THE FELDSPAR IN THE INTRUSIVE ROCKS NEAR BEAVERDELL, B. C.

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Contents

Abstract

The plagioclase and especially the potash-feldspar in the intrusive rocks near Beaverdell, B. C., were studied in considerable detail as an example for some general views on the feldspar as rock-forming minerals. General information on the Fedorov-Universal-Stage-Method as used by Nikitin is added.

Introduction

According to Reinecke (1915) two groups of intrusive rocks occur near Beaverdell, British Columbia. One is the Westkettle batholith which forms the western slope of Wallace Mountain, the second is the Beaverdell stock which intrudes the Westkettle batholith near Beaverdell. Recently W. H. White (1950) studied the silver deposits of the Beaverdell mining camp. During the preparation of his report, he asked me to determine the feldspars in a few specimens.

Although the number of thin sections examined is very small (5 thin sections of Westkettle rocks and 7 of Beaverdell rocks), data of the feldspars obtained by the Fedorov method seem to be interesting and worth publication.

GENERAL INFORMATION ON THE ROCKS

Figure 1 made by W. H. White shows the location of rock samples described in this paper. It should be noted that the Highland Lass mine which on the map appears to be in the metamorphosed sediments and volcanic rocks of the Wallace group actually are in the underlying Westkettle rocks.

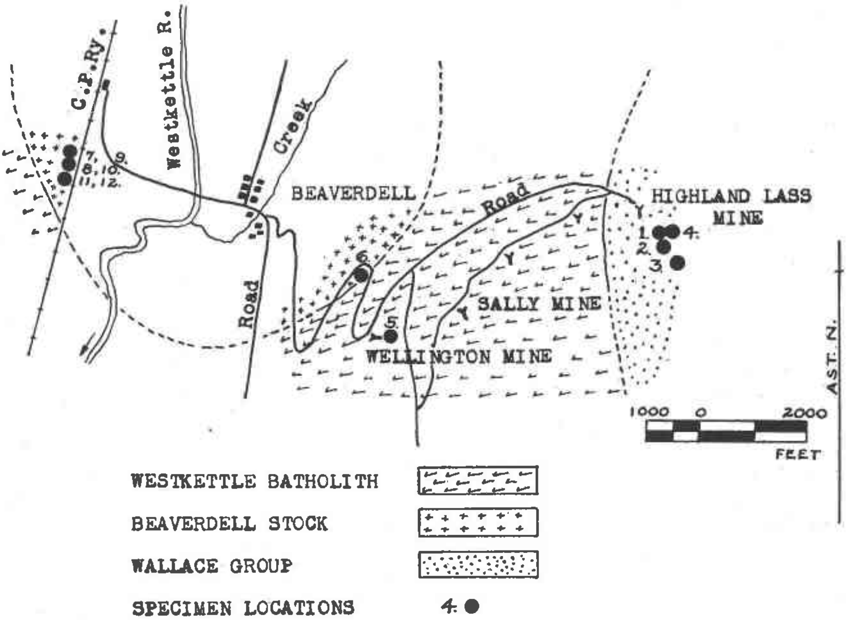

FIG. 1. The Beaverdell Silver Camp.

The following paragraph gives the classification of the samples according to Johannsen. For additional details the reader is referred to the above mentioned publication.

Thin sections No. 1, 2, and 3 represent the average quartz monzonite from the Highland Lass mine in the Westkettle rocks. Sample No. 5 is an albitic quartz monzonite from the Wellington mine, and sample No. 4 a leucocratic (albitic) quartz monzonite from the Highland Lass mine where it forms irregular tabular bodies and may represent segregations of more acid material or metasomatic alteration of the original quartz monzonite.

The other thin sections are made of mainly porphyritic rocks from the Beaverdell stock. Thin sections No. 6, 7, and 8 represent the groundmass, thin sections No. 9 and 10 the phenocrysts of specimens No. 7 and 8 respectively. Specimen No. 6 is taken right from the border, the other two from a more internal part of the stock. The groundmass of these three samples is granodioritic; No. 6 is an almost leucocratic, No. 7 an albitic, and No. 8 an albitic and almost leucocratic porphyritic granodiorite. But all three samples are very close to the respective variations of quartz monzonites if also the amount of phenocrysts (about 10 per cent) is considered.

Thin sections No. 11 and 12 are still more leucocratic rock which occurs in small irregularly tabular bodies having gradational contact with the normal Beaverdell rock. As this sample is not described in the publication mentioned, a short description may be added. The rock is generally fine-grained in contrast to the other medium- to coarse-grained samples of the stock. It shows a very typical granophyric intergrowth of quartz with plagioclase and potash-feldspar, which could develop as result of some sort of replacement or synantetic process (H. Backlund, written communication). The constituents are: quartz 33.0%, plagioclase 36.3%, K-feldspar 29.3%, and magnesium-iron minerals (magnetite, epidote, chlorite) 1.4%. The specimen is a leucocratic (albitic) quartz monzonite. The ratio of plagioclase to K-feldspar cited above is only approximate, and the non-granophyric parts suggest that, on the contrary, K-feldspar prevails over plagioclase. Even so, the rock would be classed as a quartz monzonite as the limits for this quartz monzonite are 42% K-feldspar and 23% plagioclase. The measured percentage of constituents and the composition of the plagioclase show a very close relationship to the leucocratic Westkettle rock (No. 4 of the Highland Lass mine).

For the determination of the constituents, especially the feldspar, the Fedorov method was used in its classical application as given by my teacher, the late Prof. V. V. Nikitin. Because of some deviations and modifications of the Fedorov method found in the literature of the last years a few notes are included on the details of some determinations and the recording of the observed data as used by Nikitin who was connected with the Fedorov method from its beginning in 1893 till his death in 1942.

General Notes about the Fedorov Method

The Fedorov or the Universal-Stage method is the basic method which gives exact data on both the composition and the crystallographic habit of feldspar in thin sections of rocks. As the habit of feldspar seems to become more and more important in petrologic studies (cf. Koehler, 1949, p. 597 and Tuttle & Bowen, 1950, p. 583) their crystallographic elements should be studied carefully. In this connection some details of the work, especially with the feldspar, have to be explained.

As is generally known in using the Fedorov method, the position of the three symmetry axes of the optical indicatrix in a twinned grain are determined together with the twin axis (which is deduced from the position of X, Y, and Z in both subindividuals) with the greatest accuracy. In addition it is always desirable to try to determine as exactly as possible the position of other crystallographic elements. As the measurements of the crystallographic elements are generally less sensitive than those of the indicatrix axes, the tilting angle should be read at least four times on Wright's folding arcs for the S–N axis, using a Leitz universal stage or a stage of a similar type. The crystallographic elements do not only supply additional data for determination of the composition of the plagioclases but may also be of essential use in deciding which curve, and in special cases, which part of a curve of the standard diagram should be used (e.g. for the albite twinning of the alcalic plagioclases; cf. Turner, 1937, p. 396). In the case of K-feldspar they may offer the only criterion for the kind of K-feldspar present in thin sections of rocks. But it is important to realize that in the presence of the sanidine optics with the optic plane parallel to (010) (sanidine, some adularia; Chaisson, 1950, p. 546) the coordinates of the crystallographic elements change entirely from those which are found in some classical books and diagrams (e.g. Nikitin, 1936). In these cases even the identification of (010) or (001) may be difficult. Also the angles between all crystallographic elements should be established from the observation diagram because they have to be regarded together with the coordinates of the elements for selection of the curves and poles in the standard diagram.

Thus in the present study the optic axial angles were read at least four times. The position of the emergence of the optic axis was determined using the gypsum plate. The sensitive tint was always tested by noting the colour produced by it at holes in the rock section to allow for possible anisotropism of the glass slide.

Using the findings of Nikitin (1936, p. 14) the set of hemispheres with $n=1.516$ and a liquid with $n=1.52$ was used not only for examination of feldspars but also hornblende. (The second set of hemispheres at my disposal had $n=1.649$.) In this way I had a set with following refractive indices: lower hemisphere $n=1.516$, liquid $n=1.52$, glass plate $n=1.51$–1.53 (Nikitin, 1936, p. 14), liquid $n=1.52$, slide $n=1.51$–1.53, Canada balsam $n=1.54\pm0.01$ (Winchell, 1951, p. 333), mineral?, Canada balsam $n=1.54\pm0.01$, cover glass $n=1.51$–1.53, liquid $n=1.52$, upper hemisphere $n=1.516$. The difference between the inevitable refractive indices as enumerated and that of the hemispheres with $n=1.516$ is 0.006–0.034, that with $n=1.55$ (not available to writer) is 0.000–0.040, and that with $n=1.649$ is 0.099–0.139.

For accuracy and speed the construction of the microscope and universal stage is important in every detail. During the practice with the Fedorov method the writer had occasion to work with the theodolite microscopes of C. Leiss and R. Fuess of Steglitz, near Berlin over a period of 15 years and with the universal stage-microscope of E. Leitz, Wetzlar for two years. She found the first two models corrected according to the suggestions of Nikitin to be the most suitable ones.

Determination of the Feldspar by the Fedorov Method

The migration curves for low-temperature plagioclase. For the determination of the crystallographic elements of the feldspar and the plagioclase composition, Nikitin's standard diagram (1936, Table VII) was used. Many workers prefer Nikitin's curves for determination of low-temperature plagioclase. In this connection, Larsson (1940) states that the position of the poles of plagioclases from the Nygård-pluton and the W. Swedish hyperites correspond best with Nikitin's curves for ⊥(010), ⊥(001) and the rhombic section:

"Nikitin's curve (for ⊥(010)) in the majority of cases seems to answer most closely to the conditions and is, therefore, to be given preference. Also the calibration of the curve by Nikitin is likely to be the most reliable one, as it is based upon more abundant and modern sources of measurements and analyses" (p. 366).

In agreement with this Lundegårdh (1941) uses Nikitin's curves for the bytownite from the anorthosite and states that the three curves mentioned correspond best for the basic plagioclases of intrusives (1941, p. 429). But Barth & Oftedahl state "The most complete curves are those of Duparc and Reinhard and used by Winchell in his Optical Mineralogy" (1947). It seems, however, that they refer to the plagioclase curves from 1924. Nikitin's three publications in the years 1926, 1929, and 1933 (the first two in Russian, the third in German) deal with corrections of the plagioclase curves based on determinations with the Fedorov method and partly new chemical analyses (Nikitin, 1936, p. 8).

On the other hand the following statement of Kaaden cannot be accepted: "It is only logical that Nikitin (1936) used average values (for low and high temperature plagioclases) for the construction of his determination curves" (1951, p. 11). From the cursory control of Nikitin's coordinates of 14 main faces and twin axes for An_0 and An_{100} with the analogous coordinates for low and high temperature plagioclases as listed by the same author (p. 20), it follows that only two-thirds of the 24 poles of Nikitin lie closer to the high temperature poles than those listed by Kaaden as standard low temperature poles of plagioclases of the same composition. Generally the distance of Nikitin's poles to the other low temperature poles is much smaller than to the high temperature poles. Only in four cases did the former distance exceed the latter and the poles lie almost within the range of determinative errors. This shows, furthermore, that the work on the correction of curves for the determination of the composition of plagioclases has to be continued.

The main constituents of the rocks near Beaverdell are feldspars. Plagioclase and potash-feldspar are found in all sections regardless of the amount of mafics. The plagioclase grains are subhedral, those of potash-feldspar are always anhedral. A strong replacement of plagioclase by potash-feldspar and both by quartz is visible in the Westkettle rocks, and to a much smaller extent in the groundmass of the average rocks from the Beaverdell stock.

Many of the potash feldspar show perthitic structure. Although some grains, especially those of plagioclase, are heavily altered a sufficient number of grains occurs in every thin section to permit the determination of the feldspar by the Fedorov method.

Recording the data. The general symbols for the crystallographic elements are:

B—the twin axis,
D—the composition plane,
L—the twin lamellae,
S—the cleavage plane,
K—the outline face,
RS—the rhombic section,
I—the plane of regular (dusty) inclusions,
j—the core,
s—the middle part,
p—the border zone of a zoned subindividual of a twin or of an untwinned grain.

In the tables the data are arranged in columns as follows:

1. The number for reference of the particular grain in the thin section.

2. The symbol of the crystallographic element (e.g. B, D etc.). Some symbols have a number or a letter as a suffix. The number indicates to which subindividual (e.g. twin lamella) of the grain the element belongs, the letter to which zone in a zoned plagioclase. The exact crystallographic habit is easily understood from the tables for every grain examined; e.g. in grain No. 3 thin section No. 1. The composition face (D) is developed parallel to the twin lamellae (L) in both subindividuals. Beside this a second set of twin lamellae (L′) occurs to which the cleavage face (S) is parallel but visible only in the second subindividual; etc.

3. The coordinates of the crystallographic element, i.e. the values of angles between the element and the axes X, Y and Z. It is important to use a comparative standard diagram which takes into account all three angles to X, Y, and Z because only all three coordinates define the exact position of the pole in the standard diagram and control the accuracy of the work at the same time.

4. The crystallographic symbol of the element.

5. The composition in percentage of anorthite in plagioclase, or the kind of potash-feldspar.

6. The distance and the direction of the determined pole to the migration curve or the pole in the standard diagram. This distance shows the exactness of the determination, it indicates perhaps certain characteristics in the development of the feldspar in the rock, and it may offer a help in the determination of the average composition of a grain when it becomes evident that the more distant poles should be omitted.

7. The angles between the different crystallographic elements.

8. The value of the optic angles. Figures in italics indicate angles determined by the visible emergence of *both* optic axes, giving such numbers the weight two in calculation of any average.

9. The average composition of the grain. The average composition of a plagioclase grain is calculated from the different crystallographic elements in the following way: The values which ıesult from the twin axes are taken into consideration four times; those of the composition face (if it is given for two subindividuals together in the less exact measurements) twice, and of the remaining elements once for every subindividual. The twin axes of zoned grains are naturally not used for determination of the composition as they give only the mean value of both subindividuals which are used for the determination of the twin law.

At this point the need of publication of the coordinates should be emphasized because they are directly obtained from the plotting diagram and preserve their values regardless of the eventual changes in the comparative curves of the standard diagrams. A certain change of the comparative curves is not only to be expected for the high temperature plagioclases (Koehler, 1949, p. 595) but also to a much smaller degree for the low temperature plagioclases. On the other hand the publication of extensive data offers the possibility of evaluating the conclusions and of continuing the research in related fields on the basis of work done by others.

Finally it is to be noted that for the determination of feldspar the thin sections should not be too thin. A thickness of 0.03 to 0.04 mm. is desirable. In special cases of exact determination of the crystallographic elements, especially of the potash-feldspar with their low refractive indices and birefringence, still thicker thin sections should be used. If the thin sections are not covered so that the cleavage fissures are partly filled with air, a still greater accuracy in the determination of cleavage faces is obtained (Dolar-Mantuani, 1931). But in addition normal thin sections should be made to prevent the fine twinning structure in the triclinic potash-feldspar becoming invisible.

Notes about particularities of grains are given at the end of the data for every thin section. They explain many conclusions which are made in the last two sections.

TABLE 1. DETAILED DATA ON FELDSPAR FROM THE WESTKETTLE ROCKS
Thin section No. 1

1	2	3			4	5. An %	6		7. L∧S	8. 2V	9. An %
					Plagioclase						
1	L	14°	83°	78°	⊥(010)	31	NNE	10°			31
2	D=L_1	24	66	87	⊥(010)	43	SW	3½			
	2	16	77	80½	⊥(010)	36	NNE	7			
	$3j=p$	20	70	88	⊥(010)	39½	SSW	2			
	s	26	65	85	⊥(010)	45½	SW	3½			1=2=40
	$B_{1/2}$	19½	71½	83	⊥(010)	40½	NNE	3			3j=39½
	$B_{1/3s}$	70	51½	45½	[001]						s=45½
	$B_{2/3j}$	82	44½	46	⊥[001] / (010)						p=39½
3	D=L_1	10½	80½	85	⊥(010)	31	N	3		1=−86°	
	2	13	77½	88	⊥(010)	33½	S	½		2=−88	
	L′=S_2	74	16½	84½	⊥(001)	33½	NW	3	87		
	$B_{1/2}$	11½	79	86½	⊥(010)	32	N	1½			32
4	D=L_1	14	77	85½	⊥(010)	34½	N	2½		1=−78	
	2	18	72	90	⊥(010)	37½	SSW	3½		2=−82	
	$B_{1/2}$	17	75	82½	⊥(010)	37	NNE	4½			36½
5	L	9	81	87	⊥(010)	29½	N	1			29½
6	D=L_1	9½	80½	88½	⊥(010)	30		0		1=−75	
	2	10½	79½	88	⊥(010)	31		0		2=−75	
	S_1	79	11½	86	⊥(001)	27	NE	1	88½		
	2	81	9	88	⊥(001)	26½	SW	2			
	$B_{1/2}$	10	80	89	⊥(010)	31	S	½			30
7	L_j	25	65½	85	⊥(010)	44½	SW	3		2j=+81	
	p	21	69	87½	⊥(010)	40	SSW	2½		p=+83	
	S_j	63	29	80	⊥(001)	41½	SE	2½	88½		j=43
	p	67	23	87	⊥(001)	35½	SE	3			p=38
					Potash-feldspar						
8	L=S	12½	77½	89½	⊥(010)	Micr	SSW	15		−80	
					or	Or	E	12½			
	L′=S′	71½	84	19	⊥(15.0.$\bar{2}$)	Micr	ENE	2½	83½		
					or	Or	ENE	18½			
9	S	83½	6½	87½	⊥(001)	Micr	SW	6½		90	
10	L	12	79	85	⊥(010)	Micr	SSW	11½		72	
					or	Or	WNW	12			
	L′	78	88	12	⊥(15.0.$\bar{2}$)	Micr	NW	6½	82		
					or	Or	NE	16			
11										−82	

Grain 4: As inclusion in the K-feldspar.
Grain 10: The determination of 2V is difficult as the thin section is too thin.
Grain 11: A very large grain with twin lamellae only in one corner.

Thin Section No. 2

1	2	3			4	5. An %	6		7. L∧L′	8. 2V	9. An %
						Plagioclase					
1	D = $L_{1/2}$	17°	77°	79½°	⊥(010)	36½	NNE	8°		1 = +83°	
	$B_{1/2}$	15½	75½	84	⊥(010)	36½	NNE	3½		2 = +87	36½
2	D = L_1	19	71½	85½	⊥(010)	39½	NE	½		1 = −74	
	$_2$	17	73½	86½	⊥(010)	37	N	½		2 = +80	
	$_3$	11	81	84	⊥(010)	31	NNE	4½		3 = −88	
	$B_{1/2}$	74	44½	50	[001]	42½	NW	4½			
	$B_{1/3}$	84	52	38½	⊥[001] / (010)	43	WSW	3½			
	$B_{2/3}$	13½	77½	85	⊥(010)	34	N	3			39
3	L	9½	81	86	⊥(010)	30	N	2			30
4	$L_1 = S_j$	70	26	74	⊥(001)	42	NW	6½		1j = +*76*	1j = 42
	$_s$	74	17	84	⊥(001)	33	NW	3		s = +*74*	p = 32½
	$_p$	73½	16½	88	⊥(001)	33½		0		p = +*82½*	s = 33
	$_{p^1}$	76	14	86	⊥(001)	32	NW	2½		p_1 = +*80½*	p = 32½
					or	28	NE	2½			
	L = S_2	78	13	86	⊥(001)	27½	NE	2			s = 33
					or	31	NW	3½			
	L'_2	16	74	86	⊥(010)	36½	N	1			p = 32½
	$B_{1s/2}$	76	36	57	[001]	35½	NW	1			p_1 = 28
											2 = 34
5	D = L_1	13½	77	88½	⊥(010)	34	S	½			
	$_2$	18½	72	86½	⊥(010)	38½		0			
	$_3$	12½	82	80	⊥(010)	30½	N	7			
	$_4$	18	72	89	⊥(010)	38	SSW	2½			
	$B_{1/2}$	15½	75	86½	⊥(010)	36	N	1			
	$B_{3/4}$	14	77	85	⊥(010)	34½	N	2½			
	$B_{1/3}$	77	27	66½	[001]	31	SE	4½			
	$B_{2/4}$	75	30½	64	[001]	33	SE	4			
	$B_{1/4}$	83	68	23	⊥[001] / (010)	30	NE	6			
	$B_{2/3}$	87	64	26	⊥[001] / (010)	30½	NE	½			32
						Potash-feldspar					
6	L	78½	82	14	⊥(15.0.$\bar{2}$)	Micr	W	5			
					or	Or	ENE	12½			
7	L	81	84½	10½	⊥(15.0.$\bar{2}$)	Micr	WNW	8	90		
	L′	10	86½	80½	⊥(010)	Micr	SE	8			
8	L	22	77	72½	⊥(010)	Micr	W	5½	88		
	L′	76½	81½	16	⊥(15.0.$\bar{2}$)	Micr	W	3½			
9	L	17	78	78	⊥(010)	Micr	SW	6	77		
	L′	77½	84	14	⊥(15.0.$\bar{2}$)	Micr	WNW	4½			

Grain 2: A larger grain; on a margin replaced by quartz.
Grain 3: It forms an inclusion in the large chadacryst No. 8.
Grain 4: The appearance of the grain is unusual for a Carlsbad twin. The second subindividual forms only a corner of the larger subindividual. The coordinates of the twin axis correspond to those of a Carlsbad twin and so does the angle between $\perp(001)_1$ and $\perp(001)_2=56°$, according to $[001]\wedge\perp(001)=28°$ (Nikitin, 1936, diagram VI) and $\rho_{(001)}-27°02'$ (for albite; Goldschmidt, 1897). The core of the grain is very heterogeneous; Almost 14 zones are visible between "p" and "j" zones, repeating mainly the compositions of "p" and "s" zones. The difference in the composition which follows from the extinction angles is greater than that found by the Fedorov method. The data for "p_1" give a composition of An_{28} because the distances of Z, Y, and X of this zone and of the zone "p" with $An_{33\ 1/2}$ are greater than they would be in the case of An_{32}. The border "p_1" shows a parallel intergrowth of two minerals, probably andesine and quartz, perpendicular to the margin.
Grain 5: In the subindividual 3 the more peripheral part is determined. A slight zoning is visible.
Grain 6: The other set of twin lamellae is not clear enough for measurement.
Grains 7 and 8: The lamellae are measured in the part with twin texture and the optical indicatrix in that with almost homogeneous extinction.

Thin section No. 3

1	2	3			4	5. An %	6		7. L∧L'	8. 2V	9. An %
					Plagioclase						
1	D=L$_1$	15°	76°	86°	⊥(010)	35½	N	2°		1=+83°	
	$_2$	20	70	89	⊥(010)	39½	SSW	3			
	$_3$	15½	75	85	⊥(010)	36	N	2			
	B$_{1/2}$	84½	63	28	⊥[001] / (010)	34	NE	2			
	B$_{2/3}$	75	30½	64	[001]	33	SE	4			
	B$_{1/3}$	15	75	89	⊥(010)	35½	S	1½			34½
2	D=L$_1$	13½	77½	84½	⊥(010)	34	N	3½		1=−82	
	$_2$	18½	71½	89½	⊥(010)	38	SSW	3		2=+80	
	B$_{1/2}$	15½	75	86½	⊥(010)	36	N	1			36
3	D=L$_1$	12	79	86	⊥(010)	32½	N	2	87°		
	$_{2j}$	20	70	86	⊥(010)	39½	SSW	3			
	p	11	79	89	⊥(010)	32	S	1			
	L$_1$'	81	12	82	⊥(001)	24½	NE	3			
					or	30½	NW	8½			
	$_{2j}$	67	27	78	⊥(001)	41½	NW	2			1=31½
	p	76	17	80	⊥(001)	26	NE	7			2j=40½
					or	34½	NW	7			
	B$_{1/2p}$	11½	78½	88	⊥(010)	32		0			p=33
4	D=L=S$_1$	18	72½	85½	⊥(010)	38	N	1			
	$_2$	18	75	80½	⊥(010)	38	NNE	6½			
	B$_{1/2}$	18	73	80	⊥(010)	38	NNE	7			38

Potash-feldspar

5										−84	
6	L	16	80	78	⊥(010)	Micr	SW	4½			
7	S	82	14½	78	⊥(001)	Micr	NW	4		−87	

Grain 2: The lamellae are slightly bent.
Grain 3: In both cases the higher value is taken, corresponding to the albite twin axis (An_{32} sharp).
Grain 4: Inclusion in the microcline No. 7.
Grain 6: The grain is mainly homogeneous with a slightly developed perthitic structure. The lamellae are measured in small patches which show characteristic net texture.
Grain 7: The largest grain of microcline in the thin section. Inclusions of quartz and some slightly altered, subhedral plagioclases. *Y* shows a homogeneous, *X* a heterogeneous extinction. The twin lamellae present are not sufficiently constant for measurement. "S" is a very fine, not clearly visible cleavage.

Thin section No. 4

1	2	3			4	5. An %	6		7. L∧L′	8. 2V	9. An %
					Plagioclase						
1	L	11°	79°	88°	⊥(010)	10½°		0			10½
2	L	17	74	85	⊥(010)	2	NE	3½°		+80°	1
					or	37	N	3			
3	L_1	10½	79½	88	⊥(010)	11		0			
	$D_{1/2}$	79	25½	68	RS	1	W	1			
	$B_{1/2}$	12½	78	88	[010]	3½	NE	½			4
4	$D=L_{1/2}$	10	80	88	⊥(010)	11½		0			
	$B_{1/2}$	10	80	87	⊥(010)	11½	N	1			11½
5	$D=L_{1/2}$	6	84	89	⊥(010)	15	S	1			
	$B_{1/2}$	6½	83½	87½	⊥(010)	14½	N	½			15
					Potash-feldspar						
6	S	90	9	81	⊥(001)	Or	N	4		−83	
					or	Micr	W	10½			
7	L	18	75½	80	⊥(010)	Micr	SW	9		−79	
	L′	72	89	18½	⊥(15.0.$\bar{2}$)	Micr	NNE	7	82°		
8	S_1	12½	77½	89	⊥(010)	Micr	SE	8		1=−78	
	$B_{1/2}$	80	12	83	⊥(001)	Micr	SW	1		2=−79	
9	L	20	79½	73	⊥(010)	Micr	W	3			
10	L	71	19	88½	⊥(001)	Micr	SE	10½		−81	
	L′	72	89	18	⊥(15.0.$\bar{2}$)	Micr	NNE	6	82½		

Grain 3 and 5: The refractive index is lower than that of Canada balsam.
Grain 6: The central part is almost without lamellae.
Grain 8: "D" is parallel to (001) but it is impossible to measure it. Only two lamellae

corresponding to (010) are visible in subindividual 1 and patches of perthitic intergrowth in both. The subindividual 2 was developed in the form of a lamella.

Grain 10: The axes of the indicatrix are measured in the homogeneous part of the grain.

Thin section No. 5

1	2	3			4	5. An %	6	7. L∧S L∧L′	8. 2V	9. An %
					Plagioclase					
1	$D=L_{1/2/3}$	15½°	74½°	88½°	$\perp(010)$	3	NE 1°		1= 90°	
	$B_{1/2}$	76	27	67	$\perp[100]$	3½	NW 2½		2=−82	
					(010)					
	$B_{2/3}$	82½	70	22	[100]	3	E 2½			3½
	$B_{1/3}$	15	75	89	$\perp(010)$	4	NE ½			
					or	6	NW ½			
2	$D=L_{1/2}$	16	74	88	$\perp(010)$	2½	NE 1	88½°	1=+86	
					or	5½	NW 2			
	S_2	77	19	77	$\perp(001)$	8	SE 5½		2=−87	
	$B_{1/2}$	73½	18½	81½	[001]	4½	NE 1½			5
3	$D=L_{1/2}$	79	20	73	RS	1	W 1		2=+81	
	$B_{1/2}$	11	79	87½	[010]	3	NE 1½			2½
4	$D=L_{1/2}$	16	76	86	$\perp(010)$	1	NNE 5½		2=+82	
					or	7½	NNW 5½			
	$B_{1/2}$	16	75	82	$\perp(010)$	1	NNE 5½			8
					or	8	NNW 6			
					Potash-feldspar					
5	L	73	86	17½	$\perp(15.0.\bar{2})$	Micr	W 8½			
	S	23	74	74	$\perp(010)$	Micr	W 8½		*−76½*	
	S′	73	52½	43	$\perp(\bar{1}11)$	Micr	WNW 4			
6	S	80½	11½	83	$\perp(001)$	Micr	SW 2		*−86*	
7	S	84	11	81	$\perp(001)$	Micr	W 4½			
					or	Or	NE 6½			
8	L_1	23	73½	75	$\perp(010)$	Micr	W 9	90		
	2	15	87	75	$\perp(010)$	Micr	E 5			
	3	3½	88	88	$\perp(010)$	Micr	SSE 15			
					or	Or	NW 3½			
	4	14	79	81½	$\perp(010)$	Micr	SSW 7½			
					or	Or	NW 14			
	L_1'	76	84	15	$\perp(15.0.\bar{2})$	Micr	NW 3½			
	2	75	87	15	$\perp(15.0.\bar{2})$	Micr	N 4½			
	3	87	86	5	$\perp(15.0.\bar{2})$	Micr	WNW 14			
					or	Or	NNE 8½			
	4	84½	84	9	$\perp(15.0.\bar{2})$	Micr	WNW 10½			
					or	Or	NE 8½			
	$B_{1/2}$	18	80	75	$\perp(010)$	Micr	SW 2			
9	S	74	80	19	$\perp(15.0.\bar{2})$	Micr	SSW 3		−80	

Grain 4: The value of An_8 corresponds exactly to that deduced from 2V = +82°.

Grain 5: A twin net occurs only in a part of the grain. The optic indicatrix is measured in the homogeneous part. "S" corresponds to an irregular and therefore not exactly determined parting. The angles between the faces are L∧S = 89°, L∧S′ = 55°, and S∧S′ = 73°. They correspond to the angles ⊥(010)∧⊥(15.0.$\bar{2}$) = 89½°, ⊥(15.0.$\bar{2}$)∧⊥($\bar{1}$11) = 62½° (Nikitin, 1936, table VI), and ⊥(010)∧⊥($\bar{1}$11) = 63° (Gilbert & Turner, 1949, p. 15).

Grain 6: The extinction is mainly homogeneous. In one corner of the grain an irregular wide lamella is developed but the tilting angle for its determination is too large.

Grain 7: The grain has dusty inclusions but less than the normal plagioclase. The extinction, especially parallel to X is in patches and does not show twin lamellae.

Grain 8: A large oikocryst with chadacrysts of plagioclase. The indicatrix is measured in different points of the grain: 1. in a large homogeneous area; 2. in a small homogeneous area in the form of lamella; 3 and 4. in different spots which show a clear twin net. Y is almost perpendicular to the stage. "L" is also the composition plane of subindividuals 1 and 2.

Grain 9: Regular cleavage with dusty inclusions; only in one part the twin net is visible but it is not sufficiently clear to be measured.

TABLE 2. DETAILED DATA ON FELDSPAR FROM THE BEAVERDELL ROCKS

Thin section No. 6

1	2	3			4	5. An %	6		7.	8. 2V	9. An %
					Plagioclase						
1	L=S	7½°	86°	83½°	⊥(010)	16	N	4½°	89°	+88°	
	S′	89	13	77	⊥(001)	16	NW	2			16
2	D=L_1	9	81	87½	⊥(010)	12½	N	½			
	$_2$	5	85	89	⊥(010)	16	S	1			
	$B_{1/2}$	3	87½	88½	⊥(010)	18	N	2			17
3	L_j	85	7½	84	⊥(001)	22½	SW	1		j=−89	j=22½
	$_s$	89	7	83	⊥(001)	19½	SW	2		p=−88	s_1=22½
	$_p$	80	18	75	⊥(001)	10	SE	2½			p=10
4	D=L=S_{1j}	3	88	88	⊥(010)	18½	N	1		j=+86	
	$_p$	8½	82½	89	⊥(010)	13	S	1		p=+88	1j=18½
	$_2$	8	82	89½	⊥(010)	13	S	1½			p=13
	$B_{1p/2}$	8	82	86	⊥(010)						2=13
5	S	88½	14½	75½	⊥(001)	15	NW	2		+88½	15
					Potash-feldspar						
6	S	89	6	84	⊥(001)	Or	NE	1		−67	
	i	88	21	69	⊥(001)	12	NW	7		i=+87	
	S′	74	73	23½	⊥(110)	Or	WNW	14½			
	i	69	86½	21½	⊥(1$\bar{1}$0)	12	NW	7			
	S″	81	45	46½	⊥(111)	Or	W	18			
	i	76	32	63	⊥($\bar{1}$11)	2½	NW	2			i=12
7	S	89	7	83	⊥(001)	Or	NE	2		−66½	
	S′	87	76	14	⊥(15.0.$\bar{2}$)	Or	SE	3½	69°		
8	S	77	13	87½	⊥(001)	Or	ESE	13		−67	
	S′	87	78	12	⊥(15.0.$\bar{2}$)	Or	W	3	75½		
9	S	85	5½	87½	⊥(001)	Or	E	5½		−68	

Grain 3: "j" is the almost euhedral main part of the zoned grain. The small zone "s" near the border is followed by a zone of the same composition as the core. "p" is the border, anhedral in relation to the nearby minerals and strongly different in composition from the other part of the grain.

Grain 4: The composition of one system of lamellae changes from one side of the grain to the other across the lamellae. The lamellae of the second system are very small and measurable on only one side.

Grain 5: No lamellae are visible in the grain but 2V is clearly positive.

Grain 6: Microperthitic structure is very clear. The included plagioclase is marked with "i." S corresponds to a fine cleavage; S′ to a parting and to one boundary of the plagioclase inclusion of the perthitic intergrowth; S is not very clearly visible and corresponds to the second boundary of the intergrowth. The symbols of the faces S′ and S″ are chosen according to the fast that their poles for the included plagioclase must lie near a curve which gives a reasonable anorthite value. This must correspond in the best way with that obtained from (001) as the face most exactly determined. The measured angles between the faces are: $S \wedge S' = 68°$, $S \wedge S'' = 52°$, and $S' \wedge S'' = 62°$. The angles between these faces are: $\perp(001) \wedge \perp(110) = 67\frac{1}{2}°$, $\perp(001) \wedge \perp(\bar{1}11) = 54°$, and $\perp(110) \wedge \perp(\bar{1}11) = 58\frac{1}{2}°$ (Nikitin, 1936, table VI).

Grain 8: S is the main cleavage; sericite inclusions are parallel to this cleavage. Perthitic inclusions are parallel to S′.

Thin section No. 7

1	2	3			4	5. An%	6		7. L∧S	8. 2V	9. An %
					Plagioclase						
1	$D=L_1$	19°	71½°	87°	⊥(010)	0	NW	1°		1=−85°	
	$_2$	24	67	85	⊥(010)	0	NW	6		2=−82	
	$_3$	24	66	85½	⊥(010)	0	WNW	6			
	$_4$	19½	71	84½	⊥(010)	0	NW	3			
	$B_{1/2}$	68½	24½	78½	[001]	0	NE	7			
	$B_{2/3}$	24	66	87	⊥(010)	0	WNW	6			
	$B_{1/3}$	86	82	8	⊥[001]	5½	E	1½			1½
					(010)						
2	$D=L_{1/2}$	15½	75	85	⊥(010)	2	NE	3½	86½°		
					or	7	NW	3½			
	L'_1	82	8½	88	RS	8½	W	1½			
					or	10½	N	1			
	$B_{1/2}$	75	16	83½	[001]	4½	SW	1			4½
3	$D=L=S_1$	88	21	69	⊥(001)	11½	NW	6½		1=+86	
	p	88	23	67	⊥(001)	11	NW	8		p=+86	
	$_2$	86½	15	75½	⊥(001)	14	NW	1½		2=+74	
	$_3$	72½	21½	78	⊥(001)	5	SE	9½			
	$B_{1/2}$	85½	77½	17½	[100]	10		0			
	$B_{2/3}$	12½	78	86	⊥[100]	5½	NW	1½			
					(001)						
	$B_{1/3}$	80	18	75	⊥(001)	10	SE	3			9
4	$D=L_{1/2}$	17	75	82	⊥(010)	0	NE	6½		2=+87	
	$B_{1/2}$	74	17	85	[001]	1½	SW	1½			1
5	L	22	68½	86	⊥(010)	0	WNW	4		90	0

6	D=L_1	19½	70½	89	⊥(010)	0	SW	2		1=−86	
	$_2$	8½	82	87½	⊥(010)	13½	N	½		2=−85	
	$_3$	21½	69	85½	⊥(010)	0	WSW	3½		3=+88	
	$_4$	9½	81	87	⊥(010)	12½	N	1		4=−79	
	$B_{1/2}$	14	76	89	⊥(010)	6½	NW	½			
	$B_{3/4}$	15	75	89½	⊥(010)	5	N	½			
	$B_{1/4}$	75	19	79	[001]	7	NNE	4			
					or						
					⊥[100] / (010)	11	SE	7			
	$B_{2/3}$	75	18½	79	[001]	8	NE	3			
					or						
					⊥[100] / (010)	11½	SE	7			
	$B_{1/3}$	86	79½	11	⊥[001] / (010)	10	ESE	3			
					or						
					[100]	16½	E2½				
	$B_{2/4}$	89	78½	11½	⊥[001] / (010)	12	E	½			
					or						
					[100]	16	W	1			8
					Potash-feldspar						
7	S	86½	12½	78½	⊥(001)	Or	NE	7½			
					or	Micr	NW	7½			
8	S	82½	9½	84	⊥(001)	Or	E	7	74	−76	
					or	Micr	SW	4			
	S′=I	69	83	22½	⊥(15.0.$\bar{2}$)	Micr	E	4½			
9	S	82	12	81	⊥(001)	Or	NE	9		−74	
					or	Micr	WNW	2½			
	p	84	13½	78	⊥(001)	Or	NE	9		p=−68	
10	S=I	86	85	5½	⊥(15.0.$\bar{2}$)	Or	NE	8		−62	
11	S	83½	13½	78½	⊥(001)	Or	NE	9½	74	−70	
	I	83½	85½	8	⊥(15.0.$\bar{2}$)	Or	NE	10			
12	S	87½	8	82	⊥(001)	Or	NE	4	69	−72	
	S′	90	76	14	⊥(15.0.$\bar{2}$)	Or	S	1½			
13										−67	
										−67	
14	S	77	18	78	⊥(001)	Or	NE	14	76	−55	
					or	Anor	NE	12			
	I	80	89	10	⊥(15.0.$\bar{2}$)	Or	NE	15			
15	L_p	20	85½	70½	⊥(010)	Or	NNW	20	82½		
					or	Micr	NE	4½			
	S=I_j	90	81	9	⊥(15.0.$\bar{2}$)	Or	N	3			
					or	Micr	W	15			
	p	77½	82	15	⊥(15.0.$\bar{2}$)	Or	ENE	12½			
					or	Micr	W	4			

Grain 3: The rim "p" without inclusions has the same composition as the remaining subindividual rich in inclusions.

Grain 6: The composition planes of the subindividuals form a kind of a cross. That the subindividuals 1 and 3 have actually a different composition is not very probable because of the occurrence of very narrow lamellae which interfere with accurate determination. A larger difference in 2V is found only in subindividuals 2 and 4 and the composition obtained from the twin axis $B_{1/3}$ is similar to that from $B_{2/4}$. The composition obtained from the alternative trilling complex $\perp$(010), [100], and $\perp$[100]/(010) and from both complexes with (001) as composition face differ so much within each complex that the alternative trilling complexes were excluded.

Grain 9: The nonhomogeneous extinction is somewhat different in a rim-like area but the cleavage is the same in the whole grain. According to the value of 2V the rim is an orthoclase, the other part of the grain seems to be transitional to microcline.

Grain 10: 2V has been measured three times in this very heterogeneous grain.

Grain 11: The grain is subdivided into smaller grains with sutured outlines between them similar to those occurring in quartz.

Grain 13: The perthitic grain is very heterogeneous. The indicatrix was determined twice: 1. in the middle part, 2. where it borders a partly replaced plagioclase. A fine rim of dusty inclusions indicate the former size of the plagioclase. Only 2V could be obtained.

Grain 14: The extinction of the very large perthitic grain is most heterogeneous in the position with the optical axis parallel to the tube of the microscope. The indicatrix axes were measured at least four times (*X*—7 times). If the means of all measurements were plotted on the diagram the crossing points embrace 3° to 5° less than 90°; but the corrected projections equal 90° (Nikitin, 1936, p. 36). 2 V obtained in this way is $-50°$.

The very small perthitic inclusions show some twin lamellae with sharp borders but they do not allow the determination of their optical indicatrix. Therefore, the extinction angle was measured in an orientation when the lamellae—presumably being parallel to (010)—were vertical; Wahlstrom's curve "L" in his diagram (1947, fig. 22) gave as composition of the inclusion An_7.

In addition to the perthitic intergrowth some areas of the grain show a poorly defined twin structure with no sharp outlines between the lamellae. In certain extinction positions when the grain seems to be homogeneous this twinning is not visible and the perithitic intergrowth stands out.

Grain 15: The perthitic grain shows locally a twin net, especially on the borders. The optical indicatrix was measured in the central part with no lamellae and on the border with them. Therefore, the lamellae are considered only for the border. From the position of the crystallographic elements it is concluded that microcline is developed on the borders and orthoclase in the homogeneous central part. As the optical axes could not be measured, 2V was determined in the indirect way by determining the birefringence in the section *Z X* and in a section perpendicular to it, following Nikitin's method (1936, p. 68). 2V is deduced from Boldyrev's diagram (Nikitin, 1936, plate IV) where the relationship between 2V and the birefringences $nZ-nY$ and $nY-nX$ is considered. $nZ-nX$ in the central part is 0.0057, in the peripheral 0.0050; $2V_j=-67°$ and $2V_p=-74°$. Values for $nZ-nX$ under 0.006 are normal and were found repeatedly in potash-feldspar of different rocks, e.g. of pegmatites (Dolar-Mantuani & Koritnig, 1939) and of aplites (Dolar-Mantuani; 1938, p. 377 and 1942, p. 407).

Thin section No. 9

This thin section was made from an apparently uniform phenocryst of specimen No. 7. The slide includes two large grains separated by an irregular boundary and bounded on one side by the groundmass. Both grains are relatively rich in inclusions. Plagioclase grains with some quartz occur in the form of an irregular strip about 1 mm. from the border to the groundmass. On an area of 4 sq. cm., measurement of inclusions gave the following results: 12.2% of mostly anhedral, partly euhedral plagioclases (maximum size 0.5 mm.), 0.8% of anhedral quartz grains with mainly different optical orientations, and 0.7% of accessories as crystals of magnetite, sphene, apatite, and some epidote as vein filling; 86.3% of K-feldspar.

Both grains of potash-feldspar show a very nonhomogeneous extinction in patches combined with extremely fine twinning texture which is best visible at larger tilting angles. The optical indicatrix was measured in four places resulting in different values for 2V. S=I is a fine but interrupted cleavage with inclusions. S′ is a parting. The pole of $(15.0.\bar{2})$ for anorthoclase is not plotted in Nikitin's diagram; it must lie very close to that of orthoclase.

Grain 1: S=I 89° 77° 13°$-\perp(15.0.\bar{2})-$Or$-$SE 1°; S′ 47½° 67° 51½°$-\perp(110)-$Anor$-$SE 12°; 2V=−49°, −51°, −59°; mean −53°.
Grain 2: 2V=−60°.

Thin Section No. 8

1	2	3			4	5. An %	6		7. S∧I	8. 2V	9. An %
						Plagioclase					
1	$D=L_{1/2}$	14°	76°	88½°	$\perp(010)$	7	NW	½°		1=+80°	
	$B_{1/2}$	15½	74½	89	$\perp(010)$	4	NE	½		2=+79	5
2	$D=L_{1/2}$	20	71	84	$\perp(010)$	0	NW	4		1= 90	
	$B_{1/2}$	19½	70½	88	$\perp(010)$	0	W	1½		2=−80	0
3	$D=L_{1/2}$	14½	77½	82½	$\perp(010)$	10½	N	5½		2=−84	
	$B_{1/2}$	13	78	85	$\perp(010)$	10½	N	3			10½
5	$D=L_{1/2}$	15	75½	86	$\perp(010)$	7½	NW	3		1=+82	
	$B_{1/2}$	15	75½	86	$\perp(010)$	7½	NW	3		2=−85	7½
						Potash-feldspar					
5	S	86½	3½	89	$\perp(001)$	Or	SE	5½	74½°	−72	
	I	90	75	15	$\perp(15.0.\bar{2})$	Or	S	2½			
6	S	20	88	70	$\perp(010)$	Micr	NE	6½	84		
	I	75½	84	16	$\perp(15.0.\bar{2})$	Micr	NW	2½			
7	S	86	6	85½	$\perp(001)$	Or	ESE	4	75	−67	
	S′=I	83½	71½	20	$\perp(15.0.\bar{2})$	Or	SE	9			
8	S	73	19½	80½	$\perp(001)$	Micr	W	6½		−78	

Grain 4 is a small inclusion in the large heterogeneous grain No. 8.
Grain 6: In addition to the normal cleavage a set of fine cleavage planes with dusty inclusions is developed.

Thin section No. 10

The thin section of the phenocryst includes also some groundmass. The large grain is anhedral and of the same character as described in No. 9. On the border with the groundmass the inclusions become more numerous and the potash-feldspar fills only the interstices. Very fine twin lamellae in only one direction are visible between untwinned patches with a very unhomogeneous extinction. No difference in the refractive index is visible.

At first sight it seems that the grain consists of three subindividuals. The outline between the subindividuals 1 and 2 is mainly parallel to the twinning texture of both subindividuals and only partly irregular. The outlines between subindividuals 2 and 3 is straight for a short distance, but elsewhere curved and irregular. Subindividuals 1 and 2 are twinned according to the Carlsbad twin law but 2 and 3 are not twinned. The angle between $\perp(001)_2$ and $\perp(001)_3$ is only 29°, the part of the straight border is formed by $(001)_2$, and neither the position of the faces (001) nor the extinction is symmetrical in regard to the "composition" plane. $S_2 \wedge S'_2 = 89\frac{1}{2}°$.

The optical indicatrix is measured in four places which are indicated by a, b, c, and d. 2V is the highest in subindividual 1 and measured in three places it varies very little: from $-64°$ to $-65\frac{1}{2}°$; mean $-65°$. X bisects the angle formed by the two optic axes and demonstrates the exactness of the determination. The other optical angles are smaller ($2V_2 = -59°$ and $2V_3 = -51°$) and typical for anorthoclase. $2V_1 = -65°$ and $2V_2 = -59°$ are obtained in the same central area "c" of the grain. As the character of subindividual 1 is the same as that of subindividual 2 with which it is connected by the Carlsbad law it is also regarded as being an anorthoclase.

1	2	3			4	5	6		7. S∧S′	8. 2V
					Potash-feldspar					
1a	S_1	89°	3°	87°	⊥(001)	Or	SE	3°		1 = −*64°*
					or	Anor	SW	3½		
1b	L_1	6½	83½	88	⊥(010)	Or	NW	6½		1 = −*65½*
					or	Anor	SW	4		
1c	$D = L_1$	7½	82½	88	⊥(010)	Or	WNW	7½		1 = −*65*
					or	Anor	SW	5½		
	$_2$	6½	83½	89	⊥(010)	Or	W	6½		2 = −*59*
					or	Anor	SW	5		
	$B_{1/2}$	22½	68	88½	[001]	Or	NE	2		
					or	Anor	NW	½		
1d	S_2	83½	6½	88	⊥(001)	Or	SE	7		3 = −*51*
					or	Anor	SE	4½		
	S_3	88	8½	82	⊥(001)	Or	NE	3½		
					or	Anor	NW	3		
	S'_2	5	87	86	⊥(010)	Or	NW	5		
					or	Anor	NW	½		
2	S	85½	85½	6	⊥(15.0.$\bar{2}$)	Or	NE	8½		
					or	Micr	NW	12½		
3	S	87	85½	5½	⊥(15.0.$\bar{2}$)	Or	NE	8½		
					or	Micr	NW	14½		
4	S	90	9½	80½	⊥(001)	Or	N	4	74½	−68
	S′ = I	89	83	6	⊥(15.0.$\bar{2}$)	Or	N	6½		
					Plagioclase					
5	L	17½	72½	88½	⊥(010)	1% An		0		+86

Grain 2 has a very fine and close spaced cleavage and no lamellae; only wavy extinction is visible.

Grain 3: It is heterogeneous and similar to grain No. 1. The optical data are too scarce to allow determination of the type of potash-feldspar. The pole for (15.0.2̄) falls nearer to that of (an-)orthoclase than microcline.

Grain 4: Although the extinction is nonhomogeneous, no smaller 2V can be expected. No twin lamellae are visible, only a perthitic structure.

Grain 5: As inclusion in No. 1.

Thin section No. 11

1	2	3			4	5. An %	6		7. L∧L' S∧L	8. 2V	9. An %
					Plagioclase						
1	$D=L_1$	10°	83°	83°	⊥(010)	13	N	5°	85°	2=+81°	
	2	13½	77	87	⊥(010)	9	NW	1½			
	3	12	78	85½	⊥(010)	11	N	2½			
	4	11	80	85½	⊥(010)	11½	N	2½			
	$D'=S_1$	78	31	62	⊥(001)	0	NNW	6			
	2	83	23½	67½	⊥(001)	7	NW	4½			
	3	75½	28	66½	⊥(001)	0	N	1½			
	4	83	25	66	⊥(001)	6	NW	5½			
	$B_{1/2}$	11	79	87½	⊥(010)	11	N	½			
	$B_{3/4}$	11	79	90	⊥(010)	11	S	2			
	$B_{1/3}$	88	74	26	[100]	0	SW	5½			
	$B_{2/4}$	86	67	23	[100]	0	SSW	3			
	$B_{1/4}$	79½	28½	64	⊥[100]/(010)	4	NW	7			
	$B_{2/3}$	79	25½	68	⊥[100]/(010)	7	NW	4			6
2	$D=L_{1/2}$	12½	88	86	⊥(010)	10½	NNW	2½	85		
	$D'=S_{1/2}$	80	22½	75	⊥(001)	5½	NW	1			
	$B_{1/2}$	80	19	74	⊥[100]/(010)	11½		0			10
3	$D=L_1$	89	13	77	⊥(001)	16	NW	1½		1=+85	
	2	88	18	72	⊥(001)	13	NW	4½		2=+84	
	$B_{1/2}$	87½	74½	16	[100]	12	SW	1½			13
4	$D=L_1$	15	75	90	⊥(010)	5		0		3=+85	
	2	10	80	89	⊥(010)	11½	S	1½			
	3	7½	83	87½	⊥(010)	14	N	½			
	$D'=S_2$	86	17	73	⊥(001)	12½	NW	2½			
	3	90	12	78	⊥(001)	18	NW	2			
	$B_{1/2}$	13	77	89	⊥(010)	8		0			
	$B_{1/3}$	80	18½	75	⊥[100]/(010)	11½	SE	1½			
					or [001]	13½	NE	3½			
	$B_{2/3}$	86	66	14½	[100]	12	NW	½			
					or ⊥[001]/(010)	14½	E	4			10
5	S	86	20	70	⊥(001)	11	NW	4½		+88½	11

Potash-feldspar

6	L	18	82	74	⊥(010)	Micr		0	86		
	L′=I	69½	88	20½	⊥(15.0.$\bar{2}$)	Micr	NE	6½			
7	D_1	85	7	85	⊥(001)	Or	E	5		1=−70	
	$_2$	82	10	84	⊥(001)	Or	E	8		2=−70	
	$B_{1/2}$	83½	8½	84	⊥(001)	Or	E	6			
8	L	20	87	70	⊥(010)	Micr	NE	6	90		
	L′=S=I	70	84	21	⊥(15.0.$\bar{2}$)	Micr	E	3½			

Grain 1: The form of the grain is similar to that of No. 6 in sample No. 7. As the poles of the twin axes $B_{1/4}$ and $B_{2/3}$ lie in the vicinity of only ⊥[100]/(010) the other two axes $B_{1/3}$ and $B_{2/4}$) can be only [100]—if only (010) is considered as D.

Grain 4: It is almost impossible to decide what twin laws occur in this grain. As the first subindividual extends through the length of the whole grain and only subindividuals 2 and 3 are divided by (001), the complex ⊥(010), [100], and ⊥[100]/(010) was chosen.

Grains 6 and 8: Both grains show a typical microcline net. Grain 6. is a part of a micro-granophyric intergrowth with quartz.

Grain 7: A simple twin resembling a Carlsbad twin.

Thin section No. 12

1	2	3			4	5	6		7	8. 2V	9
					Plagioclase						
1	L	14°	76°	90°	⊥(010)	6% An	SE	½°		+88°	
					Potash-feldspar						
2	D=S_1	83	13	79	⊥(001)	Micr	NW	4½		1=−80	
	$_2$	82	9	85½	⊥(001)	Micr	SW	4		2=−81	
	$B_{1/2}$	86	8	82	⊥(001)	Micr	SW	6½			
3	S	80½	10	86	⊥(001)	Or	E	10		−69	
4	S	89	5½	84½	⊥(001)	Or	E	1		−60	
					or	Anor	W	2½		−62	
5	D=S_1	86	7	84	⊥(001)	Or	E	4			
					or	Anor	NE	1			
	$_2$	87	11	79½	⊥(001)	Or	NE	6			
					or	Anor	N	5½			
	S′=I_1	87	81	9	⊥(15.0.$\bar{2}$)	Or	NNE	4½			
	$_2$	87	82	8	⊥(15.0.$\bar{2}$)	Or	NNE	5			
	$B_{1/2}$	89½	8	82	⊥(001)	Or	NNE	2½			
					or	Anor	NW	4			

Grain 2: The relatively large grain grades with the net structure into a granophyric intergrowth.

Grain 3: The central part of the grain is homogeneous and free of dusty inclusions which are conspicuous in the border zone.

Grain 4: The grain shows heterogeneous extinction and relatively large perthitic patches.

The optical indicatrix was measured twice. The extinction angle in the plagioclase is 12° in a section ⊥ (010), giving An_8.

Grain 5: As Y_1 and Y_2 are almost parallel to the microscope tube 2V was not measurable. It can not be decided if the grain is orthoclase or anorthoclase because the heterogeneous extinction shows a kind of striation. Larger perthitic patches occur together with very fine stringers parallel to (15.0.$\bar{2}$).

Summary and Conclusions for Plagioclase

Composition of the plagioclases. Table 3 shows the composition of plagioclases in different thin sections. The variation in the composition of unzoned grains in any section is not very large; the greatest variation is 14% An in the leucocratic rock from the Highland Lass mine (No. 4). In the same way the zoning of plagioclases is very slight and seems not to be present in the acid rocks with the exception of the sample from the border of the Beaverdell stock. But this lack of zoning may be partly only apparent because alteration makes the zoning less conspicuous. The differences in the composition of the cores and the borders of the zoned grains are small; the borders correspond mainly to the mean of the unzoned grains.

Table 3: Composition of Plagioclases

Thin section	An % in unzoned grains			An % in zoned grains				
	Mean	Variation	No. of grains	Borders		Cores		No. of grains
				Mean	Variation	Mean	Variation	
1	33	29½–40	6	39	38–39½	44	43 –45½	2
2	34½	30 –39	5	28		42		1
3	35	31½–38	4	33		40½		1
4	8½	1 –15	5					
5	5	2½–8	4					
6	14½	12 –17	5	11½	10–13	20½	18½–22½	2
7, 9	4	0 –9	6					
8, 10	5	0 –10½	5					
11, 12	9	6 –13	6					

The plagioclases of the average rock from the Highland Lass mine (No. 1, 2, 3) are acid andesines, all others are albites to acid oligoclases. The present andesines with the composition near An_{30} are not pseudomonoclinic and also the oligoclase is more acid than An_{20} which shows as a low-temperature plagioclase a pseudomonoclinic optical orientation (cf. Oftedahl, 1950). It is interesting that the composition of plagioclase from the Wellington mine (No. 5) corresponds to that from the inner part of the Beaverdell stock (No. 7–10), and that of the leucocratic rock from the Highland Lass mine (No. 4) to that from the granophyric rock in the Beaverdell stock (No. 11, 12). The plagioclases from the border of the Beaverdell stock are not only slightly more basic but also zoned in comparison with those of the inner part.

2V: The plagioclases from the different rocks show a wide range in the values of 2V, as shown in table 4. The values over *Z* are normal in acid

TABLE 4. 2V IN PLAGIOCLASE

Thin section	1	2	3	4	5	6	7, 9	8, 10	11, 12
Mean of 2V	−84°	+82½°	+87°	+80°	+87°	+88½°	+88½°	+87½°	+85½°
Variation	−75° to +83°	−74° to +74°	−82° to +80°		−87° to +81°	−88° to +86°	−79° to +74°	−84° to +79°	+81° to +88°
No. of deter.	8	9	3	1	6	7	13	8	6

plagioclases, and those of the other two sections (No. 2 and 3) are not so surprising as 2V changes strongly in the part of An_{30-45} (especially of An_{35-41}).[1] The usual variation in 2V of plagioclases demonstrates that it is not satisfactory, in general, to depend only on values of 2V in determining the composition of plagioclases (cf. Comucci, 1948, p. 166; Kaaden, 1951, p. 15). Anomalies in the optical properties of plagioclases (and also of K-feldspars) are often found in addition to the complexity in the optical and structural properties of the feldspars; the latter is repeatedly pointed out in recent publications on feldspars (Raaz 1947, Koehler 1949, Laves 1950, Chaisson 1950, Chayes 1950, Heald 1950, and others).

Crystallographic elements (especially the twin axes): One hundred and seventy two crystallographic elements were studied during this work. The face (010) was oriented with respect to the optical elements on one hundred occasions. It is developed as twin lamellae or a distinct composition face, seldom as cleavage face. However, (001) is normally developed as cleavage face, seldom as composition face, or lamellae. Perhaps even these apparent cases of (001) as composition face or lamellae are really still less numerous, and they should be partly replaced by the rhombic section, especially if a cleavage parallel to these twin elements

[1] From −84° to +82° (respectively from −86° to +84°)—according to the average curve of 2V for the plagioclases in Nikitin's diagram (1936, fig. 39). Compare the break of the line for the relationship between *nZ* and the An-content of natural plagioclase at An_{45} described by Chayes (1950, p. 594). Also the lines for relationship between the An-content and the line separation of the *x*-ray diffraction pattern show a break in the vicinity of An_{30-40} described by Claisse (1950, p. 419).

is not visible. As is well known, it is impossible to decide in medium plagioclases and difficult to decide in unfresh albite-oligoclases (and andesine-labradorites) whether a composition face corresponds actually to (001) or to the rhombic section. Therefore, the statements on the frequency of the pericline and acline law seem to be very uncertain for a large composition range of plagioclases and conforming to this, for plagioclases in volcanic and plutonic rocks also (Kaaden, 1951, p. 62).

Table 5 shows the frequency of the different twin laws in all thin sections examined. In the second line, only the twinning is considered for which both subindividuals were measured; in the examples on the third line the relationship between the twins was deduced including the twin lamellae. With regard to the ambiguous twin laws, it may be referred to the notes of the previous chapter. The complex ⊥(010), [001], and ⊥[001]/(010) was found four times as trilling and twice as quadrilling;

TABLE 5. TWINNING IN PLAGIOCLASE

Twin law	⊥(010)	[001]	⊥[001]/(010)	[100]	⊥[100]/(010)	[010]	⊥[100]/(001)	⊥(001)
Determ. in section	in all	1–3, 5, 7	1–3, 7	5, 11	5, 11	4, 5	7	7
No. of obs.	28 (45%)	11 (18%)	9 (14%)	6 (10%)	5 (7%)	2 (3%)	1 (1½%)	1 (1½%)
No. of obs.	43 (51%)	11 (13%)	9 (11%)	6 (7%)	5 (6%)	7 (9%)	1 (1%)	1 (1%)

⊥(010), [100], and ⊥[100]/(010) twice as trilling and once as quadrilling, and ⊥(001), [100], and ⊥[100]/(001) once as trilling.

From Table 5 it follows that twinning according to the albite law is the most frequent. If also the lamellae are taken into consideration, on the assumption that they belong to the albite and pericline twins respectively, the frequency of both twin laws increases (—the pericline twins change from the sixth to the fourth highest frequency). A still greater prevalence of the albite (70%) and pericline (16%) laws is recorded by Lundegårdh (1944, p. 373) from an ultrabasic massif, where the pericline shows the second highest frequency. The order of frequency in the present rocks agrees to a certain degree with that in plutonic (and metamorphic) rocks (90 twin axes) listed by Kaaden (1951, p. 87); but an entirely different order of frequency was found in tonalites and aplitic rocks from the Pohorje massive where the order of frequency is as follows: [001], ⊥(010), [010], ⊥[001]/(010), between 27 and 17%); ⊥[100]/(010) ⊥(0$\bar{2}$1), ⊥(001), [100], ⊥[010]/(001), ⊥[100]/(001) (less than 4% each); (172 twin axes; Dolar-Mantuani 1935, 1938 and 1942). Therefore, it can be said in agreement with Winchell (1951, p. 273) only generally that the twin laws with (010) as composition face are the most frequent (if 010 is not considered which shares, e.g., with albite twins the first highest frequency in tonalites from the Pohorje massif.

Although the greatest variability in the twin laws occurs in sections No. 5 and 7 with albites as plagioclases, this is not considered as a rule because only albite twin were determined in sections No. 6 and 8 both with acid plagioclases. On the other hand the *a*-axis and its perpendicular are important as twin axes in the aplitic rock of Beaverdell (No. 11). However, the number of grains and thin sections examined is too small to show a definite correspondence between the character of the plagioclases present or the place from which the specimens came, and the kind of twin laws developed.

It may be added that the writer's present and earlier examinations of twin laws in acid andesine do not support A. L. Culson's opinion that the $\perp[100]/(010)$ law is favored in plagioclases of composition An_{30-35} (quoted by Emmons, 1943, p. 113). No Albite-Ala B twins were found in thin sections No. 1, 2, and 3 (total 23 twin axes) and only three times (among 118 twin axes) in plagioclases of the tonalites from the Pohorje massif with an average composition of unzoned grains—An_{33} (Dolar-Mantuani 1935, p. 99 and 1942, p. 407).

Summary and Conclusions for Potash-Feldspar

As the potash-feldspar in the Westkettle rocks appears to be almost entirely microcline whereas that of Beaverdell show large variations, the data are divided into two groups according to the occurrence in different batholiths.

Microcline of the Westkettle rocks

The optical results for potash-feldspar in five thin sections show a rather wide variation in the values of 2V and in the position of the crystallographic elements in regard to the optical indicatrix. In addition to this many grains contain areas which lack the characteristic microcline grating and some grains do not show any twin structure. The question arises therefore, whether such grains of the potash-feldspar are still microcline on the whole or transitional between microcline and orthoclase, or an soda-potash-feldspar, e.g. of the same character as in the larvikite of Larvik.[2]

To decide to which potash-feldspar a grain belongs, the presence of lamellae, the value of 2V, and the following angles are important here:

[2] According to determinations of Nikitin (1942, p. 282) by the Fedorov method the homogeneous alkali-feldspar grains in the larvikite show $2V=-72°$ to $-80°$, and $Z\wedge\perp(010)=4°$, $Z\wedge\perp(001)=87°$, and $Y\wedge\perp(001)=8\frac{1}{2}°$ to $11°$. Johannsen (1939, part IV) mentions soda-orthoclase (cryptoperthite, Broegger) or soda-microcline (anorthoclase, Rosenbusch) as constituents of larvikite.

$Z \wedge \perp(010)$, $Z \wedge \perp(001)$, $Y \wedge \perp(001)$, $Z \wedge \perp(15.0.\bar{2})$, and $X \wedge \perp(15.0.\bar{2})$. After a very careful examination it was found that 13 of the 21 grains determined are undoubtedly microcline. Four of the remaining 8 grains have a high value of 2V but no twinning lamellae are visible. As two of these grains (4/8[3] and 5/6) show much better agreement in their crystallographic coordinates with those of microcline than with those of any other type of potash-feldspar the writer appears to be justified in stating that also grain 3/5 in which only the optical angle was determined, and grain 1/9 whose coordinates of (001) indeed correspond better to those of anorthoclase, are microcline.

Of the remaining four grains, grain 1/10 has a relatively low value of 2V (−72°) but it shows twinning structure as do grains 2/6 and 2/7. As the poles of all these grains and also of grain 5/7 lie nearer to those of microcline than orthoclase or soda-orthoclase on Nikitin's diagram, it is more likely that these grains also belong to microcline. Because gradations of orthoclase and microcline and vice versa are normally demonstrated by different values of 2V in different parts of one grain, as e.g. in some grains of the Beaverdell rocks or in potash-feldspar of a tonalite in the Pohorje massif (Dolar-Mantuani, 1935, p. 103).

Parts and grains without twin net are repeatedly reported for microcline. Winchell mentions that microcline devoid of multiple twinning is quite rare but not unknown (1951, p. 366) and Johannsen that it is even common in alkali granites (1939, part II, p. 146). Recently Higazy mentions analogous microclines with perthitic structure occurring in pegmatites of the Black Hills, Dakota (1949, p. 563). Microcline apparently without twinning could have very narrow and hence microscopically indistinct twin lamellae as Dana suggests for some anorthoclase (1932, p. 541). Recently F. Laves established it for microcline by *x*-ray investigations (1950, p. 550). That the lack of lamellae is connected with relatively low temperature of its origin, as suggested by Broegger for such microcline found in drusy vugs in the Langesund Fjord (quoted by Fuechtbauer, 1950, p. 248), is not established. But that twinning in the detrital microcline continues into the late outgrowth which is in optical continuity with the core of microcline from West Virginia sandstones (Heald, 1950b, p. 628), argues against this assumption.

In conclusion the potash-feldspar of the Westkettle rocks show generally values of 2V which are typical for microcline in the mainly homogeneous parts of the grains in which the determination of the optical indicatrix and, therefore, of 2V is more convenient. The optical angle is also typical of microcline in cases where the cleavage and lamellae (being

[3] The first number indicates the number of the thin section, the second of the grains in the tables of the detailed optic data.

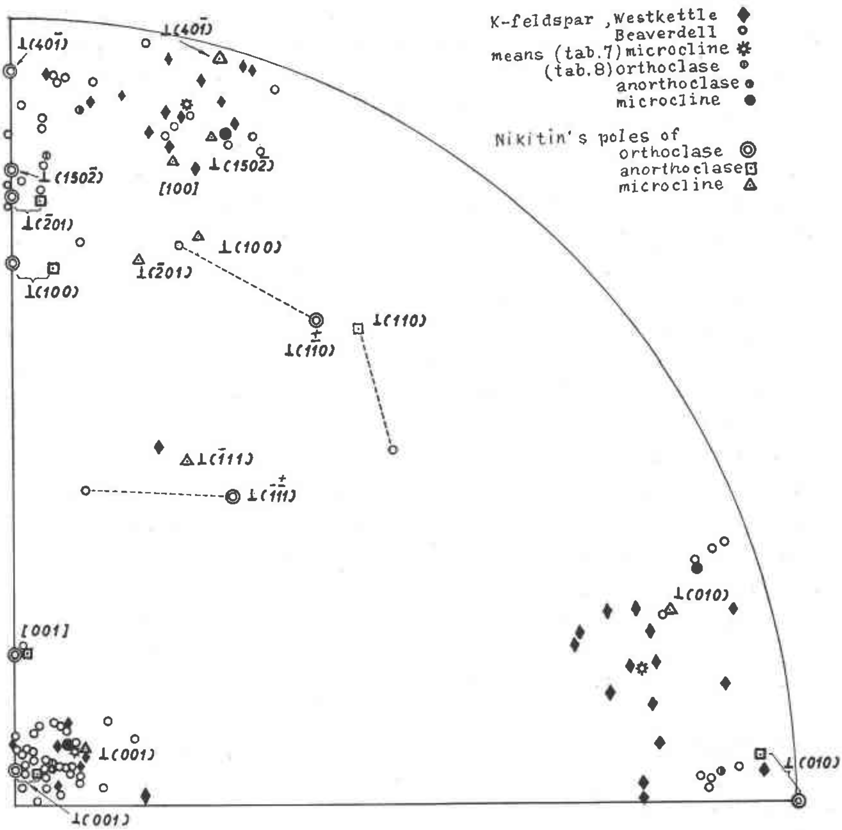

FIG. 2. The poles of the K-feldspars of the Westkettle and Beaverdell rocks shown on the one-octant diagram of Nikitin.

measured, of course, in the part with the twin net) show a relatively great distance to the microcline poles on Nikitin's diagram. Here grain 5/8 is illustrative: it shows rather good agreement for $\perp(010)$ and $\perp(15.0.\bar{2})$ with the data of microcline in the homogeneous parts of the grain and deviating data in the parts with a typical microcline net. In comparison with this grain, grain 7/15 from the Beaverdell stock is interesting because there the untwinned area shows apparently monoclinic optics (deviation for pole $\perp(15.0.\bar{2})$ of orthoclase is 3°). Laves (1950, p. 553) obtained the same result in microcline where portions of single grains were a) optically monoclinic, b) fully twinned, optically triclinic, and c) optically triclinic without observable twin lamellae. The results with the Fedorov method show therefore in accordance with the *x*-ray investigations that areas where twinning disappears completely, may be optically monoclinic or triclinic. On the other hand the lower values of 2V for potash-feldspars in the Westkettle rocks are determined in those grains in which the poles of crystallographic elements lie nearer to those of microcline than any other feldspar.

2V: The variation of the values of 2V is from $-72\frac{1}{2}°$ to 90°, taking into account all thin sections of the Westkettle rocks. The average value is $-81°$ (16 determinations, three of them determined by emergence of both optical axes). The extreme value $-72\frac{1}{2}°$ is still 1° higher than that in the microcline of the granite of the island Maddalena in Sardinia as reported by Riva (Rosenbusch-Muegge, 1927, p. 722). Some of Spencer's microclines show still smaller axial angles but they are not typical for microcline (1937, p. 460). If the average value $-81°$ is plotted in Winchell's diagram for the microcline-analbite series (1951, p. 300, Fig. 192) about 20% of the Na-component is apparently present in the Westkettle microcline.

The crystallographic elements: The position of the different crystallographic elements is shown in the following diagram together with those of the potash-feldspar from the Beaverdell rocks.

Only four different elements are determined in the potash-feldspar of the Westkettle rocks, i.e. (010), (001), $(15.0.\bar{2})$, and once $(\bar{1}11)$ (as an irregular parting face). The average coordinates of the three main faces are (number of observation in brackets):

$\perp(010)$	$16\frac{2}{3}°$	$78\frac{3}{4}°$	$78\frac{2}{3}°$	(14 times)
$\perp(15.0.\bar{2})$	76	85	$15\frac{1}{2}$	(13 times)
$\perp(001)$	$81\frac{2}{3}$	12	83	(7 times)

The smallest variation in the coordinates was obtained for $\perp(15.0.\bar{2})$ but the average coordinates for $\perp(001)$ correspond best to those of microcline as quoted by Nikitin (1936, p. 94).

Most of the data were supplied by twin lamellae (20), rather than by the cleavage plane (10). No preference could be established between the faces (010) and (001) as cleavage planes. In samples of the acid rocks, twin axes were determined twice: once in an albite and once in a Manebach twin (5/8 and 4/8 respectively).

The function of $(15.0.\bar{2})$ as a possible composition face of the microcline twinning

It is very interesting that no twin net could be determined which was composed of lamellae parallel to (010) and (001) but that the combination (010) and $(15.0.\bar{2})$ was found seven times and once that of (001) and $(15.0.\bar{2})$, (4/10). If only one set of twinning was visible it was parallel to (010) or $(15.0.\bar{2})$. As the face $(15.0.\bar{2})$ is not often mentioned in the literature, it seems to be opportune to explain its position in more detail.

The face $(15.0.\bar{2})$ which is close to $(70\bar{1})$ and $(80\bar{1})$ is more extensively described as murchisonite cleavage by Rosenbusch-Muegge in the chapter on orthoclase (1927, p. 661), although it is—according to them—very frequent also in microcline where it forms an angle of 71° to 74° with (001) (p. 721). This cleavage was described first by Lévy in the murchisonite of Dawlishland and Heavytree. The development of this cleavage can be so perfect, that it has led in the past to mistakes in the orientation of crystals. The angle of this cleavage ranges from 72°1′ to 74°15′ with (001) in (010) as given by different authors and is said to be smaller than 68° by Kraatz-Koschau and Hackman. The angle does not seem to be constant and the face is calculated as parallel to $(15.0.\bar{2})$ and $(70\bar{1})$ to $(80\bar{1})$. This murchisonite cleavage is developed especially, but not exclusively, in orthoclase of foyaitic rocks; it can be one of the faces along which the microperthitic deposition takes place. Rosenbusch points out that it may result from release of inherent tensions which are due to admixtures of a greater quantity of albite to orthoclase (in non-equilibrium space lattice) by intensive straining of the feldspar.

Dana (1932, p. 540) quotes an analogous statement of Broegger: extremely fine interlamination of albite and orthoclase exists parallel to $(80\bar{1})$ which is connected in cryptoperthites with secondary planes of parting parallel to (100) or $(80\bar{1})$.

Duhovnik (1949, p. 259) describes an intergrowth between microcline and albite in the face $(15.0.\bar{2})$ in addition to the characteristic microcline grating in sections ⊥ [100]. He calculates the symbol of the face of the perthitic intergrowth using the angle between this face and (001) which is $73\frac{1}{2}$°.

During the present study the question arose whether not only a cleavage and regular inclusions were parallel to $(15.0.\bar{2})$ but also one composition face of the cross grating twinning in microcline has the symbol $(15.0.\bar{2})$. This intersecting twinning is generally said to follow the albite and pericline twin laws. All writers agree that the composition face of the non-albite lamellae lies in the zone (100):(001) but the angle between this face and (001) ($=\sigma$) seems to vary and therefore different faces are reported as composition faces.

σ is a right angle or nearly so (Dana, 1932, p. 543). It varies from −75° to 90° with the greatest frequency between −81° and −85°, according to Boeggild (1911; Reinhard and Boechlin, 32, p. 216). σ is −75° and the composition face is $(15.0.\bar{2})$ as found by Litmanowicz (1931; Reinhard and Boechlin, 1936). Reinhard and Boechlin give the same variation range −75° to 90° for 30 grains, as Boeggild. The poles of the composition face migrate along the zone [010] between the ⊥ $(15.0.\bar{2})$ and $[\bar{1}00]$ (p. 221). Winchell mentions that σ is +99° (1951, p. 308), respectively −80°

or $\pm 100°$ (p. 269, fig. 166). In fig. 201 he sketches the trace parallel to $(40\bar{1})$.[4]

Because Winchell reports twinning on an axis normal to $(\bar{2}01)$ as often being present in (also triclinic) anorthoclase, the angles between (001) and three faces in the same zone are considered, using Goldschmidt's tables (1897, p. 144) for ϕ and ρ of orthoclase (microcline is not included) in his book).

$(001)\wedge(\bar{2}01)$	$=+80°17'$	or	$-99°43$
$(001)\wedge(40\bar{1})$	$=+99\ 01$	or	$-80\ 59$
$(001)\wedge(15.0.\bar{2})$	$=+107\ 30$	or	$-72\ 30$

If the sign is not taken in consideration the angles between the poles of these faces are (in brackets for microcline):

$\perp(001)\wedge\perp(\bar{2}01)$	$=80°17'$	(79½°)
$\perp(001)\wedge\perp(40\bar{1})$	$=80\ 59$	(81)
$\perp(001)\wedge\perp(15.0.\bar{2})$	$=72\ 30$	(72)
$\perp(001)\wedge[\bar{1}00]$	$=90$	

The coordinates of these three faces for orthoclase and microcline are (of $(\bar{2}01)$ and $(15.0.\bar{2})$ —Nikitin, 1936, p. 94; of $(40\bar{1})$ calculated for orthoclase and graphically determined for microcline, by the writer):

	Orthoclase			Microcline		
$\perp(\bar{2}01)$	90°	75¼°	14¾°	78°	70½°	23°
$\perp(40\bar{1})$	90	86	4	74½	89	15½
$\perp(15.0.\bar{2})$	90	77½	12½	73½	82¾	18¼

In Fig. 2 the pole of $(40\bar{1})$ is drawn in addition to $\perp(100)$, $\perp(15.0.2)$, $[\bar{1}00]$, and $\perp(\bar{2}01)$. It lies half-way between $\perp(\overline{15}.0.2)$ and $[\bar{1}00]$ where Reinhard and Boechlin indicate the pole of the rhombic section (1936, p. 221, fig. 5) assuming that the composition face of the pericline twin has the function of a rhombic section. As it may be seen on Fig. 2 the poles of the three faces for microcline are sufficiently distant to make the distinction among them, especially if also the interfacial angles are considered. However the distinction between $(15.0.\bar{2})$ and $(40\bar{1})$ becomes somewhat difficult if (001) is not visible or if the observations are made under inconvenient conditions. Under the same circumstances the distinction is still more difficult for orthoclase and anorthoclase, especially between the poles of $(15.0.\bar{2})$ and $(\bar{2}01)$.

From the interfacial angles it follows that Dana's data are insufficient and therefore ambiguous; Winchell's data correspond to $(40\bar{1})$, as do Boeggild's concentrations (between $-81°$ and $-85°$). It seems that the mean of poles, as they are shown on the diagram by Reinhard and

[4] Using the *x*-ray method Laves (1950, p. 568) makes the statement that planes (O*k*O) show diffuseness in a direction near [401] which corresponds to the direction in reciprocal space that connects the points $(hkl)-(\bar{h}\bar{k}\bar{l})$ of a pericline twin (in microcline).

Boechlin, would lie close to ⊥ $(40\bar{1})$. The value $\sigma = -75°$ reported by Litmanowicz is closer to that for $(15.0.\bar{2})$ than $(40\bar{1})$.

The poles for the composition face of microcline in the Westkettle rocks show migration around ⊥ $(15.0.\bar{2})$ and ⊥ $(40\bar{1})$; the mean value of the coordinates gives a pole at about half distance between the standard poles of both faces. As the interfacial angle σ is determined only twice in the present work, and this not with sufficient accuracy, only the coordinates can be considered for the determination of the type of the composition face. The fact that a cleavage parallel to the lamellae is visible not only in grain 1/8 but also in 11/6 and 11/8 from the Beaverdell rocks, and that the mean value of coordinates of this face in the Beaverdell rocks is close to those of ⊥ $(15.0.\bar{2})$, seems to justify again the statement that not only $(40\bar{1})$ but also $(15.0.\bar{2})$ must be taken into consideration as composition face of a pericline twinning in microcline.

Further work must be made to establish whether the variations in the position of the composition face are apparent and due only to difficult conditions of the determination caused by the fine twinning, or whether they depend upon the composition of microcline, or the temperature of formation as does the position of the rhombic section in the plagioclase group (Muegge 1930; Winchell, 1951, p. 268).

On the other hand it should not be overlooked that a combination of (001) and $(15.0.\bar{2})$ as twin grating was found twice in the present work but that (001) was never observed to be parallel to a single visible set of lamellae. Twin grating parallel to (010) and (001) was determined recently by G. Wilson in a microcline of a granodiorite of Gambier Island (unpublished master's thesis, 1951) and the same kind of grating seems to be present in Duhovnik's study. As the twin axes were not established and there are, in analogy with the plagioclase group, too many possibilities for multiple twinning with (001) as composition face, it is impossible to say which is the other multiple twin law in microcline in addition to the albite and pericline twin.

Similarly Winchell mentions pericline twinning with one set of "lines" at $-4°$ to $-8°$ with (001) or at $-75°$ to $-78°$ with (001) in anorthoclase (1951, p. 269). It seems that it would be better to make a distinction in form of pericline A and B—as in the Carlsbad twins—between these twins when two entirely different composition faces may be developed. But the fact that two sets of twinning lamellae which follow two faces: (001) and $(15.0.\bar{2})$ can be developed in one grain would rather, require two different names for these twinnings.[5]

[5] Cf. Barth's description of microcline-like cross-hatching in triclinic adularia, according to albite, pericline, and acline laws was confirmed by Koehler (quoted by Chaisson, 1950, p. 540).

Potash-feldspar of the Beaverdell stock

The optical data of the potash-feldspar in the seven thin sections of the Beaverdell stock were divided according to their variation into two groups: 1, from the border, 2, from the inner part of the Beaverdell stock.

K-feldspar from the border of the Beaverdell stock near the Westkettle intrusive (Specimen No. 6). The extremely small variation of the optical angle in the potash-feldspar in this thin section (from $-66\frac{1}{2}°$ to $-68°$, mean $-67°$) suggests that all grains of the potash-feldspar are of the same type although the crystallographic elements show a greater variation in their coordinates. The optic angle, the absence of twin lamellae or even simple twinning, the lack of crystallographic outlines, the occurrence in an intrusive rock and the fact that the poles of some elements are close to those of orthoclase in Nikitin's diagram, confirm that the potash-feldspar belongs to orthoclase and that no anorthoclase (or adularia) is present in this thin section. Nevertheless the average coordinates for ⊥ (001) deviate 2° and less from those in anorthoclase (⊥ (001) —87°, 6°, 85°; Nikitin, 1936, p. 94).

At this point attention should be drawn to Nikitin's statement that an apparent deviation of the crystallographic elements from the monoclinic orientation which were determined by the Fedorov method, together with the lack of twin lamellae do not indicate that the potash-feldspar is an anorthoclase. A relatively strong deviation of a monoclinic orientation seems to follow often from determinations of sanidine or orthoclase by the Fedorov method and a small optic angle may be also found in orthoclase (Nikitin, 1942, p. 285; Spencer, 1937 and others).

Potash-feldspar from the inner part of the Beaverdell stock. Average porphyritic rocks (Specimens No. 7–10), leucocratic granophyric rock (Specimen No. 11, 12). The extremely great variation of 2V and the coordinates of the crystallographic elements required an especially careful examination. The values of 2V and the crystallographic data (twin lamellae, and coordinates of the faces, i.e. the angles mentioned at the beginning of the section dealing with microcline of the Westkettle rocks) were consulted. As most of the grains show heterogeneous extinction and perthitic intergrowth, the determinations were repeated in many cases, and the optical indicatrix measured in several places of the same grain.[6] The determination of grains of apparent anorthoclase proved especially difficult because of the fine twinning and the heterogeneous extinction which both are even more pronounced in anorthoclase than in microcline. In spite of careful examination some of the grains could not be assigned to one type of the potash-feldspar group.

[6] See notes accompanying the tables of the different thin sections.

The data were classed in three groups according to three types of potash-feldspar: microcline, orthoclase, anorthoclase, regardless of some apparently transitional values of optical data. Table 6 gives the optic angles, Table 7 the means of coordinates for three main faces. (The data of section 6 are included in the orthoclase group.) For microcline the value $-74°$ was chosen as the lower limit of 2V, for orthoclase the classical value $-70°$ with the limits $+3°$ and $-3\frac{1}{2}°$. The group of anorthoclase must be especially considered because of orthoclase with a low value of 2V. The phenocrysts of the porphyritic rock (Sections No. 9 and 10) form most of this group. In addition to the normal pink colour, the lack of crystallographic outlines, the relatively small deviation of the monoclinic optical orientation—which all characterize also the orthoclase grains of the Beaverdell rocks (cf. Table 7)—the relatively low value of 2V together with the fine twinning were determining that these grains are

TABLE 6

Thin section	2V in Orthoclase		Microcline		Anorthoclase	
	Mean	Variation	Mean	Variation	Mean	Variation
6	$-67°$ (4)	$-66\frac{1}{2}°$ to $-68°$				
7, 9	-69 (5)	-67 to -72	$-75°$ (2)	$-74°$ to $-76°$	$-57\frac{1}{2}°$ (4)	$-49°$ to $-62°$
8, 10	-69 (3)	-67 to -72	-78 (1)		-57 (2)	-51 to $-65\frac{1}{2}$
11, 12	$-69\frac{1}{2}$ (3)	-68 to -70	$-80\frac{1}{2}$ (2)	-80 to -81	-61 (2)	-60 to -62

regarded as anorthoclase.[7] From the grains in the groundmass three were added to this group: grain 7/14 with $2V=-55°$, 7/10 and 12/3 with $2V=-62°$ and $-61°$ respectively. The latter two values are still lower than 2V in the anorthoclase phenocryst 10/1. (Cf. data and notes of slide No. 10.)

In this way the variation of 2V in the three groups is relatively small and a gap results between the neighbouring limit values. Also the means of 2V are rather well distinct from each other, and seem to justify the division of the potash-feldspar into three groups, although the occurrence of anorthoclase in the groundmass of the Beaverdell rocks is not clearly proved.

The crystallographic elements are determined mostly as cleavage planes and twinning lamellae ((010) and (001)); some of the composition faces in microcline were considered as $(15.0.\bar{2})$, as established in the last paragraph. Although the poles of the parting faces with a small distance to X for orthoclase and anorthoclase migrate strongly in the diagram Fig. 2,

[7] To decide if these grains are not better classified as triclinic orthoclase by analogy with the triclinic adularia determined by Chaisson (1950) and Laves (1950) chemical analyses would be highly desirable.

the average interfacial angle being 73½° (variation from 69° to 76°) agrees with the angle ⊥ (001) ∧ ⊥ (15.0.$\bar{2}$) = 72½° for orthoclase. Due to dusty inclusions of alteration material or stringers in perthites (e.g. grain 12/5) this face may be even better visible than the cleavage parallel to (001). ($\bar{1}$11) and (110) border a perthitic intergrowth and (110) is also a parting plane.

Simple twins which have the appearance of Carlsbad twins, were found to be related by the Manebach twin law in the leucocratic granophyric rock. Carlsbad twinning was recognized only in one of the two phenocrysts examined. The twin laws would indicate that the potash-feldspar in the leucocratic rock was formed at a relatively low temperature and the large crystals in the porphyritic rocks at a higher temperature, according to the statements of Koehler (1949, p. 596).

Table 7 gives the means of coordinates for all grains divided into three groups according to Table 6.

TABLE 7

Symbol	Orthoclase				Anorthoclase				Microcline			
⊥(010)					6½°	84½°	88°	(4)	19½°	85½°	71°	(4)
⊥(001)	85°	8½°	84°	(14)	85½	8½	84	(5)	82½	12	81	(6)
⊥(15.0.$\bar{2}$)	87	79	11½	(9)	85	83½	9½	(3)	72½	84	19	(5)

That the means of these coordinates as they are shown also in Fig. 2 do not lie nearer to Nikitin's standard poles is believed to be caused mainly by unhomogeneous extinction which could be due partly to submicroscopically fine twinning. No explanation can be given using only the Fedorov method why the means of coordinates for ⊥ (001) of orthoclase and of grains which are considered as anorthoclase, are so close to each other.

Perthitic intergrowth in the potash-feldspars

Most of the grains of potash feldspar in the samples of Westkettle and Beaverdell rocks show perthitic structure. However, the proportions of plagioclase and the type of the intergrowth do vary not only in different sections but also in different grains. The perthitic structure is more frequently visible in untwinned microcline, although sometimes it can be observed between the twinning net (samples No. 2 and 3). Evidently the presence of perthitic intergrowth is not related to absence of twinning although Higazy's statement (1949, p. 562) that the microcline portions of perthites are more homogeneous, is confirmed in the present work.

Generally it can be said that the plagioclase content is not only smaller in the perthites of the Westkettle rocks than those of the Beaverdell rocks but also that the blebs have mostly the form of regular or irregular stringers, seldom that of patches. In the Beaverdell rocks plagioclase blebs are more conspicuous and patches more common. These patches may be still regularly outlined as shown in grain 6/6 where two outline faces have the symbols (110) and ($\bar{1}$11). The face ($\bar{1}$11) is not mentioned by Alling in his table on "Cleavage in K-feldspar and orientation of perthitic blebs" (1932, p. 52). The perthitic orthoclase grain 8/7 whose patches seemed more convenient for measurement, gives an idea of the proportion of plagioclase (-9%; the length of the measured line was 27.55 mm.). It is not clear whether Reinecke's general proportions in the "microperthitic intergrowth of anorthoclase or soda-orthoclase and albite" given as 5:1 (1915, p. 48) should correspond to the large grains of the Beaverdell rocks or to the potash-feldspar in the groundmass.

The fact that both types (stringers and patches) are developed in Westkettle and Beaverdell rocks and that in all thin sections grains of potash-feldspar occur without perthitic structure, or that it is not developed uniformly, makes difficult a more exact classification on the conditions of their formation, as proposed by Alling or Anderson. On the other hand the simplified definition of the composite type as given by Wahlstrom (1950, p. 81) is too indefinite to be applied to these perthites. In general it can be said that the perthite of the Westkettle samples is mainly of the exsolution type and that replacement is probably involved in the perthite of the Beaverdell samples, assuming the variation in the form and amount of the blebs lies within the limits which so far have not been closely enough determined.

In three grains the composition of the plagioclase blebs was established using the albite lamellae (cf. Winchell, 1951, p. 299). The value An_{12} in grain 6/6 determined by the Fedorov method is the same as in the unzoned grains in the thin section. In two other grains (7/14 and 12/4) the values An_7 and An_8, respectively, are established from the extinction angle. They are close to the average composition of the plagioclases in these thin sections, being An_4 and An_6 respectively. Similarly two grains from an aplite from the Pohorje massive had included an oligoclase with An_{27} in full agreement with the average composition of the unzoned plagioclase grains (Dolar-Mantuani 1935, p. 83). These examples from different types of rocks explain why oligoclase and albite are mentioned as participating in the perthitic intergrowth in different publications and textbooks. The writer found the highest An-content being An_{34} (using the normative percentages) mentioned by Higazy (1949, p. 561) in perthite pegmatites but this value differs so much from the other fifteen perthites analysed (maximum $An_{12.6}$) that some special explanation seems necessary.

The occurrrence of perthitic plagioclase of the same composition as that of free plagioclase in the rock would be normal (Johannsen, 1939, Part II, p. 140). On the other hand Faessler & Tremblay (1946, pp. 62 & 66), mention an oligoclase in the replacement type of the Lauretian gneisses and albite in the exsolution perthite of the Pine Hill intrusives, both rocks having oligoclase as constituent. As the origin of the perthitic intergrowth is so variable and the composition of the examined plagioclase portion is so contradicting it is too early to make a more definite statement on the influence of the conditions of origin or of the surrounding plagioclases in the rock, on the composition of a perthite.

Conclusion

The detailed study of *plagioclases* of the Westkettle rocks show that andesine is developed in the average rock of the Highland Lass mine and albite-oligoclase in the leucocratic rock of the same mine. No evidence could be obtained that the albite which was found as the only plagioclase in the average sample of the Wellington mine, had been later introduced. Labradorite which has been reported in the rock of the nearby Sally mine (Reinecke, 1915, p. 43) could not be found in any thin section. The plagioclases from the border of the Beaverdell stock correspond to an (acid) oligoclase in agreement with Reinecke's data but from the inner part they are still more acid and correspond to an albite-oligoclase or albite.

The results of Table 5 on the frequency of the different twin laws in plagioclase demonstrate that the statement that the multiple twinning follows the albite or pericline law and the simple twinning the Carlsbad law, is too generalized in most publications. But no rule is found as yet in the order of frequency of different twin laws in relation to different types of rocks, according to these determinations and others of the writer.

The present data indicate that only microcline occurs as *potash-feldspar* in the Westkettle rocks near Beaverdell although some of the grains do not show net structure in the whole grain or in parts of them. Some deviations which are established from the normal values of 2V and of coordinates of the crystallographic elements of microcline are believed to be due to inexact determinations because of difficult conditions of observation. These data do not indicate an intergrowth of orthoclase and microcline which would be suggested by the frequently heterogeneous extinction which is typical for this type of intergrowth (Prof. M. Reinhard's written communication) neither do they confirm gradation to another type of potash-feldspar. An "undulatory" extinction in optically triclinic microcline without observable twin lamellae is explained by F. Laves as to be produced by variation of the proportions of right and left (submicroscopical) twin positions (Laves 1950, p. 553). Provided, however, a gradation be assumed in the potash-feldspar of the Westkettle rocks on Wallace mountain, it would be from microcline to orthoclase and would be limited to only a few grains. In any case the present data do not support Reinecke's statement that only orthoclase is present in Westkettle rocks.

Detailed microscopical examinations indicate that the face $(15.0.\bar{2})$ known as murchisonite cleavage in potash-feldspars, may be the composition face in microcline twinning. As no twin lamellae were wide enough to determine the optical indicatrix of each set of lamellae of the twinning with $(15.0.\bar{2})$ as composition face, the twin axis could not be determined using the Fedorov method. Also the function of (001) obtained only twice as composition face—and this always together with $(15.0.\bar{2})$—is not clear but argues for development of two different twin laws in addition to the albite law which form the cross grating structure of microcline.

From the border of the Beaverdell stock one section of the matrix was available. Only orthoclase was determined in this slide. The identification of large grains from this porphyritic rock would be interesting for comparison with the phenocrysts from the more central part of the Beaverdell stock.

The fine lamellar large grains of the rocks from the central part of the Beaverdell stock have special features. If their development as Carlsbad twins on one hand, and their irregular borders together with the amount, type and distribution of the inclusions in them on the other hand is considered, these large grains formed at a higher temperature and increased in size by later replacement. The anhedral border is in disagreement with the statement of Reinecke that "K-feldspar is very clear cut in outline and nearly always formed according to the Carlsbad law" (1915, p. 48). The formation of the phenocrysts at high temperature would be confirmed by the fact that they seem to be anorthoclase (c.f. Bowen & Tuttle, 1950 p. 509) and the replacement of their borders is supported by the evidence of replacement found in the described rock. But although the value of 2V varies in large limits in one phenocryst (tables and notes of sections No. 9 and 10) no evidence was found that the variation of 2V depends upon the place where it was measured or that some rim would show different characteristics in comparison with the core.

Some indications such as a relatively low 2V and striate extinction suggest that also some rare grains in the groundmass and in the granophyric rock from the inner part of the Beaverdell stock are anorthoclase. The presence of anorthoclase in addition to orthoclase and microcline in one rock is surprising and demands a special explanation of the origin of the rock. On the other hand the observed Manebach twins in the potash feldspars and the cross-twins in plagioclases of the granophyric leucocratic rock from the Beaverdell stock would indicate a relatively low temperature at the formation of this rock (cf. the "Roc-Tourné-type" twins in authigenic albites of the "Muschelkalk" formation near Goettingen; Fuechtbauer, 1950 p. 246). To classify these potash-feldspars, especially from the granophyric rock as triclinic orthoclase would make the petrogenesis of the Beaverdell stock much simpler. As the coordinates of $\perp$ (001) and partly $\perp$ (15.0.$\bar{2}$) are very close for orthoclase and anorthoclase in the present rocks (Table 7), further proof (chiefly using chemical tests) is needed for occurrence of anorthoclase in the Beaverdell stock.

The results also show that both orthoclase and microcline are present in some grains. No evidence could be obtained that would show whether the orthoclase grades gradually into microcline or whether it is intergrown with the latter somewhat as in the perthite the potash-feldspar and plagioclase with more or less sharply distinguishable outlines.

The type of the relatively indistinct perthitic structure in the potash-feldspar of Westkettle and Beaverdell rocks indicates that the perthite in the former rocks is of exsolution type, that in the latter of replacement type, but it is not known whether some essential difference exists between the perthitic structure in different types of potash-feldspar. It is also uncertain whether the composition of plagioclase blebs is influenced by the composition of the surrounding plagioclases as established here or by the type of origin.

The study shows some difficulties which arise using even the Fedorov method for detailed determination of the feldspar group which is seen to be more and more complicated. For the feldspars investigated, further determination on a greater number of specimens should be made to illustrate the distribution of the more acid plagioclases, their possibly special origin, and (as suggested in the study of White and Dolar-Mantuani) the closer relations between the Westkettle and Beaverdell rocks. It would be of interest to see whether some regularity can be found in the distribution or time of origin of the different types of potash-feldspar in the Beaverdell stock.

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