REPLY TO DR. CHAYES' DISCUSSION

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We wish to stress that the quoted publication of Chayes is a landmark in the field of modal analysis. The brevity of our paper caused his work to be mentioned in a critical remark only, wherefore apologies. The editor further contributed to both brevity and sharpness by changing our (among others, Chayes 1956) into (Chayes, 1956). As it stands, the curious statement is ours indeed, because the point distance is hardly treated by Chayes at all.

The weakness of our paper, as we see it, is the prerequisite that the rock should be "homogeneous". As a matter of fact, this is often not so, and anyway we do not really know it is homogeneous before we have compared several counts based on different measurement areas. Therefore, we should have welcomed the concept of analytical error as an expression of the inhomogeneity of a rock. According to Chayes, however, the analytical error is "the random error attaching to the analysis (of a thin section) as an estimate of the composition of the hand specimen from which the section is cut" (p. 58). Furthermore, he considers any difference between this analytical error and the counting error (in one thin section) to be primarily due to coarseness: "If the specimen were very fine grained, the thin sections would differ little if at all from each other; the contribution of the specimen to the analytical error would thus be virtually nil. . . ." (p. 60). If used in this sense, we are certainly "unwilling to admit the importance of the distinction between analytical error and counting error". In the Chayes procedure this distinction is necessary because the point distance leads to correlated measurements in the case of coarse-grained rocks. In a later stage, this effect is compensated by introducing an empirically determined coarseness index.

On the other hand, in our procedure the analytical error, as far as it is caused by coarseness, virtually coincides with our counting error if the point distance requirement is fulfilled. The index of coarseness can then be eliminated. An additional objection is that the analytical error of Chayes is attached to the hand specimen, while such a specimen, for instance in the case of a megacryst granite, is often itself not representative of the rock due to this same effect of coarseness. Whereas Chayes concentrates on hand specimen and thin section, we first examine the structure and coarseness of the rock and choose our measurement area accordingly. The consequences of this difference in approach will be made clearer below with the aid of an example.

For us, the measurement area in point counting should be conceived of primarily as a two-dimensional grid defined by number of points and point distance. In a discussion of the effect of coarseness on the scale of petrographic investigation, point distance should come in before the area of a thin section or the capacity of a point counter are considered (p. 93). Our statement that it is a waste of time to count a pegmatite with a point distance of 0.2 mm seems undeniable. Hence the development of macro point-counting methods. The diffi-

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culty was to find a statistical expression of the obvious need to adapt the grid to the coarseness of the rock. We think we have found this expression by realizing ourselves that in the chosen form of the standard deviation (4.7, p. 39) correlation of successive observation points is explicitly forbidden. To prevent correlation, the point distance should be as large or larger than the grain size of the rock. In this way, statistics provide us with a relation already postulated by common sense. To determine the point distance, it is of course not necessary to measure the grain size with any degree of accuracy: it is a matter of scale, not of measurement. As long as experienced petrographers can use the concept of coarseness consistently, they will be able to choose a corresponding grid, that is, a corresponding point distance.

The most efficient grid is one where the points are placed in the intersections of a net of equilateral triangles. A grid consisting of n points at a distance of a then covers a measurement area of $\frac{a^2 n \sqrt{3}}{2}$. Some approximate values are given in the accompanying table.

point distance	measurement area	
	500 points	1000 points
0.1 mm	4.5 mm^2	9 mm^2
0.5 mm	109 mm^2	217 mm^2
1 mm	433 mm^2	866 mm^2

It is seen that the measurement area depends directly on the point distance and the number of points, and these in their turn on the coarseness of the rock and the desired reliability. Whether this area is covered by one or a number of thin sections, or by a rock slab, is a practical matter without theoretical consequence.

Let us now consider whether it is worthwhile to cut down the number of points counted. We will adopt the data mentioned in the discussion: thin sections of 25 × 45 mm, in which 1500 points are counted. When dealing with a coarse-grained granite like Carnmenellis, four thin sections will have to be counted to reach an "average major mineral analytical error" $\leqslant$ 2.0 (Chayes, 1956, fig. 12). This makes 6000 points, over a total measurement area of 45 cm^2.

Following our method, about 600 unrelated observation points suffice to arrive at the same precision (remember that 2 σ is plotted instead of σ !). If it is not a megacryst granite, a point distance of about 1 cm will be a fair proposal. This leads us to a measurement area of 520 cm^2 or two etched and colored rock slabs of 20 × 13 cm, a reasonable size for a hand specimen of a coarse-grained rock. A comparison of the results leads to some interesting conclusions:

1. our method cuts down the number of points by a factor 10;
2. it enlarges the measurement area by a factor of approximately 10;
3. this larger measurement area will be more representative of the rock than the smaller one;
4. our method is to be preferred when the main components can be made easily visible in a rock slab;
5. the Chayes method is to be preferred if we are obliged to count these components in thin sections.

In the future, the results obtained with both methods should be carefully compared. Especially in inhomogeneous rocks the reliability will have to be established in an empirical way. It was certainly not our intention to oversimplify the complicated problems involved. Yet, we maintain that it was worthwhile to chart a much-used expression of the standard deviation, so that the influence of the parameters on the reliability may be overseen at a glance. At the same time, we have shown that this expression requires that the point distance be adapted to the coarseness of the rock, such as has been sensed before by various authors, without their finding an adequate statistical expression of what they felt to be true.

Reference

Chayes, Felix, 1956, Petrographic modal analysis: New York, John Wiley & Sons, 113 p.