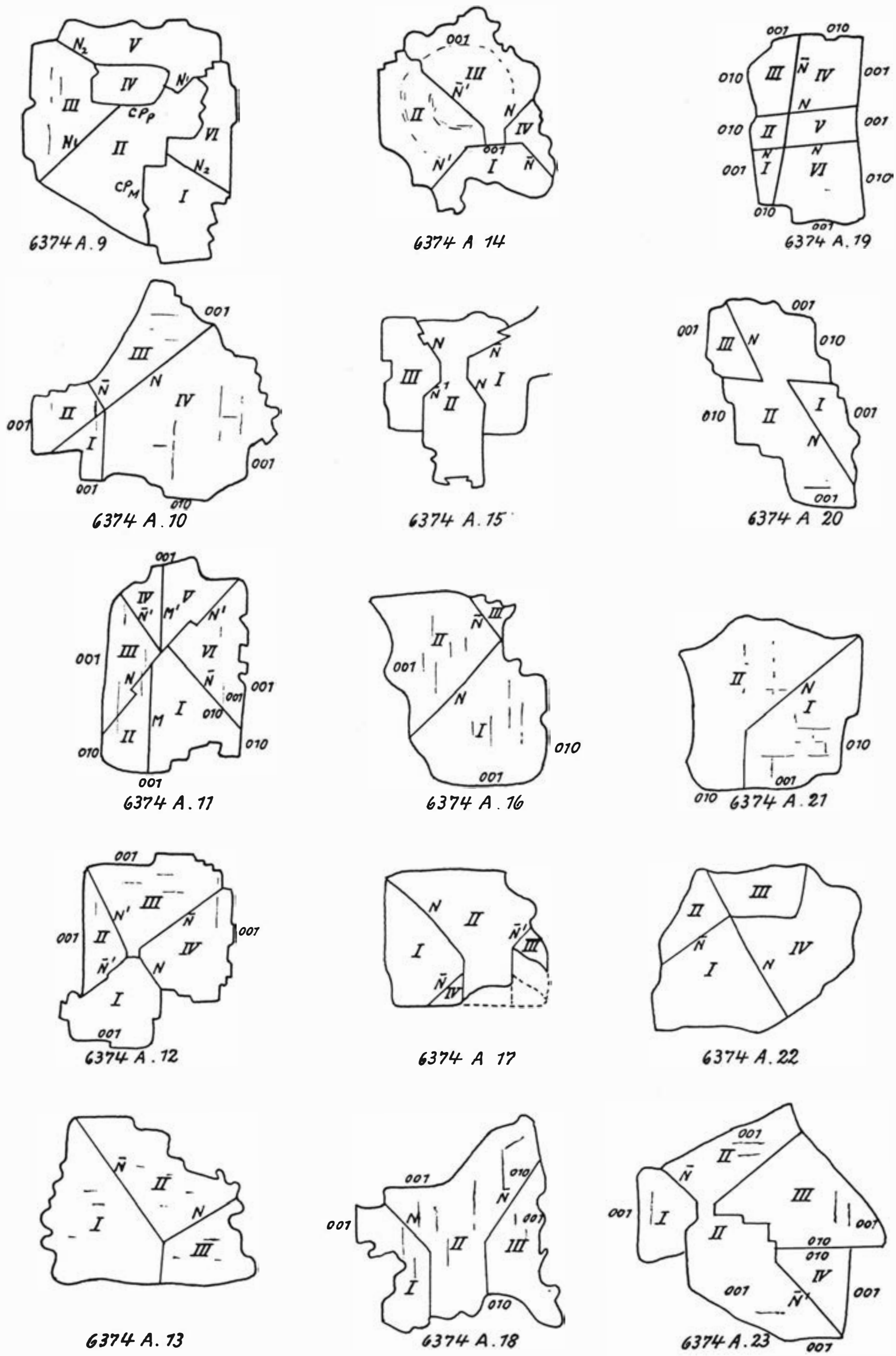

6374 A. 9
6374 A 14
6374 A. 19
6374 A. 10
6374 A. 15
6374 A 20
6374 A. 11
6374 A. 16
6374 A. 21
6374 A. 12
6374 A 17
6374 A. 22
6374 A. 13
6374 A. 18
6374 A. 23

Fig. VI.

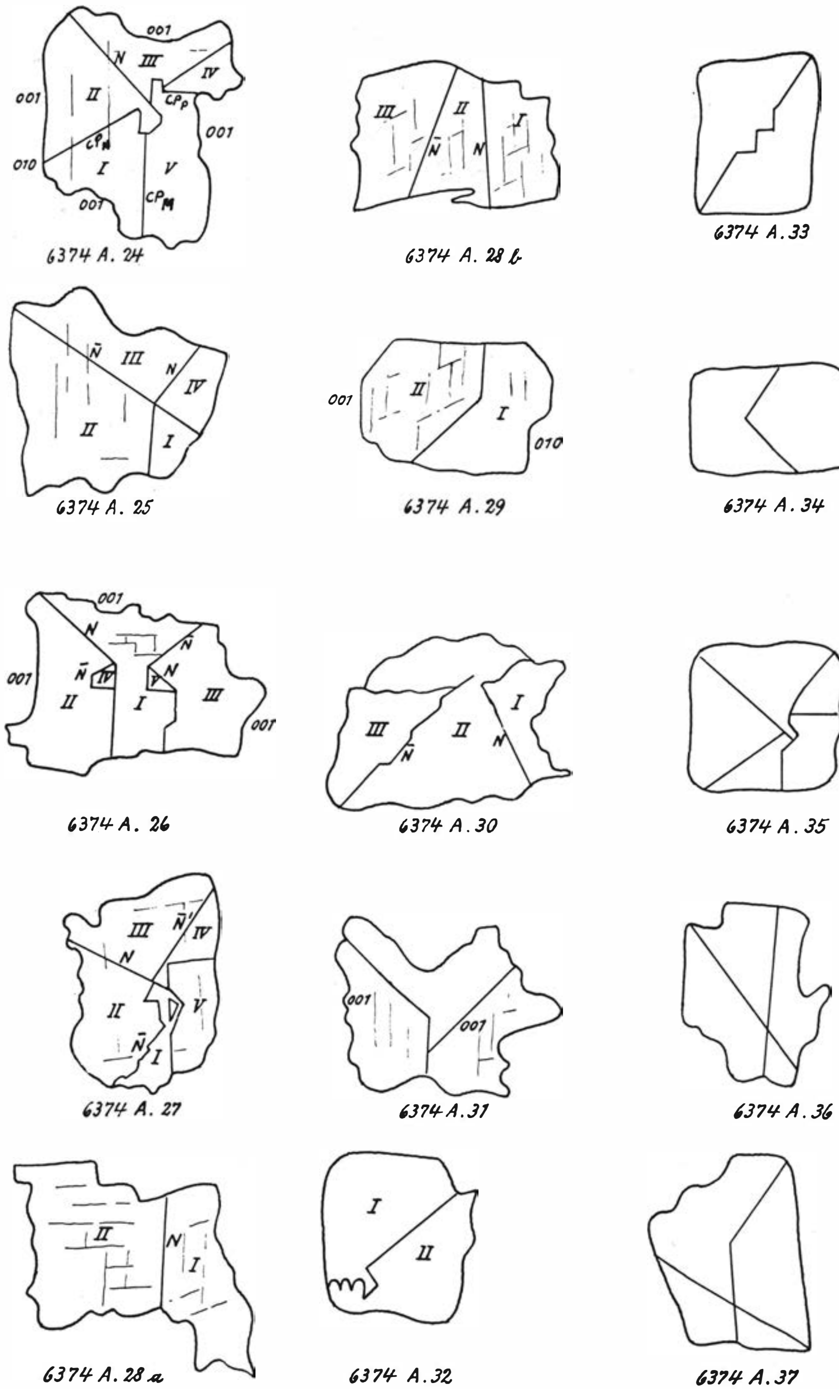
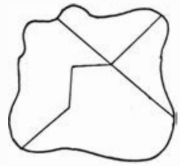
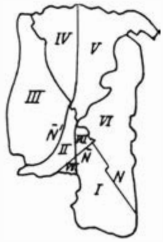

001
001
001
010
001
001
II
III
IV
I
V
N
CPp
CPM
6374 A. 24
III
II
I
N
N
6374 A. 28 b
6374 A. 33
III
IV
II
I
N
N
6374 A. 25
001
II
I
010
6374 A. 29
6374 A. 34
001
001
001
N
N
N
N
IV
II
I
III
6374 A. 26
III
II
I
N
N
6374 A. 30
6374 A. 35
III
IV
N
N'
II
V
N
I
6374 A. 27
001
001
6374 A. 31
6374 A. 36
II
N
I
6374 A. 28 a
I
II
6374 A. 32
6374 A. 37

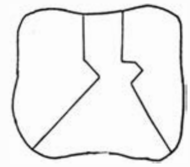
Fig. VI.



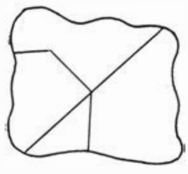
6374 A.38



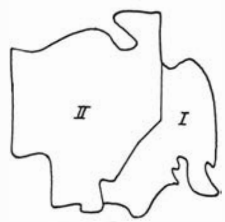
6374 B.5



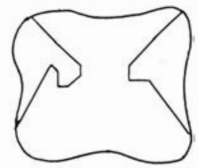
6374 A.40



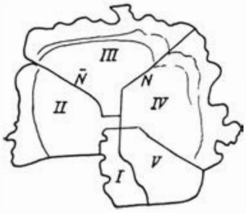
6374 A.39



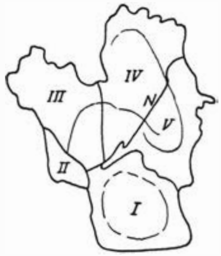
6374 B.6



6374 A.41



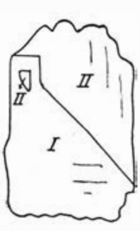
6374 B.1



6374 B.7

6374 B.2

6374 B.8



6374 B.3

6374 B.9

Fig. VI.

with the green epidote are a few grains of euhedral titanite, some muscovite and a colorless mineral, probably clinozoisite. Iron ore grains are sparse, sometimes associated with brown mica. The texture and mineral constituents of this rock indicates that it is closely connected with the orthosite.

The nepheline-syenite is medium-grained, inequigranular with subhedral to anhedral nepheline grains up to 1 cm in diameter. The rock is allotriomorphic, and reddish-grey to reddish-white in color due to the presence of nepheline. Feldspars are mostly anhedral though there are euhedral to subhedral twinned crystals. Aegirine is green, sometimes associated with epidote, both of which can be subhedral or anhedral. Melanite occurs as distinct idiomorphic black grains, but in thin sections it is brown and found to have partially altered to biotite and other alteration aggregates. Perthitic structure is not observed in the feldspars but zonal structure and very faint patchy extinction can occasionally be met with. The optic properties of the feldspar indicate also that they are rather similar to those treated in the preceding.

Sections are made of the rock specimens in two or three directions perpendicular to one another. Those made in the epidote-orthosite are numbered 6374 A and B, whereas those made in the nepheline-syenite are numbered 6345 A, B and C. All the twinned crystals are found in sketches in Fig. VI.

2. Baveno and Aveno Twinnings

First the contact twinnings are considered, since they are the fundamental form from which the highly complex forms are derived. Examples from the orthosite dyke are also cited in discussion, the twinned crystals of which are numbered 6564 according to the number of the slide. Since the optic data of the last-named have been given in Tab. III and VII of the preceding section, the data compiled in Tab. VIII and IX concern only the contact twinnings of the epidote-orthosite and the nepheline-syenite.

The extinction $\perp \gamma : \alpha/(001)$ given below seems to indicate that some barium-feldspar molecules must have taken part in the building of the concerned high-potash feldspars.[1] Furthermore, it is to be noticed that this extinction covers a very wide range, especially in feldspars of the epidote-orthosite, just as is the case in the pure orthosite dyke. This character is also shared by low-temperature adularias. As to the extinction in the [001] zone, there is again a variation between $0—3^\circ$. The axial angles vary from $36—52^\circ$, but in one and the same twinned crystal they do not always differ much in magnitude, and it is not seldom that they are entirely equal in different twinned units.

[1] According to the analysis made by WASHINGTON and KEY (NYSTRÖM 1927, p. 158), BaO is absent in the nepheline-syenite from Tzuchinshan. It depends of course on which variety of nepheline-syenite was subjected to analysis.

Table VIII a.

Slide no.	Crystal no.	Twin formation	Twinned units	⊥γ:α/(001)	⊥β:α/(010)	$2V_a$	Cleavage	a/α
6374 A	21	2-ling	1	5°	0°	46°	(001), (010)	5°
			2	5	1	40	(001), (010)	5
»	28 a	»	1	—	—	—	(001)	
			2	—	2	52	(010)	
»	29	»	1	—	3	42	(010)	
			2	6	—	42	(001)	
6374 B	3	»	1	2	0	36	(001), (010)	4
			2	7	1	46	(001), (010)	7
»	6	»	1	—	1	52	(010)	
			2	1.5	—	52	(001)	
				av. 4°.8	1°.4	45°.3		

Table VIII b.

Slide no.	Crystal no.	Twin formation	Twinned units	⊥γ:α/(001)	⊥β:α/(010)	$2V_a$	Cleavage	a/α
6345 A	1	2-ling	1	6°	0°.5	—	(001), (010)	6°
			2	3	1	—	(001), (010)	3
»	2	»	1	6	—	52°	(001)	—
			2	—	3	48	(010)	—
»	3	»	1	—	3	46	(010)	—
			2	7	—	48	(001)	—
»	4	»	1	4	—	—	(001)	—
			2	—	0	—	(010)	—
»	8	»	1	—	0	—	(010)	—
			2	7	—	48	(001)	—
6345 B	6	»	1	4	2	40	(001), (010)	5
			2	6	2	36	(001), (010)	6
»	9	»	1	4	0.5	44	(001), (010)	4
			2	4	1	44	(001), (010)	4
»	11	»	1	4	1	50	(001)	—
			2	—	1	—	(010)	—
				av. 5°	1°.1	45°.6		

Table VIII c.

Slide no.	Crystal no.	⊥γ:α/(001)	⊥β:α/(010)	$2V_a$	Cleavage	a/α
6345 A	6	—	—	50°	—	—
»	7	3°.5	—	44	(001)	—
»	9	5	—	48	(001)	—
6345 B	1	5	1°	—	(001), (010)	5°
»	1′	4	0.5	42	(001), (010)	4
		av. 4°.4	0°.7	46°		

Table IX.

Slide no.	Crystal no.	Twin formation	(#1)/(#2)	N/(#1,2)	$\bar{N}$/(#1,2)	Z/N	$\bar{Z}/\bar{N}$	Z, $\bar{Z}$/(#1, 2)	Twin type
6345 A	1	2-ling	90°, 90°5	46°, 45°	—	1°	—	46°, 45°	Baveno
»	2	»	—	—	48°	—	4°	38	Aveno
»	3	»	—	60	—	15	—	45	Baveno
»	4	»	—	—	45.5	—	0	45	Aveno
»	8	»	—	46	—	2	—	45	Baveno
6345 B	6	»	86	—	44, 42	—	5	43, 52	Aveno
»	9	»	90.5	—	44, 46	—	1	47, 44	Aveno
»	11	»	—	—	44	—	1	47	Aveno
6374 A	21	»	93	—	45, 47	—	0	43, 45	Aveno
»	28 a	»	—	38	—	5	—	42	Baveno
»	29	»	—	44	—	8	—	44	Baveno
6374 B	3	»	89	44	—	3	—	45, 47	Baveno
»	6	»	—	—	47	—	0	42	Aveno

In Tab. IX, Z and $\bar{Z}$ represent twin axes for Baveno and Aveno twins with N and $\bar{N}$ as their respective diagonal contact planes, of which the greatest part approximate the faces of *n*. Of 13 examples only 2 show a greater deviation up to 7° and 15°, while all the rest make in general only 0—3° with *n*. As to the (001) and (010) cleavages, they are mostly perpendicular to each other and only exceptionally deviate for 3°—4° from the right angle, perhaps due to summation of errors made on measurement and reading. The angle of obliquity ($Z/[N]$ and $Z/[\bar{N}]$) varies from 0—15°, which makes it again difficult to use EMMONS' method (1943, p. 111) for the recognition of normal twins. However, the most remarkable is the abundance of simple-paired Aveno twins which amount to nearly half of the measured contact twinnings. Sketches of the concerned twinnings are included in Fig. VI while their trend of development is shown in Fig. VII.

In Fig. VII twin I is the fundamental form, two units are in contact and the contact plane is entirely even and smooth. If the section is cut parallel to (100), it will be almost a square and the trace of the contact plane will be very near to the diagonal of the square. If the section is cut oblique to (100), it will be a rectangle, and the trace of the contact plane, though still more or less diagonal in position, does not form 45° angle with (001) and (010) cleavages. Finally, if the section is cut in the zone of *a*-axis, it will be also a rectangle, but the trace of the contact plane will be parallel to the cleavages of (100) or (110) (cf. Fig. XIV, 1—8). Crystals 6345 A. 1, 6345 C. 10, 6374 A. 32 and 6564. 2 are examples for the first way of cutting. Crystals 6345 A. 2, 3, 8, 6345 B. 6 and 6374 B. 3 are examples for the second, and 6345 A. 4 and 6374 A. 28a for the third. All the twinned crystals of this form are perfectly developed except crystals 6374 A. 32 and 6564. 2.

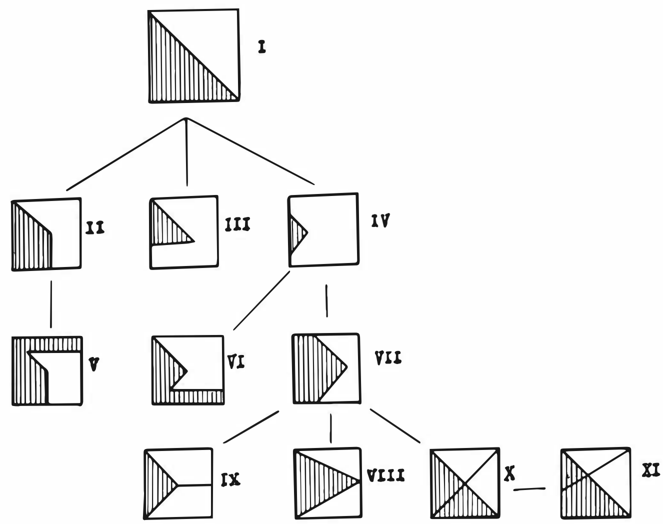


Fig. VII. Trend of development of Baveno twinning of the contact type, sections cut parallel to (100).

However, even in the last-named two the most part of the contact plane is still even and smooth with only very little irregularities.

The variation of Baveno and Aveno twin forms is based on different combination of the faces (001), (010) and *n* (021) at the twin-junction. Before form I passes into forms II and III, there are two subforms to be noted. The first is nearer to form I by having its contact plane running essentially in one diagonal position but marked by several or a number of sharp and short bends formed of segments of (001), (010), and the other face of *n* (021). Crystals 6345 B. 17; 6345 C. 3, 5, 9, 16; 6374 A. 33; 6374 B. 3 are examples for such. The second is nearer to forms II and III, the contact plane of which, though still running in one diagonal position and marked by similar bends, possesses higher tendency of developing (001) and (010) segments so that it finally passes into forms II and III. Crystals 6345 B. 12, 13, 14, 16, 18 and 6345 C. 11 are examples for such.

Form II is represented by crystals 6345 C. 18; 6374 A. 21, 29; 6374 B. 6; and form III is represented by crystals 6345 B. 11; 6345 C. 7. Crystal 6345 C. 17, which represents form *V*, may be considered as derived from form II by the development of another (001) or (010) segment. In crystal 6345 B. 15 the other face of *n* (021) begins to play an equally significant role in twin building but it is rather ill-developed. In crystals 6345 C. 6 and 6374 A. 34 both faces of *n* (021) are well-developed and one of it even forms a large part of the crystal boundary against a neighbouring crystal. Such twins with both *n* faces developed are designated as forms IV and VII in Fig. VII. By a further extension of the *n* faces or the addition of another (001) or (010) segment forms like VI, VIII, IX and X will result. Form VI is represented by crystal 6564. 23 (Fig. III), which is still a contact twinning, while forms VIII, IX and X are no longer such but trillings of the penetration type and fourlings of the contact type. The last-named is not so common, since pairs of units on the same side of the primary contact plane in contact twinning possess strong tendency to grow into one unit, and it is only occasionally or incidentally that they make some difference in the orientation of indicatrices so that the other face of *n* is developed. Single fourlings like this are not found in our rock, but as superposing structure in penetration fourling or as elements of a twin structure of still higher order crystals 6374 A. 19 and B. 5 of Fig. VI (cf. Fig. XI a and i) may be mentioned. Form XI stands near form X, which may be derived from form I through the introduction of an oblique contact plane which does not correspond to *n*. As to trillings of the penetration type these are very common, for adjacent and opposite units of the contact twinning are apt to insert or penetrate into each other during twin growth.

3. Baveno and Aveno Trillings

In different units of trillings the extinction in the [001] zone varies between 0—4° while the extinction $\perp \gamma : \alpha/(001)$ varies from 2—10°.5 in the epidote-orthosite and 5—8° in the nepheline-syenite (Tab. X). The axial angles have a range of 38—52°. The development of twin building is rather perfect, in several cases the opposite units of the same individual show the same magnitude of axial angle and extinction. If there is any difference, it lies more in extinction than in axial angle. This means that the indicatrices concerned are of more or less the same size and shape but their orientation with respect to (001) and (010) may be quite different.

In Tab. XI, the three trillings (6564. nos. 3, 4, 16, Fig. III) from the orthosite dyke are also included. It has been pointed out that the (001) and (010) cleavages continue from one unit into the other without break or change of direction, but the indicatrix yields easily to displacement so that γ becomes no longer parallel to the *b*-axis and α deviates at a certain angle from the (010) cleavage. It is chiefly a rotation without deformation of the indicatrix, therefore we often come upon axial angles of the same magnitude in opposite units of the same individual which takes part in the interpenetrant twin-building. If the displacement takes place in such a manner that both indicatrices bear the same angular relation to the (001) and (010) faces, extinctions in the opposite units will then be of the same magnitude. Crystals 6564 no. 4, 6374 A. nos. 13 and 28 b (Tab. III and X) are examples for such behaviour. If there is neither displacement nor deformation, the same indicatrix extends in continuation over the two opposite units, which will then show equal illumination in all positions. Examples for such are crystals 6374 A. nos. 2, 20 and 6374 B. no. 9 (Tab. X). In trillings of this

Table X.

Slide no.	Crystal no.	Twin formation	Twinned units	$\perp\gamma:\alpha/(001)$	$\perp\beta:\alpha/(010)$	$2V_\alpha$	Cleavage	a/α
6345 B	4	3-ling	1	6°	—	—	(001)	—
			2	—	1°	—	(010)	—
			3	—	0	44°	(010)	—
»	7	»	1	5	4	42	(001), (010)	6°
			2	8	1	44	(001), (010)	7
			3	8	4	44	(001), (010)	8
6374 A	2	»	1	8	1.5	48	(001), (010)	7
			2	7	0.5	48	(001), (010)	7
			3	8	0.5	48	(001), (010)	7
»	8	»	1	4	1	46	(001), (010)	4
			2	2	1	45	(001), (010)	3
			3	5.5	3	52	(001), (010)	6
»	13	»	1	—	0	42	(010)	—
			2	7	—	54	(001)	—
			3	—	0	42	(010)	—
»	15	»	1	—	—	40	—	—
			2	—	—	40	—	—
			3	—	—	42	—	—
»	16	»	1	5	3.5	39	(001), (010)	5
			2	3	0.5	40	(001), (010)	4
			3	6	3	42	(001), (010)	7
»	18	»	1	5	—	50	(001)	—
			2	—	3	48	(010)	—
			3	8	—	50	(001)	—
»	20	»	1	4	1	48	(001), (010)	4
			2	2	0.5	42	(001), (010)	2
			3	4	1	48	(001), (010)	4
»	28 b	»	1	4	—	52	(001)	—
			2	—	0	—	(010)	—
			3	4	—	52	(001)	—
»	30	»	1	3	—	42	(001)	—
			2	—	0	42	(010)	—
			3	5	—	42	(001)	—
6374 B	9	»	1	9	3	38	(001), (010)	10
			2	10.5	4	48	(001), (010)	11.5
			3	9	3	38	(001), (010)	10

type the angle $Z/\bar{Z}$ is 0 (see Tab. XI b), i.e., Z and $\bar{Z}$ coincide and there will be only one common twin axis. It is, however, not seldom that both displacement and deformation go together, then we have crystals 6564 nos. 3 and 16 and 6374 A. nos. 8, 16 (see Tab. III and X). The last-named is by far most common in twin-buildings of still higher order.

To summarize the data given in Tab. XI, the (001) and (010) cleavages (#1)/(#2), form an angle from 88—90°, the angle between the two diagonal

Table XI a.

Slide no.	Crystal no.	Twin-pair contact plane and twin-axis (I/II/III)	(#1)/(#2)	$N/\bar{N}$	$N/\bar{N}'$	N/N'	$\bar{N}/\bar{N}'$	N/(#1, 2)	$\bar{N}$ (#1, 2)	N' (#1, 2)	$\bar{N}'$ (#1, 2)
6374 A	2	$N, Z;\ \bar{N}, \bar{Z}$	92°	92°	—	—	—	40°, 48°	47°, 45°	—	—
»	8	$\bar{N}, \bar{Z};\ N, Z$	89	89	—	—	—	47, 45	44, 45	—	—
»	13	$\bar{N}, \bar{Z};\ N, Z$	—	90	—	—	—	50	41	—	—
»	15	$\bar{N}, \bar{Z};\ N, Z$	—	90	81°	—	9°	—	—	—	—
»	16	$N, Z;\ \bar{N}, \bar{Z}$	92	89	—	—	—	46, 42	47, 47	—	—
»	18	$N, Z;\ \bar{N}, \bar{Z}$	—	89	—	—	—	45	46	—	—
»	20	$N, Z;\ N' Z'$	91	—	—	2°	—	42, 47	—	43°, 46°	—
»	28 b	$N, Z;\ \bar{N}, \bar{Z}$	—	86	—	—	—	44	49	—	—
»	30	$N, Z;\ \bar{N}, \bar{Z}$	—	88	—	—	—	45	47	—	—
6374 B	9	$N, Z;\ N, Z$	92	—	—	—	—	45, 43	—	—	—
6345 B	4	$N, Z;$ —	—	—	—	—	—	45	—	—	—
»	7	$N, Z;\ N, Z$	90	—	—	—	—	44.5, 45	—	—	—
6564	3	$N, Z;\ \bar{N}, \bar{Z}$	—	82	—	—	—	40	59	—	—
»	4	$N, Z;\ \bar{N}, \bar{Z}$	—	89	—	—	—	44	45	—	—
»	16	$N, Z;\ \bar{N}, \bar{Z}$	91	87	—	—	—	47.5, 44.5	45, 47	—	—

Table XI b.

Slide no.	Crystal no.	Twin-pair contact plane, Twin-axis (I/II/III)	$Z, \bar{Z}/[N]$	$Z, \bar{Z}/[\bar{N}]$	$Z, \bar{Z}/[N']$	$Z, \bar{Z}/[\bar{N}']$	$Z/\bar{Z}$	Z/(#1,2)	$\bar{Z}$/(# 1, 2)
6374 A	2	$N, Z;\ \bar{N}, \bar{Z}$	4°, 4°	89°, 89°	—	—	0°	45°, 44°	45°, 44°
»	8	$\bar{N}, \bar{Z};\ N, Z$	6, 6.5	84, 86	—	—	4, 5	50, 41	52, 39
»	13	$\bar{N}, \bar{Z};\ N, Z$	4, 2	88, 88	—	—	3	48	48
»	15	$\bar{N}, \bar{Z};\ N, Z$	2.5, 4	88, 88	—	97°, 96°	3	—	—
»	16	$N, Z;\ \bar{N}, \bar{Z}$	2, 4	89, 92	—	—	5	46, 42.5	43, 45
»	18	$N, Z;\ \bar{N}, \bar{Z}$	2, 5	86, 91	—	—	6.5	49	45
»	20	$N, Z;\ N', Z'$	2.5, 2.5	— —	1.5°, 1.5°	—	0	44.5, 45	44.5, 45
»	28 b	$N, Z;\ \bar{N}, \bar{Z}$	3, 5	90, 90	—	—	4	41	41
»	30	$N, Z;\ \bar{N}, \bar{Z}$	1, 4	88, 92	—	—	4	44	41
6374 B	9	$N, Z;\ N, Z$	0	— —	—	—	0	45, 43	—
6345 B	4	$N, Z;$ —	4	— —	—	—	—	49	—
»	7	$N, Z;\ N, Z$	2.5, 3	— —	—	—	4	48, 42	—
6564	3	$N, Z;\ \bar{N}, \bar{Z}$	4, 4	77, 77	—	—	2.5	45	43.5
»	4	$N, Z;\ \bar{N}, \bar{Z}$	3, 4	88, 92	—	—	4.5	47.5	44.5
»	16	$N, Z;\ \bar{N}, \bar{Z}$	16.12	93, 90	—	—	5	46, 43.5	46, 43.5

planes, $N/\bar{N}$, varies between 82—90°, but is in most cases near 90°, the angle between contact planes and cleavage planes, $N/$(#1, 2) and $\bar{N}/$(#1, 2), fall respectively into the range 40—45° and 30—45° but mostly around 45° or 40—45°, and about the same are angles Z and $\bar{Z}/$(#1, 2), which show variation between 40—45° and 38—45° respectively, with again the highest frequency around 45° or 40—45°. $Z/\bar{Z}$ varies between 0—6.5°; Z and $\bar{Z}/[N]$ at 0—16° but mostly under 6.5°. Z and $\bar{Z}/[\bar{N}]$ varies around 77—90°, but in the majority of cases between 84—90°. The angular relations obtained from normally twinned pairs are as a rule more regular than from the parallel twinned pairs. The contact planes usually do not change their main direction, but two examples are noticed (Tab. XI a and b), one in crystal 6374 A. 20 wherein the twinning plane shows a 2 degrees deviation (N/N'), and the other in crystal 6374 A. 15, in which the composition plane shows a 9 degrees deviation ($\bar{N}/\bar{N}$). Such deviations are also very common in twin crystals with more than three units.

Sketches of trillings from the epidote-orthosite and the nepheline-syenite are given in Fig. VI (cf. p. 40 ff., 6345) and their trend of development in Fig. VIII; in the latter, examples from the orthosite dyke are also cited.

In Fig. VIII, forms I, II and III represent three main types of twinning which give rise to trillings of different forms. Only one of the diagonal contact planes is developed in twinning form I, from which form IV is derived by the development of one (001) or (010) segment throughout the crystal in the unruled area. This is illustrated by crystal 6345 B. (Fig. VI) in which the units II and III, corresponding to the two units of the unruled area in form I (Fig. VIII), are not twinned but possess indicatrices slightly displaced with respect to each other. Form V is represented by crystal 6374 A. 28 b, of which 3 units form 2 alternating pairs of Baveno twinning, one in normal, and the other in parallel twin position. The lately introduced segment of contact plane in V resembles apparently that of IV in cross-section, but here it is in reality the trace of one of the n (021) faces which coincides with the edge of (001)/(010) in the section cut parallel to [100]. The indicatrices in flanking units I and III have the same orientation and both show their β and γ reversed with respect to the central unit; therefore it is in reality already a trilling growth of the penetration type. In form III we have both faces of n (021) developed, which gives rise to forms VI and VIII by a mere shift of the initial position of the concerned contact planes, or to forms VII, IX and X by the addition of one (001) or (010) segment. The former are represented by crystals 6374 A. 16, 6564 no. 3 and 6564 no. 16 (Tab. III and Fig. III); the latter by crystals 6374 A. 13, 31 and 6345 B. 7 resp. In forms VII, IX and X all the flanking units, which are twinned with the central unit alternately in normal and parallel position in the habit of Baveno and Aveno laws, are not twinned with each other since their indicatrices are of similar orientation. In twinning II we have

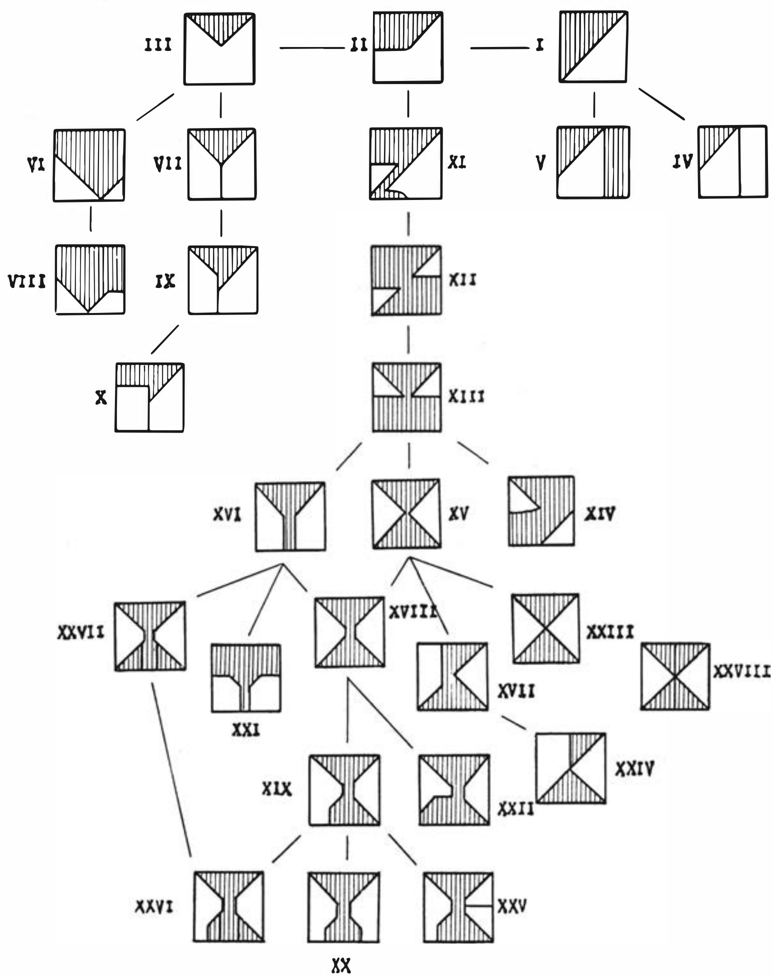


Fig.VIII. Trend of development of trillings of the penetration type. (Form IV, which is in reality a contact twinning with three units, is not included.)

already a (001) or (010) segment participating in building up the twin junction and we see also how the penetration growth initiates in form XI which is represented by crystal 6564 no. 1 (Fig. III). By a further extension of the penetrating area and the development of another (001) or (010) segment in the twinned crystal, it will pass to form XII (crystal 6374 A. 20, Fig. VI), while a symmetrical arrangement of the penetrated or embedded area in the penetrating part gives form XIII (crystal 6374 A. 30). A further variation in combination of contact elements leads to forms XIV, XV and XVI, represented respectively by crystals 6345 C. 4, 6374 A. 18 and 41 (Fig. VII). From these forms, still more complicated combinations like XVII, XVIII, XIX, XX, XXI and XXII may be easily derived, which are exemplified by crystals 6374 A. 40, 6374 A. 2, 6564, no. 4, 6374 A. 15, 6374 A. 8 and 2 resp. From these highly varied forms of penetration trillings, twins of still higher order like fourlings, fivelings and sixlings of the penetration type may be formed through some further addition of (001) and (010) segments or by further extension of the *n* (021) faces as is shown by XXIII, XXIV, XXV, XXVI, XXVII and XXVIII. This will be discussed in detail in the following section.

4. Baveno and Aveno Twins of still Higher Order

A comparison of Tab. XII with Tab. III, VIII and X, reveals that the optic axial angles cover nearly the same range of magnitude among single crystals as well as twinned crystals of different order, and their average values are also nearly identical. This means that the indicatrix of the feldspars does not bear much deformation due to twin building however complicated it may be.[1] On the other hand, it shows that the position of the indicatrix in the feldspars with respect to (001) and (010) is easily affected by twin building. This is best illustrated by crystals 6345 C. 1, 6374 A. 6, 10, 12, 14, 23 and 6374 B. 2, 8 etc. (see Tab. XII, columns of extinction). The higher the order of twin building, the larger the amount of displacement of the indicatrix in corresponding units of the twinned crystal. A correlation of extinctions and optic axial angles is given below in Tab. XIII.

Straight extinctions in the [001] zone can still be met with now and then in high-order twin formation, but the tendency as well as the magnitude of inclined extinction increases with the rise of order of twin formation. In Fig. X we shall see how trillings pass to twinned crystals of still higher order through further displacement of indicatrices in corresponding units which brings into existence the lately introduced segments of contact planes corresponding to either faces of *n* (021) and (010) faces.

Forms I, II, III, IV and V (Fig. IX) are trillings closely related to one another in morphological development. By addition of one (001) or (010) segment trilling I passes to form VI (crystal 6374 A. 23). By extension of *n* (021) faces, trilling II passes to forms VII (6374 A. 17) from which through addition of (001) and (010) segments forms IX (6374 A. 5), X (6374 A. 26) develop. Trilling III gives place to form VIII (6374 A. 10, 25) by conjugation of contact planes in the center, from the latter form crystals like forms XI (6374 A. 7, 24, 27, 35), XII (6374 B. 1), XIII (6374 A. 39), XIV (6374 A. 38) are formed through further introduction of (001) and (010) segments. Trilling III changes to form XVI (6345 C. 2 and 6374 A. 36) by continued penetration of the ruled area into the unruled area. Through change in

[1] Our result differs from that reached by DOLAR-MANTUANI (1931, p. 286) in the respect that the optic axial angle of the feldspars, though variable within a certain range in different crystals, does not seem to differ so much in magnitude in different units of a single twinned crystal.

Table XII.

Slide no.	Crystal no.	Twin formation	Twin units	⊥γ: α/(001)	⊥β: α/(010)	2 V_α	Cleavage	a/α
6345 A	5	4-ling	1	—	0°	—	(010)	—
			2	6°	—	54°	(001)	—
			3	5	—	50	(001)	—
			4	—	1.5	—	(010)	—
» C	1	»	1	11	—	48	(001)	—
			2	—	4	46	(010)	—
			3	2	3.5	46	(001)	—
			4	—	—	46	(010)	—
6374 A	1	»	1	7.5	2	52	(001), (010)	7°
			2	5	3	40	(001), (010)	6
			3	5.5	1.5	52	(001), (010)	6
			4	6	1.5	40	(001), (010)	5
»	3	»	1	4	0	58	(001), (010)	4
			2	4	1.5	38	(001), (010)	6
			3	5	2	58	(001), (010)	3
			4	3	1.5	40	(001), (010)	3
»	4	»	1	5	—	48	(001)	—
			2	—	1	—	(010)	—
			3	3	—	48	(001)	—
			4	—	1	—	(010)	—
»	5	5-ling	1	—	—	52	—	—
			2	—	—	52	—	—
			3	—	—	44	—	—
			4	—	—	44	—	—
			5	—	—	48	—	—
»	6	4-ling	1	2	3	42	(001), (010)	3
			2	7	0.5	42	(001), (010)	7
			3	6	2	48	(001), (010)	6
			4	3	1	48	(001), (010)	5
»	7	5-ling	1	—	—	44	—	—
			2	—	—	44	—	—
			3	—	—	36	—	—
			4	—	—	56	—	—
			5	—	—	52	—	—
»	9	6-ling	1	9	14	44	*(001)*, (010)	16
			2	9	1	48	(001), (010)	9
			3	6	0	38	*(001)*, *(010)*	6
			4	10	11	42	(001), (010)	16
			5	17	12	42	(001), (010)	22
			6	20	2.5	40	(001), (010)	21
»	10	4-ling	1	2	2	42	(001), (010)	2.5
			2	6	3	44	(001), (010)	6.5
			3	7	0	44	(001), (010)	6
			4	6	1	40	(001), (010)	6

Table XII (cont.).

Slide no.	Crystal no.	Twin formation	Twin units	$\perp\gamma:\alpha/(001)$	$\perp\beta:\alpha/(010)$	2 V_α	Cleavage	a/α
6374 A	11	6-ling	1	—	1°	39°	(010)	—
			2	—	2	40	(010)	—
			3	3°	—	52	(001)	—
			4	—	2	—	(010)	—
			5	—	0	38	(010)	—
			6	3	—	52	(001)	—
»	12	4-ling	1	3	1.5	44	(001), (010)	3°
			2	3.5	0	42	(001), (010)	4
			3	7.5	2	48	(001), (010)	8
			4	5	0	38	(001), (010)	5
»	14	»	1	0	1	48	(001), (010)	2
			2	5	3	48	(001), (010)	6
			3	9.5	2	44	(001), (010)	10
			4	5	2	44	(001), (010)	5
»	17	5-ling	1	6	0	44	(001), (010)	6
			2	4	2	44	(001), (010)	4
			3	5	1.5	42	(001), (010)	5
			4	6	1	44	(001), (010)	6
			5	—	—	—	—	—
»	19	6-ling	1	—	2	—	(010)	—
			2	5	—	40	(001)	—
			3	3.5	—	46	(001)	—
			4	—	2	—	(010)	—
			5	—	1.5	—	(010)	—
			6	5	—	42	(001)	—
»	22	4-ling	1	—	—	50	—	—
			2	—	—	46	—	—
			3	—	—	50	—	—
			4	—	—	50	—	—
»	23	»	1	6	3	44	(001), (010)	6
			2	3	2	46	(001), (010)	4
			3	3	2	46	(001), (010)	5
			4	5	0	40	(001), (010)	5
»	24	5-ling	1	7	1	46	(001), (010)	6
			2	4	1.5	42	(001), (010)	5
			3	6	1	46	(001), (010)	6
			4	8	1	46	(001), (010)	7
			5	3	1	48	(001), (010)	4
»	25	4-ling	1	5	1	42	(001), (010)	5
			2	6.5	2	44	(001), (010)	7
			3	6.5	1	44	(001), (010)	6.5
			4	3.5	2	44	(001), (010)	3
»	26	5-ling	1	6	—	48	(001)	—
			2	—	1	42	(010)	—
			3	—	1	43	(010)	—
			4	4	—	48	(001)	—
			5	4	—	48	(001)	—

Table XII (cont.).

Slide no.	Crystal no.	Twin formation	Twin units	$\perp\gamma:\alpha/(001)$	$\perp\beta:\alpha/(010)$	$2V_\alpha$	Cleavage	a/α
6374 A	27	5-ling	1	6.5°	3°	48°	(001), (010)	6°
			2	0	1	48	(001), (010)	2
			3	4	4	50	(001), (010)	5
			4	11	2	44	(001), (010)	11
			5	4	4.5	48	(001), (010)	5
6374 B	1	»	1	7	—	44	(001)	—
			2	—	0	40	(010)	—
			3	5	—	44	(001)	—
			4	—	2	42	(010)	—
			5	5	—	44	(001)	—
»	2	6-ling	1	—	6	52	(010)	—
			2	13	—	50	(001)	—
			3	10	—	—	(001)	—
			4	—	3	40	(010)	—
			5	1	—	—	(001)	—
			6	2	—	50	(001)	—
»	5	8-ling	1	—	1	52	(010)	—
			2	—	6	48	(010)	—
			3	—	1.5	50	(010)	—
			4	4	—	50	(001)	—
			5	9	—	52	(001)	—
			6	5	—	50	(001)	—
			7	—	5	50	(010)	—
			8	—	3	50	(010)	—
»	7	5-ling	1	—	—	46	—	—
			2	—	—	42	—	—
			3	—	—	48	—	—
			4	—	—	46	—	—
			5	—	—	48	—	—
»	8	4-ling	1	5	1.5	40	(001), (010)	6
			2	8	2	40	(001), (010)	8
			3	9	0.5	40	(001), (010)	8
			4	8	1	42	(001), (010)	8

direction of growth of contact plane or introduction of new segments it leads to forms XVII (6374 A. 37), XVIII (6374 B. 7) and XIX (6374 A. 11 and 6374 B. 2). As to trilling V, its evolution into forms of higher order seems to have taken place along two lines, one by direct conjugation of the two *n* (021) faces and introduction of new segments, the other by introduction of some minor local complicacy in the center. The former are represented by forms XX (6345 C. and 6374 A. 3), XIX (6374 A. 11 and 6374 B. 2), XXII (6374 A. 19) and XXIII (6374 B. 6); the latter by forms XXI (6374 A. 3), XXIV (6374 A. 6, 12) and XXV (6374 A. 4). The relative displacements of indicatrices in corresponding units of the latter forms are sometimes so

Table XIII a.

Slide no. 6374	$\perp\gamma:\alpha/(001)$		$\perp\beta:\alpha/(010)$		$2\,V_a$	
	Min.—Max.	av.	Min.—Max.	av.	Min.—Max.	av.
Twinnings	1.5 — 7.0°	4.8°	0 — 3°	1.4°	36 — 52°	45.3°
Trillings	2.0 — 10.5	5.6	0 — 4	1.5	38 — 54	45.1
Twins of higher order ..	0 — 20.0	5.7	0 — 14	2.1	36 — 56	45.5

Table XIII b.[1]

Slide no. 6345	$\perp\gamma:\alpha/(001)$		$\perp\beta:\alpha/(010)$		$2\,V_a$	
	Min.—Max.	av.	Min.—Max.	av.	Min.—Max.	av.
Twinnings	3.0 — 7.0°	5.0°	0 — 3°	1.1°	36 — 52°	45.6°
Trillings	5.0 — 8.0	6.7	0 — 4	2.0	42 — 44	43.5
Twins of higher order ..	2.0 — 11.0	6.0	0 — 4	2.2	46 — 54	48.3

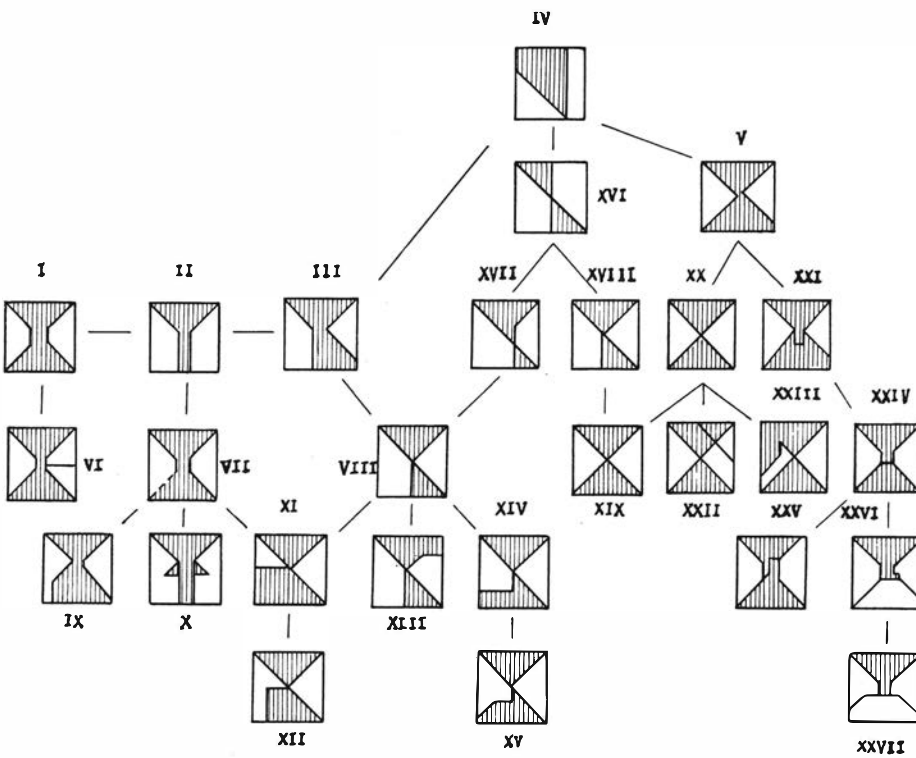


Fig. IX. Trend of development of fourlings, fivelings and sixlings of the penetration type.

[1] Some of the arithmetic means given in Tab. XIII b are calculated from not more than 4 figures. However, it still speaks for the postulation mentioned above.

slight that a trilling growth is only visible if the section is not turned to other positions where unequal illumination of the corresponding units and their intricate conjugation trace in the center (e.g. 6374 A. 3 etc.) are subject to observation. Forms XXVI (6374 A. 6) and XXVII (6374 A. 14) resemble such type of penetration fourling in outline, but in reality they are combination of a penetration trilling and a Manebach twinning, units II and IV in the first-named and I and III in the second crystal being twinned according to the Manebach law.

5. Miscellaneous Baveno and Aveno Twins

Single-paired twinnings on *n* faces, so far discussed being either Baveno or Aveno twins, are always contact twins, whereas similar twin building of higher order belongs in most cases to the penetration type of twin. There are exceptions, but exceptions are rare. One is form IV among the trillings (Fig. IX), in which the two units of the unruled area have indicatrices of corresponding orientation, and accordingly the two flanking units cannot be considered to belong to the same individual. This concerns therefore a contact twinning, and there is in reality only one pair of twin though it contains three units. Another example calling for discussion is form XXII (Fig. IX). This is a sixling, but not of the simple penetration type. The primary structure is a penetration fourling with AB as its twinning plane and CD as its composition plane, as is reproduced in Fig. X a (cf. Fig. VI, 6374 A. 19). Among the adjacent units, I—II and V—VI are Baveno twins, I—VI and II—V Aveno twins while the opposite units I—V and II—VI having indicatrices of corresponding orientation are not twinned with each other but belong to two separate interpenetrant individuals with indicatrices displaced to some degree respectively in their composing units. The secondary structure is the superposing contact fourling of which adjacent units II—V and III—IV and opposite units II—IV and III—V are twinned but not the remaining pairs of the adjacent units II—III and IV—V. In this subsequent superposing structure the twinned pairs are Aveno contact twins, the primary composition plane CD of the original penetration fourling being adopted as composition plane. The fundamental structure of the twinned crystal is therefore a penetration fourling which is converted into a sixling by the introduction of another diagonal contact plane, EF, which is parallel to AB, the twinning plane of the primary fourling, through a relative displacement of indicatrices in units II : III and IV : V about EF. Here the plane EF functions only as most (001) and (010) segments do in the other twinned structure, and is therefore, strictly speaking, not a composition plane.

However, if AB is a composition plane and CD the twinning plane in the primary penetration fourling (Fig. X b), pairs I—VI and II—V in the

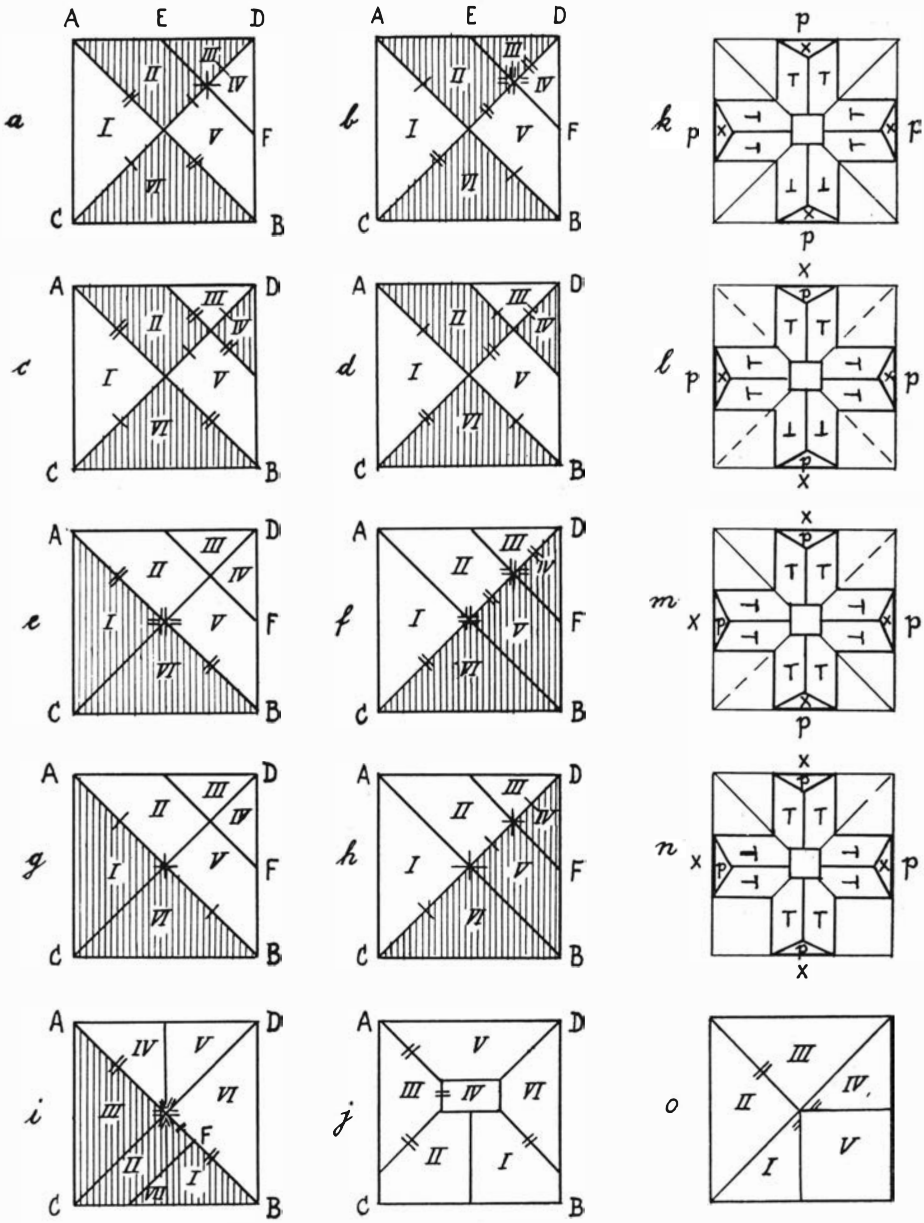


Fig. X. *a—i* showing different ways of superposing between contact and penetration twins. Type *a* is represented by crystal 6374 A. 19. Types *j* & *o* exemplified respectively by crystals 6374 A. 9 & 24 are comparable to *k*, which is reproduced from RAMDOHR's revision of KLOCKMANN's Lehrbuch der Mineralogie, 1936. Types *l*, *m* & *n* represent three other ways of combination. Type *l* is not recorded in our rock, *m* is the type for penetration fourlings found over all in our nepheline syenites while *n* is exemplified by crystals 6374 A. 6 & 14.

superposed and II—V and III—IV in the superposing structure get Baveno twins. For the rest, pairs I—II and V—VI will be Aveno twins in the superposed structure, but the corresponding pairs II—III and IV—V in the superposing structure are not twinned, the other twinned pair being instead the opposite units II—IV and III—V. If two penetration twins are found superposing each other the structure will be like that shown in Fig. X c and d. If it happens to be two contact twinnings it will be like that shown in Fig. X e, f, g, h. The structure shown in Fig. X a is exemplified by crystal 6374 A. 19 in our epidote-orthosite while all the others are absent except that shown by Fig. X e. Crystal 6374 B. 5 (Fig. X i) is an example approaching this, the only difference consists in the presence of a (001) or (010) segment throughout the crystal (Fig. X i) and the position of the late introduced contact plane EF, which is now entirely limited in one of the primary twin units of the contact twinning. This is an eightling, in which at least 6 pairs of Baveno twins can be reckoned across the twinning plane AB, namely, III—IV, VI—VIII, I—VI, IV—VII, II—V and V—VIII, and there will be 15 twinned pairs all told if we count all units in twinned positions. As it is a highly complicated structure, the contact planes are not so regular as is idealized here in the sketch.

Fig. X j is another example worth notice. It is represented by crystal 6374 A. 9 (Fig. VI). The adjacent pairs II—III, III—IV, III—V and VI—I are all Baveno twins, the opposite units III—VI, I—IV and I—V are in twinned position according to the Manebach law, while units I—II is twinned according to the albite law. Units IV—V are not twinned, neither the pairs IV—VI and V—VI, but their indicatrices being relatively displaced with respect to one another (Fig. XI a) and the separating planes between them being merely contact planes, longitudinal, transverse and diagonal all alike. This reminds in some way of the figure given by RAMDOHR (1936, p. 562) which is reproduced here in Fig. X k. The four adjacent or juxtaposed individuals form four alternative pairs twinned according to the Baveno law, and the two diagonal contact planes are both twinning planes, while the opposite units are, according to RAMDOHR, in the twinned position according to the Manebach law. The same point of view is also held by KÖHLER and RAAZ (1947, p. 168) but is discarded by OFTEDAHL (1948, p. 40), who argued that the opposite pairs are twinned according to the Ala A law. This type of twins is not found in the Oslo region but is specified in the Shansi alkaline rocks by the above-mentioned example. The difference in our case is shown by an additional albite twin with the longitudinal contact plane, that separates units I and II and functions as twinning plane. The units on either side of this plane are reversed upside down with respect to each other, therefore one unit of it (unit I) holds a twinning position according to the Manebach law to the opposite units IV and V, but the other (unit II) not. The presence of this albite twin in the

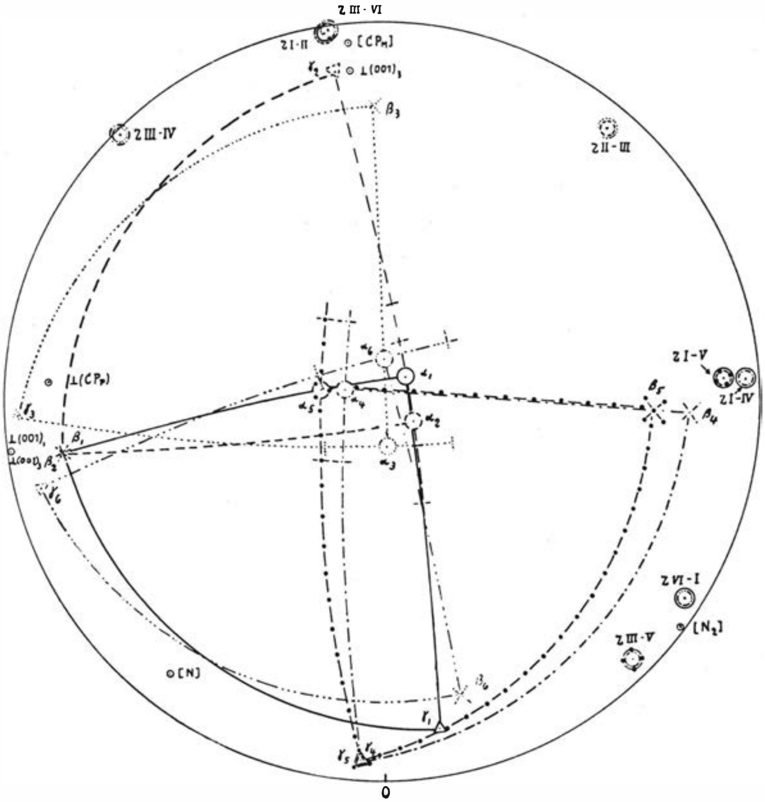


Fig. XI a. Stereographical projection of a Baveno sixling of the contact type showing the introduction of albite and Manebach twins reduced the total number of Baveno twins in the whole twin-edifice. (Crystal 6374 A. 9.)

lower central unit gets a difference with RAMDOHR's in another respect, viz. units V—VI are no longer twinned pairs, neither are units IV—VI. They possess now indicatrices of similar orientation and the diagonal twinning plane separating units V and VI is converted into a mere contact plane. At first sight the reader may misunderstand that the present work does support the assumption of RAMDOHR or KÖHLER and RAAZ, but in reality it is just opposite, for if not the above-mentioned superposing albite twin-structure existed, all the alternately pairs would be Baveno twins and neither of the opposite pairs would be twinned according to the Manebach law. This can easily be understood by conversion, on the annexed stereogram (Fig. XI a), the indicatrices of units I and VI through an 180° turn into the position assumed by those of units II and V. It results that units I—II do not form albite twin, and units I—V, I—IV and III—VI will not be twinned according to the Manebach law while units II—III, VI—IV, III—V, IV—VI, V—III, VI—I will form 6 Baveno twins. GONNARD (1910, p. 252) seems to be of the opinion that fourlings in question can be con-

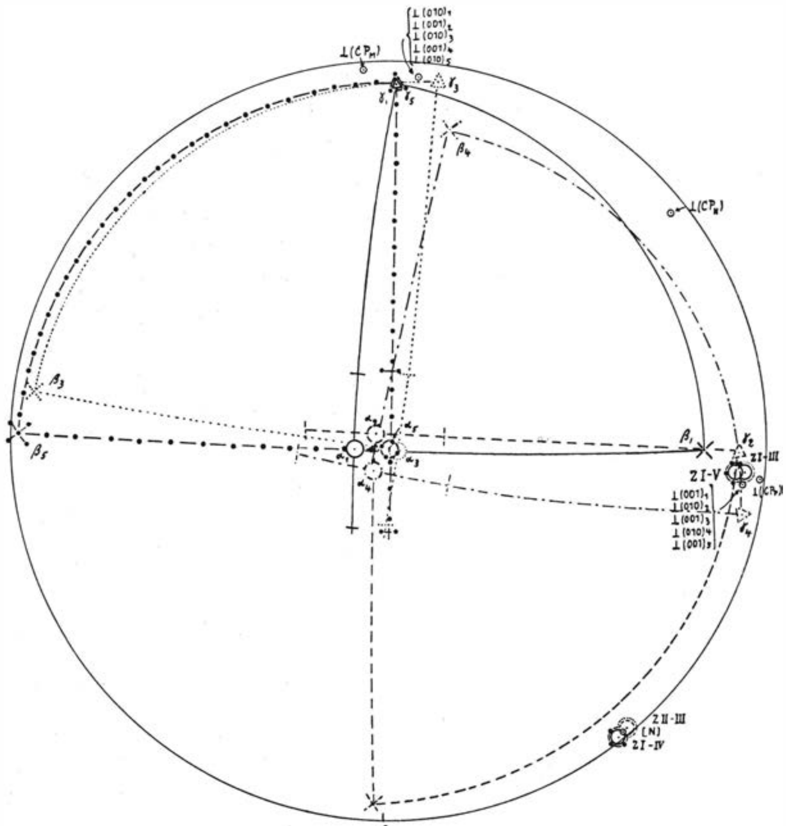


Fig. XI b. Stereographical projection of a Baveno fiveling of the contact type showing the introduction of Manebach twins reduced the number of Baveno twins in the whole twin-edifice. (Crystal 6374 A. 24.)

sidered either as a combination of two Baveno twins on *n* (021) faces, or as a pair of intercrossing Manebach twins. These can at the same time show their opposite units twinned according to the Manebach or the Ala A law. If the opposite units are twinned to the Baveno law, the alternating adjacent units will not be so twinned. Crystal 6374 A. 24 (Fig. X o) is another example in support of the author's argument. On the annexed stereogram (Fig. XI b) it is seen that units I and V in the central lower part are twinned according to the Manebach law instead of the albite law, and unit I is again twinned with the opposite unit III according to the Manebach law, but unit V does not. In the meantime the total number of Baveno twins is reduced to two, units I—VI and II—III are twinned according to the normal Baveno law but I—II and III—IV are not twinned, that is to say, one of the *n* (021) faces has been reduced to a mere contact plane through the presence of Manebach twins. In Fig. XI the four alternating twinned pairs, instead of being Baveno, are all Aveno twins, and the two diagonal contact planes are both composition planes, but this type is not recorded in our rock. The third type (Fig. X m) is the most common one in the nepheline-syenites. Of the contact planes one is the twinning plane and the other the composition plane. The four juxtaposed units form two Baveno and two Aveno twins, but the two opposite pairs are not twinned, since they belong to two separate individuals of interpenetrant growth. However, there is a fourth type to be added for the completion of fourling combination, this is represented by crystals 6374 A. 6 and 14 (Fig. VI). The two transverse units in Fig. X n, or the two flanking units of the concerned crystals in Fig. VI, are not twinned with each other but form parts of one individual twinned alternately in the habit of Baveno and Aveno law with the central upper unit, while the central lower, which is the reflection of the central upper, constitutes a Manebach twinning with the latter but is not twinned with the side units. This is very natural, because if the central upper unit forms Baveno twins with the side ones, the reverse of it cannot retain the same relation to them as was before the reflection or the reverse operation. In cross-sections one can even perceive that zonal structure occasionally developed in the crystals is continuous and concentric in the two side units and in the central upper unit, but it ends abruptly at the contact against the central lower unit.

Baveno fourling like form X of Fig. VII is not observed in the rocks investigated. This form is derived principally from a Baveno contact twinning through the introduction of another diagonal contact plane as in Fig. X e, f, g, h or i. However, the lately introduced contact plane maybe not corresponds to $n(021)$ but is quite oblique to the (001) and (010) cleavages, though the twin building practically follows still the same principle. Crystals 6345 A. 5 and 6345 C. 12, 13 (Fig. VI) are examples of this type. The first of the three is taken as an example. Here the diagonal contact plane $\bar{N}$ is the composition plane and pairs I—II, III—IV, II—IV and I—III are all Aveno twins while pairs II—III and I—IV are not twinned. The lately introduced contact plane CD makes an angle of 77° with the diagonal contact plane $\bar{N}$, 84° with the (001) or (010) cleavage, and 26° with the dominant parting, which last makes in turn 71° with the (001) cleavage. The coordinates for the pole of this plane in relation to the three principal indices are tabulated below:

Table XIV.

Unit	α	β	γ
1	26	63	85
2	26	76	67
3	27	78	66
4	27	63	85

By plot of the pole against NIKITIN's diagram (1936), it is seen that it lies in the prismatic zone somewhere between (100) and *m* (110).

6. Bound-Faces of Baveno and Aveno Twins

HESSENBERG (1855, p. 31) summarized Baveno fourlings of the Alpine adularia into two idealized types, one is the penetration type with (010) as bound faces and the other is the contact type with (001) as bound faces. RATH (1862) approved of HESSENBERG's classical division but amended that even the second type may happen to be penetration fourling. The concerned types are reproduced by PARKER (1942, p. 292, Fig. 6 a and b), who adopted RATH's revision but added another type of contact fourling with (010) as bound faces (l. c. Fig. 6 c). According to PARKER (l. c.), penetration fourlings with (001) and (010) as bound faces are very common but corresponding contact fourlings are rare. In the investigation of Baveno and Aveno twins in orthoclases, the present author reached the conclusion that in twins of higher order the (010) face is by far not found as principal or essential bound face. HESSENBERG's first type of penetration fourling bound by (010) faces is not observed, while his second type, being bound by (001) faces, is represented over all by penetration intergrowth (Fig. X m). HESSENBERG's second type of contact fourling, corresponding to RAMDOHR's figure 580 (1936, p. 562) or Fig. X k of the present author, is found only once among 42 measured examples, while the third type of contact fourling bound by (010) faces is again not observed. The absence or underdevelopment of (010) faces in adularias is sometimes considered to be a possible explanation for the rarity of such fourlings with (010) as bound faces, but this does not hold for orthoclases which have its (010) faces well developed.

7. Baveno and Aveno Fourling Structure on Stereograms

In the preceding different combination types of Baveno and Aveno fourlings have been discussed (Fig. XI), and it has been pointed out that the secondary contact fourling formed by the introduction of another diagonal plane as a mere contact plane, is bound by 2 adjacent (001) and 2 adjacent (010) faces; it consists of 2 juxtaposed and 2 opposite pairs of Baveno or Aveno twins. Now we shall see how the primary fourling structures appear on the stereograms, which are bound on all sides either by (001) or by (010) faces. The numeration of the units is like that given in Fig. XII 1 while their indicatrices are drawn schematically in such a way that they form also twins on (001) and (010) faces other than on *n* (021) faces. The sections are thus mostly cut in the zone of the a-axis with some obliquity so that all units are included in the section, and the poles of the *a*-axis appear on or near the margin of the stereograms.

In Fig. XII 2 a units I—IV and II—III among the juxtaposed pairs

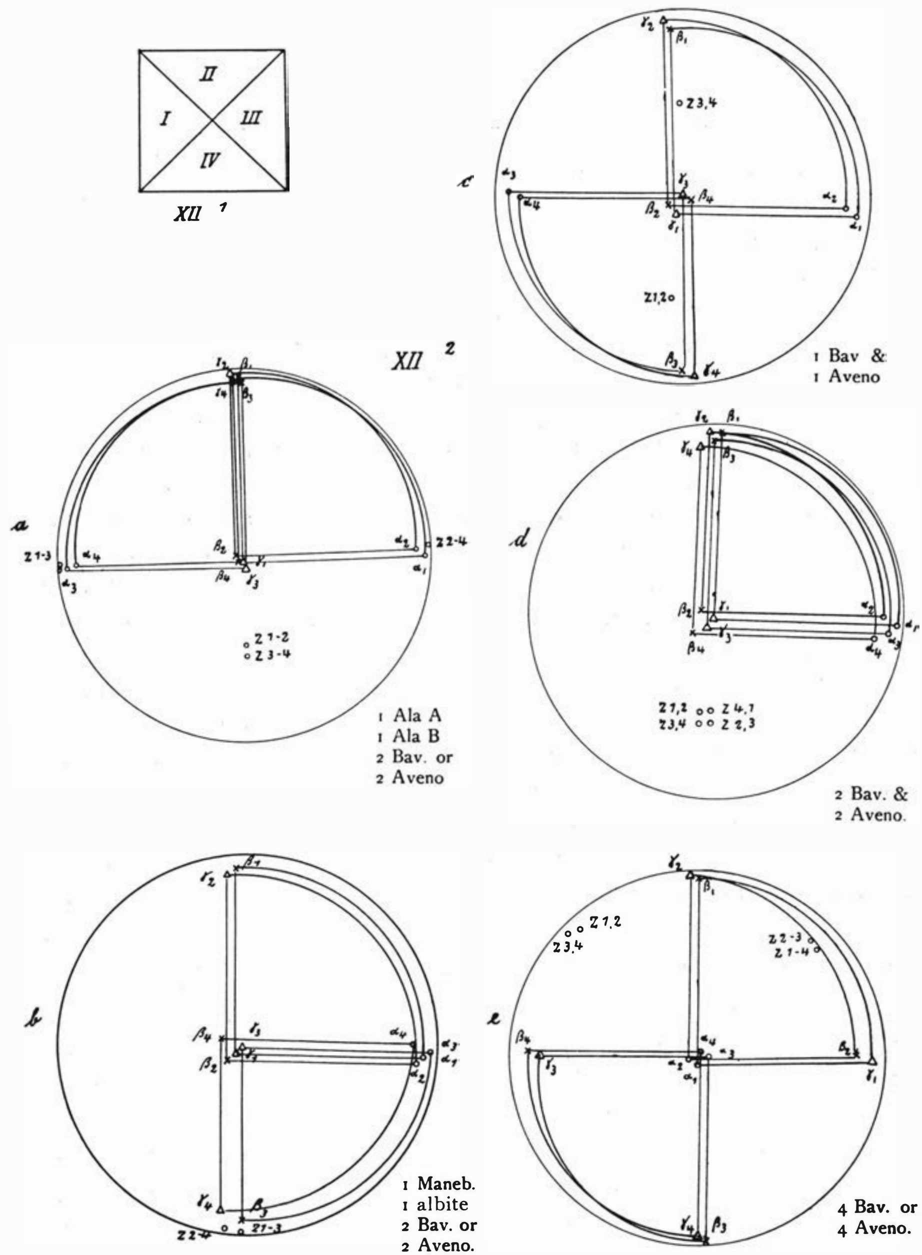

XII 1
II
I
III
IV
XII 2
a
1 Ala A
1 Ala B
2 Bav. or
2 Aveno
c
1 Bav &
1 Aveno
d
2 Bav. &
2 Aveno.
b
1 Maneb.
1 albite
2 Bav. or
2 Aveno.
e
4 Bav. or
4 Aveno.

Fig. XII.

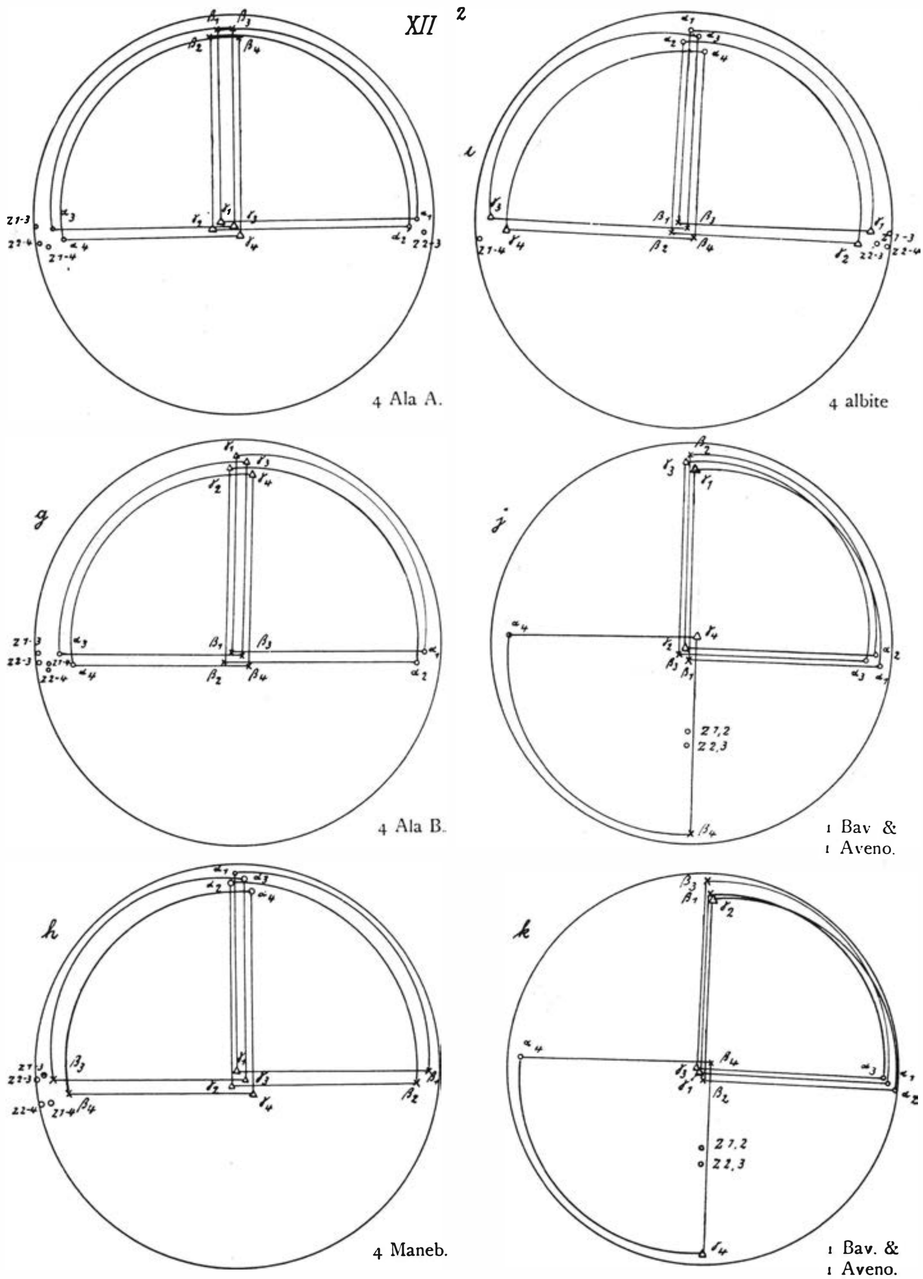

XII 2
i
4 Ala A.
4 albite
g
4 Ala B.
j
1 Bav. &
1 Aveno.
h
4 Maneb.
k
1 Bav. &
1 Aveno.

Fig. XII.

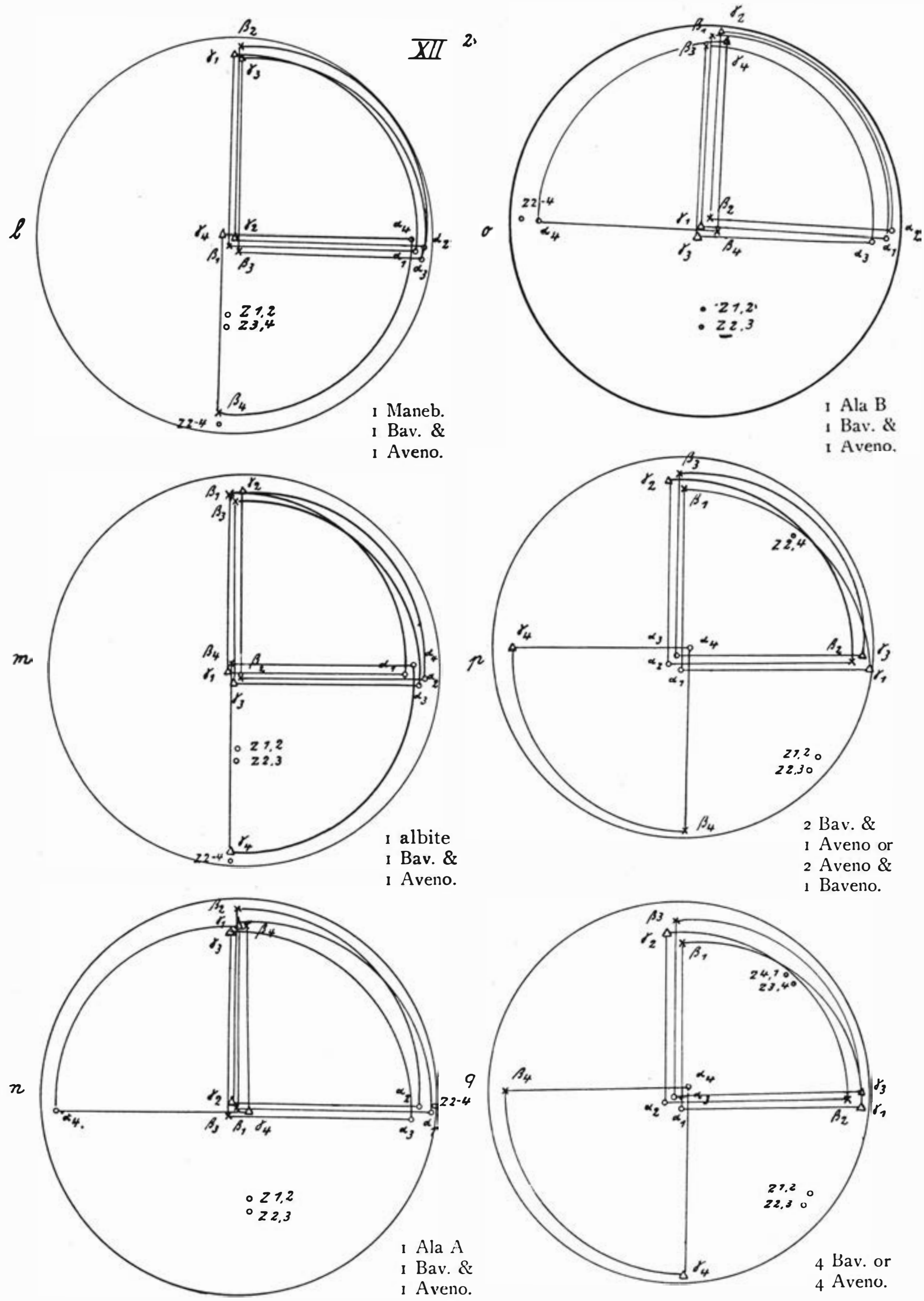
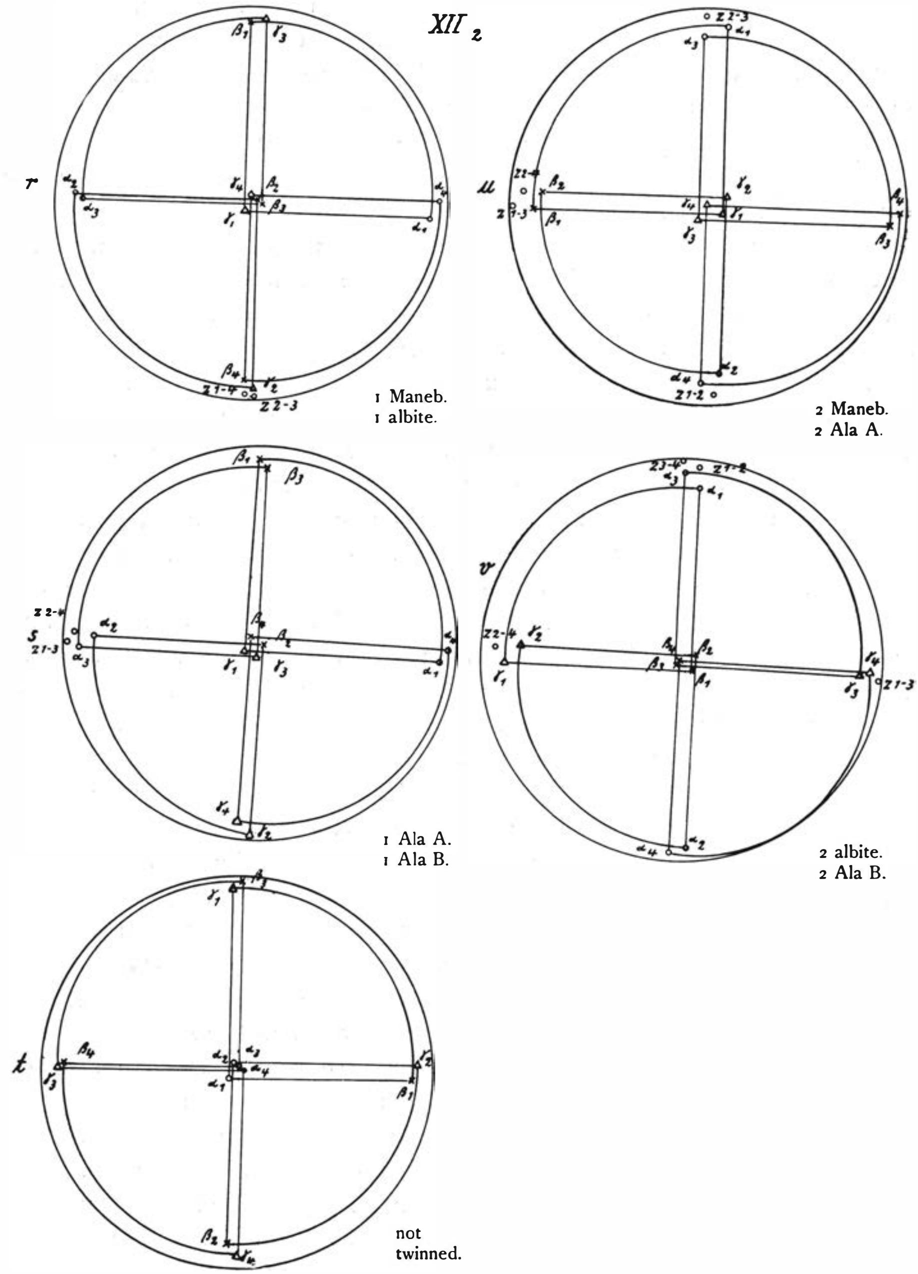

XII
l
1 Maneb.
1 Bav. &
1 Aveno.
o
1 Ala B
1 Bav. &
1 Aveno.
m
1 albite
1 Bav. &
1 Aveno.
p
2 Bav. &
1 Aveno or
2 Aveno &
1 Baveno.
n
1 Ala A
1 Bav. &
1 Aveno.
q
4 Bav. or
4 Aveno.

Fig. XII.



r: 1 Maneb. 1 albite.

u: 2 Maneb. 2 Ala A.

s: 1 Ala A. 1 Ala B.

v: 2 albite. 2 Ala B.

t: not twinned.

Fig. XII.

are not twinned, units I—II and II—IV are twinned on one and the same diagonal contact plane, being therefore either both Baveno or both Aveno twins, while the 2 opposite pairs I—III and II—IV are twinned respectively according to Ala A and B law. Here one of the diagonal contact planes is merely a contact plane while the other may be either a twinning or a composition plane. The twinning axis for both opposite pairs is the *a*-axis but the composition plane represents (001) in one and (010) in the other. Therefore one pair forms an Ala A twin and the other an Ala B twin. In Fig. XII 2 b, everything is the same as in Fig. XII 2 a except that the opposite pairs now form a Manebach and an albite twin instead of an Ala A and an Ala B twin. In Fig. XII 2 c, pairs I—IV and II—III among the juxtaposed are again not twinned, but units I—II and III—IV form one Baveno and one Aveno twin while the opposite units I—III and II—IV are not twinned. Since the two twinned pairs are twinned on different segments of one and the same diagonal plane, this plane functions in part as twinning plane and in part as composition plane while the other diagonal plane is merely a contact plane. In Fig. XII 2 d, the opposite units I—III and II—IV are not twinned but the four juxtaposed units form 2 Baveno and 2 Aveno twins, therefore one diagonal plane is a twinning plane and the other is a composition plane. In Fig. XII 2 e, the two opposite pairs are not twinned while the 4 alternating pairs of juxtaposed units are either all Baveno or all Aveno twins and therefore the two diagonal planes function either both as twinning planes or both as composition planes. Fourlings with units possessing indicatrices related to one another as shown by Fig. XII 2 a, b, and c are not observed in our rocks but those shown by Fig. XII 2 e is exemplified with some modification by crystals nos. 6374 A 9 and 24 (Fig. VI, cf. also Fig. X j and k). This speaks for the argument that the 2 diagonal planes are very seldom both twinning planes or both composition planes, and if they are, the opposite units in the fourling are not twinned at all, forming neither Ala A nor Manebach twins. If they are not both twinning planes or composition planes, the opposite units are either not twinned as is the case in the very common penetration fourlings, or twinned separately in different ways as shown in Fig. XII 2 a and b, which are not yet definitely known in Nature. However, under the two-by-two combination of indicatrices, there is still a possibility for the opposite units to form Ala A, Ala B, Manebach or albite twins. This is shown by Fig. XII 2 f, g, h and i. In this case there won't be any Baveno or Aveno twin structure and the crystal is no longer bound by (001) or (010) faces on all sides but two opposite sides will be (001) and the other two (010). The diagonal contact planes characteristic of Baveno or Aveno twins are converted into mere contact planes and won't survive any longer since they now have nothing to do with the twin structure in question.

However, there are other ways of combination (Fig. XII 2 j—g), e.g., three adjacent units, I, II and III, have overlapping indicatrices on the stereogram to which the indicatrix of unit IV assumes different positions. In such combinations the 2 diagonal planes are always one twinning and one composition plane on which units I—II and II—III form respectively one Baveno and one Aveno twin, while the side units I—III are always not twinned. The total number of Baveno and Aveno twins formed in this way depends on the manner the fourth is joined to the first three. It can remain to be 2 or can be raised to 3 or 4. In Fig. XII 2, j and k there are only one Baveno and one Aveno twin. In Fig. XII 2 l and m the total number of Baveno and Aveno twins is also 2 but the opposite units II—IV now form a Manebach and an albite twin respectively. In Fig. XII 2 n and o the condition for Baveno and Aveno twins is not changed but the opposite units II—IV form an Ala A and an Ala B twin. Fig. XII 2 p is a special case, in which three sides of the crystal are bound by (001) and one side by (010) or vice versa. There are either 2 Baveno and 1 Aveno or 1 Baveno and 2 Aveno twins, the third twinned pair being formed of the opposite units II—IV. In Fig. XII 2 q both opposite pairs, I—III and II—IV are not twinned, but the number of Baveno and Aveno twins is raised to 4, being either all Baveno or all Aveno twins. Among these combination types the only one represented in our rock is that shown by Fig. XII 2 l (crystal 6374 A. 6 and 14 of Fig. VI, cf. Fig. X n). Finally if neither of the indicatrices are overlapping and there exists no Baveno twin structure the combination will be like that shown in Fig. XII 2 r—t, which are neither observed in our rock. In Fig. XII 2 t there is present no twinning structure at all, in Fig. XII 2 r and s the opposite pairs form respectively first a Manebach and an albite and then an Ala A and an Ala B twin. However, if not all sides are bound by faces of the same character, then we may have the types shown by Fig. XII 2 u and v, first two Manebach and 2 Ala A and then 2 albite and 2 Ala B twins form the combination. In the last two cases 2 sides of the fourling are bound by (001), the other two by (010).

8. **Baveno and Aveno Trilling Structure on Stereograms**

As to trillings, there are also different ways of combination of indicatrices. However, the resulting twin structure will be like those shown in Fig. XIII a—e, provided that at least one of the contact planes functions as a twinning or a composition plane of the Baveno twin structure. In Fig. XIII a, two of the alternative pairs are twinned on *n* faces, one being a Baveno and the other an Aveno twin while the remaining pair is not twinned. Such twin structure is exemplified abundantly by penetration trillings in different morphological developments as is shown in Fig. VIII. What separates the two units of the untwinned pair may be a line as in forms V, VI and VIII, a plane surface as in forms VII, IX and X or two plane surfaces with an enclosed space occupied by the penetrating individual. The last type is best illustrated by forms XVI and XXI. However, the space occupied by the penetrating individual may be quite irregular as is shown by other forms of Fig. VIII. If what separates the untwinned units is a line, it will be parallel to the edge of (001)/(010) and the section of the twinned crystal will resemble that of crystals 6374 A. 16, 6564 nos. 3 and 16 (Fig. VI). If it is a plane surface, it will be parallel to either (001) or (010) and the section of the crystal parallel to (100) will be like crystals 6374 A. 13 and 31 (Fig. VI). Such plane surface which functions merely as contact plane participates also in twin buildings of higher order as is shown by forms VI, XI, XII, XVIII and XIX in Fig. IX and their corresponding crystals in Fig. VI.

In Fig. XIII b—e, one of the three alternative pairs forms a Baveno or an Aveno twin, the other pair forms an Ala A, an Ala B, a Manebach or an albite twin while the third is always untwinned. Such twin structures are not observed in our rock as single crystals, but crystals 6374 A. 6, 9, 14, 24 may be mentioned as superposing structure in twin buildings of higher order, in which Manebach and occasionally also albite twin structures participate. As a single crystal Fig. XIII b is exemplified by a perthitic microline in the Swiss granite of the Aar region (GYSIN 1948, pp. 241—242, Fig. 1) and is also reported from the Oslo region by OFTEDAHL (1948, pp. 40—41, Fig. 10 c—d). By separating the Oslo trillings into two varieties and identifying the second variety with GYSIN's type, OFTEDAHL held that in both cases both n(021) faces function as twinning planes on which two alternative pairs form two Baveno twins while the third pair, separated by the contact plane corresponding to (001), forms an Ala A twin. However, in GYSIN's type only one of the two diagonal contact planes functions as a twinning plane and only one of the three alternative pairs forms a Baveno twin while the second pair forms an ala A twin and the third is not twinned. This conforms well to what theory demands as is shown in Fig. XIII b. Baveno trillings of the contact type, in which both n faces function as twinning planes, do occur in Nature (VIGIER 1909, pp. 166—167, Fig. 14); its stereogram projection will be like that shown by Fig. XIII f. In this case there are indeed two normal Baveno twins but the third pair is still not twinned, just as is the case with trillings of the penetration type. GONNARD (1910, p. 252) regarded Baveno trillings to consist of two pairs of adjacent units twinned according to Baveno law and the third according to Manebach law. Neither is this assumption theoretically possible as is seen from the stereograms, Fig. XIII a—f. PARKER (1942, p. 278, Fig. 1) figured another trilling which can belong to any of the types represented in our Fig. XIII, the only difference being one more (001) or (010) segment developed as twin junction.

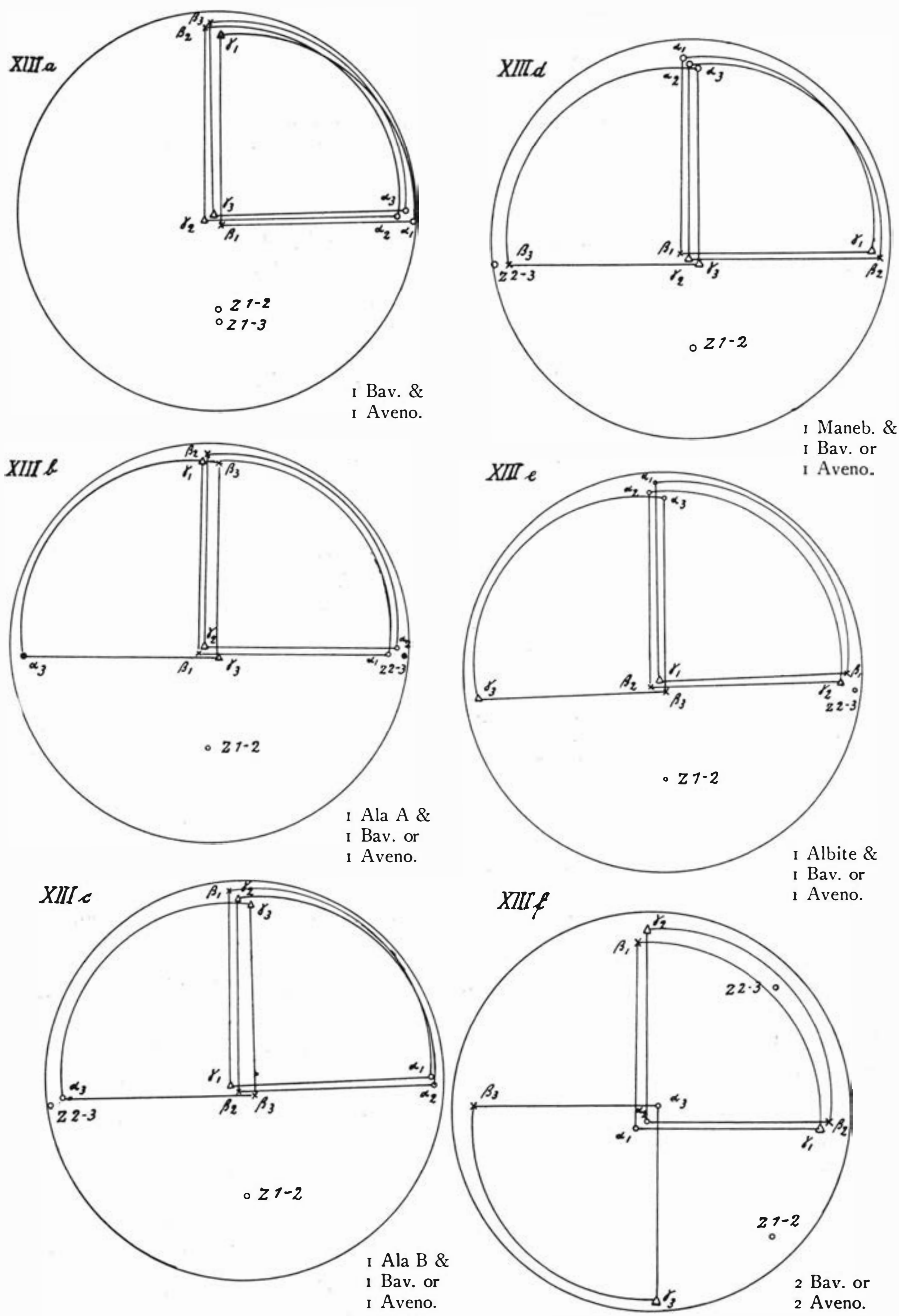

XIII a
1 Bav. &
1 Aveno.
XIII d
1 Maneb. &
1 Bav. or
1 Aveno.
XIII b
1 Ala A &
1 Bav. or
1 Aveno.
XIII e
1 Albite &
1 Bav. or
1 Aveno.
XIII c
1 Ala B &
1 Bav. or
1 Aveno.
XIII f
2 Bav. or
2 Aveno.

Fig. XIII.

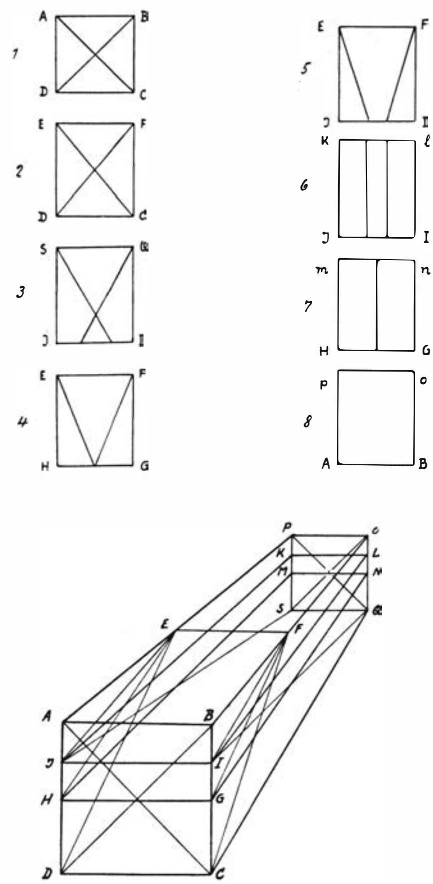


Fig. XIV. Sections showing different ways of cutting through a Baveno fourling.

9. Remarks on Pole-Diagrams of Baveno and Aveno Twin Elements

Baveno (including Aveno) twins are reported to have developed everywhere in different species of feldspars whether it is monoclinic or triclinic, ultrabasic or pure alkalic, but its frequency of occurrence is much reduced toward the anorthite end of the plagioclase family and is greatly increased toward the potassic end of the alkali feldspars. It is, thus, especially characteristic of adularias and low-temperature aplitic-pegmatitic feldspars (see KÖHLER 1948, p. 54 and 1949, p. 596, also IWASAKI 1899, pp. 157—158) as far as frequency of occurrence and morphological complexities are concerned, since Baveno and Aveno twins are growth twins which seem to prefer low-temperature formation. Among Baveno and Aveno twins, simple contact twinnings and high-order penetration twins are by far the most common. The former is the fundamental appearance while the latter is derived from the former by insertion or penetration growth of one primary unit into the

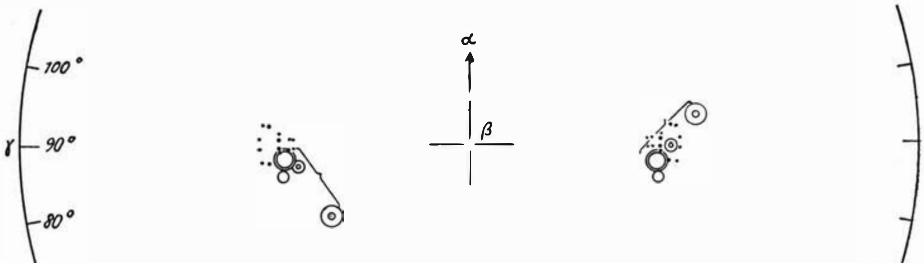


Fig. XVa. Poles of twin axes for Baveno & Aveno twins in alkali feldspars of the orthosite dyke, plotted against Nikitin's diagram, 1936. Slide no. 6564.

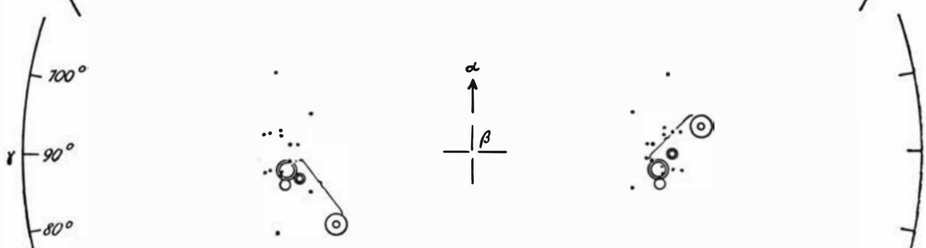


Fig. XVb. Poles of diagonal contact planes for Baveno & Aveno twins in alkali feldspars of the orthosite dyke, plotted against Nikitin's diagram, 1936. Slide no. 6564.

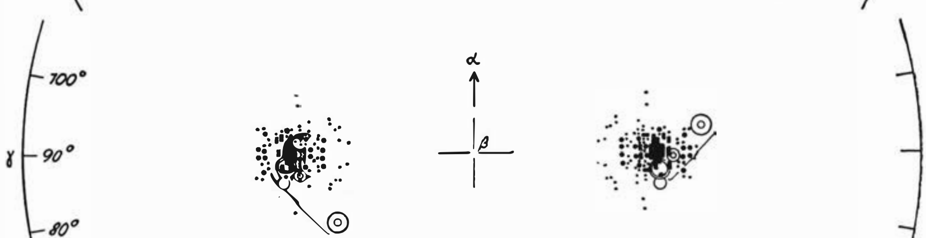


Fig. XVc. Poles of twin axes for Baveno & Aveno twins in alkali feldspars of the epidote-orthosite, plotted against Nikitin's diagram, 1936. Slide no. 6374.

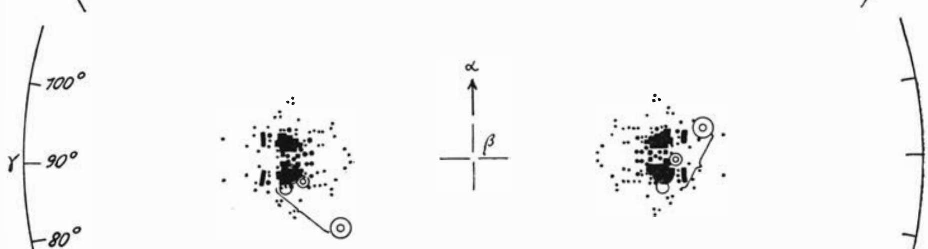


Fig. XVd. Poles of diagonal contact planes for Baveno and Aveno twins in alkali feldspars of the epidote-orthosite, plotted against Nikitin's diagram, 1936. Slide no. 6374.

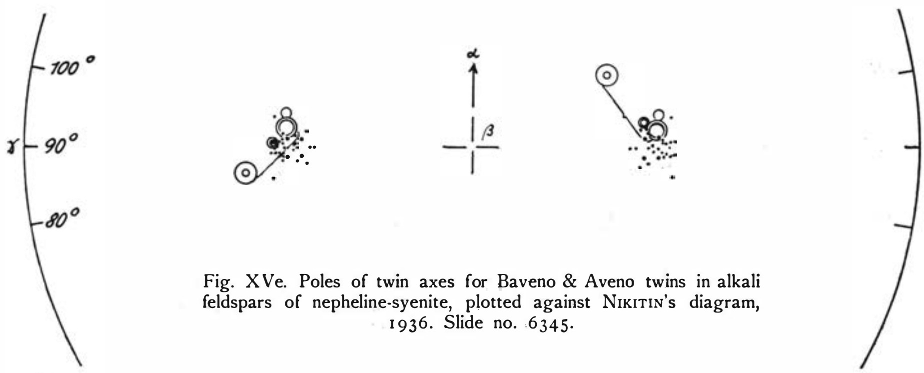


Fig. XVe. Poles of twin axes for Baveno & Aveno twins in alkali feldspars of nepheline-syenite, plotted against NIKITIN's diagram, 1936. Slide no. 6345.

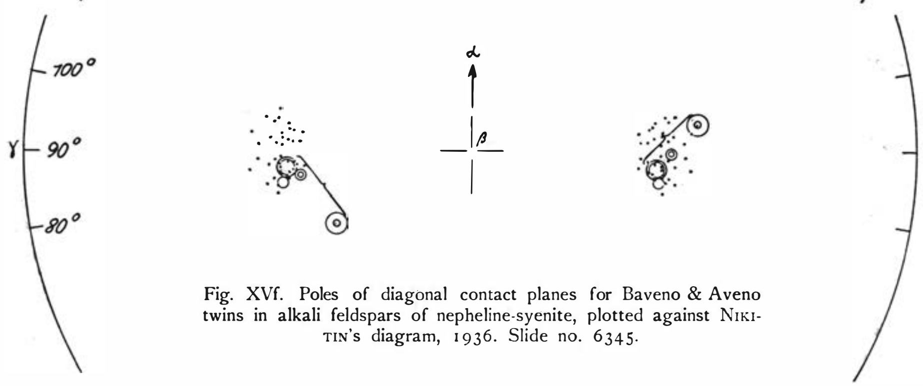


Fig. XVf. Poles of diagonal contact planes for Baveno & Aveno twins in alkali feldspars of nepheline-syenite, plotted against NIKITIN's diagram, 1936. Slide no. 6345.

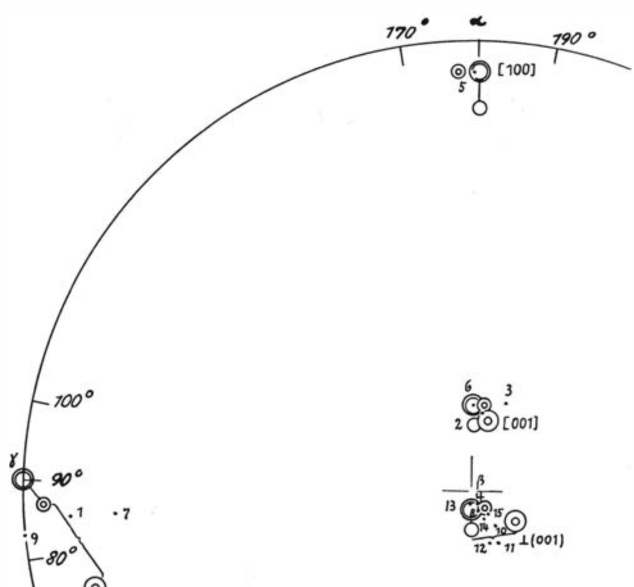


Fig. XVII. Poles of twin axes of Ala A, albite, Manebach & Carlsbad twins in alkali feldspars of the epidote-orthosite and nepheline-syenite, plotted against NIKITIN's diagram, 1936. Slide no. 6374 A & B and 6345 A, B & C.

other. Contact trillings and fourlings are uncommon among the ordinary orthoclases which are products of simultaneous crystallization, but may perhaps easily be found in adularias which enjoy especially a long duration of crystallization in sufficiently free space. Therefore one can say that the repeated growth of contact twinning is in reality nothing but result of the fargoing process of cyclic twin-growth proceeding in free space at low temperatures.

The drawing of a crystal model is given in Fig. XIV. Eight different figures can be obtained from one and the same crystal through different ways of cutting. It may mislead one to think that they represent separately a singling, a twinning and several independent types of trilling and fourling if we don't pay any attention to the outline of the crystal in section and the position of α, β and γ on the stereograms. By means of geometrical measurements twinned crystals can be recognised but they fail to disclose the interior of growth twins and sometimes cannot fix exactly the twinning law which is operating. Serial sections are therefore necessary, but in case there is no single crystal available, no distinguished type or growth stage should be established from the study of random sections unless it is definitely known that the section is cut more or less normal to the crystallographical a-axis and no part of the twinned crystal is excluded in the section due to random cutting.

All the poles of Baveno and Aveno twin axis and the poles of their diagonal contact planes are plotted against NIKITIN's diagram, 1936, as is given in Fig. XV a, b, c, d, e and f. It is seen that most or at least more than half of the poles fall outside the circular area of orthoclases.

In Tab. XV below, it is seen that in high-order Baveno and Aveno twin buildings the angle af obliquity varies between 0°—14°, the change of direction of twinning and composition planes between 0°—13° while the deviation of twin axes and diagonal contact planes may be up to 11° and 9° respectively from the 45° position. So it is no wonder that their plotted poles will fall outside the circular areas of orthoclase on NIKITIN's diagram. This tendency, as is pointed out in the preceding, is greatly increased with the raise of the order of twin formation. So far no statistic work has been done on the data included in this paper, but it is expected to come out in connection with the later papers treating the twinning problem.

In Tab. XV, (1, 2) indicate the (001) and (010) cleavages, N and $\bar{N}$ the twinning and composition plane of Baveno and Aveno twins, N' and $\bar{N}'$ being their respective deviations while Z, Z', $\bar{Z}$ and $\bar{Z}'$ represent the Baveno and Aveno twin axes with respect to these planes. The figures in the column of twin type represent the number of units included in the twinned crystal, whereas C and P are abbreviations of contact and penetration twins, respectively.

Table

Slide no.	Crystal no.	Twin type	(#1)/(#2)	$N/\bar{N}$	$N/\bar{N}'$	N/N'	$N'/\bar{N}$	$N'/\bar{N}'$	$\bar{N}/\bar{N}'$	N/(#1,2)
6345 A	5	4, C.	—	—	—	—	—	—	—	—
6345 C	1	4, P.	—	97	—	—	—	—	—	41, 42
6374 A	1	4, P.	89	93	—	—	—	—	—	48, 43
»	3	4, P.	88.5	93	91	—	—	—	2	46, 41
»	4	4, P.	—	89	86	—	—	—	4	47, —
»	5	5, P.	—	92	91.5	—	—	—	—	—
»	6	4 ([1])	91	89	—	—	—	—	—	46, 46
»	7	5, P.	—	90	—	—	—	—	—	—
»	9	6 ([2])	88	89	—	—	—	—	—	45, 44
»	10	4, P.	89	90	—	—	—	—	—	44, 47
»	11	6, P.	—	88	88	6	90	85	8	48, —
»	12	4, P.	87	88	89	3	88	91	4	42, 44
»	14	4 ([3])	86	90	88	9	80	84	4	51, 45
»	17	5, P.	91	90	90	—	—	—	5.5	45, 44
»	19	6, C–P.	—	88	—	—	—	—	—	47, —
«	22	4, P.	—	89	—	—	—	—	—	—
»	23	4, P.	88	93	82	—	—	—	11	47, 45
»	24	5 ([4])	92	90	—	—	—	—	—	44, 44
»	25	4, P.	90	88.5	—	—	—	—	—	43, 47
»	26	5, P.	90	92	—	—	—	—	—	44, 46
»	27	5, P.	90	85	85	—	—	—	12	47, 43
6374 B	1	5, P.	—	93	—	—	—	—	—	44, —
»	2	6, P.	—	90	—	—	—	—	—	37, —
»	5	8, C.	—	82	93	—	—	—	13	50, —
»	7	5, P.	—	—	—	—	—	—	—	—
»	8	4, P.	90	89	—	—	—	—	—	44, —

10. **Further Prospects: (001) and (010) Twins**

Independent twin structures with (001) or (010) as twinning or composition plane are very rare among the swarms of Baveno and Aveno twins. So far only 7 examples are noticed; none in the orthosite dyke, 1 in the epidote-orthosite and 6 in the nepheline-syenite. It seems to the author that the development of the tetragonal prism of the Baveno and Aveno twins prefers the light-colored orthosite rocks, which represent the last stage of crystallization, to the dense dark-colored nepheline-syenite. We shall see later that the Baveno and Aveno twin prisms disappear nearly altogether in the typical Nepheline-aegirine-syenite described by NORIN (1921, pp. 64—65), in which the nepheline and the aegirine constituents are so greatly

[1, 3, 4] The reduction of the total number of twin pairs according to the Baveno and Aveno law is due to the participation of Manebach twin structure in the edifice. See Fig. VI, X n, XI b and XII 2 l.

[2] The reduction of the Baveno twins is due to the participation of albite and Manebach twin structures. See Fig. VI, X j and XI a.

XV.

$N/(\#1,2)$	$N'/(\#1,2)$	$\bar{N}'/(\#1,2)$	$Z/[N]+Z'/[N']$	$\bar{Z}/\bar{N}+\bar{Z}'/\bar{N}'$	$Z, Z', \bar{Z}, \bar{Z}'/(\#1, 2)$
47, —	—	—	—	5, 5, 5, 5	47, –; 47, –; 47, –; 47, –
42, 41	—	—	3, 2	8, 3	41
45, 45	—	—	3, 7	4, 1	41, 50; 46, 45; 46, 45; 41, 50
41, 47	—	43, 46	4, 4	1, 3	45, 47; 48, 45; 47, 45; 45, 48
44, —	—	47, —	7, 2	4, 10	54, –; 49, –; 49, –; 54, –
—	—	—	7.5, 6	4, 3	—
46, 46	—	—	0	1	45, 46.5; 46, 45.5
—	—	—	2, 4	0, 8	—
45, 48	—	—	9, 9, 9, 5	0	43, 45; 53, 39; 53, 40; 40, 53
44, 44	—	—	3, 2	1, 2	46, 44; 44, 46; 45, 47; 46, 45
51, —	44, —	39, —	4.5, 3.5, 9	0, 3	48, –; 46, –; 54, –; 42, –; 46, –
44, 45	42, 44	40, 43	3, 1	6, 0	43, 44; 43, 44; 43, 44; 43, 44
49, 44	50, 37	47, 48	3	6	43, 44; 43, 44
45, 44	—	45, 47	4	0, 4	47, 42; 45, 44; 49, 41
45, —	—	—	4, 1	10, 2, 11, 1	50, –; 47, –; 47, –; 49, –; 46, –; 56, –
—	—	—	4, 3	1, 1	41, 46; 44, 45; 43, 45; 42, 44
47, 41	—	36, 52	2	12, 14	45, 47; 42, 50; 40, 52
47, 46	—	—	1, 0.5	—	43, 45; 45, 43
45, 45	—	—	2, 1	3, 2	49, 42; 48, 42.5; 47, 42; 48, 43
46, 46	—	—	6.5, 6	0, 0	50, 40; 46, 45; 46, 45; 50, 40
47, 41	—	48, 42	9, 5	4, 0	39, 52; 43, 47; 38, 52; 44, 48
42, —	—	—	7, 3	1, 2	49, –; 45, –; 49, –; 45, –
54, —	—	—	5, 2	4, 0	40, –; 36, –; 41, –; 36, –
46, —	—	—	6, 6, 10, 8	—	44, –; 44, –; 40, –; 40, –
—	—	—	2, 8	—	—
45, —	—	—	3, 2.5	3.5, 0	48, 43; 46, 44; 48, 42; 46, 45

increased and evenly distributed that the rock presents a dark brownish color. In the last-named rock, crystal tablets bound by well-developed (010) faces are always twinned according to the albite-Carlsbad law. CHAPMAN (1936) tried to find out the factors which control the distribution of different twin types in a differentiated sill, but didn't succeed to reach any definite conclusion. However, it is perhaps not impossible to find out some solution of this problem through a comprehensive study of the twin crystals in the present rock assemblage.

Of the 7 above-mentioned samples 3 are Carlsbad twins (Fig. XVI b, c and f), 2 are albite twins (Fig. XVI a and g), while 1 Ala A (Fig. XVI e) and 1 Manebach twin (Fig. XVI d) form the rest. Their optic data are given below in Tab. XVI a and b together with the data of those albite and Manebach twin structures superposing on Baveno and Aveno twins.

From Tab. XVI a it is seen that in simple albite, Carlsbad, Manebach and Ala A twins the optic axial angle ranges from 42°—48° forming an average of 44°. The intercleavage angle between (001) and (010) is in most

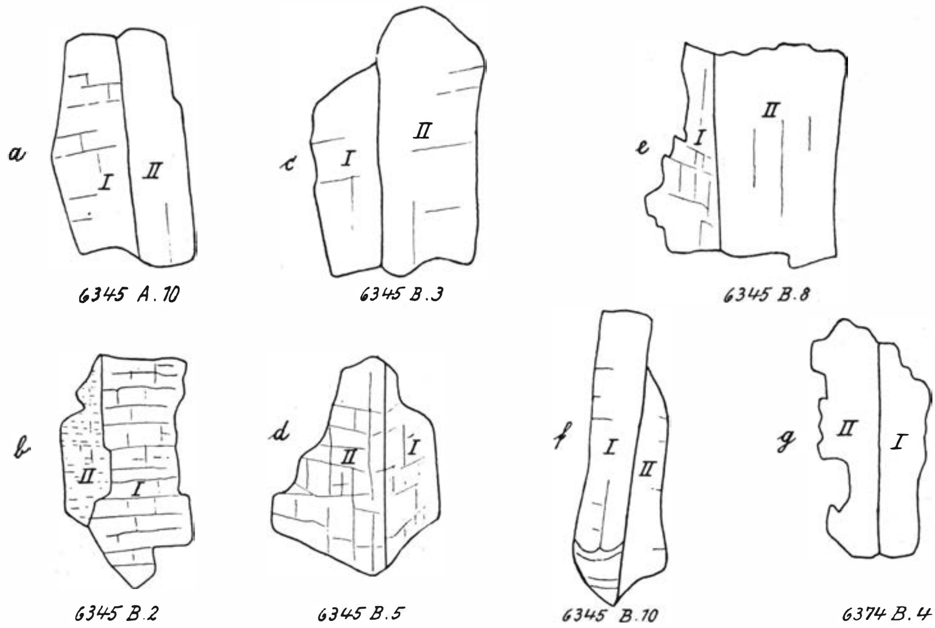


Fig. XVIII. (001 & (010) twins of alkali feldspars in epidote-orthosite & nepheline-syenite in the Ala A, albite, Manebach & Carlsbad law. Slide no. 6374 A & B and 6345 A, B & C.

cases 90°, but as is shown by the variation of extinctions, the same sort of relative displacement of the indicatrix has also taken place during twin building in such twins. The angle $\perp \gamma : \alpha/(001)$ varies within 1—5° but mostly around 5° while the other, $\perp \beta : \alpha/(010)$ lies between 0—6° with all transitional gradations. As to the occurrence of such twins as superposing or subordinate structure in Baveno and Aveno twins, much broader range of variation is observed (Fig. XVI b), being 38—48° for the optic axial angle, 86—92° for the intercleavage angle and 0—9.5° and 0.5—2° for both extinctions in simple fourlings but amounting to 0—20° and 0—25° in the highly complex twin growth exemplified by crystal 6374 A. 9 (Fig. VI, see also Fig. X j, cf. also Tab. XII and XIV). In the last-named example, (001) cleavage is found in unit I but both (001) and (010) cleavages are developed in unit III, with respect to them the both extinctions are all very reasonable. However, based on the assumption that in Baveno and Aveno twins all the corresponding faces of (001) and (010) are parallel or nearly parallel, we can assume that the cleavages of units I and III do extend into other units without any remarkable change in direction. In this way we get all possible extinctions for other units, which seem at first sight to be quite intolerable if we don't see how great the variation of extinctions can be in triclinic adularias. According to GRANDJEAN (1910, pp. 96—97) the extinction on (010) varies between 5—10° while the extinction on (001)

Table XVI a. Independent (001) and (010) Twins.

Slide no.	Crystal no.	Twin type	Twin unit	$\perp\gamma:\alpha/(001)$	$\perp\beta:\alpha/(010)$	$2V_\alpha$	Cleavage (001)/(010)	a/α
6345 A	10	albite	I	4°	6°	44°	90°	6°
			II	—	4	—	—	—
» B	2	Carlsbad	I	5	1.5	48	86	5
			II	5	0.5	46	89	5
»	3	Carlsbad	I	5	2	42	90	5
			II	1	3	44	90	4
»	5	Manebach	I	4	—	—	—	—
			II	4	—	—	—	—
»	8	Ala A	I	5	—	—	—	—
			II	3	—	—	—	—
»	10	Carlsbad	I	5	0	42	90	5
			II	5	0	42	90	5
6374 B	4	albite	I	—	—	—	—	—
			II	—	—	—	—	—

Table XVI b. Superposing (001) and (010) Twins.

Slide no.	Crystal no.	Twin type	Twin unit	$\perp\gamma:\alpha/(001)$	$\perp\beta:\alpha/(010)$	$2V_\alpha$	(001)/(010)	a/α
6374 A	6	Manebach	II	7°	0.5°	42°	91°	7°
			IV	3	1	48	91	5
»	9	albite	I	9	14	44	88	16
			II	9	1	48	88	9
»	»	Manebach	I	9	14	44	88	16
			IV	10	11	42	88	16
»	»	Manebach	I	9	14	44	88	16
			V	17	12	42	88	22
»	»	Manebach	III	6	0	38	88	6
			VI	20	25	40	88	21
»	14	Manebach	I	0	1	48	86	2
			III	9.5	2	44	86	10
»	24	Manebach	I	7	1	46	92	6
			III	6	1	46	92	5
»	»	Manebach	I	7	1	46	92	6
			V	3	1	48	92	4

can be as high as 20°. CHAISSON (1950, pp. 538 and 546) also mentioned that the optic deviation of triclinic adularia from the monoclinic symmetry may amount to 15.5° in terms of the angle. In our case, though the both extinctions may amount to 20 and 25°, the average is only about 12 and 10.5° respectively. However, since they differ so much in magnitude in different units (Tab. XVI b), it goes without saying that the arrangement of indicatrix in such units is necessarily asymmetrical with respect to (001)

Table

Plot no.	Slide no.	Crys-tal no.	Twin type	Twin-ned units	Z/(001)	Z/(010)	Z/a	CP/(001)	CP/(010)	$(001)_1/(001)_2$
1	6345 A	10	albite	I	78°	11°	91°	92°	5°	—
				II	—	—	—			
2	6345 B	2	Carlsbad	I	23	94	66	90	3.5	133
				II	23	89	66	91	2	
3	6345 B	3	Carlsbad	I	20	84	63	90	0	130
				II	22	84	69	90	0	
4	6345 B	5	Manebach	I	3	—	—	0	—	0
				II	3	—	—	0	—	
5	6345 B	8	Ala A	I	89	—	—	6	—	0
				II	89	—	—	6	—	
6	6345 B	10	Carlsbad	I	27	90	63	90	0	127
				II	27	90	63	90	0	
7	6374 B	4	albite	I	—	—	—	—	—	—
				II			—	—	—	
8	6374 A	6	Manebach	II	2	89	91	0	89	0
				IV	2	89	91	0	89	
9	6374 A	9	albite	I	89	8	96	93	4.5	0
				II	89	8	96	93	4.5	
10	6374 A	9	Manebach	I	4	92	88	—	—	0
				VI	4	92	88	—	—	
11	6374 A	9	Manebach	I	9	91	85	—	—	0
				V	9	91	85	—	—	
12	6374 A	9	Manebach	III	8	90	97	—	—	0
				VI	8	90	97	—	—	
13	6374 A	14	Manebach	I	6	91	86	2	88	0
				III	6	91	86	2	88	
14	6374 A	24	Manebach	I	2	90	90	—	—	0
				III	2	90	90	—	— (1)	
15	6374 A	24	Manebach	I	2	90	88	90	9	0
				V	2	90	88	90	9 (2)	

and (010) planes and accordingly neither true Manebach nor true albite twins can be expected. This is best illustrated by the position of the poles of the concerned twin axes plotted against NIKITIN's diagram (1936), on which most of them lie quite outside the limitation of the area for the concerned twin types (Fig. XVII 1, 3, 7, 9, 10, 11, 12 and 14).

The optic data of the treated (001) and (010) twins are given in Tab. XVII in the order they are plotted while in Tab. XVIII all the data are summarized in groups in order to show how much such twin structures may deviate from the theoretical requirements. In both tables *CP* represents the abbreviation of the contact plane. In Tab. XVII one can see that in one and the same crystal the respective coordinates for the pole of the contact plane with respect to α, β and γ are different in the two twinned

XVII.

$(010)_1/(010)_2$	$Z/[CP]$	Z/α	Z/β	Z/γ	$[CP]/\alpha$	$[CP]/\beta$	$[CP]/\gamma$	$[CP]/\alpha$	$[CP]/\beta$	$[CP]/\gamma$
								average value		
0°	11.5°	85°	83.5°	8°	91°	87°	4°	89.5°	80.5°	10°
					90	74	16			
6	90	71	19	88	92	93	4	89	87.5	3.5
					90	92	3			
0	84	68	23	83	91	90	2	88	83	8
					93	76	14			
—	3	86	4.5	88	94	90	4	86	88	5
					86	86	6			
—	91	4.5	86	88	86	6	88	86.5	6	87
					87	6	86			
—	90	68	22	90	90	90	0	90	90	0
					90	90	0			
—	8	85	77	14	86	69	21.5	85	77	15.2
					96	95	9			
0	2	84.5	6	88	83	6	85	84	5.2	87.5
					85	4.5	90			
0	4	83	90	7	81	94	10	83.5	86	8
					94	94	6			
0	—	81	11	84	—	—	—			
					—	—	—			
0	—	77	15	97	—	—	—			
					—	—	—			
0	—	77	14	85						
0	4	86	4.5	90	92	2	89	81.5	5	89
					81	8	89			
0	—	96	7 93		—	—	—	—	—	—
		84	7 87		—	—	—			
0	99	95	6 94		91	96	6	91.5	85	6
		85	6 86		92	86	6			

units and their average is in most cases not equal to the corresponding coordinates for the pole of the twinning axis or the pole of the composition plane. In such cases an angle of obliquity (Tab. XVIII) always exists and the contact plane is always an apparent twinning or composition plane. One can also easily see, by calculating the angular relations between *Z*, *CP*, (001) and (010) planes from the data given in Tab. XV, that the poles of any three of the four lie very seldom on one and the same great circle or in one and the same crystallographic zone.

BARTH (1928, pp. 473—474) reported twinning on the acline law in triclinic adularia, now we have a simple twinning on the Ala A law in the triclinic variety of orthoclase (Fig. XVI e), the twin axis of which lies precisely within the circular area representing poles of *a*-axis of orthoclase

Table XVIII.

Twin type	$Z/(001)$	$Z/(010)$	Z/a	$CP/(001)$	$CP/(010)$	$(001)_1/(001)_2$ $(010)_1/(010)_2$	angle of obliquity
Manebach	2–9°	88–90°	85–90°	0–2°	88–89°	0°	2–4°
Ala A	89	—	—	6	—	—	1
albite	78–89	8–11	84–89	88	4.5–5	0	4–11.5
Carlsbad	1–4	84–90	63–69	89–90	0–3.5	0–6	0–6

(Fig. XVII 5). The lamellar albite and pericline twinning as well as the microcline-like cross-hatching reported by a number of authors in triclinic adularias is not observed, but 1 superposing and 2 simple albite twinnings (Fig. XVII 1, 9 and 7) are recorded. Simple albite twins were reported by CHAISSON (1950, pp. 543—545) in adularias from Vesuvius of Italy and Guanajuato of Mexico, but the contact plane is (100) instead of (010). In orthoclases it has been reported by VIGIER (1909, pp. 165—168) from Issoire and GONNARD (1883 and 1911, pp. 53—55, Fig. 3) from Baveno and Four-la-Brouque (Puy-de-Dôme), the contact planes are in all cases (010). Carlsbad twins with more than 2 units recorded by FRIES (1939, p. 787), EMMONS and GATES (1943, p. 298), BARTH (1944, p. 88), OFTEDAHL (1948, pp. 38—39) and SØRENSEN (1950, p. 524) are not observed in the treated Shansi rocks. Of the 3 Carlsbad twinnings (Fig. XVII 2, 3 and 6), 2 have their twin axis lying within the orthoclase circle but 1 falls outside. As to Manebach twins, the twin axes of those independent twinned pairs lie quite inside the orthoclase circle (Fig. XVII 4, 8 and 13), but those of the superposing twin structures fall mostly outside (Fig. XVII 10, 11, 12, 14 and 15).

By the way it should be pointed out that the simple Ala A and the simple Manebach twinnings (Fig. XVI e and d) may be, not independent twins, but part of a Baveno or Aveno trilling or fourling, if we consider that the section is cut exactly through the center of the crystal parallel to (001) or (010) so as to include the intersecting line of the two n (021) faces (cf. Fig. XIV 7). Then the stereographical projection of the trilling or fourling will be like that shown by Fig. XIII b and d or Fig. XII 2 n and l. The argument is strengthened by the fact that the section of the crystal is rectangular in one and rhombic in the other and in both cases poles of α lie very near the margin of the diagram (Fig. XVIII a and b).

11. Combination of (001) & (010) Twins with (021) Twins

Fig. XVIII a, b and c are stereographical projections of simplepaired Ala A, Manebach and albite twins respectively. Comparing these with Fig. XVIII d or those stereograms in Fig. XII and XIII, one can easily see that twin structures like these are possible to superpose on, or combine with, Baveno and Aveno twin structures. In such combined structures the three principal optic directions in different units are more or less parallel to one another, that is to say, the indicatrix of one unit is so oriented that their axes make only extremely low angles with those of the other. It is this low-angled deviation which makes the combination possible, since it is easily fulfilled. Should it happen at the very beginning of twin growth that the arriving molecules or atoms from a certain direction oriented themselves in the Baveno and Aveno twin edifice in such a slightly displaced position that the requirement of the low-angled deviation is fulfilled, there would be present a superposing twin structure on the Ala A, Ala B, the Manebach or the albite law in accordance with the adjustment of the indicatrix.

However, it should be pointed out that the so-called superposing structure is in reality a replacing structure, since it occupies part of the space of the Baveno and Aveno twin edifice which now can no longer keep its integrity or uniformity. That is why the total number of Baveno and Aveno twin-pairs will be reduced when such exotic structures are present in the trillings or fourlings in question. However, where all the local factors are favorable for the development of *n* (021) faces and (021) twins, it is unnatural that the whole Baveno and Aveno twin edifice will be entirely replaced by the exotic twin structure and changed into quite another type of twin. This explains why in trillings and fourlings, where both diagonal contact planes are equally developed, there is always at least one plane which functions as a twinning or composition plane on the Baveno or Aveno law. The other diagonal contact plane, which is often relatively ill-developed, irregular and deviating more from the true diagonal position, is converted into a mere contact plane through the presence or introduction of the exotic structure. (See, e.g., GYSIN 1948, pp. 241—242, Fig. 1.)

MIERS (1929, pp. 515—516) found it difficult to say which law is operating in the much discussed fourlings and suggested that one must be extremely careful in order to be able to distinguish whether it is a Baveno quartet or an interpenetration of 2 Manebach twins *perched on n* (021) *planes*.[1] It is quite unlikely that in Baveno twins the Baveno twin structure should disappear altogether and the whole thing be converted into a pair of intercrossing Manebach twins without yet developing any (001) faces as twinning planes but perching on diagonal contact planes which are characteristic of Baveno or Aveno twin structures. There might be exceptions, but exceptions are rare. In Fig. XVIII e, the stereographic projection of a Carlsbad twin is given, in which the two α normally make about 42° angle with each other. Comparing Fig. XVIII e with Fig. XVIII d and the stereograms in Fig. XII 2 and XIII, it is easily seen that the Carlsbad twin structure cannot be superposed on Baveno or Aveno twin structures

[1] The italics are put in by the present author, it reads in original "twinned together on the Baveno law" which cannot be the case as was pointed out in the preceding.

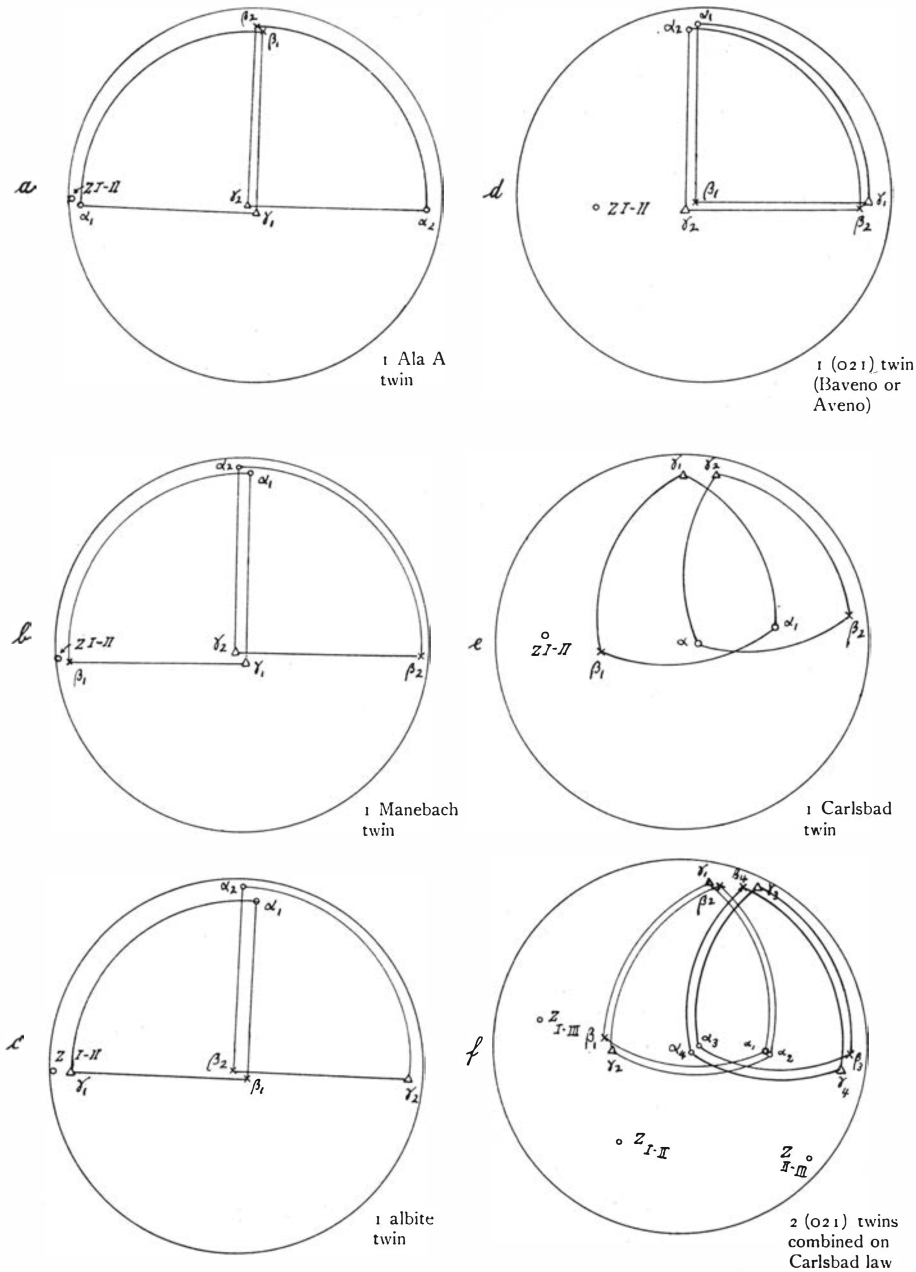


Fig. XVIII. Stereographical projections showing some simple (001) & (010) twin types and their combination with the (021) twins.

like the Ala, the albite or the Manebach twins in order to build up the rectangular or columnar prisms of trillings or fourlings. The combination of Carlsbad and Baveno or Aveno twins is not impossible, but the configuration will then be quite otherwise (see VIGIER 1909, pp. 163—165, Fig. 11) and the stereogram will be like that shown by Fig. XVIII f.

III. Conclusions on the Orthoclase Optics

In conclusion it can be said from the optic study of the Shansi alkali feldspars that a triclinic variety is present among the ordinary orthoclase just as is the case with adularias. Under a combined optic and X-ray study, LAVES (1950, p. 562) together with CHAISSON (1950, p. 589) succeeded to prove that triclinic adularia does exist as a distinct mineral species or subspecies, and its 'triclinity' is lower than microcline, which in turn has lower 'triclinity' than the low- and high-temperature albites, while the high-temperature albite possesses the highest 'triclinity' among them all. However, no such investigations have been made in ordinary orthoclase.

TAYLOR, DARBYSHIRE and STRUNZ (1943, p. 494) and CHAISSON (1950, p. 546) pointed out that optic examinations are much more sensitive than X-ray examination to a change in symmetry as well as to small distorting forces. Extremely small structural differences which cannot be easily detected by X-ray investigations may cause striking changes in the shape and orientation of the indicatrix within the crystal. If we accept that α of the indicatrix emerges on the (010) trace in monoclinic alkali feldspars and deviates from it in triclinic ones, we must admit that the structure of the ordinary orthoclase is not very stable and therefore easy to be deformed through twin formation or else so as to become triclinic, though the 'triclinity' it possesses by then may be very low and approximates nevertheless very closely to the monoclinic symmetry. The alkali feldspars in the orthosites are high-potash ordinary orthoclase, but they show repeatedly oblique extinction on (001) and are twinned on several occasions according to the albite law. The feldspars in the nepheline-syenite, which are optically almost identical, exhibit similar inclined extinctions and are twinned in cases on the albite and the Ala A law. It is evident that within the crystal the indicatrix in different twinned units has been so displaced that the (010) plane is no longer a symmetry plane optically, otherwise such triclinic twins cannot be formed and the poles of a number of monoclinic twin-axes won't fall in the microcline or anorthoclase areas on NIKITIN's diagram (1936).

By crystal habit, structure and mode of occurrence, anorthoclase can be easily distinguished from the orthoclase which shows triclinic optics, but optically and chemically there seems to be no sharp boundary between the two. The extinction of orthoclase on (001) is inclined in the triclinic variety while those alkali feldspars chemically referable to anorthoclase may exhibit straight extinction (SPENCER 1937), and both may have almost identical values in $2V$, $N_m - N_p$, $N_g - N_m$ and $N_g - N_p$. It is true that in general the refractive indices of anorthoclase are much higher than that of orthoclase, but the entrance of celsian molecules into orthoclase can raise the indices to a considerable degree. The interstial potash-feldspars in a syenite treated by DOLAR-MANTUANI (1931) show also oblique extinction on (001) and may perhaps belong also to the triclinic variety of orthoclase. According to BIELIANKIN (DOLAR-MANTUANI 1931, pp. 305), they contain also some 2 % of celsian, but the soda-content is higher.

On the other hand the triclinic variety of orthoclase can easily be distinguished from microcline by the absence of cross-hatching twinnings and the magnitude of extinctions on (001) and (010). Microcline represents a rather stable structure and never shows such variation of extinctions like the triclinic variety of adularia and ordinary orthoclase. Adularias are distinguished from the ordinary orthoclase chiefly by crystal habit and mode of occurrence. Optically our orthoclase showing triclinic optics can be distinguished from the triclinic adularia by the position of the optic axial plane, which is in no case converted into the symmetry plane. It seems to the present author that the triclinic variety of ordinary orthoclase may possess a structure very similar to, if not identical with, that of the triclinic adularia. The high frequency of Manebach twins participating in Baveno and Aveno twin building, the variation of both extinctions and the refractive indices speak altogether for this argument. Though the optic axial plane of our orthoclase is not yet converted into the symmetry plane, but there is already a tendency for β drawing near to γ. Its triclinity is certainly much lower than that of microcline and it is not improbable that it is even lower than, if not identical with, that of the triclinic adularia.

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