

*The feldspars of the Rosses Granite Complex, Donegal,
Ireland*

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Summary. An examination has been made of the composition and structural state of the feldspars in each of the units of the Rosses granite complex. The compositions of the plagioclases are systematically related to the compositions of the rocks, but the alkali feldspars are much more uniform as a result of postmagmatic recrystallization. In the granites both alkali feldspar and plagioclase are in low-temperature structural states, but alkali feldspar phenocrysts from one of the porphyry dykes associated with the complex show a higher-temperature state.

THE geology of the Rosses complex has been described by Pitcher (1953). The complex consists, in order of emplacement, of a peripheral assortment of microgranite sheets, an outer ring of biotite-granite (G1), an intermediate ring of biotite-granite (G2), a north-south swarm of porphyry dykes, an inner intrusion of biotite-granite (G3), and a final small intrusion of muscovite-granite (G4). The G3 and G4 granites contain small areas of greisenisation. Numerous small sheets of pegmatite and aplite are also present.

The feldspars were separated from 12 rocks, representing each of the units in the complex, in order to study their variation in composition and structural state. A combination of magnetic and heavy liquid methods was used for separation, but no attempt was made to separate plagioclase from quartz because its specific gravity and magnetic susceptibility overlap those of quartz. It was not possible to separate sufficient feldspar from any of the porphyry dykes for chemical analysis, but indirect methods were used to determine the composition of the phenocrysts in one sample of quartz-porphyry, R17. The phenocrysts of alkali feldspar and plagioclase were separated from the rock and from one another by a combination of hand-picking and centrifuging in heavy liquids.

The composition of the feldspars

The feldspars in the granites. The compositions of the feldspars were obtained from partial chemical analyses. Calcium was determined gravimetrically, and sodium and potassium by flame photometry, and the

compositions were calculated on the assumption that the feldspars consisted of the pure end-members KAlSi_3O_8 , $\text{NaAlSi}_3\text{O}_8$, and $\text{CaAl}_2\text{Si}_2\text{O}_8$. In calculating the compositions of the plagioclases it was also necessary to

TABLE I. Partial chemical analyses of feldspars from the Rosses granite complex

| No. | Rock type | Locality | Alkali feldspar | | | Plagioclase + quartz | | |
|-----|------------------------|-----------|------------------|-------------------|------|----------------------|-------------------|------|
| | | | K ₂ O | Na ₂ O | CaO | K ₂ O | Na ₂ O | CaO |
| R12 | Biotite microgranite | B 751 098 | 14.59 | 1.22 | 0.97 | 1.28 | 5.45 | 2.66 |
| R4 | Biotite microgranite | B 816 118 | 14.63 | 1.09 | 0.86 | 0.72 | 5.10 | 2.56 |
| R20 | Granite G1 | B 743 171 | 15.00 | 1.26 | 0.41 | 1.02 | 5.05 | 1.09 |
| R3 | Granite G2 | B 780 164 | 15.13 | 1.04 | 0.31 | 0.83 | 5.02 | 0.81 |
| R16 | Granite G3 | B 783 131 | 14.72 | 1.47 | 0.22 | 0.66 | 4.76 | 0.90 |
| R10 | Muscovite microgranite | B 743 188 | 15.30 | 1.23 | tr. | 0.60 | 4.49 | 1.11 |
| R23 | Granite G4 | B 775 125 | 15.18 | 1.11 | 0.24 | 0.55 | 3.89 | 0.65 |
| R9 | Muscovite microgranite | B 724 145 | 15.30 | 1.09 | 0.18 | 0.97 | 4.70 | 0.58 |
| R22 | Greisenized G3 granite | B 762 144 | 15.35 | 0.98 | 0.14 | 0.50 | 3.18 | 0.62 |
| R5A | Aplite | B 787 115 | 14.98 | 1.11 | 0.11 | 0.20 | 6.49 | 0.68 |
| R5B | Pegmatite | B 787 115 | 15.24 | 0.99 | tr. | 0.20 | 6.40 | 0.59 |
| R19 | Muscovite granite | B 775 149 | 15.80 | 0.72 | tr. | 0.46 | 5.80 | 0.58 |

Localities are given as Irish National Grid References.

Indirect methods were used to determine the composition of the feldspars in one of the quartz-porphry dykes of the complex (R17—Grid Ref. B 770 207); details are given in the text.

TABLE II. Compositions of feldspars from the Rosses granite complex expressed as molecular percentages of end-members

| No. | Alkali feldspar | | | Plagioclase | | | Composition of rock (CaO + FeO + Fe ₂ O ₃ + MgO) % |
|-----|-----------------|------|-----|-------------|------|------|---|
| | Or | Ab | An | Or | Ab | An | |
| R12 | 85.0 | 10.2 | 4.8 | 10.9 | 70.2 | 18.9 | 7.5 |
| R4 | 86.5 | 9.2 | 4.3 | 6.8 | 73.0 | 20.2 | 5.5 |
| R20 | 87.5 | 10.6 | 2.0 | 10.6 | 79.8 | 9.5 | 2.9 |
| R3 | 89.8 | 8.8 | 1.5 | 9.1 | 83.5 | 7.4 | 2.6 |
| R16 | 86.6 | 12.4 | 1.1 | 7.6 | 83.7 | 8.8 | 2.4 |
| R10 | 89.7 | 10.3 | — | 7.2 | 81.7 | 11.2 | 2.1 |
| R23 | 89.3 | 9.4 | 1.2 | 7.8 | 84.3 | 7.8 | 1.8 |
| R9 | 90.0 | 9.2 | 0.9 | 11.3 | 83.2 | 5.6 | 1.6 |
| R22 | 91.0 | 8.3 | 0.7 | 8.5 | 82.6 | 8.9 | 1.3 |
| R5A | 90.0 | 9.5 | 0.5 | 1.9 | 92.8 | 5.4 | 1.1 |
| R5B | 91.3 | 8.6 | — | 1.9 | 93.3 | 4.8 | 1.0 |
| R19 | 93.8 | 6.1 | — | 5.1 | 89.5 | 5.4 | 1.0 |

allow for the presence of admixed quartz, and it was assumed for this purpose that the quartz was pure SiO_2 . The results of the analyses are given in tables I and II. In order to compare the compositions of the feldspars with the compositions of the rocks, the sum (CaO + FeO + Fe₂O₃ + MgO %) is given in table II as a measure of the latter. These values are from unpublished analyses by the author, and are quoted in preference to the SiO_2 contents, which show only a small variation from rock to rock.

The compositions of the plagioclases are closely related to the

compositions of the rocks, the anorthite content tending to decrease with $(\text{CaO} + \text{FeO} + \text{Fe}_2\text{O}_3 + \text{MgO})$. The high potassium contents of the plagioclases reflect the presence of very fine-grained sericitic muscovite, which is concentrated particularly in the more calcic parts of zoned crystals. The alkali feldspars on the other hand are much more uniform in composition, the albite content varying from 6 to 13 %, and there is no systematic relationship between the amount of sodium and the composition of the rock. Petrographic examination suggests that the alkali feldspars have not only unmixed, but that much of the perthitic albite has been lost by recrystallization. The recrystallized albite is seen as small grains on the boundaries of alkali feldspar crystals and as outgrowths on neighbouring plagioclases, in both cases replacing the adjacent potassium feldspar. The amount of perthitic albite remaining in the alkali feldspar is small in comparison to the amount of recrystallized albite.

The fact that the sodium contents of alkali feldspars from different rocks are similar, and unrelated to the compositions of the rocks, suggests that recrystallization of unmixed albite has proceeded to a point determined by the common conditions of cooling of the rocks and has then ceased. There is no apparent relation between the amount of recrystallization and the proximity of the later Trawenagh Bay Granite.

Although there is very little calcium in the alkali feldspars the amount does show some relation to the compositions of the rocks, the highest calcium contents being found in the alkali feldspars of the most calcic rocks. The correlation between calcium content and rock composition implies that the calcium has not migrated as readily as sodium from the alkali feldspars. Possibly the migration of sodium is easier than that of calcium because it has the same ionic charge as potassium and can change places with potassium without altering the balance of charges in the structure.

The feldspars of the porphyry dykes. The composition of the alkali feldspar phenocrysts from the porphyry dyke R17 was determined by the $20\bar{1}$ X-ray method. The crystals were heated to 1000°C for 72 hours, which homogenized them without inversion to monoclinic symmetry, and the X-ray powder pattern was then obtained using a diffractometer, with potassium bromate as an internal standard. From the determinative data of Orville (1960) their composition was found to be 83 wt. % Or. In thin section the alkali-feldspar phenocrysts show no evidence of recrystallization of unmixed albite, which probably accounts for their comparatively high albite + anorthite content.

The composition of the plagioclase phenocrysts was determined by X-ray and optical methods. The powder pattern was obtained using a diffractometer, and the separations 2θ (131)– 2θ ($\bar{1}\bar{3}1$) and 2θ ($\bar{1}\bar{3}1$)– 2θ (220) measured for Cu- $K\alpha$ radiation. The composition was derived from the low-temperature determinative curves of Smith and Yoder (1956). Both peak separations gave a result of mol. % An = 22. The composition was also determined optically by Tsuboi's method, using a double-variation apparatus to measure the refractive indices of (010) and (001) cleavage flakes. The measurements were referred to Tsuboi's (1934) dispersion curves, modified in accordance with the low-temperature refractive index data of Smith (1960), and the mean composition obtained was mol. % An = 25. The assumption of a low-temperature structural state for the plagioclase may be justified by the fact that the X-ray method gives a lower An-content than the optical method, whereas the opposite result would be obtained if the structural state were not low-temperature. However, neither method is very precise because of strong zoning of the phenocrysts.

It has been suggested that the compositions of coexisting feldspars may be used as a geological thermometer, and if the compositions of the Rosses feldspars are plotted on Barth's composition–temperature diagram (Barth, 1962, fig. 4) the temperatures indicated are 500° C for R17 and below 420° C for all the granites. This difference arises from the higher sodium content of the alkali feldspar in R17, but since this is the result of a difference in the degree of postmagmatic recrystallization no real significance can be attached to these temperature values.

The compositions of the potassic phases. The amount of sodium remaining in the microclines after unmixing was measured by the $20\bar{1}$ X-ray method, using potassium bromate as an internal standard, and the results are given in table III. All the specimens examined, except R17, are near-maximum microclines, and their compositions were therefore estimated from the determinative data for microclines given by Orville (1960). The potassium feldspar in R17 is a mixture of orthoclase and microcline, and the value given may therefore be too low by up to 3 %.

The amount of sodium in solid solution in the microclines does not exceed 5 %, and is not related either to the bulk composition of the perthite or to the proximity of later granite intrusions.

The structural state of the feldspars

The alkali feldspars. The variations in properties of the potassium feldspars depend on both composition and structural state, but in the

Rosses complex the amount of sodium in solid solution in the microclines is so low that compositional variations may be ignored. The structural state of the Rosses feldspars has been inferred from measurements of $2V$ and obliquity, and from the extinction angles on (001), which are also affected by submicroscopic twinning. The optic axial angles were

TABLE III. Compositions and crystallographic data for the potassic phases of the alkali feldspars

| Specimen no. | Wt. % (Ab+An) | α^* | γ^* | Δ | $2V_\alpha$ |
|--------------|---------------|------------|------------|----------|-------------|
| R3 | 1.5 | 90° 20' | 92° 13' | 0.93 | 84° |
| R4 | 1.9 | 90° 13' | 92° 01' | 0.88 | 75° |
| R5A | 4.1 | 90° 28' | 92° 12' | 0.97 | 82° |
| R5B | 0.0 | 90° 21' | 92° 15' | 0.93 | 79° |
| R9 | 2.9 | 90° 24' | 92° 13' | 0.94 | 83° |
| R10 | 4.1 | 90° 22' | 92° 15' | 0.93 | 80° |
| R12 | 2.5 | 90° 15' | 92° 10' | 0.88 | 81° |
| R16 | 2.0 | 90° 23' | 92° 15' | 0.95 | 80° |
| R17 | 0.3 | varies | varies | 0 & 0.77 | 80° |
| R19 | 0.6 | 90° 26' | 92° 15' | 0.99 | 83° |
| R20 | 1.7 | 90° 18' | 92° 03' | 0.86 | 80° |
| R22 | 0.3 | 90° 22' | 92° 17' | 0.96 | 82° |
| R23 | 4.6 | 90° 29' | 92° 15' | 0.96 | 83° |

determined by direct orthoscopic observation on a universal stage, several grains being measured in each sample. Obliquities were measured from the X-ray powder patterns, obtained using a diffractometer with Cu- $K\alpha$ radiation. The reciprocal lattice angles α^* and γ^* were calculated from the spacings of lattice planes with indices (hkl) and ($h\bar{k}l$), the pair (130) and ($1\bar{3}0$) being used to measure γ^* and the two pairs (111)—($1\bar{1}1$) and (131)—($1\bar{3}1$) being used to measure α^* . The latter pair was also used to calculate the obliquity value, $\Delta = 12.5(d_{131} - d_{1\bar{3}1})$, of Goldsmith and Laves (1954). The results of all the measurements are given in table III.

All the samples have optic axial angles near to the maximum possible value ($2V_\alpha \approx 84^\circ$), and with the exception of R17 they also have near-maximum obliquities. For example, Δ varies from 0.86 to 0.89, compared with 1.00 for maximum microcline, and γ^* varies from 92° 01' to 92° 17', compared with 92° 16' for maximum microcline. The powder pattern of R17 shows a wide (131)—($1\bar{3}1$) peak with three maxima, corresponding to a mixture of intermediate microcline ($\Delta = 0.77$) with monoclinic orthoclase. The extinction angle $\alpha' \wedge (010)$ on (001) is near its maximum value of about 16° in all the specimens except R17, indicating the absence of submicroscopic twinning.

The high $2V_\alpha$ and obliquity values of the potassium feldspars from

the granites indicate a near-maximum degree of Si-Al order, and these feldspars are therefore in a low-temperature structural state. The low (and variable) obliquity of R17 shows that attainment of a low-temperature structural state has been less complete than in the feldspars from the granites. If the chemical and crystallographic data for R17 are compared, it will be seen that some of the changes that have taken place on cooling have occurred more readily than others. Whereas unmixing has been almost complete, attainment of a low-temperature structural state has been only partly achieved, and recrystallization of the unmixed albite has hardly taken place at all.

The changes in structural state of the alkali feldspars that take place on cooling are governed by a number of factors, of which the most important are probably the rate of cooling, the water content of the rocks, and deformation, for which there is no evidence in the Rosses complex. The relative importance of rate of cooling and water content is difficult to assess because the amount of water needed to catalyse the structural changes is very small, and there is no way of measuring the amounts involved (Donnay, Wyart, and Sabatier, 1959). The differences in structural state between volcanic and plutonic feldspars are equally consistent with differences in the rate of cooling and differences in the water pressure during cooling.

The absence of chilled margins to the granitic units of the complex, intruded both before and after the porphyry dykes, shows that the country rocks were at a fairly high temperature during their emplacement. The porphyry dykes were probably also intruded into hot country rocks, and owe their fine grain-size and porphyritic texture to a release of pressure on the magma rather than to rapid cooling.¹ Thus it is likely that all the units of the complex cooled at a similar rate, in which case the intermediate structural state of the phenocrysts from the porphyry dyke (R17) must be attributed to a relatively low water content during cooling. There is no obvious reason why the water contents of the rocks

¹ According to Pitcher (1953) the porphyry dykes were intruded into relatively cold country rocks, but the following features shown by the dykes are believed to be more compatible with the interpretation given above. Firstly, there are few phenocrysts at the margins of the dykes, and they are small; and secondly, the plagioclase phenocrysts, including those near the margins, frequently show oscillatory zoning in which each zone grades from calcic to sodic outwards and is abruptly terminated, indicating alternate crystallization and resorption. From this evidence it is inferred that the phenocrysts were not present in the magma before intrusion, or at least only as small crystals, and that the crystallization of the phenocrysts was not particularly rapid. Thus the country rocks can not have been much colder than the magma at the time of emplacement.

should differ; possibly there is a relationship between the residual water content of the rocks and the water pressure in the magma at the time of crystallization.

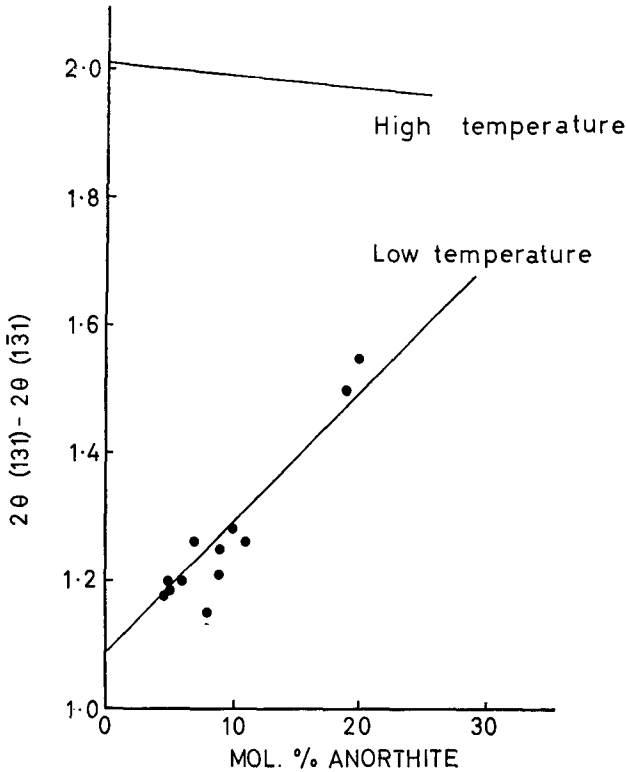


FIG. 1. Plot of $2\theta (131) - 2\theta (\bar{1}31)$ against composition for plagioclases from the Rosses granites. Cu- $K\alpha$ radiation was used for measurement.

The plagioclases. The X-ray powder patterns of all the plagioclase-quartz samples were obtained using a diffractometer with Cu- $K\alpha$ radiation. Because of the zoning the reflections were broad and difficult to measure accurately, whereas the peaks of quartz, which was present in all the samples, were quite sharp. Although all the samples fall in the compositional range in which peristerite unmixing would be expected to occur, there is no indication of unmixing in the powder patterns.

The lattice parameters of plagioclase, and hence the positions of the X-ray reflections, depend on both composition and structural state, and the latter can be determined by plotting appropriate peak separations

against composition. In fig. 1, in which the separation $2\theta(131) - 2\theta(1\bar{3}1)$ is plotted against composition, all the samples lie near the low-temperature curve determined by Smith and Yoder (1956), and a similar result is obtained when other peak separations are plotted against composition.

The structural state of the plagioclase from the quartz-porphry, R17, could not be determined in this way because no chemical analysis was available. However, as has already been mentioned, a comparison of the X-ray and optical determinations of its composition indicates no appreciable deviation from the low-temperature state.

Conclusions

There is very little variation in either the composition or structural state of the alkali feldspars in the Rosses granites. The high degree of unmixing and recrystallization, and the high values of $2V_\alpha$ and obliquity, all show that adjustment to low temperature conditions is essentially complete. No further ordering or exsolution could take place, and very little recrystallization. The only exception is in the phenocrysts from the quartz-porphry dyke, R17, although even these crystals show almost complete exsolution and a relatively high degree of Si-Al order.

The structural states of the plagioclases are less sensitive indicators of the conditions of cooling than are those of the alkali feldspars, but because of the absence of large scale unmixing and recrystallization their compositions are much more closely related to the compositions of the original magmas.

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