SIMPLE METHOD FOR THE DETERMINATION OF THE PLAGIOCLASE FELDSPARS

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ABSTRACT

Precise refractive index data on synthetic plagioclase feldspar glasses have been available for over forty years. However, no routine method based upon these data has come into general use for the determination of the natural feldspars. Such a method possesses certain advantages over the many other procedures presently followed. Its theoretical accuracy is about twice that obtainable with established refractive index methods. Index determinations, involving no particular refinements of technique, were made on the glasses of ten chemically analyzed natural plagioclase feldspars. The anorthite contents derived from these data agreed with those calculated from the chemical analyses within about two per cent. The method is simple and rapid, and calls for no costly equipment; some platinum foil for enclosing the feldspar sample, and a blowpipe capable of yielding a 1550° C. flame, are the only "extras" needed. It is therefore recommended for inclusion among the standard methods for the determination of the plagioclase feldspars.

INTRODUCTION

Numerous methods are available whereby the composition of the plagioclase feldspars may be determined by the measurement of various physical properties (1) (2) (3). Poldervaart (4) has recently discussed the advantages and limitations of many of the standard methods. It is generally recognized that no single method is universally applicable, and that the determinative charts presently available are not entirely adequate. New techniques continue to be devised, such as the *x*-ray diffraction method recently proposed by Claisse (5). In view of the great importance to the petrologist of accurate plagioclase determination, further developments in this field are to be expected.

In 1909 Larsen (6) recorded the refractive indices of six pure synthetic glasses of the albite-anorthite series. Four years later Bowen (7) utilized these data to locate several liquidus points on the now-famous phase-equilibrium diagram of the plagioclase feldspars. Little if any determinative use has since been made of Larsen's data, and the possibilities of the feldspar glasses in analytical work, thus early recognized by Bowen, have been subsequently neglected. With the exception of the specific gravity curve presented by Poldervaart (4), no curves for the physical properties of the glasses have ever appeared among the determinative charts of the plagioclase series. Whereas refractive index curves for the crystalline feldspars have been widely used in determinative work, the curve derivable from Larsen's refractive index data for the feldspar glasses has never been recommended for similar use.

To the writer it appeared that the excellent agreement obtained by

Bowen between optical and thermal determinations in the laboratory system augured well for the usefulness of glass indices in routine analyses of the natural plagioclases. Before advocating its general use for such a purpose, however, it was considered advisable to test the method on natural analyzed feldspars, while employing a technique of glass-formation readily accessible to the average petrographer. A suite of eight analyzed feldspars previously studied by Meen (8) was made available to the writer, and was used in preliminary tests. The bulk of the determinations were made on ten analyzed feldspars furnished by N. L. Bowen, and for which chemical analyses have been presented by Kracek and Neuvonen (9).

Determinative Procedure

The basis of the proposed method is the data previously provided by Larsen (6). The lowermost curve of Fig. 1 is a plot of these data. For

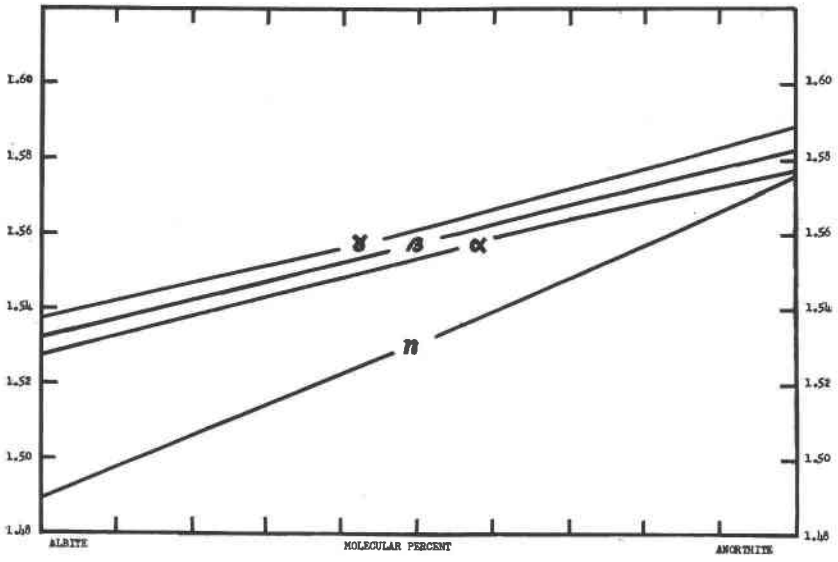

Fig. 1. Refractive indices of the plagioclase feldspars. Lower curve: feldspar glasses (after Larsen). Upper curves: crystalline feldspars (after Kennedy).

comparison, curves for the three principal indices of the crystalline feldspars, after Kennedy (10), are also included. In accordance with almost universal practice, these data have been plotted on a molecular basis. It is recommended that for determinative use the vertical scale be increased by a factor of 2:1 over that shown in the illustration. For the convenience

of the reader who wishes to prepare his own working-curve the required data, after Larsen (6), are presented in Table 1.

The procedure involved in obtaining the feldspar glasses is simple and rapid. A "pinch" of feldspar powder, or a tiny sliver, is wrapped in a small piece of thin platinum foil and held for several minutes in the hottest flame of the blowpipe. An oxygen-gas blowpipe is much to be preferred over the ordinary mineralogical blowpipe, because of greater convenience of operation, and of the ready attainment of melting temperatures as high as 1550° C. The heat-treated platinum-wrapped sample is plunged directly into water, in order to quench the molten charge to a glass. Although unnecessary for the albitic feldspars, this precaution is required in the case of the anorthite-rich feldspars, if recrystallization is

TABLE 1.

Molecular Composition	*Refractive Indices of Glasses* (sodium light)
Ab (100%): An (0%)	1.4890
Ab (66⅔%): An (33⅓%)	1.5166
Ab (50%): An (50%)	1.53075
Ab (33⅓%): An (66⅔%)	1.5452
Ab (16⅔%): An (83⅓%)	1.5600
Ab (0%): An (100%)	1.5755

to be avoided. The glassy charge is then broken free of its platinum wrapping, and its refractive index is measured with the aid of a reliable set of standardized immersion media. The immersion oils used in this study were separated by index-increments of 0.005. If employed at some temperature other than that at which they were standardized, the oils should be re-calibrated with the aid of a refractometer during use, or a suitable temperature-correction should be applied. Sodium light is recommended as the illumination-source. The refractive index of the glass is easily estimated to the nearest 0.001 of index. The anorthite content is then estimated, to the nearest 0.5%, from the appropriate refractive-index curve. Further refinement of technique, such as that involved in the double-variation method of Emmons (11), would doubtless enhance the accuracy obtainable with the procedure described above. For present purposes, however, it seemed preferable to outline a routine method which might be utilized in even the most modestly-equipped petrographic laboratory.

Results

The results of duplicate determinations on glasses of each of the ten analyzed feldspars furnished by Bowen are presented in Table 2.

Table 2. Anorthite Contents of 10 Analyzed Natural Plagioclase Feldspars

*Number of Sample	Molecular Percentages from Chemical Analyses			Molecular Percentages from Indices of Glasses	
	% Or	% Ab	% An	% An(I)	% An (II)
13	0.7	98.7	0.6	0.0	0.0
8	1.3	81.9	16.8	17.5	17.5
10	3.9	74.5	21.6	20.5	21.5
6	2.4	45.7	51.9	50.0	51.0
7	1.2	35.0	63.8	63.0	62.0
5	(trace)	30.3	69.7	70.5	70.0
4	1.0	23.0	76.0	75.5	75.5
3	0.5	19.5	80.0	79.5	80.0
2	0.3	13.9	85.8	85.0	84.5
1	0.3	7.1	92.6	93.5	93.0

* Sample numbers are from Tables 1 and 3, Kracek and Neuvonen (9).

In the above table are included also the proportions of the orthoclase, albite and anorthite components calculated from the chemical analyses (9). In this calculation the assumption has been made that each of the oxides, K_2O, Na_2O, and CaO, is wholly confined to the Or, Ab, and An components, respectively.

It is apparent from an examination of Table 2 that the anorthite contents experimentally determined from the refractive index measurements are in reasonably good agreement with those calculated from the chemical analyses. Larsen, Irving, Gonyer, and Larsen (12) considered their determination of plagioclase feldspars of the San Juan, Colorado, volcanics to be correct to within $\pm 3\%$ of the anorthite content. Poldervaart (4) has recently stated that the plagioclase series is normally determined optically with an accuracy of $\pm 2\%$. A comparable accuracy is indicated for the method under discussion.

Discussion of Method

Many of the standard methods of plagioclase determination suffer from the drawback that ambiguous results are given for certain portions of the composition range. Even the method based upon the refractive indices of the crystalline feldspars is not free from this defect. The index-curves presented by different authorities often show significant differ-

ences. Then too, the selection of one of the three principal indices, or of a specific intermediate index, is attended with some uncertainty. The presence of zoning, or of intimate exsolution-intergrowths of two feldspars of different composition, poses the question as to whether the grain or grains measured are representative of the average plagioclase composition. Poldervaart (4) proposed to overcome the difficulty of strong zoning, by forsaking optical methods entirely in favor of a mean specific gravity test on the feldspar powder. But this does not appear to be too satisfactory a solution to the problem, in the light of the results of Meen (8). He found that, in spite of careful separation, his purified feldspars contained inclusions which materially affected the specific gravity measurements. Indeed, two feldspars shown by Meen to differ by as much as 23% in anorthite content were found by him to have closely similar specific gravities. The presence of the orthoclase component in solid solution is believed by some to have a substantial effect on the feldspar optics (8). A further complication in feldspar determination is inserted by the recent recognition of high- and low-temperature feldspars of identical composition, yet different optical constants (13, 14). All of these factors conspire to render determinations based on standard refractive index curves of doubtful accuracy.

The simple method herein proposed is free of most of the defects enumerated above. Uncertainty due to possible misinterpretation of the orientation of the measured grain is eliminated. There is but a single index to be measured on the feldspar glass, regardless of grain-orientation. Comparison of the lower curve of Fig. 1 with the upper trio of curves in the same figure readily reveals the greater determinative accuracy of the former. The difficulties introduced by zoning and unmixing of feldspars are also surmounted in the present method. Thus, in preparing the feldspar glass it is possible to employ a sample involving hundreds of grains. Any inhomogeneity in feldspar composition in the original granular sample may be removed by repeated crushing and fusion, prior to index-measurement. A reliable value for the average plagioclase composition can thus be assured. And what about the possible effect of the orthoclase component present in solid solution in the plagioclase? In this connection it is to be noted that the refractive indices of the glasses of orthoclase and albite are almost identical: 1.487 and 1.489, respectively. The determination of the anorthite content of a feldspar glass would therefore be but little affected by the substitution of even substantial amounts of the orthoclase for the albite component. It is also immaterial whether the original crystalline feldspar exhibited a high- or a low-temperature form or both. In view of the advantages enumerated above, this simple method would certainly appear less precarious in the hands of the novice than presently accepted methods.

Probably the most severe criticism that can be levelled at the proposed method is that it calls for a reasonable degree of purification of the feldspar prior to fusion and index-measurement. However, this does not seem to be too serious an obstacle. The coarser specimens of feldspar will yield suitable material directly, without need for purification. Finely disseminated feldspar, however, requires a refining process. But even this need involve no more elaborate procedure than crushing, sorting, magnetic extraction, and suspension in bromoform suitably diluted with benzene, as proposed by Meen (8). The indications, too, are that a small amount of impurity is not too disturbing. It is common experience in silicate equilibrium research that homogeneous glasses approximating the feldspars are attained only after prolonged and repeated fusion. It is very doubtful that the short fusion time generally employed in the present method would permit appreciable diffusion of the impurities through the glass. It is therefore believed that only in the occasional case of repeated fusions, carried out to counteract zoning or exsolution effects, need the impurity factor cause concern. It was earlier remarked that two feldspars found by Meen (8) to differ by 23% in their anorthite contents yielded specific gravities which were roughly the same. Meen attributed these erratic specific gravity data to foreign inclusions. Yet in the present study the glasses of these two feldspars checked the anorthite contents calculated from their respective chemical analyses to within 2%. Apparently, impurities capable of invalidating specific gravity data as an analytical tool had no adverse effect in the determination of the anorthite contents by the glass-index method.

Another possible disturbing factor merits at least passing comment. It is well known that a glass may exhibit index-variations involving the fourth, and even the third decimal place, depending on its thermal history (15). A glance at Fig. 1 reveals that each 0.001 of index-variation would correspond to about 1% change in anorthite content. But fortunately it is only between the annealed and the un-annealed specimens of a given glass that substantial index-contrasts are displayed. Since the technique proposed in this paper involves quenched un-annealed glasses exclusively, no difficulty should be introduced by such a factor.

Why has this simple method been so long and so completely ignored, when every other possibility has been thoroughly scouted? In this connection it is to be recalled that Larsen's data (6) were obtained on glasses synthesized from the purest available chemicals. Their use by Bowen (7) likewise involved pure synthetic mixtures. There has always been some reluctance to assume that data obtained on pure laboratory melts are directly applicable to systems involving natural minerals.

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