TABLE II. VOLBORTHITE; X-RAY POWDER PATTERN

I	d(meas) Å	I	d(meas) Å	I	d(meas) Å
1	7.9	3	2.64	4	1.79
10	7.18	6	2.57	4	1.71
½	5.15	<½	2.46	3	1.68
½	4.43	6	2.39	½	1.57
½	4.26	½	2.28	½	1.55
2	4.10	2	2.23	5	1.51
½	3.59	½	2.13	3	1.50
2	3.10	3	2.04	1	1.49
4	3.00	<½	1.96	1	1.47
6	2.88	½	1.92	1	1.46
2	2.72	3	1.80	2	1.44
				1	1.43

Ellsworth (1932), no additional carnotite or uranium minerals have been found in the area. The maximum reported value of V_2O_5 in the sediment is over 3 per cent, but the lack of sufficient quantities of the copper and vanadium-bearing rock has resulted in the deposits generally being classified as uneconomical.

ACKNOWLEDGMENT

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REFERENCE

ELLSWORTH, H. V. (1932): Rare-element Minerals of Canada; *Geol. Surv., Canada, Economic Geol. Ser.* **11,** 139.

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THE BULK COMPOSITION OF A ZONED CRYSTAL*

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Quantitative petrographic studies often require an estimate of the bulk composition of zoned crystals, such as plagioclase feldspars. Bowen (1928, p. 143) pointed out in this connection that "the outer shell of a crystal requires to have only about one-tenth the thickness of the whole crystal in order to constitute half the volume." X-ray or oil immersion methods of bulk composition determination suffer from similar diffi-

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culties and, furthermore, require extracting the entire grain from the rock. Chemical analysis, homogenization, refractive index of glass, or specific gravity determination also require removal of the entire grain. A simple and direct method is based upon measurements of zoned crystals in thin section. It is assumed that the compositional variation can be expressed by two components and that the section cuts the nucleus of the grain being studied.

Let r be the distance from the nucleus of a crystal to any point on the rim and let x be some lesser distance from the nucleus along this line. Let V be the volume of the crystal and V_x be the volume at the earlier moment of growth when x was on the rim, with the assumption that there has been no change in crystal shape throughout growth. Then:

$$V = kr^3 \tag{1}$$

$$V_x = kx^3 \tag{2}$$

$$dV_x = 3kx^2dx. \tag{3}$$

Further, let D be the composition difference between the nucleus and the rim, and let D_x be the composition difference between the nucleus and x. As a first approximation many crystals are zoned so that D_x can be expressed as some power function of x, or, specifically x/r, in order to normalize the measuring unit:

$$D_x = ax^p = D\left(\frac{x}{r}\right)^p. \tag{4}$$

Even in the case of discontinuously zoned crystals or limited zone reversals, a plot of composition against radius can often be arbitrarily smoothed to approximate a power function. It is assumed that this power function holds for any direction of r, *i.e.* that p and a are constant.

In order to compute the bulk composition we need to know the average composition difference (D_{av}) between the nucleus and the rim. This difference is added to the composition of the nucleus to obtain the bulk composition of the crystal. As is the case for any average property of a variable sample, D_{av} is computed by summing the products of the individual increments of volume (dV_x) by their composition difference (D_x) and dividing this sum by the total volume of the crystal. This is expressed in integral form as:

$$D_{\mathrm{av}} = \frac{\int_0^r D_x dV_x}{V}. \tag{5}$$

Substituting (1), (3), and (4) into (5) gives:

$$D_{\mathrm{av}} = \frac{3D}{r^{p+3}}\int_0^r x^{p+2}dx = \frac{3D}{p+3}. \tag{6}$$

This result may then be added to the nucleus composition to give the bulk composition.

Fig. 1 provides a graphical solution for bulk composition and a way to approximate p. A plot of normalized composition difference against normalized radius is made for the crystal concerned and scaled to match Fig. 1. Then the two diagrams are superimposed and the approximating power function ascertained, interpolating when necessary. The intersection of this power function with the bulk composition curve (indicated by the heavy line on the right side of the diagram) determines the bulk composition. This may be read off the vertical scale. As a simplified example let us imagine a zoned plagioclase crystal ranging from An_{60} at the nucleus to An_{30} on the edge. Suppose the crystal has a composition against radius plot which approximates a power function where p equals 7. This power function will intersect the bulk composition curve at a

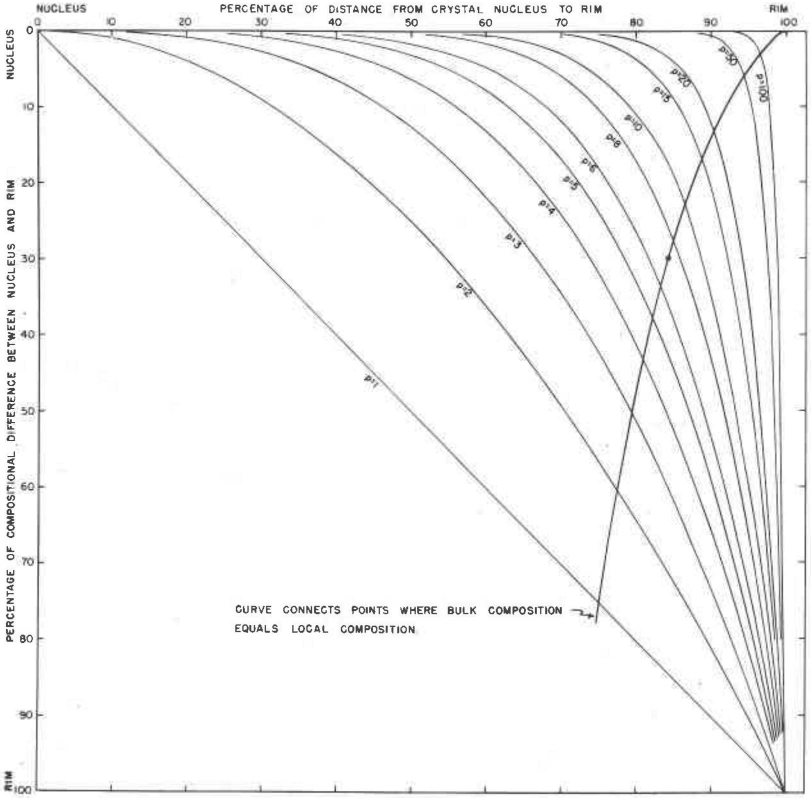

Fig. 1. Graph used to approximate the bulk composition of certain zoned crystals. Explanation in text.

point (shown as a dot on the figure) which is compositionally thirty percent of the way from An_{60} to An_{30}. Hence the bulk composition is An_{51}. The horizontal intercept of this point is about 84, indicating that the An_{51} position is .84 of the way from the center out to the rim. The result may also be computed from relation (6).

Some crystals have a composition distribution so complex that a piecemeal integration is necessary if one wishes to know the bulk composition. However experience indicates that many rocks do contain crystals having a composition distribution which can be approximated by a power function. For these rocks the method finds useful application. The method is equally applicable for determining the bulk composition of one zone of a complexly zoned crystal should the composition distribution between the inner and outer edges of the zone approximate a power function.

REFERENCE

Bowen, N. L. (1928), The evolution of the igneous rocks: Princeton Univ. Press, Princeton, New Jersey.

We regret to announce the deaths of two Fellows of the Mineralogical Society of America:

Dr. A. B. Edwards, The University of Melbourne, Melbourne, Australia.

Dr. John T. Lonsdale, University of Texas, Austin, Texas.

Dr. Paul F. Kerr, Newberry Professor of Mineralogy at Columbia University, has been spending eight weeks at the University of Oslo, as NATO guest professor in the Department of Geology.

A forty page booklet on the minerals of Boron, California, has been published by the Mineral Research Society of California, at Montebello, California, with Earl Pemberton as editor. A short account of the history and geology is followed by brief descriptions and some photographs of 21 of the most significant minerals of this locality.