FELDSPARS FROM THE FOYN AND BOWMAN COASTS, GRAHAM LAND

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ABSTRACT. Five new chemical analyses of potash feldspars, together with their X-ray and optical data and that of five other potash feldspars, from igneous and metamorphic rocks from the east coast of Graham Land are presented. The zoning and twinning of co-existing plagioclases are briefly outlined, and some quantitative measurements on the types of twin forms present in the different rocks are recorded. No important petrogenetic conclusions are reached because of the incompleteness of the present study, but several aspects are suggested as topics for future more representative investigations.

THIS paper gives the analytical results and some discussion on the petrogenetic significance of a limited study on feldspars in some of the metamorphic and igneous rocks from the Foyn and Bowman Coasts, Graham Land. The petrography of the parent rocks and their field relations are described elsewhere (Stubbs, in press; Stubbs and Marsh, in press).

METHODS AND TECHNIQUES

Quantitative measurements were made on the twin forms of the plagioclase in 20 representative metamorphic, plutonic and hypabyssal rocks (Fig. 1), and they have been classified according to Gorai's (1951) scheme in three categories: untwinned crystals (U), crystals with polysynthetic twinning and its modifications (A) and crystals with simple (dominantly Carlsbad and Carlsbad-albite) twinning (C). In a preliminary investigation, only 200 plagioclase crystals were counted for each rock because of the size of the available thin sections. When larger sections were examined, it was found that the U : A : C ratios did not differ appreciably for counts of 500 to 1,000. It was concluded that a count of 200 is probably sufficient and therefore the results obtained from these counts have been included in Fig. 1. Tobi (1962, p. 271) has shown that it is qualitative rather than quantitative results that are apparently of petrogenetic significance.

All measurements of 2V and extinction on (010) for the potash feldspars were made using a Universal Stage and standard techniques; 2V was measured directly in all cases. Because of the difficulty in determining optically the 2V on these potash feldspars, X-ray diffraction methods were adopted to measure their degree of structural ordering. All of these potash feldspars are perthitic, microperthitic or cryptoperthitic, and some of them carry a distinctive red granular (?) alteration product. Specimens of potash feldspars for chemical and X-ray analyses were obtained from whole-rock samples which had been ground in a Tema mill with a Colomnoy grinding barrel to pass 100 mesh (152 μm.) sieve size. It was found that this grain-size was the most satisfactory for the heavy-liquid separation technique (a solution of tetrabromo-ethane in acetone) used; either a mixture of bromoform and decaline (Plas, 1966) or acetylene tetrabromide (Nilssen, 1967) would probably have been more satisfactory. Grains larger than 100 mesh contained poecilitically included quartz and plagioclase, and powders with a grain-size smaller than 200 mesh tended to coagulate. The purity of the separations was ascertained by point counts on stained powders, and the purity of the grains themselves was ensured by examining thin sections made from the powders mounted in Lakeside 70C resin. Staining plagioclase with barium rhodizonate and potash feldspar with sodium cobaltinitrite (Bailey and Stevens, 1960) is not satisfactory in this size range; it was possible to stain both quartz and plagioclase grains in the 50 μm. range with sodium cobaltinitrite. Separation is not claimed to be better than 95 per cent. One chemical analysis (TL.222.1; Table I, analysis 7) was rejected because the powder was thought to contain more than 10 per cent of quartz, which occurs poecilitically in this feldspar. The chemical analyses for the major oxides were carried out by rapid colorimetric methods. Barium oxide was initially determined as chromate by a colorimetric method but this was unsatisfactory (values for blank solutions were of the same order as those for the unknowns). Ba, Sr, Rb and total iron (as Fe) were determined by X-ray fluorescence with the assistance of Dr. G. L. Hendry, who provided an analysed potash feldspar for use as a standard. There was some difficulty in obtaining absolute values for these

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minor elements because insufficient powder was available to make full-sized pellets. Therefore, only the Sr : Rb ratios are given in Table I; these ratios appeared to be unaffected by the amount of powder used in the pellet.

The temperatures of (?) formation of the potash feldspars were calculated from their chemical analyses (Table I), and from the chemical and modal analyses of the parent rocks (Stubbs, in press; Stubbs and Marsh, in press), using both Barth's (1962) method and Banham's (1966) suggested modification.

The obliquity ($\Delta = 12 \cdot 5\ (d(131) - d(1\bar{3}1))$; Goldsmith and Laves, 1954*a*) of the specimens was measured on the (131) doublet in preference to either the (130) or the (111) ones because these specimens are strongly perthitic and the (131) doublet is relatively free of albite lines. The samples, which included an amazonite (from the Goodchild Collection, Department of Geology, University of Birmingham), orthoclase from the Shap granite and some pure albite, were run on the Philips PW 1050 X-ray diffractometer by Dr. J. Tarney. The time constant was set at 4 sec. and the sample was scanned at $\frac{1}{4}°$/min. with a counting rate of 400 counts/sec. using Cu Kα radiation between 29° and 30°20′, as recommended by Donnay and Donnay (1952). The peaks were annotated with reference to the *d* spacing given by Goldsmith and Laves (1954*b*) and the obliquity was calculated by Dietrich's (1962) method. The albite peaks were removed from the diffractometer trace (by comparison with the pattern for pure albite) proportional to the albite content of the sample (obtained by chemical analysis). The R.D. index was estimated by comparing the shapes of the traces with those given by Christie (1962), who introduced this measure of random disorder. It is noticeable that specimens with the lower R.D. index values have intermediate values of obliquity (0·7–0·4), suggesting that the obliquity measured is an average value for potash feldspars in the whole-rock specimen and not that of an individual potash feldspar. The sample may contain several different potash feldspars each with a slightly different obliquity; Dietrich (1961) has pointed out the apparent absence of feldspars with obliquities in the range 0·30–0·65. The diffractometer trace obtained from one sample (TL.117.1; Table I, analysis 5) had three pronounced peaks, and because of this it is suggested this pattern was produced by two (or more) structurally distinct potash feldspars, one of which having near-maximum obliquity (i.e. (?) microcline) and the other being (?) orthoclase (with a single "sanidine" peak). There is some petrological support for this contention: two different types of twinning and three different degrees of alteration have been described from the potash feldspars in some of these rocks (Stubbs and Marsh, in press) and two different 2V values have been obtained. The potash feldspar from the granodioritic gneiss (TL.212.1; Table I, analysis 4) shows comparable features but the three peaks are less distinct, and it has not been possible to obtain 2V values for the altered and heavily stained potash feldspar.

Plagioclase Twinning

The plots of the twin forms of plagioclase from rocks of the metamorphic complex (Stubbs and Marsh, in press) mostly fall in the field of metamorphic plagioclase, as delineated by Turner (1951), on the U : A : C diagram (Fig. 1). Two plotted analyses fall close to but outside this field; one is the epidiorite sill (Fig. 1, No. 6) and the other is an augen-gneiss from the banded gneisses of eastern Joerg Peninsula (Fig. 1, No. 3). The epidiorite had not reached the extremes of regional metamorphism and (?) primary magmatic twinning and zoning were recognizable, and therefore it could not be expected to fall within this zone. The augen-gneiss contains plagioclase which displays (?) magmatic twin forms, but since it has been argued that these rocks are *para*gneisses (Stubbs and Marsh, in press) it is believed that they are not primary. These twin forms could possibly have appeared during anatexis. However, it is possible that the position of this point on Fig. 1 has arisen from the misidentification of non-lamellar albite twinning. Tobi (1962, p. 266) has pointed out the difficulties in distinguishing between non-lamellar albite twins and Carlsbad twins even when using a Universal Stage. It is significant that the dyke rocks (Fig. 1, Nos. 19 and 20) and the discordant plutonic intrusion (Fig. 1, No. 18) possess less than 10 per cent of A twins, whereas the "red" granites, the metagabbro and the (?) Jurassic older plutonic rocks contain between 10 and 30 per cent of A twins. The metagabbro (Fig. 1, No. 7) plots nearer the metamorphic field than any of the other plutonic rocks.

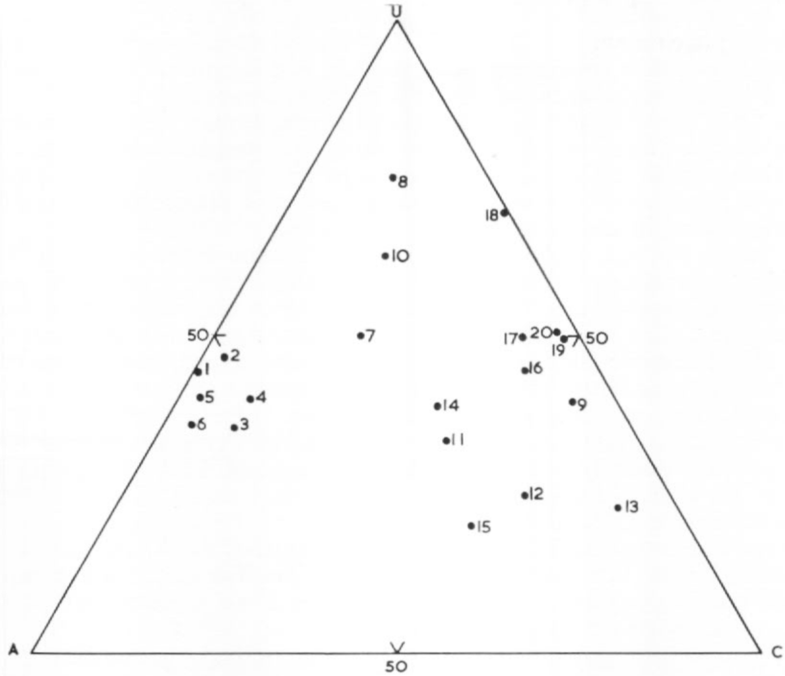

Fig. 1. U : A : C ratios in plagioclases from igneous and metamorphic rocks from the Foyn and Bowman Coasts.

1. TL.124.1 Biotite-gneiss from banded gneisses at eastern Joerg Peninsula, Bowman Coast.
2. TL.126.2 Biotite-gneiss from banded gneisses at eastern Joerg Peninsula, Bowman Coast.
3. TL.124.2 Augen-gneiss from banded gneisses at eastern Joerg Peninsula, Bowman Coast.
4. TL.126.3 Augen-gneiss (leucocratic band) from banded gneisses at eastern Joerg Peninsula, Bowman Coast.
5. TL.212.1 Granodioritic gneiss from a supraglacial boulder near Friederichsen Glacier, Foyn Coast.
6. TL.133.1 Epidiorite sill, eastern Joerg Peninsula, Bowman Coast.
7. TL.213.3 Metagabbro, Mount Hulth, Foyn Coast.
8. TL.105.1 Porphyritic "red" adamellite, "D Pyramid", western Joerg Peninsula, Bowman Coast.
9. TL.215.1 Coarse-grained "red" adamellite, "B Ridge", Mount Denucé, Foyn Coast.
10. TL.219.1 Marginal "red" adamellite, Mount Denucé, Foyn Coast.
11. TL.222.1 "Red" granite, Mount Haskell, Foyn Coast.
12. TL.223.5 Marginal "red" adamellite, Mount Holmes, Foyn Coast.
13. TL.249.1 (?) Jurassic hypersthene-bearing gabbro, eastern Cape Robinson, Foyn Coast.
14. TL.227.1 (?) Jurassic xenolithic granodiorite, western Mount Hayes, Foyn Coast.
15. TL.249.2 (?) Jurassic xenolithic granodiorite, eastern Mount Hayes, Foyn Coast.
16. TL.258.3 Xenolith in the xenolithic (?) Jurassic grandiorite, north-east Mount Hayes, Foyn Coast.
17. TL.225.2 Coarse-grained "white" microcline-granite, northern Mount Hayes, Foyn Coast.
18. TL.242.1 Fine-grained "white" adamellite, northern Mount Hayes, Foyn Coast.
19. TL.204.2 Granite-porphyry dyke, Spur Point, Foyn Coast.
20. TL.272.1 Granite-porphyry dyke, southern Mount Hayes, Foyn Coast.

Plagioclase Zoning

Although no detailed work has been done on the zoning of the plagioclases in the various rock types, some pattern has emerged. The details of the zoning in the plagioclases of the metamorphic and plutonic rocks are given in the appropriate petrographic descriptions elsewhere (Stubbs, in press; Stubbs and Marsh, in press). In general, the distribution of plagioclase zoning and associated twin forms is:

i. In rocks of the metamorphic complex (Stubbs and Marsh, in press, table III), zoning of crystals with calcic cores is absent (except in the epidiorite) and the only indication of compositional differences is given by the shadowy extinction; twinning is almost exclusively on the albite law.

ii. In the metagabbros there is some shadowy patchy zoning but no regular zoning; twinning is commonly on the albite law but occasional Carlsbad twin forms occur. Bending of albite twin lamellae is common and it appears to be a secondary effect involving the replacement of simple twin forms and patchy zoning.

iii. The "red" granites contain plagioclases which display both the simplest and the most complex forms of zoning and twinning; the marginal foliated contact rocks have plagioclase with zoning and twinning comparable to that of the metagabbros, and the central porphyritic part of the intrusion contains plagioclase with oscillatory and patchy zoning in addition to normal compositional zoning.

iv. In the (?) Jurassic gabbros and to a lesser extent in the concordant (?) Jurassic "white" adamellites, the plagioclases occur as untwinned crystals with patchy zoning, crystals twinned on the albite and Carlsbad-albite laws with patchy zoning (patchy zoning and glide twinning, especially with bending of twin lamellae, appear to be mutually exclusive; glide twinning replaces patchy zoning) and normal compositional (occasionally oscillatory) zoning with indistinct compositional boundaries.

v. The (?) Jurassic xenolithic granodiorites of Mount Hayes, Foyn Coast (Stubbs, in press), have normal compositional zoning in the mantles of crystals, whereas their cores are always either patchily zoned or patchily saussuritized. Both these twin forms and the patchy zoning could have been inherited from the Jurassic gabbros, which may have been the source of the xenoliths.

vi. Normal and patchy zoning are rare in the gabbros of the Andean Intrusive Suite but twinning on the Carlsbad-albite law is common. The discordant granites, some of which possibly belong to the Andean Intrusive Suite, seldom contain patchy zoned plagioclase; normal zoning is common.

The origin of patchy zoning in plagioclase has been discussed by Vance (1965, 1966) and Fraser (1966). Vance (1966, p. 519) listed the features of the "normal" type of patchy zoning as:

i. A relict subhedral core.
ii. A rim of sodic composition.
iii. Patchy inclusions in the core that have the composition of the rim.
iv. The poecilitic inclusion of other minerals in the sodic patches.

He attributed this zoning to a two-stage replacement process in which early crystals are partly resorbed, rehealed and overgrown by a later more sodic plagioclase. This description and explanation could be applied to the patchy zoning in the plagioclases of the "red" granites, and the (?) Jurassic gabbros, granodiorites and granites. Fraser (1964, 1965, 1966) has described the presence of patchy zoning in plagioclases of the "*ortho*gneisses" from Stonington Island and banded gabbros of the Anagram Islands (lat. 65°12′S., long. 64°20′W.), where it occurs both in zoned and unzoned crystals and is not solely restricted to their cores. Fraser (1966, p. 514) interpreted this as a two-stage mechanism involving exsolution and replacement. Patchy zoning, where the sodic rim described by Vance (1966) is absent, is the only type of zoning in the plagioclase of the metagabbros, but it is common either with or without these rims in the "red" granites and Jurassic gabbros. The metagabbros and the "red" granites exhibit many replacement phenomena such as perthite and the corrosion of plagioclase by quartz and potash feldspar. It is therefore possible that the patchy zoning of the type described by Vance (1966) is magmatic in origin, whereas that without the sodic rims (Fraser, 1966) is either metamorphic or metasomatic. Hence the occurrence of both of these forms in the same rock suggests a state of disequilibrium. It is significant that the co-existing potash feldspars in the "red" granites are probably randomly disordered, also indicating disequilibrium.

Potash Feldspars

Five of the potash feldspars separated from these rocks have been chemically analysed for all major oxides (Table I). Their compositions are remarkably uniform except for the orthoclase-microperthite from the "white" adamellite of northern Mount Hayes (TL.242.1; Table I, analysis 8). Although it is possible that the separation technique used could have contributed to the uniformity of these compositions, it is considered unlikely because of this

TABLE I. CHEMICAL ANALYSES, OPTICAL AND X-RAY DATA ON POTASH FELDSPARS FROM ROCKS FROM THE FOYN AND BOWMAN COASTS, GRAHAM LAND

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	68·08		66·25		66·03	68·07		68·12			64·28
TiO_2	0·02		0·06		0·01	0·01		—			—
Al_2O_3	17·44		18·25		18·21	17·08		18·07			19·40
Fe_2O_3	0·26		0·78		0·16	0·07		0·14			0·34
FeO	—		—		—	0·03		—			—
MnO	0·01		0·05		0·01	0·01		0·01			—
MgO	0·13		—		—	—		0·45			tr
BaO	—		0·28		—	0·23		0·34			—
CaO	0·60		1·20		0·75	0·43		0·40			0·48
Na_2O	2·55		2·25		2·45	3·10		4·25			2·74
K_2O	10·55		10·25		12·15	11·79		8·55			11·80
H_2O+	0·11		0·34		0·23	0·14		0·12			0·58
TOTAL	99·75		99·71		100·00	100·96		100·45			99·62

MINOR ELEMENTS DETERMINED BY X-RAY FLUORESCENCE

	1	2	3	4	5	6	7	8	9	10	11
Fe_2O_3	0·21	0·16	0·64	0·08	n.d.	n.d.	0·29	0·21	n.d.	n.d.	n.d.
BaO	0·10	0·04	0·16	0·15	n.d.	n.d.	0·04	0·04	n.d.	n.d.	n.d.
Sr : Rb	0·55	0·80	0·36	0·83	n.d.	n.d.	0·04	0·22	n.d.	n.d.	n.d.

NUMBER OF IONS ON THE BASIS OF 32 OXYGENS (using chemical analyses)

	1	2	3	4	5	6	7	8	9	10	11
Si^{+4}	12·59		12·307		12·118	12·387		12·382			11·825
Al^{+3}	3·80		3·995		3·938	3·663		3·871			4·207
Fe^{+3}	0·04		0·109		0·022	0·01		0·019			0·027
Ti^{+4}	0·003		0·008		0·001	0·001		—			—
Mg^{+2}	0·036		—		—	—		0·122			—
Fe^{+2}	—		—		—	0·005		—			—
Mn^{+4}	0·002		0·008		0·002	0·002		0·002			—
Na^{+1}	0·912		0·81		0·872	1·094		1·497			0·977
Ca^{+2}	0·119		0·239		0·147	0·084		0·078			0·095
K^{+1}	2·488		2·429		2·844	2·737		1·982			2·768
Z	16·42		16·42		16·08	16·06		16·26			16·05
X	3·56		3·51		3·87	3·94		3·69			3·84
Composition—molecular percentage Or	72·7		74·8		75·4	75·8		56·2			72·1
Composition—molecular percentage Ab	25·1		23·1		22·0	24·2		40·8			25·4
Composition—molecular percentage An	2·2		2·1		2·6	—		3·0			2·5

OPTICAL AND X-RAY DATA

	1	2	3	4	5	6	7	8	9	10	11
$2V\alpha \pm 2°$	88°	75°	75°	85–90°	85° 60–64°	56–64°	62–66°	68°	69°	64°	61°
Approximate extinction on (010)	6°	7°	7°	8°	9°	—	—	10°	6°	3°	—
Obliquity	0·91	0·82	0·79	0·78	0·66	0·54	0·41	0·38	0·36	0·16	0·06
R.D. Index	7	5	5	4–3	4–3	4	5–6	4	5	3–2	1

THE TWO-FELDSPAR GEOTHERMOMETER

	1	2	3	4	5	6	7	8	9	10	11
Composition of the co-existing plagioclase	An_{10}	An_4	An_{28}	An_8	An_{10}	An_5	An_{9-5}	An_{10}	An_{10}	An_{10}	—
Barth K ratio	0·279	—	0·319	—	0·244	0·303	0·480	0·453	—	—	—
Indicated temperature of formation (Barth, 1956) —$T°$ C	550°	—	560°	—	510°	575°	725°	710°	—	—	—
Barth K ratio as calculated by Banham (1966)	0·315	0·284	0·232	0·236	—	—	0·383	0·253	—	0·248	—
Indicated temperature of formation—$T°$ C	575°	550°	500°	500°	—	—	640°	525°	—	525°	—

tr Trace. n.d. Not determined.

1. TL.136.4 Microcline-microperthite from "white" microcline-adamellite, eastern Joerg Peninsula, Bowman Coast.
2. TL.225.1 (?) Microcline-microperthite from "white" microcline-granite, Mount Hayes, Cape Robinson area, Foyn Coast.
3. TL.121.2 Microcline-microperthite from "pink" adamellite ((?) Andean Intrusive Suite), eastern Joerg Peninsula area, Bowman Coast.
4. TL.212.1 Randomly disordered alkali-feldspar from granodioritic gneiss, near Friederichsen Glacier, Cape Robinson area, Foyn Coast.
5. TL.117.1 (?) Microcline-microperthite and orthoclase-microperthite from foliated marginal part of the "red" granite batholith at "D Pyramid", western Joerg Peninsula area, Bowman Coast.
6. TL.216.1 (?) Microcline-microperthite and orthoclase-microperthite from marginal adamellite of the "red" granite batholith of Mount Denucé–Mount Holmes–Mount Haskell, Cape Robinson, Foyn Coast.
7. TL.222.1 (?) Orthoclase-microperthite from the central porphyritic part of the "red" granite batholith of Mount Denucé–Mount Holmes–Mount Haskell, Cape Robinson, Foyn Coast.
8. TL.242.1 Orthoclase-microperthite from a fine-grained "white" adamellite, northern Mount Hayes, Cape Robinson area, Foyn Coast.
9. TL.239.1 Orthoclase-microperthite from a fine-grained "white" adamellite, northern Mount Hayes, Cape Robinson area, Foyn Coast.
10. TL.235.1 Orthoclase-microperthite from a fine-grained "pink" adamellite ((?) Andean Intrusive Suite), northern Mount Hayes, Cape Robinson area, Foyn Coast.
11. Orthoclase-microperthite from the Shap porphyritic granite. Chemical analysis by Spencer (1938, p. 112); X-ray results obtained from a specimen in the collection of the Department of Geology, University of Birmingham.

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and one other exception (TL.222.1). The orthoclase-microperthite from the porphyritic "red" granite (TL.222.1; Table I, analysis 7) was analysed but the results were rejected because of suspected contamination by poecilitically included quartz (p. 1). The percentage composition of the feldspar given by the analysis was Or = 47·9, Ab = 44·6, An = 7·5. This potash feldspar is extremely perthitic in thin section and therefore this composition is probably correct. The parent rock of the first orthoclase-microperthite (TL.242.1) was chemically analysed (Stubbs, in press; table II, analysis 3) but it does not appear to follow closely the differentiation trends for most of the other (?) Jurassic intrusions. It is suggested (Stubbs, in press) that this rock is closely related in age, origin and chemistry to the pyroclastic rocks and the quartz-porphyry dykes of Mount Hayes. It could well be a residuum of the magma which produced these rocks and this might account for the high albite component in the potash feldspar.

The consistent compositions of the other analysed potash feldspars provide a useful background for a comparison of their minor elements (Ba, Sr and Rb). The X-ray fluorescence results for BaO are used here in preference to the colorimetric ones, because the latter are believed to be spurious. According to Barth (1961), barium concentrates in potash feldspar at the temperatures of igneous rocks but below 250° C plagioclase is the preferred host mineral. The concentration of BaO in the potash feldspar from the adamellite of the Andean Intrusive Suite (Table I, analysis 3) appears to be the greatest and it is closely followed by the one from the gneiss of the metamorphic complex (Table I, analysis 4); these values are almost double those obtained for the potash feldspars from the Jurassic intrusions. However, no significance can be deduced from so few results. The high BaO concentration in the potash feldspar from the Andean adamellite could be a measure of high temperature and that in the potash feldspar from the granodioritic gneiss could indicate either high temperature during its intrusion or during potash metasomatism. As should be expected, the concentration of BaO appears to be proportional to the CaO percentage in the feldspar. (This trend is not shown by the BaO results obtained by wet chemical methods, thus tending to confirm they are unsatisfactory.) The Sr : Rb ratio (Table I) appears to be highest for the potash feldspar from the granodioritic gneiss and lowest for the one from the Andean adamellite (with the exception of the two analyses which have been excluded). Strontium concentrates in plagioclase below 450° C (Barth, 1961). It is, however, not concluded that the Andean adamellite crystallized between 250° and 450° C, since no analyses of the co-existing plagioclases are available for comparison of their minor oxide contents.

It has been observed that many of the potash feldspars, especially those in the "red" and "pink" rocks, carry a distinctive red granular (?) stain or alteration product; it is not simply a weathering effect. It was originally thought that the red-stained potash feldspar was "orthoclase" because, with one exception (TL.121.2; the Andean adamellite), it never displays cross-hatch or grid twinning, whereas the microclines in the rocks of the metamorphic complex from eastern Joerg Peninsula are commonly fresh and unstained. This contention was difficult to prove or disprove optically because the stain itself made the measurement of 2V extremely difficult. Chemical analyses do not really assist in resolving this problem because there are too few; the samples containing only red-stained potash feldspar are those with microcline-microperthite (TL.121.2) and orthoclase-microperthite (TL.235.1), whereas samples with other forms of alteration or fresh unstained feldspar are those with microcline-microperthite (TL.136.4, 225.1) and orthoclase-microperthite (TL.239.1, 242.1). Of these six samples, three have been analysed by wet chemical methods and four by X-ray fluorescence. There appears to be some measure of agreement between the two methods, indicating that the feldspars with this colour have a high percentage of Fe_2O_3, but they are equally divided between "microcline" and "orthoclase". It is suggested that this red stain is haematite resulting from the exsolution of iron from the feldspar lattice. Smith (1962, p. 250) has suggested that the presence of iron atoms in the potash feldspar lattice may assist in the transformation of orthoclase to microcline. This could account for the presence of microcline-microperthite in the high-level Andean adamellite (TL.121.2), which contains almost 1 per cent of Fe_2O_3 (almost of the same order as recorded in iron-rich orthoclases from Madagascar (Coombs, 1954)).

The 2V's obtained for these feldspars have been plotted against their chemical compositions (Fig. 2) and they fall near the curves given by Deer and others (1963). The classification of the

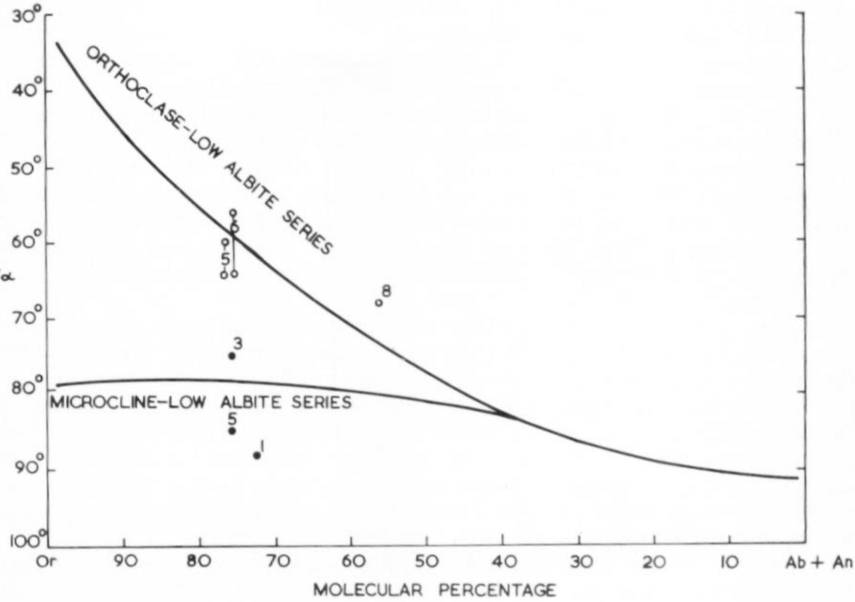

Fig. 2. Variation of 2Vα with the chemical composition for the analysed potash feldspars from the Foyn and Bowman Coasts (numbered as in Table I; ○ for (?) orthoclase–low albite series, ● for (?) microcline–low albite series). The curves are based on those given by Deer and others (1963, p. 58, fig. 28).

potash feldspars has been deduced from their positions relative to these curves. There appears to be reasonable agreement between the results for these potash feldspars and previous analyses quoted by Deer and others (1963, table 5). With the exception of Nos. 5, 6 and 7, the measured 2V's also appear to be consistent and almost linear with the measured obliquity (Fig. 3). The 2V of feldspars Nos. 2 and 3 were difficult to measure because of their degree of alteration; the values given in Table I are probably low. The diffraction patterns for the feldspars from the "red" granitic rocks have been discussed (p. 2); these samples either contain two or more distinct potash feldspar phases (i.e. TL.117.1; Table I, analysis 5) or a whole range of randomly disordered potash feldspars. This could easily be checked by single-crystal work on hand-picked material. It would be of significance if it were possible to demonstrate that there were two distinct potash feldspars in rocks from the metamorphic complex, randomly disordered potash feldspars in the older (?) Jurassic intrusions ("red" granites) and one potash feldspar phase in the younger (?) Jurassic intrusions (the discordant "white" granites) and rocks of the Andean Intrusive Suite. It is interesting to note that two different potash feldspars have been described from single rocks from the Basement Complex of western Graham Land (Adie, 1954, p. 13; Hoskins, 1963, p. 36). The *ortho*gneisses of Stonington Island were the subject of the only previous detailed study of feldspars from Graham Land rocks (Fraser, 1965). On the basis of about 40 measurements of 2V, which vary by as much as 20° for different parts of the same crystal, Fraser (1965, p. 25, table IV) has suggested that the potash feldspars in these rocks have partially disordered structures. These disordered potash feldspars are associated with patchy zoned plagioclase comparable to that described from the "red" granites of the Foyn and Bowman Coasts. The age of the *ortho*gneisses of Stonington Island is not known; Fraser (1965, p. 47) correlated them with dioritic gneisses described by Adie (1954) and Hoskins (1963), and he concluded that they belong to the Basement Complex. It should, of course, be stressed that age correlations cannot be based solely on the petrographic and chemical characteristics of the feldspars. It is, however, quite feasible that identical conditions of crystallization could have occurred during metamorphism or orogenesis in different places at different times.

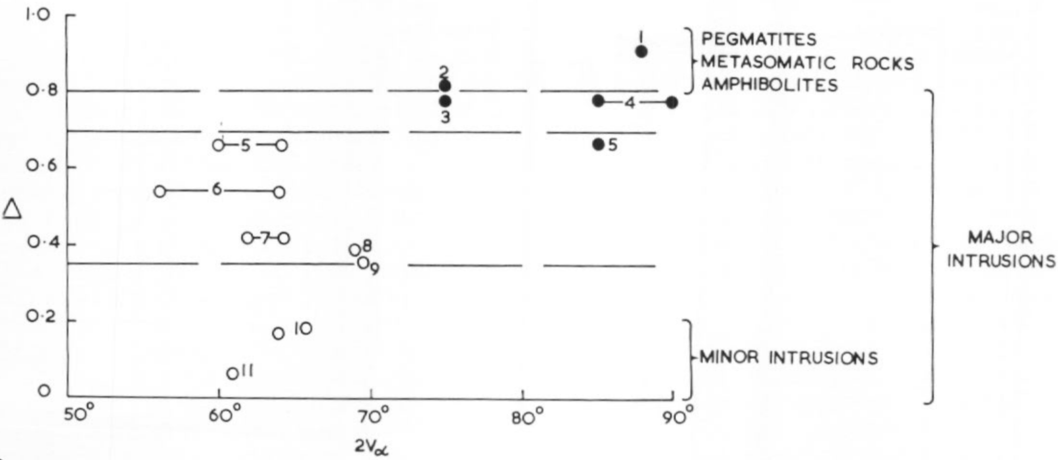

Fig. 3. Plot of obliquity against 2Vα for some potash feldspars from the Foyn and Bowman Coasts (numbered as in Table I; ○ for (?) orthoclase–low albite series, ● for (?) microcline–low albite series). The grouping of rocks shown does not correspond to the parent rocks from which the feldspar samples were separated; it is based on the distribution of obliquity with rock type given by Dietrich (1962, fig. 4).

The temperatures of formation of the potash feldspars have been calculated using both the Barth (1956) geothermometer and the method suggested by Banham (1966); the latter could be used because the necessary modal and chemical analyses were available. Some use has also been made of these results in discussing the metamorphism of the metamorphic complex (Stubbs and Marsh, in press). It is interesting that the highest calculated temperature is for the the centre of the largest intrusion (Table I, analysis 7; 725 °C (Barth) and 640° C (Banham)). The temperature of formation calculated by Barth's method for the "white" adamellite (Table I, analysis 8; 710° C) may either be spurious or it could indicate that the small pluton was chilled suddenly, preserving high-temperature forms of co-existing plagioclase and potash feldspar. It has been suggested that there is some correlation between 2V and obliquity of the feldspars from these rocks and, since there is a direct relationship between 2V and chemical composition, there must also be some relationship between chemical composition and obliquity. However, there need not necessarily be a correlation between 2V and obliquity because the 2V may depend on short-range order and the obliquity on long-range order; the lack of correlation may depend on the variabilities in domain structure caused by calcium (Retief, 1962). Furthermore, the presence of fine microperthite and fine grid twinning may lead to errors in the determination of 2V which will give high values, and this might affect the relationship between 2V and obliquity.

For the microcline–low albite series, 2V does not vary appreciably with chemical composition (in terms of molar per cent orthoclase (Fig. 2)) but for the orthoclase–low albite series 2V decreases as the potash feldspar content increases. Therefore, there should be some positive correlation between low obliquity and high K_2O, low Na_2O and possible CaO in the orthoclase–low albite series (Table I, analyses 8, 9, 10, 11); this appears to be the case for K_2O and Na_2O. It is significant that the two analysed specimens which are thought to contain randomly disordered potash feldspars or two distinct feldspars, one of which belongs to the orthoclase–low albite series and the other to the microcline–low albite series (TL.117.1, 216.1; Table I, analyses 5, 6), do not show a proportional decrease in K_2O and increase in Na_2O with increasing obliquity. Nilssen and Smithson (1965) have suggested that the concentrations of CaO, Fe_2O_3, TiO_2 and MgO are significantly higher in rocks (whole rock chemistry as opposed to feldspar chemistry) from the Precambrian Herefoss granite which contain low-obliquity potash feldspars and the reverse for K_2O. There appears to be no such relationship between the obliquity and the chemistry of the parent rocks of these feldspars, except in the alkali oxides, and this is probably because they are all from different intrusions.

Discussion

Aspects of the twinning and zoning of the plagioclases, and the chemistry, optics and structure of the potash feldspars in metamorphic and plutonic rocks from the Foyn and Bowman Coasts of Graham Land have been described. The results given here are for rocks of distinctly different ages and origins; nearly all of these rocks have been affected to some degree by subsequent geological events. Consequently, the structures and compositions of the feldspars generally reflect the complex history of the rocks. The present study is an extremely general one but it was undertaken for a specific purpose: to discover petrographic criteria that could possibly be used for correlating rocks whose ages have not been determined by other means. The dangers of making such correlations are appreciated, since all feldspar textures and structures described here can result from several different processes. It has been stated that the feldspars from the margins of the larger batholiths display twin forms and textures comparable to those in rocks of the metamorphic complex and that those from the various high-level plutons, which are possibly of different age, are also usually indistinguishable.

The plagioclases appear to show a progression from crystals which have primary twin forms and normal magmatic zoning (in high-level plutonic rocks) to ones with only secondary glide twinning (in metamorphic complex rocks). The major Jurassic intrusions contain plagioclases which have had a complex history, involving replacement (and (?) resorption), and this has resulted in different types of zoning at (?) different stages during their formation. It has been suggested that the larger intrusions are composite, comprising several distinct stages of emplacement. The xenolithic granodiorites of Mount Hayes (Stubbs, in press) are considered to be hybrid rocks and therefore it is to be expected that the plagioclase twin forms should also be hybrid. The feldspars of the metagabbros appear to show the transition between the complex zoning and twinning in the feldspars of the (?) younger Jurassic rocks and those of the metamorphic complex. There are descriptions of crystals in which one half of a Carlsbad-albite twin has patchy zoning and the other displays multiple albite twinning which it is thought must have replaced the patchy zoning. Bending of albite twin lamellae, which is common in the metagabbros and the "red" granites, has also been described in plagioclases from gabbros of the Anagram Islands by Fraser (1964, p. 28). He ascribed this to recrystallization controlled by strains set up in the individual crystals by reorganization of the structure during the elimination of patchiness and zoning. It must be the result of strain within the crystals rather than external stress because it has neither developed throughout the rock nor throughout all crystals.

General studies on potash feldspars as petrogenetic indicators have, according to Parsons (1965), very little value. It can be seen from Fig. 3 that the measured obliquities of these feldspars only approximately meet the petrogenetic groupings suggested by Dietrich (1962). Potash feldspars with high obliquity could have many different origins. Cross-hatch twinning in microcline is thought to indicate a transition from orthoclase (Laves, 1950); it is widespread in the rocks described here, especially those from the metamorphic complex. Patchy ill-formed cross-hatching, such as occurs in some of the potash feldspars from the metamorphic complex rocks and the "red" granites (and possibly that described by Fraser (1965, p. 24) in *ortho*-gneisses from Stonington Island), is thought to have arisen by replacement of plagioclase (Smith, 1962, p. 249). Undulatory extinction in potash feldspars is restricted to rocks from the metamorphic complex in which it is thought to indicate a metamorphic transition from orthoclase to microcline (Heier, 1961). It has not yet been established whether the potash feldspars in the rocks of the metamorphic complex and the "red" granite are two distinct phases or a whole range with intermediate and variable obliquities. According to Smithson (1962), randomly disordered potash feldspars form as a result of an interplay between the growth rate, shear temperature and volatiles present, and they are characteristic of metasomatic rocks exhibiting replacement features. Both the metamorphic complex rocks and the "red" granites show replacement features and both contain large idioblastic (?) porphyroblasts which are thought to indicate metasomatism (probably autometasomatism). The potash feldspars from the discordant plutonic intrusions appear to show the existence of a single ordered phase which is usually an orthoclase-microperthite.

Until a study has been made of the variations in the obliquity of potash feldspars from individual intrusions, no meaningful conclusions can be reached from the present study. Single-crystal X-ray work might indicate some significant differences between the potash feldspars from granites of different ages. The potash feldspars should reflect the cooling history of an intrusion but, as has been stated before, many other factors can contribute to and complicate the cooling history. Nilssen and Smithson (1965) have suggested that, if potash feldspar has crystallized under stable conditions, its obliquity may be an indicator of temperature but, if it formed under metastable conditions, its obliquity is a kinetic indicator. It is suggested that monoclinic potash feldspar formed in the rocks of the metamorphic complex in a metastable environment, and under stable conditions at relatively low temperatures in most of the high-level plutonic intrusions. The one triclinic potash feldspar recorded from a high-level plutonic intrusion (TL.121.2) could have formed rapidly by chilling at a high temperature, or reversion to the triclinic phase could have been accelerated by local faulting or (as suggested on p. 5) by the presence of a high percentage of iron in the lattice.

Conclusions

The zoning and twinning of the plagioclases provide evidence of the petrogenesis of these rocks and consequently provide useful criteria for distinguishing between rocks of various ages which have had different histories of crystallization and/or metamorphism. They do not afford any evidence that can be used to distinguish between the high-level "white" granitic intrusions which are considered to be Jurassic (Fleet, 1968; Stubbs, in press) and those (the "pink" granites) which are thought to be members of the Andean Intrusive Suite. The structure and chemistry of the potash feldspars can provide useful petrogenetic evidence if the data are sufficiently comprehensive. The results presented here are too generalized for direct application. However, it is hoped that the present results have indicated the potential of detailed work on feldspars (especially chemical analyses for minor and trace elements) as a means of disentangling the complex history of the many granites of the Antarctic Peninsula.

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