

DETERMINATION OF THE COMPOSITION OF ZONED PLAGIOCLASES FROM GRANITIC ROCKS

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ABSTRACT

The bulk compositions of 23 samples of zoned plagioclase from the Donegal Granite have been determined by chemical, optical and x -ray methods. The results of the indirect methods are compared with the results of the chemical analyses. The mean differences between the x -ray and optical values and the chemical analyses are 1.6% and 2.5% An respectively. On average the x -ray and optical results are low by 0.7% and 0.6% An respectively.

INTRODUCTION

Many of the principal methods of determining plagioclase compositions are not applicable to zoned samples. In such cases it is necessary to separate the feldspar from the rock if the accurate bulk composition is required. In the course of a petrological examination of part of the Donegal Granite, Ireland, samples of plagioclase were separated from a number of granitic rocks and their compositions determined by chemical, optical and x -ray methods. The results obtained by these methods are compared below, with particular reference to the accuracy of the optical and x -ray methods when applied to zoned material.

The granites whose plagioclases were studied are those of the Rosses Ring Complex (Pitcher 1953) and the Ardara Pluton (Akaad 1956). In both complexes the predominant rock type is granodiorite or adamellite, although diorites also occur in the Ardara Pluton. There are minor intrusions of pegmatite and aplite in both granites.

In nearly all the rocks the plagioclases are strongly zoned, the only exceptions being some of the most acid rocks, plagioclases of which are very sodic (An₀ to An₁₀). These are muscovite-granites, pegmatites and aplites. The nature of the zoning in the other rocks is by no means the same in every sample. In the majority the zoning is progressive, with the outer parts of crystals being more sodic than the inner parts. In the more highly contaminated granites, which occur particularly in the outer parts of the Ardara Pluton, the compositional variation is more irregular, resulting in undulatory extinction.

METHOD OF SEPARATION

The rocks were crushed and sieved, the grain sizes used for separation varying from 60–120 mesh for the coarsest-grained rocks to 191–300 mesh for the finest-grained rocks. Magnetite was separated by means of a hand magnet and an isodynamic magnetic separator used to remove muscovite, biotite, hornblende, epidote, garnet and any other magnetic

accessory minerals. The concentrate of feldspars and quartz was then centrifuged several times in bromoform-acetone mixtures to remove any material with a specific gravity less than 2.580–2.585 or more than 2.75–2.80. No attempt was made to separate quartz from plagioclase since their specific gravities and magnetic susceptibilities are too close for magnetic or heavy liquid separation to be used. The purity of the plagioclase-quartz samples was checked by examining them microscopically using an immersion oil with a refractive index of 1.530. They were free of potassium feldspar and any other impurities except sericitic muscovite.

The size of the sericite grains in the sericitized plagioclase is much smaller than the grain sizes used for mineral separation so that complete separation of the sericite would necessitate the removal of some of the plagioclase from each sample. This involves the danger of bias in separation since the most calcic parts of zoned crystals are often the most heavily sericitized. It is therefore not only undesirable to try and remove the sericite but also necessary to take great care in the preliminary magnetic separation of coarse muscovite, since the magnetic susceptibility of sericitized plagioclase may be expected to lie in between those of pure plagioclase and pure muscovite. In most of the samples which were separated in this study the proportion of sericitized material was roughly the same as was observed in thin sections of the rocks.

CHEMICAL ANALYSIS

The chemical analyses were made on the plagioclase-quartz mixtures and then recalculated to exclude quartz. SiO_2 , Al_2O_3 and CaO were determined gravimetrically and Na_2O and K_2O by flame photometry. All the analyses were made in duplicate. A small amount of potassium was in all the samples, reflecting the presence of sericitic muscovite.

The results of the analyses are given in Table 3 as molecular % $\text{Ab/Ab} + \text{An}$. The numbers of the samples are prefixed with either A or R to indicate that they came from the Ardara Pluton or Rosses Ring Complex respectively.

X-RAY DETERMINATION

The x -ray powder patterns of all the samples were obtained using a diffractometer with chart recorder. $\text{Cu K}\alpha$ radiation was used and the angular range $2\theta = 22^\circ\text{--}38^\circ$ was studied.

In general the reflections were broad and difficult to measure accurately, although the peaks of quartz, which was present in all the samples, were quite sharp. The poor quality of the plagioclase peaks may be attributed to the zoning. Although most of the specimens fall in the peristerite composition range there is no tendency for the peaks to be

split into two. Peristerite unmixing cannot definitely be detected from any of the powder patterns, even in the middle of the peristerite compositional range.

The composition was estimated from the separations of several pairs of peaks, using the determinative curves of Smith (1956) and Smith and Yoder (1956). The pairs which were used for measurement were (111) and ($\bar{1}\bar{1}\bar{1}$), (131) and ($\bar{1}\bar{3}\bar{1}$) and ($\bar{1}\bar{3}\bar{2}$) and (131). The pair (220) and ($\bar{1}\bar{3}\bar{1}$) was also used for those samples with more than 20% An, but can not be applied to more sodic plagioclases. Although some peaks are much more clearly defined than others no extra weight has been given to any particular peak separation. The shape of each peak depends on the distribution or anorthite contents within the sample, and measurement of low or broadened peaks are not necessarily less accurate than those of sharp peaks. It was assumed in all cases that the specimens were low-temperature plagioclases. Associated alkali feldspars which were studied at the same time were all found to be low-temperature forms, i.e. microcline-microperthites, mostly of near-maximum triclinicity.

The results are given in Table 1 as molecular per cent anorthite. It may be seen that there were considerable differences between the compositions measured from different pairs of peaks. The mean difference between *x*-ray and chemical values is 2.6 for the (111)–($\bar{1}\bar{1}\bar{1}$) pair, 2.2 for the (131)–($\bar{1}\bar{3}\bar{1}$) pair, 2.0 for the ($\bar{1}\bar{3}\bar{2}$)–(131) pair and 1.6 for the average *x*-ray values. These results show the value of measuring more than one peak separation and taking the average value for mol. % An.

OPTICAL DETERMINATION

The Tsuboi method of refractive index determination is the most suitable method for determining the bulk composition of the plagioclase in a rock because many grains may be measured in a short time, enabling the average composition to be calculated. This method consists of the measurement of refractive indices on (001) and (010) cleavage flakes. Great speed of measurement can be obtained by using the dispersion method for matching the refractive indices of the crystals and liquid.

In this case a single liquid (*o*-nitrotoluene) was used for all the measurements, its refractive index range being extended by raising the temperature. A double variation apparatus was used for measurement, enabling the temperature to be controlled accurately, and only fast vibration directions were measured. The determinative curves used were based on the original dispersion curves of Tsuboi (1934) modified in accordance with the low-temperature refractive index data of Smith (1960). From these curves a graph was plotted relating the wavelength of the crystal-liquid match directly to mol. % An for several different tem-

peratures. Fifteen grains were measured in each sample and each result given in Table 2 is the mean of all except the highest and lowest values obtained.

Table 2 also gives the range of measured values and the standard deviation for each sample. These figures provide a quantitative measure of the degree of zoning, which is not provided by either the chemical analysis or the *x*-ray method. However they also reflect to a certain extent the precision of the optical method itself, since a small spread of values was obtained from samples which did not show any zoning in thin section, *i.e.* R5A, R5B, R9, R19D and R22.

It may be noted that in most cases the distribution of anorthite con-

TABLE 1. PLAGIOCLASE COMPOSITIONS: X-RAY DETERMINATIONS

Sample	1	2	3	4	5	6	7
A39A	22	21	20	18	—	20	21
A41	10	12	11	13	—	12	13
A42A	21	22	21	22	24	22	22
A45A	22	25	24	26	25	25	27
A47B	16	10	9	11	—	12	15
A49	15	13	12	16	—	14	15
A52	19	22	21	20	24	21	24
A54	29	23	22	23	23	24	26
A55	>30	>30	>30	>30	>30	>30	43
A57A	4	2	1	10	—	4	9
A58A	17	18	17	18	—	18	15
R3	9	9	8	14	—	10	8
R4	19	23	22	23	21	22	22
R5A	3	6	5	7	—	5	5
R5B	6	6	5	6	—	6	5
R9	8	7	5	7	—	7	6
R10	9	9	8	10	—	9	12
R12	21	21	20	25	—	22	21
R16	10	9	8	10	—	9	10
R19D	10	7	5	7	—	7	6
R20	6	10	9	14	—	10	11
R22	15	7	6	8	—	9	10
R23	5	4	3	7	—	5	8

1. Mol. % An. from 2θ (111)— 2θ ($\bar{1}\bar{1}$ 1). Smith, 1956.
2. Mol. % An. from 2θ (131)— 2θ ($\bar{1}\bar{3}$ 1). Smith, 1956.
3. Mol. % An. from 2θ (131)— 2θ ($\bar{1}\bar{3}$ 1). Smith and Yoder, 1956.
4. Mol. % An. from 2θ ($\bar{1}$ 32)— 2θ (131). Smith, 1956
5. Mol. % An. from 2θ (220)— 2θ ($\bar{1}\bar{3}$ 1). Smith and Yoder, 1956.
6. Mean value of Mol. % An.
7. Mol. % An. from chemical analysis.

TABLE 2. PLAGIOCLASE COMPOSITIONS: OPTICAL DETERMINATIONS

Sample	Mol. % An	Range	Standard Deviation
A39A	18.9	12-26	3.7
A41	13.9	9-20	3.2
A42A	22.4	15-32	3.8
A45A	28.4	20-36	3.3
A47B	13.2	11-17	1.8
A49	17.0	11-24	3.2
A52	26.4	18-38	6.0
A54	20.5	9-28	6.0
A55	44.0	35-52	5.2
A57A	7.0	4-11	3.2
A58A	16.2	13-19	1.7
R3	12.9	8-18	3.0
R4	26.7	20-33	3.7
R5A	3.4	1-9	2.2
R5B	2.5	0-7	2.6
R9	2.0	0-6	1.9
R10	6.8	1-14	4.2
R12	20.8	16-27	3.2
R16	10.0	6-14	2.1
R19D	1.9	0-5	2.6
R20	8.1	1-14	4.2
R22	6.8	0-10	3.3
R23	5.0	0-11	2.8

tents was roughly symmetrical about the mean. In all cases where it was not symmetrical it was positively skewed, *i.e.* there were more measured values below the mean than above it. Skewness was most noticeable in samples A42A and A45A, and may be measured by comparing the mode of the measured values with their mean:

A42A. 38 readings. Mode = An₂₁. Mean = An_{22.4}.

A45A. 35 readings. Mode = An₂₇. Mean = An_{28.4}.

COMPARISON OF DETERMINATIVE METHODS

The compositions obtained by the three methods are listed in Table 3 and compared graphically in Figs. 1-3. On the whole the *x*-ray results agree with the analyses slightly better than do the optical results. The mean difference between chemical and optical results is 2.5% An, whereas the mean difference between chemical and *x*-ray results is 1.6% An. There is very little systematic error in the *x*-ray results. On average they are low by only 0.7% An.

The optical results are low by only 0.6% An. on average, but there appears to be some systematic error in samples with less than about 12% An. These give consistently low optical results. The reason for this is probably a bias in measurement. These samples come from the Rosses granites in which there is a marked tendency for the most calcic zones to be heavily sericitized. The refractive indices of these grains are difficult to measure, and the most calcic zones are therefore under-represented in the measurements.

In a study of plagioclase from the granites of the Port Clyde peninsula, Maine, Suzuki and Chayes (1961) found that *x*-ray determinations were consistently lower than optical determinations, especially for low anorthite contents. They attributed this to a skewed distribution of anorthite in the plagioclases. A skewed distribution would be reflected in the *x*-ray patterns, whose peaks would indicate the mode of the anorthite contents, not the mean. The optical results, which are averages, would not be affected. The good agreement between different methods for the

TABLE 3. COMPARISON OF PLAGIOCLASE DETERMINATIONS

Sample	Rock	Chemical	X-ray	Optical
A39A	Granodiorite	20.9	20	19
A41	Granodiorite	12.7	12	14
A42A	Granodiorite	22.0	22	22
A45A	Diorite	26.9	25	28
A47B	Granodiorite	14.9	12	13
A49	Granodiorite	14.5	14	17
A52	Granodiorite	23.8	21	26
A54	Granodiorite	25.8	24	21
A55	Diorite	43.0	>30	44
A57A	Pegmatite	8.8	4	7
A58A	Pegmatite	14.7	18	16
R3	Adamellite	8.2	10	13
R4	Microgranodiorite	21.7	22	27
R5A	Aplite	5.5	5	3
R5B	Pegmatite	4.8	6	3
R9	Microadamellite	6.4	7	2
R10	Microadamellite	12.0	9	7
R12	Microgranodiorite	21.2	22	21
R16	Adamellite	9.5	9	10
R19D	Adamellite	5.7	7	2
R20	Adamellite	10.7	10	8
R22	Greisen	9.8	9	7
R23	Adamellite	8.5	5	5

All the results are given as molecular % An/Ab+An.

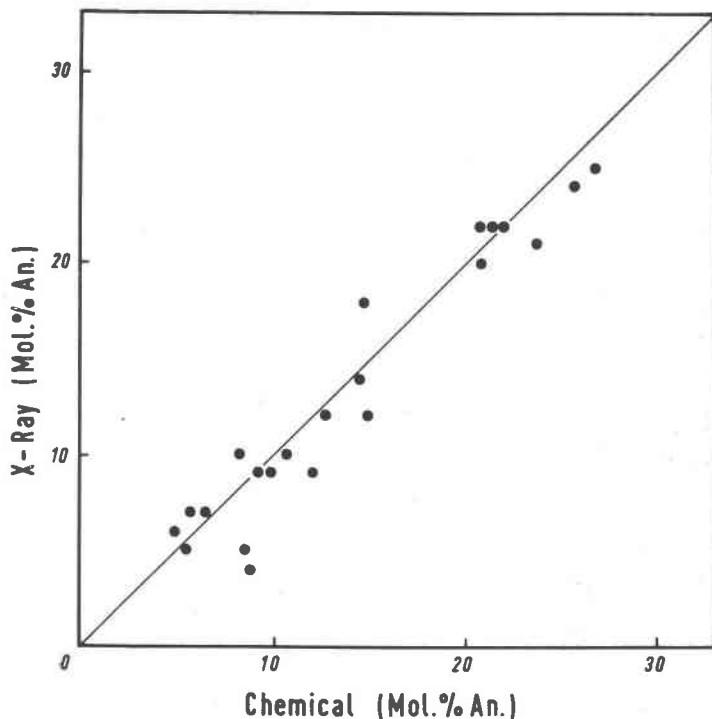


FIG. 1. Comparison of x -ray and chemical determinations of composition.

Donegal plagioclases reflects a general absence of severe skewness in the anorthite distributions. It also suggests that the assumption of a low-temperature structural state for the samples is justified, since any deviation from the low-temperature state would give high results for the x -ray measurements and low results for the optical measurements.

CONCLUSIONS

From this comparison it is possible to draw the following conclusions of the usefulness of the indirect methods of determination.

The x -ray method is generally superior to the optical method, as long as the anorthite distributions are not severely skewed. Unfortunately it is not possible to know whether this is the case or not without using one of the other methods. For the most accurate results it is necessary to measure several peak separations and take an average.

The optical method is not affected by skewness of anorthite contents but is generally not as accurate as the x -ray method, and is unreliable if

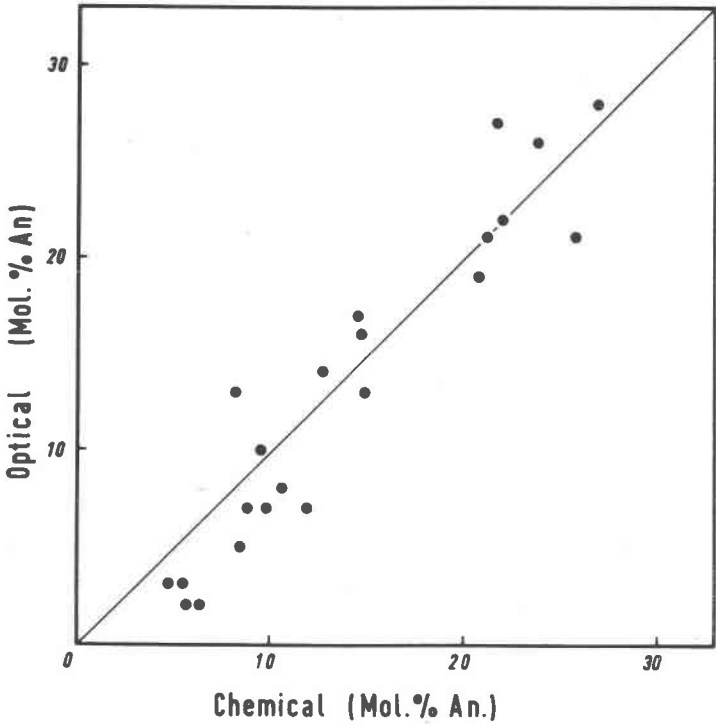


FIG. 2. Comparison of optical and chemical determinations of composition.

the samples are heavily sericitized. It is useful for indicating the degree of zoning.

Neither method has the precision of the zonal method used to study zoning in thin section, but the latter does not give the overall composition.

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REFERENCES

- AKAAD, M. K. (1956) The Ardara granitic diapir of County Donegal, Ireland. *Quart. Jour. Geol. Soc. London*, **112**, 263-288.
- PITCHER, W. S. (1953) The Rosses granitic ring complex, Co. Donegal, Eire. *Proc. Geol. Assoc., London*, **64**, 153-182.
- SMITH, J. R. (1960) Optical properties of low-temperature plagioclases. *Mem. Geol. Soc. Am.* **80**, Appendix 3.

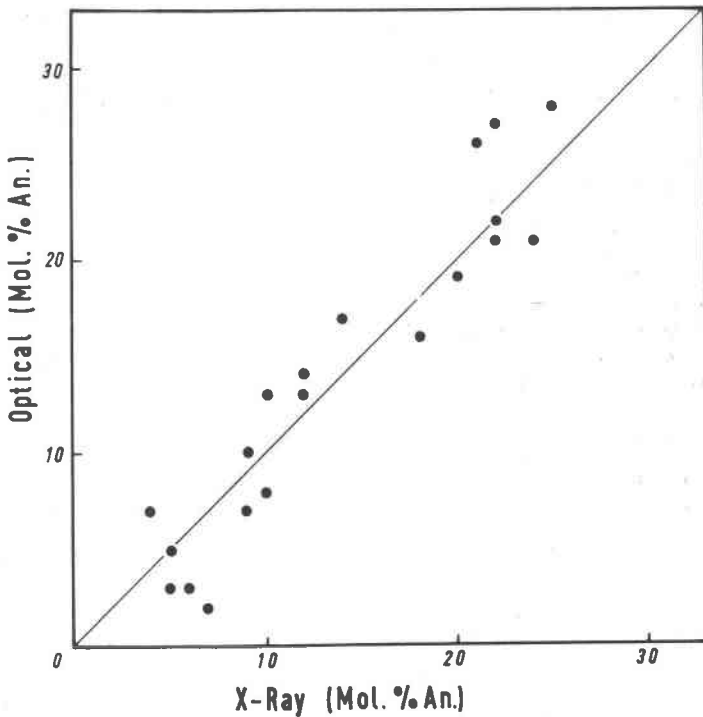


FIG. 3. Comparison of x-ray and optical determinations of composition.

- AND H. S. YODER (1956) Variations in x-ray powder diffraction patterns of plagioclase feldspars. *Am. Mineral.*, **41**, 632-647.
- SMITH, J. V. (1956) The powder patterns and lattice parameters of plagioclase feldspars. I. The soda-rich plagioclases. *Mineral. Mag.* **31**, 47-68.
- SUZUKI, Y. AND F. CHAYES (1961) Estimating the composition of zoned plagioclase. *Carnegie Inst. Wash. Year Book*, **60**, 169-172.
- TSUBOI, S. (1934) A straight-line diagram for determining plagioclases by the dispersion method. *Jap. Jour. Geol. Geogr.* **11**, 325-326.

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