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COMPOSITION AND STRUCTURAL STATE OF PLAGIOCLASES FROM THE LOWER PART OF THE EASTERN BUSHVELD COMPLEX, SOUTH AFRICA

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ABSTRACT

Fifteen plagioclase concentrates with a range of An_{60} to An_{80} from the lower part of the Eastern Bushveld Complex have been analyzed by microprobe techniques and X-ray powder diffractometer studies to establish a revised determinative curve of composition versus the X-ray parameter $\Gamma(\Gamma = 2\theta(131) + 2\theta(220) - 4\theta(1\bar{3}1)$ for CuK_α radiation) for the ordered- or low-structural state plagioclases. The present curve is shifted to a lower An-content and differs from that of Smith and Gay (1958) by 5 percent An at An_{60} and 2 percent An at An_{80}. Heating of the analyzed samples at 975°C for periods of time ranging from $6\frac{1}{2}$ to $36\frac{1}{2}$ days significantly disordered most of the specimens.

GENERAL

The objective of this investigation was to establish a powder X-ray method for the rapid determination of the composition of bulk plagioclase concentrates from rocks of the lower part of the Eastern Bushveld Complex. Relatively precise analyses of a large number of samples is needed for critical assessment of the genesis of this portion of the complex.

A revised X-ray determinative curve for ordered plagioclases in the composition range An_{65} to An_{83} has been determined using the parameter Γ [$\Gamma = 2\theta(131) + 2\theta(220) - 4\theta(1\bar{3}1)$] for CuK_α radiation) of Smith and Gay (1958). Powder X-ray diffraction data was obtained for fifteen plagioclase samples that were chemically analyzed by electron microprobe methods. The structural state of these samples was evaluated by measurement of the Γ and β parameter($\beta = 2\theta(1\bar{1}1) - 2\theta(20\bar{1})$) before and after heat treatment.

The samples included both cumulus and post-cumulus (interstitial) plagioclase and were taken from pyroxenite, anorthosite, chromite-anorthosite, norite and gabbro. The specimens were selected from drill core representing a stratigraphic interval of more than 3,500 feet extending from below the Steelport chromite seam to a position above the Merensky Reef (Cameron, 1963, Fig. 4).

The present curve of Γ versus composition should be applicable to plagioclases in other stratiform mafic complexes which were slowly cooled and contain low-K plagioclases in the composition range An_{65}–

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An_{80}. It should also apply to low-K plagioclase in this composition range from other geologic environments in which ordered—or low-structural state plagioclases occur.

X-ray Methods

Between 1 and 3 grams of plagioclase was split from 5 to 15 gram concentrates extracted from each of the fifteen rock specimens. This material was finely ground in a tungsten carbide-lined mechanical mortar, dried, back-packed against a polished stainless steel plate and contained in a standard aluminum X-ray diffractometer mount. Two to four separately packed mounts were prepared for each specimen, and each separately packed mount was traversed five times from 28.0 to 31.5°2θ utilizing Ni-filtered Cu radiation (35 kv, 18 ma). Four degree slits, a scale factor of 4, a time constant of 4, a scan speed of 1/4°2θ per minute, and a chart speed of 2 in/°2θ were used.

The distance between $2\theta(1\bar{3}1)$ and $2\theta(131)$, and the distance between $2\theta(1\bar{3}1)$ and $2\theta(220)$, respectively, were measured on chart paper using a rule divided into 50 parts per inch. The center of each peak was established as follows: At a vertical distance between 0.6 to 0.8 units above background (at which the peak was bilaterally symmetrical), a horizontal line was drawn and the midpoint of this line was determined. This midpoint was taken as the center of the peak. After establishing the midpoints of the peaks, the linear separation of the peak centers was measured and this value was converted to degrees 2θ, *i.e.* 1 inch = 0.5°2θ. The parameter $°2\theta(1\bar{3}1) - °2\theta(131)$ is termed SY_2, and the parameter $°2\theta(1\bar{3}1) - °2\theta(220)$ called SY_1 as these parameters were used by Smith and Yoder (1956) in evaluating plagioclase structural state (Table 1). The difference in degrees 2θ between SY_2 and SY_1 is equal to the value Γ (Table 1) which was used by Smith and Gay (1958) in plagioclase structural state studies. The precision of measurement of SY_1 and SY_2 is $\pm 0.01°2\theta$ or better and the precision of measurement of Γ is correspondingly $\pm 0.02°2\theta$ as indicated in Figure 1. The values shown in Table 1 are the average of 10 to 20 traces for each plagioclase concentrate.

Microprobe Analysis

Microprobe analysis was performed utilizing the ARL electron microprobe in the Department of Geophysical Sciences at the University of Chicago under the supervision of Professor J. V. Smith. The standards used were the synthetic plagioclase glasses prepared by D. H. Lindsley and natural plagioclases analyzed previously by Ribbe and Smith (1966). The composition of 10 to 12 grains was determined for each of the fifteen specimens. Microprobe settings were 15 kv, 0.1 μA, 10 sec. count and

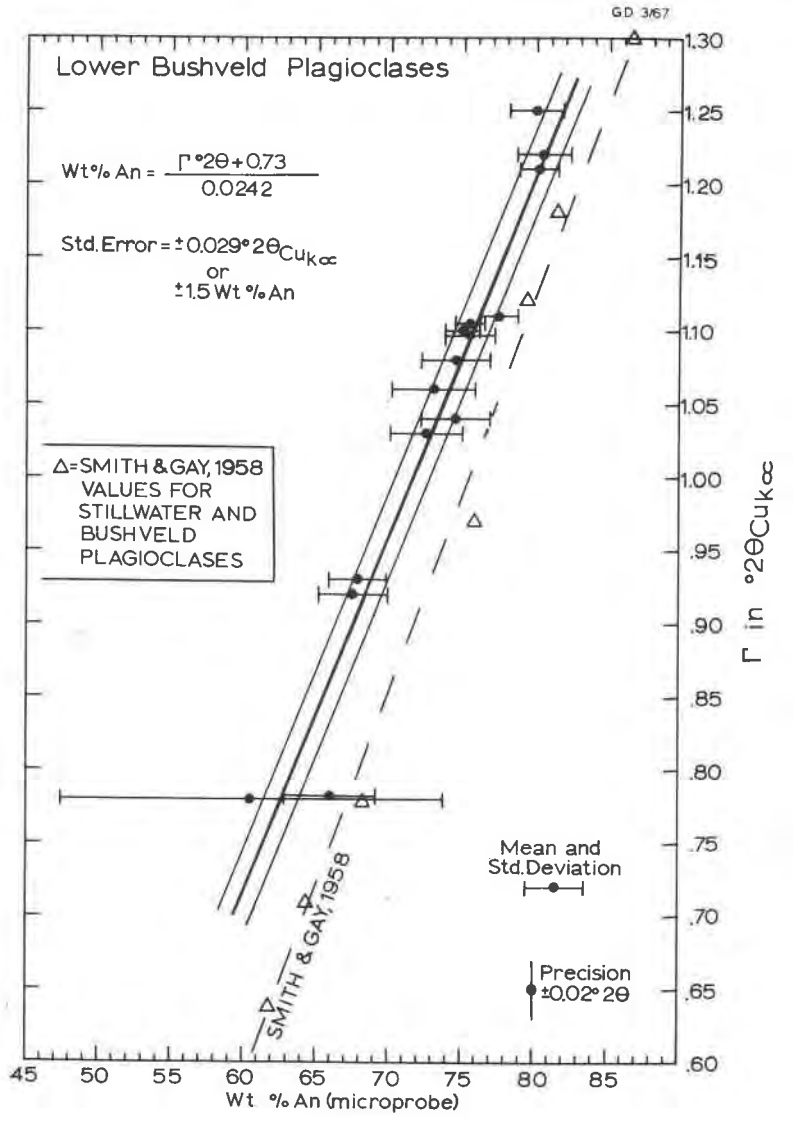

FIG. 1. Composition versus Γ of Bushveld plagioclases. Lines on both sides of the present curve indicate the standard error for the curve for comparison. The broken line shows the composition versus Γ curve which Smith and Gay (1958) constructed from a large number of analyzed feldspars, including some (shown here by triangles) from the Bushveld Complex.

TABLE 1. X-RAY POWDER DIFFRACTION, ELECTRON MICROPROBE AND HEATING DATA FOR 15 PLAGIOCLASES FROM THE EASTERN BUSHVELD COMPLEX

Microprobe analysis					X-ray powder data[a] in °2θ CuKα				Heating data and x-ray powder data (after heating) in °2θ CuKα				
Specimen Number	Mean wt. % An	Range wt. % An	Std. dev. wt. % An	No. of grains	Γ	SY_2	SY_1	β	Heating period in days	Γ	SY_2	SY_1	β
16-78-4-A	60.5	33.5	13.2	11	0.78	1.94	1.16	0.86	14	0.78	1.93	1.16	0.81
15-1248	66.0	9.0	3.1	12	0.78	1.93	1.16	0.87	14	0.84	1.96	1.13	0.85
US-9-255	67.5	7.0	2.4	11	0.92	2.01	1.08	0.84	14	0.96	2.02	1.07	0.82
US-9-160	67.8	6.0	2.0	12	0.93	2.02	1.08	0.83	14	0.99	2.04	1.06	0.82
US-7-761	72.5	7.5	2.5	11	1.03	2.06	1.03	0.84	36-1/2	1.16	2.12	0.96	0.785
US-9-1980	73.0	6.0	2.8	12	1.06	2.08	1.02	0.83	36-1/2	1.205	2.14	0.935	0.785
15-969	74.5	6.5	2.4	12	1.04	2.06	1.02	0.83	36-1/2	1.14	2.11	0.975	0.80
15-65	74.5	7.0	2.4	10	1.08	2.08	1.01	0.82	6-1/2	1.125	2.10	0.975	0.80
15-276	75.0	4.0	1.2	10	1.10	2.09	1.00	0.82	6-1/2	1.16	2.12	0.960	0.80
UDA-6	75.5	7.0	1.7	11	1.10	2.08	0.99	0.81	36-1/2	1.16	2.12	0.965	0.785
11-44	75.5	3.0	1.0	11	1.10	2.10	0.99	0.815	14	1.165	2.125	0.960	0.805
LDA-3	77.5	4.0	1.3	11	1.11	2.10	0.99	0.81	6-1/2	1.16	2.115	0.960	0.81
LDA-2	80.0	6.0	1.8	10	1.25	2.17	0.92	0.80	6-1/2	1.29	2.18	0.90	0.795
J15-1960	80.2	4.0	1.4	10	1.21	2.15	0.93	0.805	6-1/2	1.24	2.17	0.93	0.79
LDA-17	80.5	4.5	1.9	11	1.22	2.15	0.94	0.785	36-1/2	1.29	2.195	0.905	0.775

[a] Symbols for X-ray powder data:

$\Gamma = 2\theta(131) + 2\theta(220) - 4\theta(1\bar{3}1)$.

$\beta = 2\theta(1\bar{1}1) - 2\theta(20\bar{1})$.

$SY_2 = 2\theta(1\bar{3}1) - 2\theta(131)$ refers to J. R. Smith and Yoder (1956) parameters.

$SY_1 = 2\theta(1\bar{3}1) - 2\theta(220)$ refers to J. R. Smith and Yoder (1956) parameters.

between 30 and 50×10^3 counts for Ca. In addition, the Al and K contents were determined, the former as a check on the Ca. For each of the 15 specimens, the An content is an average of the counts for 10 to 12 grains (Fig. 1). The maximum K content in the 15 specimens is about 0.2 wt. % corresponding to about 1.5 mol % Or, the minimum K content is about 0.05 wt. % K corresponding to 0.4 mol % Or. Because of the very small quantities of K in these plagioclases, Or has been disregarded in preparation of the determinative curve (Fig. 1). Bambauer *et al.*, (1965) have observed an influence of Or in plagioclase on the $2\theta(131)-2\theta(1\bar{3}1)$ value in the region $An_{20}-An_{60}$; for the present work the Or content is so small that this factor may be disregarded.

For eight specimens the uncertainty in composition due to instrumentation was $\pm1.5\%$ An; for the other seven the uncertainty was $\pm1.0\%$ An. The mean and the standard deviation for each specimen, as determined by the microprobe are shown in Figure 1 and Table 1. The linear relation of Γ *vs* An content shown in Figure 1 differs from that of Smith and Gay (1958). The present curve is shifted to a lower An content by 2 percent at An_{80} and 5 percent at An_{60}. The difference in the two curves seems not to be due to differences in degree of ordering of the plagioclases; rather, it appears to be due to the fact that the An values of the original chemical analyses taken by Smith and Gay (1958) for specimens in this composition range were too high. This is evident in critical evaluation of two of the same specimens recently reanalyzed by the microprobe (Ribbe and Smith, 1966, Table 3); specimens E-23 and EB-18. According to these new analyses, both fall within 1 percent of the Γ *vs* An curve of the present paper (Fig. 1).

The standard error of estimate for the Γ *vs* An content curve corresponds to about ±1.5 weight percent An. The two specimens having compositions of An_{66} and $An_{60.5}$, respectively, are both post-cumulus plagioclase. The one with an average composition of $An_{60.5}$ contains grains which have a composition between An_{35} and An_{40}. (The range of composition found for each specimen is shown in Table 1). Such grains are probably due to late-stage modifications that significantly affect the value of Γ, which is an average for hundreds or thousands of grains in any sample.

The β parameter $(2\theta(1\bar{1}1)-2\theta(20\bar{1}))$ was also measured for the same plagioclase concentrates. A plot of β *vs* An content shows an essentially linear relationship for the samples studied but the change in β is so small compared to the corresponding change in An in the $An_{60}-An_{80}$ composition range that the precision of measurement of β is not sufficient for precise composition determination. This poor precision is due largely to the fact that the $(1\bar{1}1)$ peak is of low intensity.

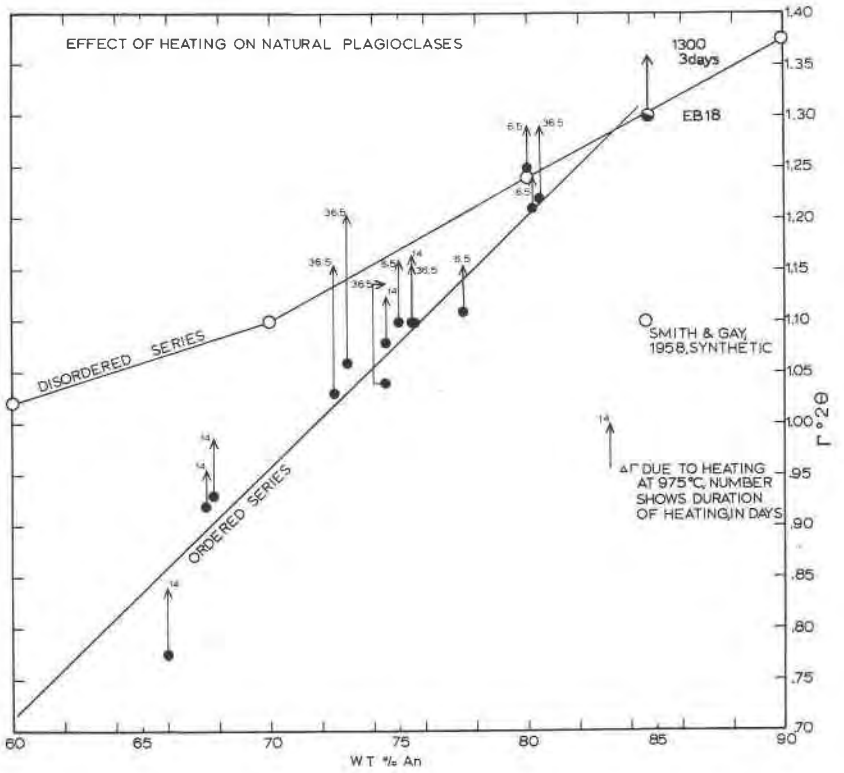

FIG. 2. Effect of heating on the structural state of natural plagioclases as indicated by measurement of Γ on heated and unheated concentrates. Specimen EB-18 is from the Stillwater Complex; the Γ value is from Smith and Gay (1958) and the composition is from Ribbe and Smith (1966).

EFFECT OF HEATING ON BUSHVELD PLAGIOCLASES

For further evaluation of the degree of ordering in the Bushveld plagioclases, splits from the fifteen standard specimens were heated. The specimens prepared for heating were composed of grains in the size range 35–170 mesh. These were heated in platinum boats in three groups at 975°C, one group for $6\frac{1}{2}$ days, another for 14 days and the third $36\frac{1}{2}$ days. After heating, each specimen was quickly cooled to room temperature (but not quenched in a cold bath) and finely ground in a mechanical mortar. The Γ and β parameters were measured as previously described and are listed in Table 1. The changes in Γ are shown in Figure 2, and for comparison, the most highly disordered series illustrated by Smith and Gay (1958, Fig. 1) is also shown. In addition, a specimen from the Stillwater Complex (EB-18) heated by Smith and

Gay (1958) is shown with the composition corrected from the data of Ribbe and Smith (1966, Table 2).

It is apparent from the data that the value of Γ was significantly increased by heating and except for one specimen, all the natural specimens became disordered. The lack of any change in the value of Γ due to heating for specimen 16-78-4-A (Table 1) cannot be satisfactorily explained at present but it is surmised that the high proportion of grains more albitic than An_{60} in the sample may have masked the change in Γ, inasmuch as the sample has a more heterogeneous composition than any other.

The greatest changes occurred in those specimens heated for longer periods of time, but significant changes occurred even in the shorter runs. At present it is not understood why some of the heated natural specimens appear to be more "disordered" than the synthetic ones. However, based on the value of Γ this appears to be the case. The Stillwater Complex specimen (EB-18) examined by Smith and Gay (1958) and also heated by them is shown for comparison (Fig. 2); it displays a response to heating similar to some of the specimens of the present study, *i.e.* it has a Γ value higher than the synthetic disordered series portrayed by Smith and Gay (1958, Fig. 1). The results of the heating studies of the Eastern Bushveld plagioclases suggest that they are as well ordered as other natural plagioclases in this composition range and can be disordered to some extent by heating.

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