THE RELATIONSHIP BETWEEN SPECIFIC GRAVITY AND STATE OF ORDER IN PLAGIOCLASE FROM ANORTHOSITIC ROCKS

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Plots of specific gravity, state of order as inferred from X-ray powder films, and anorthite content of 43 plagioclases from anorthositic rocks and in the composition range $An_{42-62.5}$ indicate that in this composition range relatively disordered plagioclases of a given anorthite content have lower specific gravities than do relatively ordered plagioclases of the same composition.

PRESENTATION AND DISCUSSION OF DATA

Data from previous studies (among them those of Smith 1956, Brown 1960, Orville 1967, and Wright & Stewart 1968) of sodic plagioclases have shown that the unit cell dimensions of disordered sodic feldspar (high albite) are greater than those of more ordered sodic feldspar (low albite). [The relationship is less clear for sanidine-orthoclase-microcline as indicated by cell dimensions quoted by Deer, Howie & Zussman (1966). Wright & Stewart (1968, Table 2) give unit cell volumes for the relatively disordered polymorph of K feldspar, orthoclase, that are slightly greater than those for the relatively ordered polymorph, microcline, of the same Or content; but other data of Wright (1967) do not agree completely.]

Unit cells of both ordered and disordered plagioclase of given composition should contain the same total number of ions, and therefore disordered forms should in general be less dense than ordered forms. In order to determine whether or not this relationship holds true in intermediate plagioclases from anorthosite, the specific gravities, anorthite contents, and several separations of X-ray lines on powder patterns, thought (see, for example, Smith & Gay 1958 and Bambauer et al. 1967) to be dependent on both anorthite content and state of order, were determined for 43 plagioclases (composition range $An_{42-62.5}$) from anorthositic rocks. The data are given in Table 1.

It is well known that specific gravity of plagioclases changes with anorthite content, and, therefore, in attempting to determine the relationship of structural state and specific gravity one must compare plagioclases of about the same anorthite content. Plagioclases studied were grouped for plotting purposes into the ranges $An_{42-47.5}$, $An_{48-52.5}$, $An_{53-57.5}$, and $An_{58-62.5}$. Plots for $\Gamma =$

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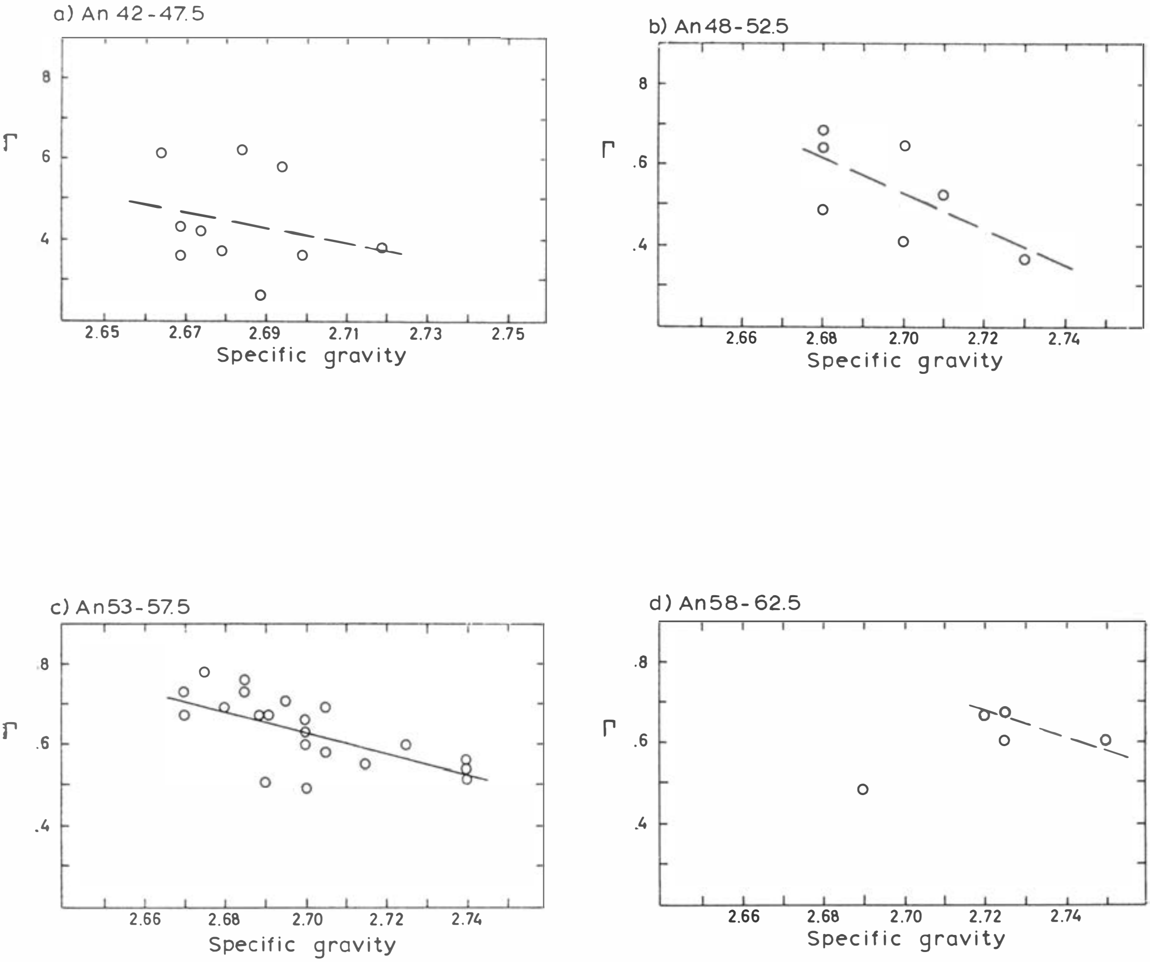
$2\Theta_{(131)} + 2\Theta_{(220)} - 4\Theta_{1\bar{3}1}$ versus specific gravity are given in Fig. 1. Although there is a spread of data on each of the graphs, straight lines tend to emerge. The best line is obtained in the range $An_{53-57.5}$ where the greatest number of data are available. The 4 curves obtained for the different composition ranges are plotted together in Fig. 1e to summarize the trends observed. It can be seen that within a given composition range plagioclases with higher Γ values have relatively lower specific gravities. According to the data of Smith & Gay (1958) relatively high Γ values at a given anorthite content indicate relatively disordered structural states.

In order to test this relationship further, plots were made of specific gravity versus three other 2Θ separations thought to reflect state of order (Fig. 2). Only data from the composition range $An_{53-57.5}$ are plotted for these parameters. A curve for the angular separation $2\Theta_{(131)} - 2\Theta_{(1\bar{3}1)}$ shows a decrease in the distance between these X-ray lines with increase in specific gravity. The curves for the separation $2\Theta_{(\bar{2}41)}$-$2\Theta_{(\bar{2}\bar{4}1)}$ shows a systematic increase in the distance between these X-ray lines with increase in specific gravity. Note, however, that the curve for $\beta = 2\Theta_{(1\bar{1}1)} - 2\Theta_{(\bar{2}01)}$ shows only a very slight increase in β as specific gravity increases, and this is within the range of determinative errors. These curves, with the possible exception of the curve for β, confirm the observation that specific gravity increases as the structure of the plagioclase becomes more ordered. Relatively disordered structures are found in plagioclases of lower density.

The relationships reported here would appear to shed additional light on the nature of the disorder that causes differences in the distances between various X-ray lines. The unit cell of disordered intermediate plagioclase is apparently less dense and thus probably larger than the unit cell of disordered plagioclase with the same composition. This difference may be a result of differences in packing geometry rather than Al/Si substitution disorder only.

APPENDIX ON ANALYTICAL PROCEDURES, PRECISION, AND ACCURACY

Specific gravities of cleavage fragments (ranging in weight from 6 to 100 mg, with an average of 28 mg) were determined on a Berman balance. Two or three determinations of each grain were averaged, with a precision of $\pm$ 0.015 or better. The grain was then ground in an agate mortar. Half the powder was mixed with $Pb(NO_3)_2$ as an internal standard and x-rayed using Fe $K\alpha_1$ radiation, on a Guinier-deWolff quadruple focusing camera. Values for Fe $K\alpha_1$ were then converted to values for Cu $K\alpha_1$, using a program created for this investigation by Mrs. K. Thoresen, whom I wish to thank especially for her assistance. The average precision of film measurements was determined to be within the margin $\pm$ 0.03 for Γ, and $\pm$ 0.01 for β, $2\Theta_{(131)} - 2\Theta_{(1\bar{3}1)}$ and $2\Theta_{(\bar{2}41)}$–$2\Theta_{(\bar{2}\bar{4}1)}$. Several standards were used for which independently determined values were available from the X-ray laboratory at Syracuse University, U.S.A. Virtual-



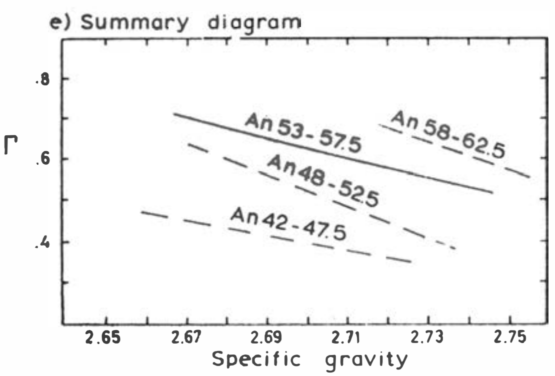


Fig. 1. Plots of Γ value ($\Gamma = 2\Theta_{(131)} + 2\Theta_{(220)} - 4\Theta_{(1\bar{3}1)}$) versus specific gravity for various ranges of anorthite content. Within the composition ranges given, high values of Γ are indicative of relatively disordered structure and low values are indicative of relatively ordered structure.

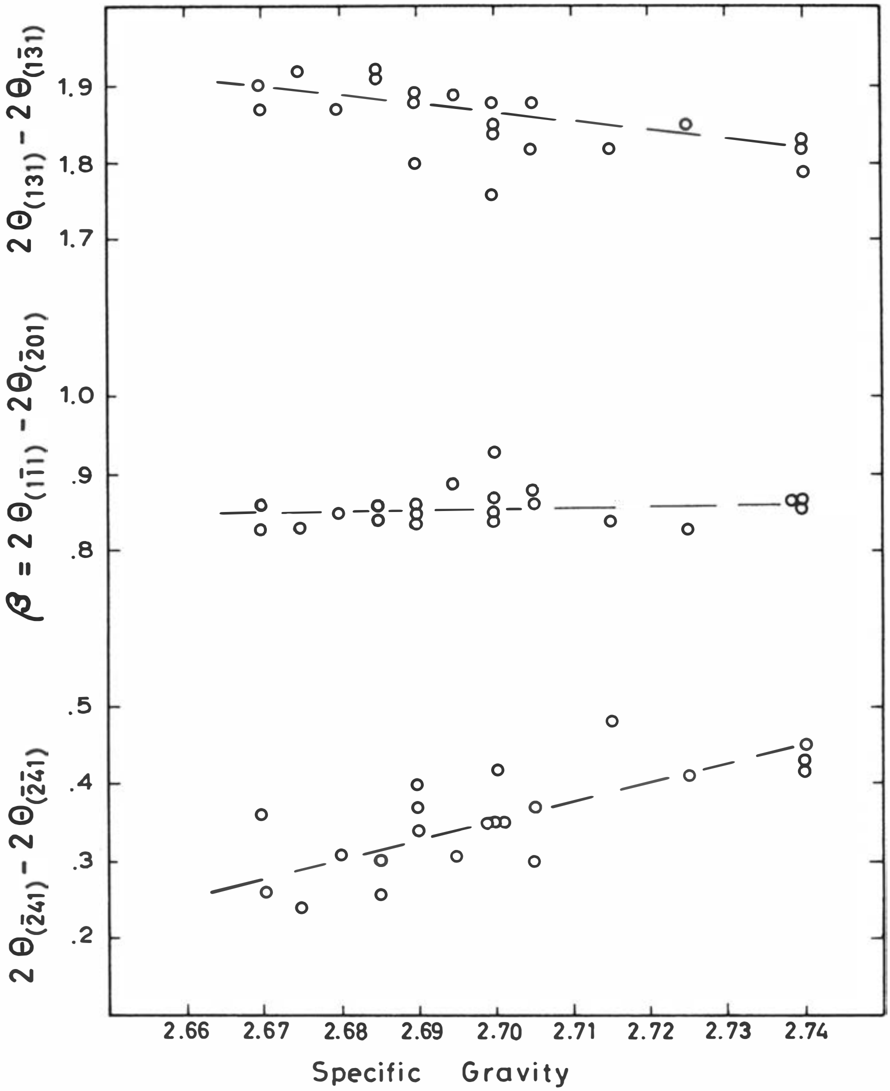


Fig. 2. Plots of $2\Theta_{(131)}-2\Theta_{(1\bar{3}1)}$, β value ($\beta=2\Theta_{(1\bar{1}1)}-2\Theta_{(\bar{2}01)}$), and $2\Theta_{(\bar{2}41)}-2\Theta_{(\bar{2}\bar{4}1)}$ for plagioclases in the composition range $An_{53-57.5}$. For the separation $2\Theta_{(131)}-2\Theta_{(1\bar{3}1)}$ high values indicate relatively disordered structures and low values represent relatively ordered structures. For the diagram of β, high values indicate relatively ordered structures and low values represent relatively disordered structures. For the separation $2\Theta_{(\bar{2}41)}-2\Theta_{(\bar{2}\bar{4}1)}$ high values indicate relatively ordered structures and low values represent relatively disordered structures.

ly identical results in the two laboratories where greatly different techniques were used suggest that the x-ray values are also accurate. Anorthite content was inferred by fusing the other half of the powder made from each plagioclase grain and determining the refractive index of the glass using sodium light. Precision of measurements of anorthite content is estimated at $\pm$ 1 percent

Table 1. Numerical Data for Figs. 1 & 2

Field No.	Rock type & location	An Wt. %	Γ	$(131)-(1\bar{3}1)$	$(\bar{2}41)-(\bar{2}\bar{4}1)$	β	Specific gravity
$N13Y_1$–2	norite, Lofoten, N. Norway	57.5	.705	1.89	.31	.89	2.695
$N13Y_1$–3	”	61	.675	1.89	.35	.86	2.725
N28M–1	anorthosite, Lofoten, N. Norway	57.5	.69	1.87	.31	.85	2.680
N28M–2	”	55	.505	1.80	.40	.86	2.690
N28–0–1–3	”	53.5	.54	1.82	.45	.87	2.740
N28–0–1–2	”	53	.49	1.76	.42	.93	2.700
X309–1	noritic anor., Snowy Mtn. Dome, Adirondacks	47	.43	1.76	.32	.87	2.670
X309–2	”	46	.61	1.87	.38	.87	2.665
131–1	anorthosite, Oregon Dome, Adirondacks	50.5	.37	1.74	.54	.88	2.730
131–2	”	50.5	.41	1.75	.51	.88	2.700
900–1	anorthosite, Giant Mtn., Adirondacks	52	.49	1.77	.48	.88	2.680
900–2	”	52.5	.53	1.81	.42	.83	2.710
L–9–1	anorthosite, Kiglapait, Labrador	57.5	.56	1.83	.43	.87	2.740
L–9–2	”	59	.49	1.80	.47	.87	2.690
L–33–1	anorthosite, Nain, Labrador	53	.73	1.90	.26	.83	2.670
L–33–2	”	54	.78	1.92	.24	.83	2.675
N–32A–1	anorthosite, Egersund, S. Norway	43	.36	1.72	.56	.92	2.670
N–32A–2	”	42.5	.26	1.65	.59	.87	2.690
N33A–1	”	58	.61	1.85	.33	.81	2.750
N33A–2	”	58	.67	1.88	.37	.83	2.720
$N13D5_{II}$ –1	troctolite, Lofoten, N. Norway	53.5	.67	1.89	.34	.85	2.690
$N13D5_{II}$ –2	”	52	.65	1.87	.36	.83	2.700
$N22I_1$–1	anorthosite, Lofoten, N. Norway	55	.60	1.85	.41	.83	2.725
$N22I_1$–2	”	54	.55	1.82	.48	.84	2.715
B–1	anorthosite, Magnet Hts., Bushveld	56.5	.52	1.79	.42	.86	2.740
P–1–1	anorthosite, Tellnes, S. Norway	44	.36	1.71	.58	.91	2.700
B–2–1	norite, Magnet Hts., Bushveld	60.5	.61	1.85	.37	.85	2.725
N22E–1	anorthosite, Lofoten, N. Norway	57.5	.69	1.88	.30	.86	2.705
N22E–2	”	57	.73	1.91	.30	.86	2.685

Table 1. Continued from previous page

Field No.	Rock type & location	An Wt. %	Γ	(131)-(1$\bar{3}$1)	($\bar{2}$41)-($\bar{2}\bar{4}$1)	β	Specific gravity
$N13H_1$–1	norite, Lofoten, N. Norway	46	.62	1.85	.39	.85	2.685
$N13H_1$–2	”	42	.58	1.82	.41	.85	2.695
900–3	anorthosite, Giant Mtn. Adirondacks	53	.67	1.88	.37	.84	2.690
X309–4	noritic anor. Snowy Mtn. Dome, Adirondacks	46	.42	1.74	.51	.91	2.675
$N23C_3$	troctolite, Lofoten, N. Norway	53	.67	1.87	.36	.86	2.670
N36A	anorthosite, Åna-Sira, S. Norway	46.5	.37	1.73	.56	.86	2.680
N22H	anorthosite, Lofoten, N. Norway	51	.685	1.87	.30	.81	2.680
N24D	norite, Lofoten, N. Norway	56.5	.63	1.85	.35	.84	2.700
N17B	”	53.5	.60	1.84	.35	.87	2.700
$N13I_2$	”	56.5	.58	1.82	.37	.88	2.705
N19F	anorthosite, Lofoten, N. Norway	56.5	.66	1.88	.35	.85	2.700
$N19F_3$	”	50.5	.645	1.87	.36	.81	2.680
N14E	”	55	.76	1.92	.26	.84	2.685
P–1–2	anorthosite, Tellnes, S. Norway	45	.38	1.73	.57	.89	2.720

anorthite. Determinative curves for An content were based on standards of chemically analyzed plagioclases from anorthosite and represent An/An+Ab+Or. From plots of $2\Theta_{(131)} - 2\Theta_{(1\bar{3}1)}$ versus $2\Theta_{(\bar{2}41)} - 2\Theta_{(\bar{2}\bar{4}1)}$ the Or content of the plagioclase studied is estimated from the curves of Bambauer et al. (1967) to be about 4 percent.

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Note added in proof: At the suggestion of Professor G. M. Boone, linear regression equations and correlation coefficients (r) have been calculated for the data in Figs. 1 and 2 since this paper went to press. The following results were obtained:

Fig. 1a: $y = -1.7347x + 5.0967$; $r = -0.2336$

Fig. 1b: $y = -4.2933x + 12.1197$; $r = -0.6533$

Fig. 1c: $y = -2.5200x + 7.4388$; $r = -0.6541$

Fig. 1d: No regression equation was calculated because of the small number of points and the suggestion of non-linearity. The line plotted for $An_{58-62\cdot5}$ in Fig. 1d is a visual best fit based only on the 4 points from specific gravity 2.72 to 2.75.

Fig. 2 (upper curve): $y = -1.1400x + 4.9347$; $r = -0.5768$

Fig. 2 (middle curve): $y = 0.2200x + 0.2636$; $r = 0.2128$

Fig. 2 (lower curve): $y = 2.1000x - 5.3138$; $r = 0.7207$