

PHYSICAL PROPERTIES OF ANORTHOCLASE  
FROM ANTARCTICA<sup>1</sup>

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ABSTRACT

The lattice parameters of anorthoclase [ $\text{Or}_{15.7}\text{Ab}_{74.2}\text{An}_{10.1}$  (mol per cent)] from the Crary Mountains, and anorthoclase [ $\text{Or}_{16.8}\text{Ab}_{64.8}\text{An}_{18.4}$  (mol per cent)] from Cape Royds, Ross Island, Antarctica, have been determined from *x*-ray diffractometer patterns by a least-squares cell refinement program. Chemical and spectrographic analyses and optical data are also furnished from the feldspar and Quaternary alkaline trachytes in which they occur. The Cape Royds feldspar is markedly higher in An content than any anorthoclase in which lattice parameters have been determined. Both suites of new data compare favorably with data from other modern work, considering that different methods of measurement are involved.

The antarctic anorthoclase is believed to be highly disordered and it differs optically from average anorthoclase by higher indices of refraction and 2*V*. The Cape Royds rock which bears the anorthoclase contains 7.4 per cent normative nepheline which is manifested by sodalite(?) in the mode. The partitioning of sodium to the sodalite is believed to be responsible for the unusually high An content of the Cape Royds feldspar, although the latter is not predicted in the norm.

INTRODUCTION

The composition, optical properties, and lattice parameters of anorthoclase from the Crary Mountains, West Antarctica (lat. 76°05'S.; long. 118°15'W.) and from Cape Royds, Ross Island, East Antarctica (lat. 77°30'S.; long. 166°15'E.) (Fig. 1) have been determined as part of a study of Quaternary rhomb porphyry trachytes associated in an antarctic alkaline basalt-trachyte province. The crystals occur as conspicuous phenocrysts in trachyte flows that were first described in detail on Ross Island by Prior (1907) and subsequently aroused considerable interest for their comparison to kenyte of the African Rift. These phenocrysts have been classified variously as anorthoclase or plagioclase in antarctic literature (see for example David and Priestly, 1914; Jensen, 1916; Woolnough, 1916; Smith, 1954; and Treves, 1962).

The present work was undertaken to clarify the nature of these feldspars and to compare them to the ternary feldspars recently described by Carmichael and MacKenzie (1964).

Trachyte from the Crary Mountains was collected in 1959 by Boudette as a member of the 1950-60 U.S. Byrdland Oversnow Traverse. The Cape Royds trachyte was collected in 1961 by Ford and J. M. Aaron in conjunction with special field studies of the occurrence of the trachyte.

<sup>1</sup> Publication authorized by the Director, U.S. Geological Survey.

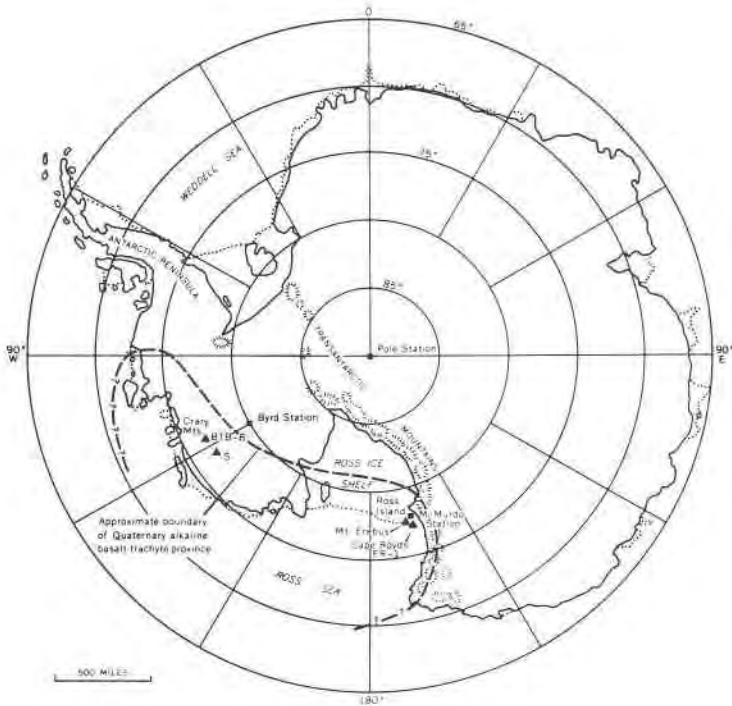


FIG. 1. Index map of Antarctica showing extent of Quaternary alkaline basalt-trachyte province and anorthoclase trachyte localities ( $\blacktriangle$ ). Anorthoclase from locality "S" (at Mt. Sidley, Executive Committee Range) is not specifically described.

#### METHODS AND SAMPLES

Neither of the samples has been previously analyzed chemically or studied structurally. However, Carmichael and MacKenzie (1964, p. 950–957, sample No. 8) describe anorthoclase from the summit of Mt. Erebus on Ross Island, Antarctica (Fig. 1, Table 1) that is comparable in occurrence. The occurrence, chemical analysis, texture and morphology of Mt. Erebus feldspar have been reported by Mountain (1925) and Jensen (1916); Carmichael and MacKenzie do not specify which sample was used in their work.

Calculations of the theoretical feldspar molecules from the analyses were made on the basis of 32 oxygens (Deer, *et al.* 1963, p. 106–107). We assumed that Ba substitutes for K, and Sr for Ca, but have not computed Cn and  $Fs_{(Sr)}$  in the theoretical molecule (Table 1).

The chemical analyses, modes and norms of the rocks containing the feldspars described herein are given in Table 2. Crary Mountains sample

TABLE 1. CHEMICAL ANALYSES IN WEIGHT PER CENT AND CALCULATED COMPOSITION OF ANORTHOCLASE FROM ANTARCTICA

	Crary Mts, <sup>1</sup> BTB-8	Cape Royds, <sup>1</sup> Ross Island FR-1	Summit Mt. Erebus, Ross Island			
			No. 8 <sup>2</sup>	A <sup>3</sup>	B <sup>4</sup>	C <sup>5</sup>
SiO <sub>2</sub>	65.4	62.8	65.23	62.79	62.49	60.83
Al <sub>2</sub> O <sub>3</sub>	21.3	22.2	20.68	22.12	21.86	23.92
Fe <sub>2</sub> O <sub>3</sub>	.10	.18	.20	.36	.30	.11
FeO	.10	.20	—	.41	1.31	2.14
MgO	.10	.05	—	.00	.16	.07
CaO	2.0	3.7	.87	3.76	3.74	3.39
BaO	.2*	.15*	.18	—	—	—
SrO	.07*	.15*	.22	—	—	—
Na <sub>2</sub> O	8.2	7.2	8.45	7.35	7.20	6.11
K <sub>2</sub> O	2.6	2.8	3.78	2.98	3.26	2.96
H <sub>2</sub> O <sup>+</sup>	.12	.28	.26	.19	.04	.07
H <sub>2</sub> O <sup>-</sup>	.00	.00	.06	.07	.00	.12
TiO <sub>2</sub>	.05	.15	—	—	—	.36
P <sub>2</sub> O <sub>5</sub>	.07	.06	—	—	—	—
MnO	.00	.00	—	—	—	—
Total	100	99.6	99.93	100.03	100.36	100.08
Number of ions on the basis of 32(O) <sup>6</sup>						
Si	11,5804	11,2771	11,6686	11,257	11,211	10,9289
Al	4,4409	4,6961	4,3583	4,675	4,623	5,0657
Fe <sup>+3</sup>	.0213	.0215	.0215	0,048	0,041	0,0215
Ti	.0107	.0216	—	—	—	0,0539
Mg	.0319	.0107	—	—	0,043	0,0216
Fe <sup>+2</sup>	.0106	.0323	—	0,061	0,196	0,3233
Na	2,8048	2,4988	2,9198	2,554	2,504	2,1340
Ca	.3825	.7109	.1718	.722	.719	.6575
Sr	—	—	.0215	—	—	—
K	.5950	.6462	.8588	.681	.746	.6682
Ba	—	—	.0107	—	—	—
ΣZ	16,0533	16,0163	16,0484	15,98	16,07	16,07
ΣW	3,8248	3,8989	3,9826	4,02	4,01	3,80
Or	15.7	16.8	21.8	17.0	18.6	19.3
Ab <sup>7</sup> (Mol%)	74.2	64.8	73.3	63.5	62.4	61.7
An <sup>7</sup>	10.1	18.4	4.9	19.5	19.0	19.0
α	1,5308	1,5372	—	1,536	1,536	—
β	1,5364	1,5416	—	1,539	1,539	—
γ	1,5380	1,5430	—	1,541	1,541	—
2Vα <sup>7</sup>	55.9	59.3	—	61,6°	61,6°	—
2Vα <sup>8</sup>	53.2°	61,9	—	62°	62°	—
Ext. on {010}	6°-7°	—	—	4,7°	2,6°	—
Sp gr	2,54**	2,50**	—	2,620	2,620	—

<sup>1</sup> Chemical analysis by Paul Elmore, Sam Botts, Gillison Chloe, Lowell Artis, and H. Smith by x-ray fluorescence methods supplemented by methods described by Shapiro and Brannock (1962).

<sup>2</sup> Specimen No. 8 of Carmichael and MacKenzie (1964, p. 950, Table 1).

<sup>3</sup> "Potash-oligoclase, Type 1" of Mountain (1925, p. 336); Analyst: E. D. Mountain. Theoretical molecule from Deer *et al.* (1963, p. 42).

<sup>4</sup> "Potash-oligoclase, Type 1" of Mountain (1925, p. 336); Analyst; E. D. Mountain. Theoretical molecule from Deer *et al.* (1963, p. 42).

<sup>5</sup> "Anorthoclase" of Jensen (1916, p. 122); Analysts: G. E. Burrows and A. B. Walkom.

<sup>6</sup> After the method of Deer, *et al.* (1963, p. 106-107).

<sup>7</sup> Calculated from refractive indices.

<sup>8</sup> Direct optical measurement methods. BTB-8 and FR-1 measured by universal stage techniques.

\* Semiquantitative spectrographic analysis by J. L. Harris. Results are reported in percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1, etc.; which represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30% of the time. *Not included in analysis summation.*

\*\* Determined with specific gravity bottle and toluene by Blanche Ingram. Precision ± 0.05.

TABLE 2. CHEMICAL ANALYSES, NORMS, MODES, AND SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSES OF ANTARCTIC ANORTHOCLASE TRACHYTES

Field No. Lab. No.	BTB-8 159615	FR-1 163086					
			Plagioclase*		0.7		
			Clinopyroxene*	<0.3	1.3		
			Olivine*	0.3	0.4		
			Ore minerals*	0.2	5.1		
			"K-feldspar"***	3.0	2.1		
			Plagioclase**	10.4	14.5		
			Orthopyroxene	Sp	—		
			Clinopyroxene**	—	Sp		
			Olivine**	Sp	Sp		
			Amphibole**	Sp	—		
			Apatite	Tr	Tr		
			Calcite	Tr	—		
			"Iddingsite"***	Tr	Tr		
			"Zeolites"	0.1	—		
			Glass**	A	Sp-A		
			Ore minerals**	Sp	Sp-A		
			(A+Sp+Tr)	54.7	42.6		
			Estimated % An in groundmass plagioclase	(25)	(25)		
Sum	99	100	Sum	100	100		
Powder density by air pycnometer	2.69	2.68	A = major component, Sp = sparse, Tr = trace amount. * Reported as phenocryst, may also be in groundmass if indicated. ** Groundmass constituent.				
C.I.P.W. Norms			Semiquantitative spectrographic analyses <sup>3</sup>				
Orthoclase	21.1	22.8	B	.0007	.0007		
Albite	58.7	49.8	Ba	.15	.1		
Anorthite	7.0	6.7	Be	.0005	.0007		
Nepheline	2.6	7.4	Ce	.07	.07		
Corundum	—	1.0	Co	—	.0037		
Diopside { Wo 0.4 En 0.2 Fs 0.1 Fo 1.3	0.7	2.1	Cu	.001	.0007		
Olivine { Fa 0.8			4.3	Ga	.003	.003	
Magnetite				5.6	2.8	La	.02
Ilmenite			1.5	2.3	Mo	.0007	.001
Hematite	—	—	Nb	.01	.015		
Apatite	0.7	3.0	Nd	.02	.03		
Sum	100	100.1	Sc	.0005	.0005		
			Sr	.05	.15		
			V	—	.002		
			Y	.005	.005		
			Yb	.0005	.0005		
			Zr	.1	.15		
			Looked for, but not found: Ag, As, Au, Bi, Cd, Cr, Eu, Ge, Hf, Hg, In, Li, Ni, Pb, Pd, Pt, Pr, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, U, W, Zn, Pr.				
Modes (volume per cent) <sup>2</sup>							
Anorthoclase*	31.0	33.3					

<sup>1</sup> BTB-8, Crary Mountains, West Antarctica; FR-1, Cape Royds, Ross Island, Ross Archipelago, Antarctica. Analysts: Paul Elmore, Samuel Botts, Gillison Chloe. Analyzed by methods similar to those described by Shapiro and Brannock (1962).

<sup>2</sup> The ratios of phenocrysts to groundmass in the trachyte were made by a macroscopic grid counting of sawed slabs; groundmass modes were point counted microscopically by the Chayes method and then combined with the macroscopic count and recalculated as the reported rock modes.

<sup>3</sup> Analyst: J. L. Harris. Results are reported, in per cent, to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1, etc.; which represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30% of the time.

(BTB-8) is from a moraine, but the location of the source can be inferred from the radial flow of ice from the mountain slopes and the abundance of the lithology in the moraine. The sample from Cape Royds, Ross Island, (Fr-1) is from the upper part of a flow about 50 feet thick. The similarity of the texture of the Crary Mountains specimen to that of the FR-1 trachyte (Fig. 2 a, b) leaves little doubt that the former is also from a similar flow.

The anorthoclase is optically homogenous but extremely poikilitic; the latter feature necessitates careful purification. The inclusions are olivine, pyroxene, apatite, ore minerals, and groundmass microlites and glass. BTB-8 is noticeably zoned in oscillatory habit; the zoning in FR-1 is not conspicuous (Fig. 2). The anorthoclase is partly glomeroporphyritic and partly in mosaic aggregates which appear in hand specimen as single morphological euhedra (Fig. 2 a, b). Some individual crystals appear to be complexly twinned, in part on the Carlsbad law, but the most conspicuous twinning is close spaced (0.05 mm) lamellar albite twinning which is present in all individuals, and commonly a second, finer reticulated polysynthetic pericline(?) twinning is developed nearly at right angles which produces a fine cross-hatch (microcline-like) twinning pattern (Fig. 2 c, d). Textural evidence for "flow cataclasis" in the trachyte leaves the explanation of the second polysynthetic twinning open to reasonable doubt; it may be strain twinning and not truly pericline, although we favor the interpretation that it is pericline on the basis of its orientation.

Preliminary preparation of samples was done by gravity and magnetic purification of the 100–200 mesh fraction of crushed anorthoclase crystals handpicked from broken large sawed slabs of trachyte. We therefore consider the samples to be representative of the bulk specimens. Purified anorthoclase was first checked on the  $x$ -ray diffractometer for possible contamination and homogeneity by scanning between  $7^\circ$  and  $60^\circ 2\theta$ ; neither sample required further purification and both were reasonably homogeneous. Individual samples, after being ground in an agate mortar with fluorite ( $a=5.4620 \text{ \AA}$ ) for 5–10 minutes, were made into a smear mount on a (0001) quartz plate and were traversed 3 times between  $13^\circ$  and  $56^\circ 2\theta$  on a diffractometer using Ni filtered Cu radiation at 45KV and 20 ma. The diffractometer settings were: scale factor 2; multiplier 1; time constant 4, divergence and scatter slits  $1^\circ$ ; receiving slit 0.006; scanning speed  $\frac{1}{2}^\circ 2\theta$  per minute; and chart speed  $\frac{1}{2}$  inch per minute. All recognizable reflections were measured at the top of the peak, and the measurements were adjusted by the amount indicated by the internal standard. The average of the three measurements were used in the refinement, with Cu  $K\alpha_1=1.5405 \text{ \AA}$ . The feldspar patterns were refined using



FIG. 2. Photomicrographs showing texture of anorthoclase trachyte BTB-8 (a) and FR-1 (b), and twinning in anorthoclase phenocrysts in BTB-8 (c), and FR-1 (d). crossed polars.

TABLE 3. LATTICE PARAMETERS OF HOMOGENEOUS ANORTHOCLEASE FROM ANTARCTICA

	$a\text{\AA}$	$b\text{\AA}$	$c\text{\AA}$	$\alpha$	$\beta$	$\gamma$	$V\text{\AA}^3$	$a^*\text{\AA}^{-1}$	$b^*\text{\AA}^{-1}$	$c^*\text{\AA}^{-1}$	$\alpha^*$	$\beta^*$	$\gamma^*$	Std. error unit Wt.	Number of observations
BTB-8 $\pm$	8.211 .004	12.910 .002	7.129 .002	92°39.4' 1.3'	116°21.9' 1.9'	90°14.0' 1.5'	676.1 ~1.0	.1360 .0001	<.0001	0.1569	86°55.2' 1.1'	63°35.5' 1.9'	88°25.3' 1.2'	0.0150	(22)
FR-1 $\pm$	8.228 .003	12.915 .002	7.127 .001	92°35.6' 1.4'	116°18.2' 1.2'	90°16.9' 1.5'	677.9 ~1.0	.1356 .0001	<.0001	.1567	86°58.0' 1.1'	63°39.1' 1.2'	88°24.1' 1.3'	0.0099	(18)
"8" <sup>1</sup>	8.263	12.935	7.138	92°15.6'	116°19.8'	90°10.8'	683.0	.1350	.0770	.1560	87.39°	63.64°	88.68°		

<sup>1</sup> From Carmichael and MacKenzie (1964, p. 956, Table 3).

TABLE 4. INDEXED POWDER PATTERNS OF ANORTHOCLASES FROM ANTARCTICA

hkl	BTB-8		FR-1		$\bar{2}41$	2.529	2.525	2.531	2.527
	$d_{\text{calc}}^1$	$d_{\text{obs}}^2$	$d_{\text{calc}}^1$	$d_{\text{obs}}^2$					
$\bar{1}10$	6.465		6.479		$\bar{2}41$	2.520		2.523	
020	6.446	6.449	6.448	6.453	$\bar{1}\bar{1}2$	2.519		2.522	
001	6.378	6.388	6.380		$\bar{3}12$	2.517		2.520	
110	6.313		6.325		112	2.470		2.473	
$\bar{1}\bar{1}1$	5.832		5.832		221	2.458		2.463	
$\bar{1}11$	5.693		5.698		$\bar{2}40$	2.457		2.461	
0 $\bar{2}1$	4.661		4.660		$\bar{1}50$	2.454		2.456	
021	4.417		4.420		$\bar{3}10$	2.421		2.427	
$\bar{2}01$	4.062	4.064	4.069	4.068	$\bar{1}\bar{5}1$	2.419		2.419	
$\bar{1}\bar{1}1$	3.888	3.889	3.893	3.894	150	2.412		2.414	
111	3.781	3.781	3.787	3.787	310	2.396		2.402	
$\bar{1}30$	3.775	3.757	3.760	3.760	240	2.391		2.394	
200	3.677		3.686		$\bar{1}51$	2.369		2.371	
130	3.666	3.666	3.669	3.667	$\bar{2}03$	2.348		2.348	
$\bar{1}\bar{3}1$	3.625	3.626	3.625	3.627	042	2.330		2.330	
$\bar{1}31$	3.526		3.529		$\bar{1}\bar{1}3$	2.322		2.321	
$\bar{1}\bar{1}2$	3.474	3.473	3.472	3.471	$\bar{2}42$	2.313		2.317	
$\bar{2}21$	3.442		3.446		$\bar{3}31$	2.313		2.313	
$\bar{2}21$	3.431		3.436		$\bar{3}31$	2.297		2.300	
112	3.392	3.391	3.392	3.391	$\bar{1}13$	2.281		2.281	
$\bar{2}20$	3.232		3.240		$\bar{2}42$	2.2444		2.246	
040	3.223	3.223	3.224	3.223	1 $\bar{3}2$	2.2399		2.242	
$\bar{2}02$	3.220		3.221						
002	3.189		3.190						
220	3.157	3.190	3.163	3.191					
1 $\bar{3}1$	3.008	3.008	3.011	3.010	$\bar{2}23$	2.2363		2.2353	
041	2.941	2.940	2.941	2.940	$\bar{3}32$	2.2222		2.2234	
0 $\bar{2}2$	2.922	2.921	2.922	2.921	$\bar{1}51$	2.2193		2.2207	
$\bar{2}22$	2.916		2.916		042	2.2083		2.2100	
131	2.865	2.867	2.868	2.869	$\bar{3}32$	2.1941		2.1971	
$\bar{2}22$	2.847		2.849		$\bar{2}23$	2.1770		2.1777	
041	2.816		2.818		$\bar{3}30$	2.1549		2.1597	
$\bar{1}\bar{3}2$	2.807	2.806	2.805	2.806	060	2.1485	2.1498	2.1494	2.1493
022	2.799		2.801		151	2.1228	2.1214	2.1247	
201	2.707		2.713		$\bar{2}41$	2.1182		2.1212	2.1214
$\bar{1}32$	2.681	2.681	2.682	2.683	061	2.0038	2.0035	2.0051	
$\bar{3}11$	2.676		2.682		260	1.8332	1.8332	1.8347	
$\bar{3}11$	2.667		2.673		0 $\bar{6}2$	1.8280	1.8280	1.8279	
$\bar{2}21$	2.535		2.540		$\bar{3}50$	1.8015	1.8010	1.8046	1.8027
$\bar{3}12$	2.531		2.533		$\bar{2}04$	1.7802	1.7804	1.7799	1.7800

<sup>1</sup> All calculated spacings are given for  $d \geq 2.150 \text{ \AA}$ ; calculated spacings less than  $2.150 \text{ \AA}$  are given only when they correspond to an indexed observed reflection.

<sup>2</sup> Average of three observations with annealed  $\text{CaF}_2$  as internal standard,  $a = 5.462 \text{ \AA}$  at  $25^\circ \text{ C}$ . Ni-filtered  $\text{CuK}\alpha$  radiation ( $\lambda = 1.5405 \text{ \AA}$ ). Lower limit of  $2\theta$  measured =  $13^\circ \text{ CuK}\alpha$  ( $6.809 \text{ \AA}$ ). Pattern obtained at  $26^\circ \text{ C}$ .

the variable index option of the least-squares refinement program devised by Evans, Appleman, and Handwerker (1963). Between 18 and 22 unambiguous reflections of the 25 or so present were used to calculate the lattice parameters in the 3rd or 4th cycle of the refinement. The standard deviation between observed and calculated  $2\theta$  for each sample was 0.0151 or less (Table 3). Observed and indexed lines are given in Table 4.



## RESULTS

In the nomenclature of Smith and MacKenzie (1958) our samples are anorthoclase (Fig. 3). Comparison of the measured lattice parameters with those of the anorthoclase from Antarctica described by Carmichael and MacKenzie (1964) is given in Table 3. A graphical comparison of our

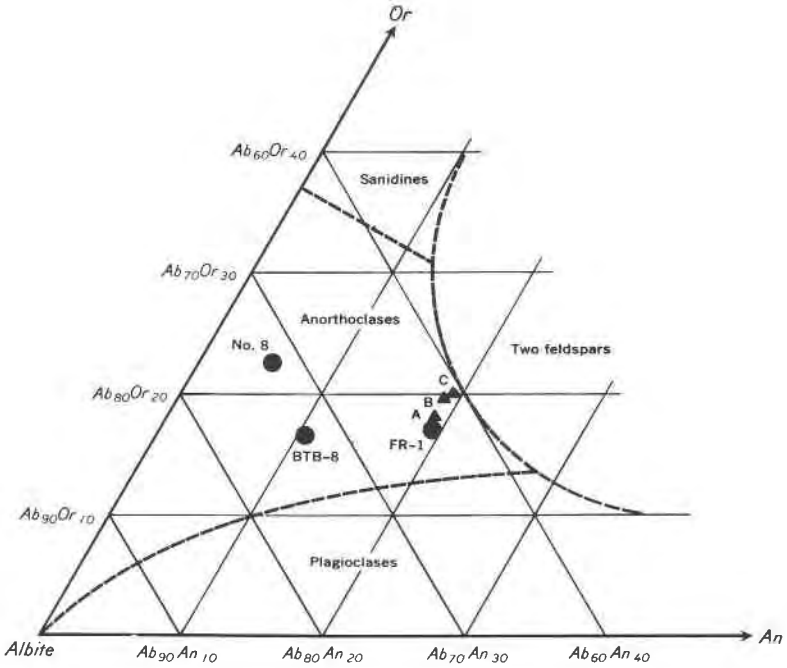


FIG. 3. Ternary diagram (after Smith and MacKenzie, 1958, p. 874) showing plots (weight percent) of analyzed anorthoclase from Antarctica. BTB-8 and FR-1, this report; No. 8, Carmichael and MacKenzie (1964); A and B, Mountain (1925, p. 336); and C., Jensen (1916, p. 122). Anorthoclase of this report and sample No. 8 of Carmichael and MacKenzie shown as circles; other Ross Island anorthoclases (Table 1) shown as triangles (lattice parameters *not* available).

anorthoclase with the anorthoclase described by Carmichael and MacKenzie (1964, figs. 1, 2, and 3) has been made on Figs. 4, 5, and 6 (Table 5). It is important to note that composite samples were used for the present study in contrast to the selected crystals used by Carmichael and MacKenzie, the Cn and Fs<sub>(Sr)</sub> components are not computed in the ternary composition calculations of BTB-8 and FR-1 (Tables 1 and 5), the samples were not heated, and a different method of measurement was used in the determination of the lattice parameters.

The chemical analysis of the Mt. Erebus summit sample given by Carmichael and MacKenzie (1964) differs markedly in CaO and K<sub>2</sub>O content from the comparably occurring anorthoclase described herein, as well as from a previous analysis of anorthoclase from Mt. Erebus (Table 1, Fig. 3). The "Z" and "X" summations of both the old and the new

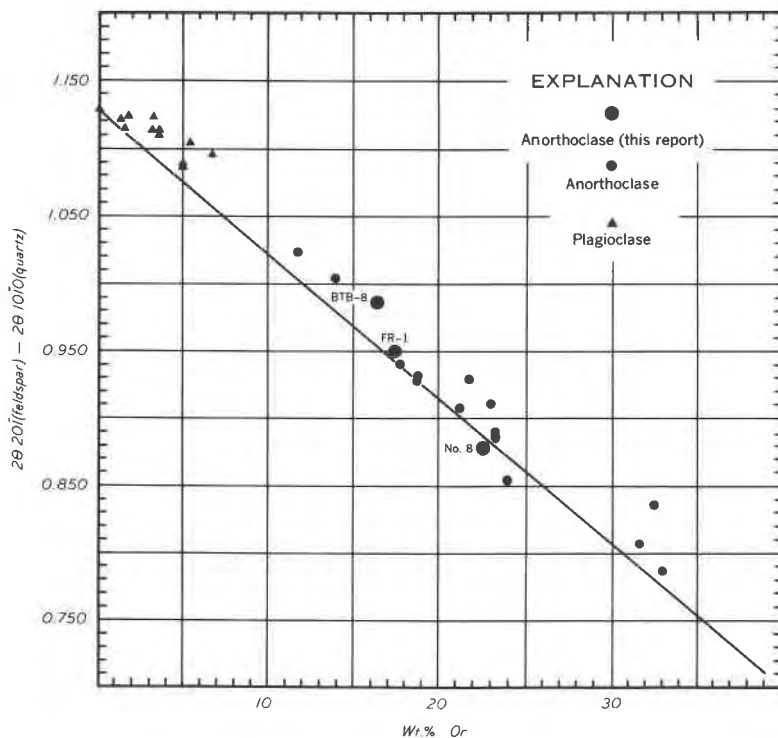


FIG. 4.  $2\theta(201) - 2\theta(1010)_{\text{quartz}}$  of anorthoclase and plagioclase plotted against Or content found by chemical analysis (after Carmichael and MacKenzie; 1964; p. 953, Fig. 1) showing comparison of anorthoclase of this report (Table 5).

analyses are good. Carmichael and MacKenzie (1964), however, worked on a selected crystal which when compared to the composite sample reported by Deer *et al.* (1963) may account for the difference in composition.

The  $2\theta(201)_{\text{Fs}} - 2\theta(1010)_{\text{Qtz}}$  separation plotted against weight per cent Or for BTB-8 shows the most divergence from the curve of Carmichael and McKenzie (1964, p. 953, Fig. 1), and its analysis is possibly suspect; however, it was made at the same time by the same analysts as FR-1

(Table 1) which is apparently a good analysis by the criteria of the  $2\theta$  separation used and  $\Sigma X$  and  $\Sigma Z$  (Table 1).

The determined lattice parameters  $\alpha^*$  and cell volume are reasonably compatible with the findings of Carmichael and MacKenzie (Figs. 5 and 6). FR-1 plots outside the anorthoclase field erected by Carmichael and MacKenzie (1964, Figs. 2 and 3), but it may furnish valid data for ex-

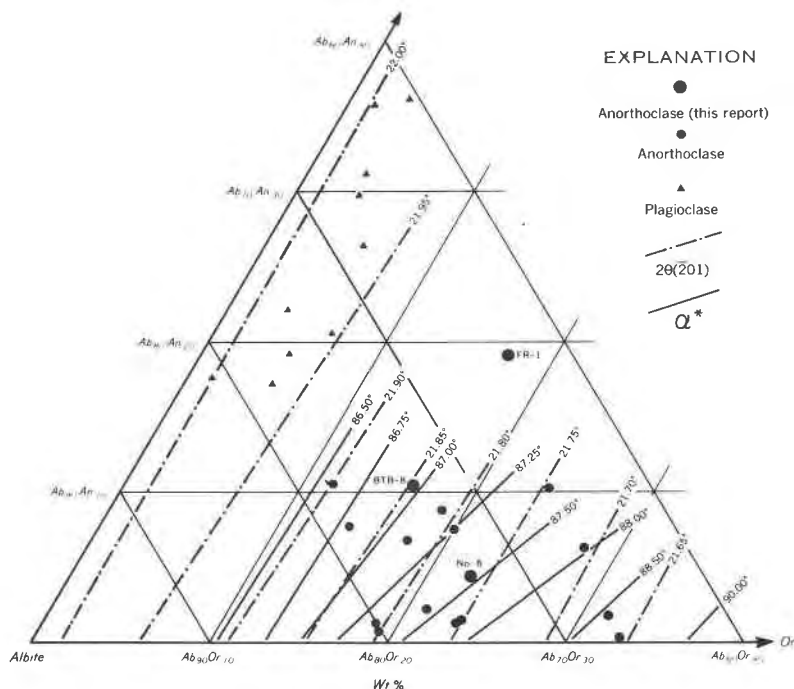


FIG. 5. Analyzed anorthoclase and plagioclase plotted in the Ab-rich portion of the ternary feldspar diagram (after Carmichael and MacKenzie; 1964, p. 954, Fig. 2) showing comparison of theoretical to measured  $2\theta(201)$  and  $\alpha^*$  of anorthoclase from this report (Table 5).

tending the  $2\theta(201)$ ,  $\alpha^*$ , and cell volume curves in the direction of the tie line between  $Or_{40}Ab_{60}$  and  $An_{40}Ab_{60}$  because of the good agreement with the curve in Fig. 2, and it is anorthoclase of the highest An content for which the lattice parameters are known to us.

Carmichael and MacKenzie (1964, p. 960) believe that the curves of variation of  $\alpha^*$  and  $2\theta(201)_{Fs} - 2\theta(1010)_{Qtz}$  when used in combination provide an x-ray method of determining ternary composition of feldspars more potassic than  $Or_{15}$ . Our determined parameters for BTB-8 and FR-1

would not, however, provide an accurate ternary composition (compared to the chemical analyses) using the curves (Figs. 4 and 5). FR-1 plots outside the data field, and although its Or content can be predicted quite accurately, the Ab-An ratio cannot be determined from the  $\alpha^*$  curve intersection. If the  $\alpha^*$  curves are extrapolated for FR-1, the feldspar would be estimated to be more sodic than its analysis shows. BTB-8

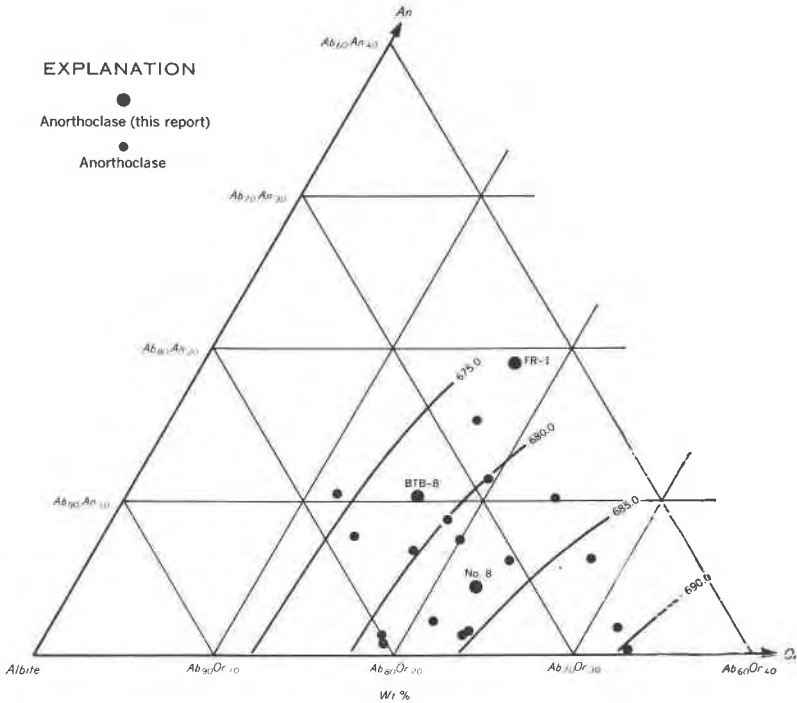


FIG. 6. Analyzed anorthoclase plotted in the Ab-rich corner of the ternary feldspar diagram showing variation in the cell volume (after Carmichael and MacKenzie; 1964, p. 955, Fig. 3). The comparison of anorthoclase of this report is shown (Table 5).

would be initially estimated to contain less than  $Or_{15}$  (Fig. 4), and hence the above curves would not be applicable.

The danger of rigidly comparing our lattice parameter determinations to the curves erected from the data of Carmichael and MacKenzie (1964) has been indicated above. Because of possible differences in the method of measurement it may not be possible to compare rigorously the results. It is obvious that duplicate samples should be run before a more quantitative comparison is made.

Simple criteria are not available to determine with confidence the

structural state of each of the antarctic anorthoclases (*cf.* Carmichael and MacKenzie, 1964, p. 961). Our graphic comparison (Figs. 4, 5, 6) with the homogeneous anorthoclases of Carmichael and MacKenzie (1964) indicates, however, that sample FR-1 is highly disordered and sample BTB-8 may be somewhat more ordered. It is possible that the divergence of the plot of BTB-8 from the  $2\theta(\bar{2}01)_{Fs} - 2\theta(10\bar{1}0)_{Qtz}$  curve (Fig. 4) is attributable to structural state. A general comparison of the optics reported herein and the optics reported in the literature for all anorthoclases indicates many similarities; refractive indices and  $2V$ 's of antarctic anorthoclases tend to be higher than usual. That the refractive

TABLE 5. SOME COMPARISONS OF PARAMETERS FOR ANORTHOCLEASE FROM ANTARCTICA

[Ternary composition is given for each sample as calculated from  $K_2O$ ,  $Na_2O$ , and  $CaO$  by direct weight per cent molecular proportion. These values are given for comparison in Figs. 3, 4, 5 and 6, and differ somewhat from ternary composition (mol per cent) determined by the 32 oxygen method (see Table 1)]

	Weight per cent			$2\theta(\bar{2}01)^1$	$2\theta(\bar{2}01) - 2\theta(10\bar{1}0)_{Qtz}^2$	$-\alpha_n^*$	V Å <sup>3</sup>
	Or	Ab	An				
BTB-8	(16.3)	(73.3)	(10.4)	21.8630°	0.987	86.92°	676.1
FR-1	(17.4)	(63.4)	(19.2)	21.8257°	.950	86.97°	677.9
No. 8 <sup>3</sup>	(22.9)	(72.0)	(5.1)	21.7550°	.879	87.39°	683.0
A	(18.0)	(19.7)	(20.0)	Lattice parameters not available			
B	(63.1)	(61.5)	(60.3)	Lattice parameters not available			
C	(18.9)	(18.8)	(19.7)	Lattice parameters not available			

<sup>1</sup> Cu radiation, Ni filtered.

<sup>2</sup>  $2\theta = 20.876^\circ$ .

<sup>3</sup> Specimen 8 of Carmichael and MacKenzie (1964, p. 950); includes Cn and Fs (st).

indices and optic angle of the Cape Royds anorthoclase (FR-1) is significantly higher than the rest is attributable to its notably higher An content.

The FR-1 rock is distinctly more silica undersaturated than rock BTB-8 to the extent that 7.4% normative nepheline is present (Table 2). The Or-Ab-An ratio in the normative feldspar in rocks FR-1 and BTB-8 are closely comparable (Table 2), and hence the partitioning of feldspar components, in particular Ab, is not accurately predicted in the norm as compared to the analyses. We have made a tentative identification of sodalite in rock FR-1. We believe that the sodium was partitioned into the sodalite, resulting in corresponding decrease in the relative Ab-An ratio.

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## REFERENCES

- CARMICHAEL, I. S. E. AND W. S. MACKENZIE (1964) The lattice parameters of high-temperature triclinic sodic feldspars. *Mineral. Mag.* **33**, 949-962.
- DAVID, T. W. E. AND R. E. PRIESTLEY (1914) *Glaciology, physiography, stratigraphy, and tectonic geology of South Victoria Land, British Antarctic Expedition 1907-9*. v. 1, *Geology*.
- DEER, W. A., R. A. HOWIE AND J. ZUSSMANN, (1963), *Rock-forming Minerals* v. 4, *Framework Silicates*: John Wiley & Sons, Inc., New York.
- EVANS, H. T., JR., D. E. APPLEMAN AND P. S. HANDWERKER (1963) The least squares refinement of crystal unit cells with powder diffraction data by an automatic computer indexing method [abs.]. *Am. Cryst. Assoc., Ann. Mtg., Cambridge, Mass., Mar. 1963, Program and Abs.* **E-10**, 42-43.
- JENSEN, H. I. (1916) Report on the petrology of the alkaline rocks of Mount Erebus, Antarctica. In *British Antarctic Expedition 1907-9, Rep. Sci. Investigations, Geol.* v. 2, (7), 93-128.
- MOUNTAIN, E. D. (1925) Potash-oligoclase from Mt. Erebus, Antarctica and anorthoclase from Mt. Kenya, East Africa. *Mineral. Mag.* **29**, 331-345.
- PRIOR, G. T. (1907) Report on the rock specimens collected during the *Discovery* Antarctic Expedition 1901-4. *Natl. Antarctic Exped. Nat. Hist.*, v. 1, *Geology*, 101-140.
- SHAPIRO, L. AND W. W. BRANNOCK (1962) Rapid analysis of silicate, carbonate and phosphate rocks, *U.S. Geol. Survey Bull.* **1144-A**.
- SMITH, J. V. AND W. S. MACKENZIE (1958) The alkali feldspars, IV, The cooling history of high temperature sodium-rich feldspars. *Am. Mineral.* **43**, 877-89.
- SMITH, W. C. (1954) *The volcanic rocks of the Ross Archipelago, British Antarctic Expedition 1910, Natural History, Geology*. v. 2.
- TREVES, S. B. (1962) The Geology of Cape Evans and Cape Royds, Ross Island, Antarctica. In *Antarctic Research. Am. Geophys. Union, Geophys. Mon.* **7**, 40-46.
- WOOLNOUGH, W. G. (1916) Petrological notes on some of the erratics collected at Cape Royds. In *British Antarctic Expedition 1907-9, Rept. Sci. Invest. Geol.* v. 2, (11), 169-180.

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