calculated the parameters in Eqs. I-IV as well as the predicted values cited in Table 1.

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COMBINED ROCK AND THIN SECTION MODAL ANALYSIS

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During recent years the theory of modal analysis has been extensively developed (Chayes, 1956), and has been shown to be a valuable tool in the precise determination of the proportions of minerals present in fine to medium grained rocks. It is also being used extensively in the estimation of areal variation of granitic complexes (Whitten, 1961).

Similarly, techniques and apparatus have been described to facilitate point count analysis on coarse grained rocks (more especially granites) which otherwise would have required a large number of counts over several thin sections, (Jackson and Ross 1956; Emerson 1958; Fitch 1959; Smithson 1963).

While studying "granitic" rocks from South Greenland (Nesbitt 1961 and in preparation) the writer encountered difficulty in obtaining reliable modal analysis data from rock types which were of medium to coarse grain and were characterized by irregularly spaced microcline and plagioclase phenocrysts amounting to about 20% of the rock. The results given in Table 1 indicate that the modal analyses of single thin sections of rocks of this texture are most unreliable.

The writer considers that the modal analysis of rock slabs is an unsatisfactory solution to the problem because fine-grained components,

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quartz-feldspar intergrowths, inclusions, and intergrowths of biotite and amphibole are not taken into account.

To test the precision of modal analysis on rocks of this texture, ten thin sections whose average area was 400 mm^2 were examined and modal values obtained (thin sections were stained to facilitate identification of the alkali feldspar). Two thousand counts were made on each section. This was achieved by accumulating 1000 counts along traverses in one direction, then turning the slide through 180° and counting again up to 2000. Thus each thin section was covered by two grid systems, the distance between them being in the region of 1 mm and that between adjacent point counts along one traverse, $\frac{1}{6}$ mm. The variation of the major components is given in Table 1.

TABLE 1. VARIATION OF MAJOR CONSTITUENTS IN TEN THIN SECTIONS OBTAINED BY CONVENTIONAL POINT COUNT ANALYSIS ON SPECIMEN 42888[1]

Constituents	Limits (%)	Standard Deviation (%)
Plagioclase	27.0–49.8	9.0
Microcline	22.0–48.5	7.8
Quartz	14.7–22.5	5.1
Amphibole	1.0– 6.1	1.6
Biotite	3.6–10.4	2.7

[1] Numbers correspond to those in the Greenland Geological Survey catalogue.

The large variability seen in the experimental data is in accord with the conclusions of Bayly (1960) and is discussed later.

As a check on the operator error, ten thin sections from a fine to medium grained granite (23882) were cut, stained and point counted under similar conditions to those for 42888. The results expressed as standard deviations were: plagioclase 1.61, microcline 2.13, quartz 1.46 and biotite 0.56. It can be seen from these figures that the modal analysis of a fine to medium grained rock is much more satisfactory than that obtained from a rock showing variable grain size.

METHOD USED

Following a suggestion of Dr. C. H. Emeleus, a rock slab and thin section method was attempted in which the proportions of the phenocrysts in the rock are derived from the modal analysis of the rock slab. A 55 cm^2 surface was cut on 42888[1] which was ground, stained and those

[1] This area is probably too small, but can be increased by cutting successive slabs from the rock.

phenocrysts over 3 mm. in length were outlined in ink for convenience of counting.[2] The actual operation of point counting was achieved by tracing off the shapes of the phenocrysts and laying the tracing paper on graph paper. Traverses at set intervals were then carried out, point counting plagioclase phenocrysts, microcline phenocrysts and matrix when they occurred under the intersection of line crossings.

The ten thin sections were next examined. Modal analysis was carried out, omitting phenocrysts over 3 mm in size.

The results of the point count on the thin sections were then recalculated so that the total was equal to that obtained for the matrix on the rock slab analysis. Values for the plagioclase and microcline phenocrysts obtained on the rock slab were then added so that the analysis totalled

Table 2. Results for Combined Rock and Thin Section Modal Analysis on Specimen 42888

Constituents	Limits (%)	Standard Deviation (%)
Plagioclase	35.0–40.0	1.49
Microcline	29.0–32.2	0.92
Quartz	16.0–21.5	1.9
Hornblende	2.5– 6.5	1.07
Biotite	4.8– 9.5	1.30

100%. In the case of 42888 for example, the actual point count of the rock slab gave 4.8%, 15.7% and 79.5% for plagioclase, microcline and matrix respectively. Thus the values obtained on the thin section were recalculated in terms of 79.5% and then the actual values obtained for the phenocrysts added, so that the final total was 100%. The results of these operations are shown in Table 2.

Comparison with Other Results

It is of interest to compare these results with measurements made by Chayes (1951). Sixteen modal analyses of the Westerly Rhode Island granite (G1) have been carried out by Chayes, and the variation within the individual components and the standard deviation obtained by him are reproduced in Table 3.

It will be noted that the data given for specimen 23882 agrees favorably with the results of Chayes and the values for 42888 obtained by the

[2] This value is purely arbitrary, being the most convenient for the specimen. Each rock should be considered individually, the choice depending on the grain size variation.

combined rock and thin section method (Table 2) would appear to have the same degree of precision. There is little doubt that the precision on 42888 could be improved by increasing the number of sections sampled. At least two thin sections were of doubtful value because the area remaining to be counted after the phenocysts were omitted was small. Under ideal conditions the areas counted on the thin sections would be equal, but in practice, and in this particular case, the random distribution of the phenocrysts means that it is rarely achieved. The results presented in Table 2 would probably be much improved if it had been possible to use equal measurement areas and the two sections, previously referred to, had been omitted.

TABLE 3. RESULTS OF MODAL ANALYSIS ON WESTERLY RHODE ISLAND GRANITE (G1), AFTER CHAYES, (1951), TABLES 25, 26

Constituents	Limits (%)	Mean	Standard Deviation (%)
Plagioclase	29.1–33.0	31.4	1.40
Alkali Feldspar	32.0–37.1	35.4	1.40
Quartz	25.5–29.6	27.5	1.40
Biotite	2.2– 4.2	3.2	0.60
Muscovite	0.7– 1.9	1.3	0.40

CONCLUSIONS

An obvious step in drawing any conclusions on the proposed method is to compare the averages obtained on 42888 using the ten thin sections and those from the combined rock and thin section analysis. This has been done in Table 4, which shows the near correspondence of the two averages. It is suggested from this result that it is possible to obtain reliable modal values on rocks of this type either by point counting a large number of thin sections (that is covering a large area) or by using a combination of point counts on a rock slab and one or more thin sections. The actual number of areas (thin sections) counted, will depend on the degree of precision required and the coarseness of the rock. If the grain size of the whole matrix is unusually coarse, then the estimate of the minerals from a single thin section will probably be in error. In these circumstances, point counting of two or more sections to increase the counting area, will improve the accuracy.

This conclusion is, in fact, not unexpected if the theoretical observations of Bayly (1960) are correct. Bayly points out that in any coarse-grained rock, attention to sample area is as important as the number of

TABLE 4. AVERAGE VALUES OBTAINED ON TEN THIN SECTIONS OF 42888, COMPARED WITH THOSE OBTAINED USING A COMBINED ROCK SLAB AND THIN SECTION METHOD

Constituents	1	2	3
Plagioclase	39.0	37.0	35.0
Microcline	30.0	31.0	30.2
Quartz	19.0	19.0	21.5
Hornblende	3.4	4.0	2.8
Biotite	7.2	7.5	8.5

1. Ten thin sections.
2. Rock slab and ten thin sections.
3. Rock slab and one thin section, chosen from ten determinations to show the greatest divergence from the average.

points counted. The counting of a large number of points on one thin section of a coarse grained rock does not improve the accuracy of the estimation of the bulk composition, only the counting variance. Data given by Bayly (1960), relating the degree of coarseness (the I. C. number[1] of Chayes, 1956) to the size of the sample area required to reduce the variance produced by grain size, is only practical when a fairly uniform texture is present. (However, see the arguments of Bayly, 1960 on this point.)

Solomon (1963), suggests that the factors, grain radius (R), percentage of the mineral present (p), area counted, and grid size (that is, the distance between point counts), control the variance of the analysis. Thus for a (uniformly) coarse grained rock where $R=0.5$ mm. he has calculated that an area of 1900 mm^2 (five average thin sections), at a grid interval of 1 mm, and 1900 points would be required to produce a standard deviation of 1.41%, provided that p is 25% or less. Other limitations placed on the estimates are that the grains are randomly distributed and are more or less regularly shaped. Unfortunately, as in the work of Bayly (1960) no provision is made for rock types displaying randomly distributed phenocrysts, except by calculation of the I. C. value (Bayly) or the average radius of the grains (Solomon), this the writer believes unpractical.

The writer is indebted to Dr. C. H. Emeleus for supervision of the work and to Dr. A. W. Kleeman and Miss E. M. McBriar for their critical reading of the manuscript.

[1] The I.C. number is obtained by noting the number of grain boundaries crossed in a traverse 25 mm long, or the length of traverse required to cross a fixed number of grain boundaries (Bayly)

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PSEUDOMORPHS OF ANATASE AFTER SPHENE FROM ROANOKE COUNTY, VIRGINIA

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Well-formed pseudomorphs of anatase after sphene occur in an allanite-bearing pegmatite near the crest of the Blue Ridge in Roanoke County, Virginia. The pseudomorphs are nearly identical to xanthitane (xanthotitane, xanthotitanite) from Henderson County, North Carolina, originally described as a new mineral by Shepard (1856) and Eakins (1888), and later shown by Frondel (1941) to be anatase after sphene. Pough (1934) summarized the earlier literature relating to anatase as an alteration product of sphene, and Deer *et al.* (1962) have reviewed the more recent literature on the subject.

The pseudomorphs vary in size up to 4 cm in their longest dimension, and have the typical wedge-shape of sphene. The interfacial angles on the largest and most perfectly developed of these were measured on a one-circle reflecting goniometer. Although many of the faces reflect light, it was necessary to put water on some of them to increase their reflectivity. The forms present, listed here according to decreasing size, are n $\{111\}$, a $\{100\}$, c $\{001\}$, v $\{\bar{1}01\}$, m $\{110\}$, t $\{\bar{1}11\}$, and Y $\{101\}$