

*On a new barium plagioclase felspar.*

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IN the memoir dealing with the geology of the Broken Hill district, New South Wales, mention is made<sup>1</sup> of a remarkable rock type found in a few places in the vicinity of Broken Hill, which looks not unlike an aplite in the field. A brief description of its appearance in thin section is given. It consists mainly of what appears to be very basic plagioclase. A fair amount of quartz, some epidote and bluish-green hornblende were noticed, whilst a notable amount of sphene is present. The rock was analysed by H. P. White with the result quoted below (p. 454). This analysis proved the rock to be unique in its barium content. The authors supposed the barium to be contained in the felspar, but a calculation showed that there was not enough alumina present in the rock to satisfy the felspar formula, assuming all the barium and lime to be present in that mineral. They remarked that the matter must remain unexplained for the present.

The present investigation was undertaken in order to explain the discrepancy in alumina, noted above, and to obtain further particulars about the felspar. For this purpose the original analysed specimen (B. 222) was used.

In thin section the rock is granular in texture, and is composed mainly of a plagioclase felspar and quartz. The quartz usually shows a development of strain shadows. The 'epidote' referred to in the original description is fairly common and is, in reality, a clinozoisite with  $\gamma:(001)$  cleavage =  $22^\circ$ , biaxial, positive. The sphene is a brown, granular variety which is pleochroic from pale to darker brown. It may sometimes be rimmed with clinozoisite. Occasionally a little ilmenite occurs as cores to some of the sphene. The green hornblende, present in small quantity, has positive elongation, is biaxial negative

<sup>1</sup> W. R. Browne, Appendix I of Mem. Geol. Survey, N.S.W., 1922, no. 8, p. 337.

with  $\gamma : c = 17^\circ$  and  $\alpha$  pale yellowish-green,  $\beta$  dull green,  $\gamma$  greenish-blue. Apatite is not uncommonly present, chiefly as needles enclosed in feldspar. Finally, there is a certain amount of orthite present as crystals which have been more or less altered. This orthite may be rimmed with clinozoisite. When the crystals of orthite are enclosed in feldspar, the feldspar is traversed by a series of cracks stretching out from the orthite. These have no doubt been caused by expansion during the alteration of the orthite.

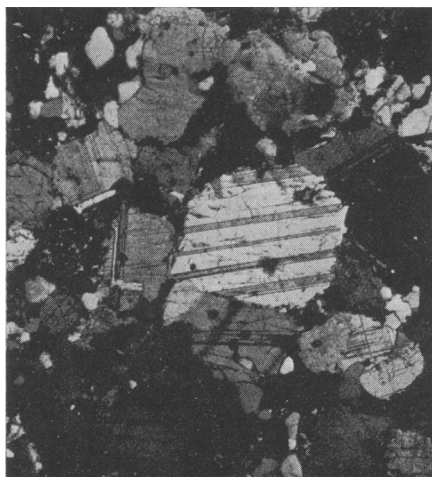


FIG. 1. Thin section showing twinning in the barium plagioclase. Crossed nicols.  $\times 24$ .

The mode of this rock measured on a Leitz integrating stage is :

|                                      | Volume %.     | Assumed sp. gr. | Weight %      |
|--------------------------------------|---------------|-----------------|---------------|
| Quartz ... ..                        | 37.52         | 2.65            | 35.05         |
| Plagioclase ... ..                   | 53.22         | 2.872           | 53.88         |
| Clinozoisite ... ..                  | 6.28          | 3.36            | 7.44          |
| Sphene ... ..                        | 2.28          | 3.48            | 2.80          |
| Orthite ... ..                       | 0.56          | 3.43            | 0.67          |
| Fe-Mg minerals<br>and apatite ... .. | 0.14          | 3.24            | 0.16          |
|                                      | <u>100.00</u> |                 | <u>100.00</u> |

The plagioclase feldspar is present as grains (fig. 1) which look very much like those of any other plagioclase. The average size of the grains is  $0.55 \times 0.40$  mm. The largest grain measured was  $1.66 \times 1.00$  mm.,

the grain size of the quartz being rather less. A number of these plagioclase grains were examined on the universal stage. The readings and results are detailed below :

| Crystal |     | $\alpha$ . | $\beta$ . | $\gamma$ . | Twinning-type.    | 2V.  |
|---------|-----|------------|-----------|------------|-------------------|------|
| 1.      | T*  | 50°        | 63½°      | 49°        | Albite-Ala B      | -80° |
|         | P*  | 66½        | 56        | 42         |                   |      |
| 2.      | T   | 55         | 55        | 54         | Albite-Ala B      | -82  |
|         | P   | 68         | 63        | 36         |                   |      |
| 3.      | T   | 51         | 64        | 50         | Albite-Ala B      | -74  |
|         | P   | 69½        | 54        | 43½        |                   |      |
| 4.      | T   | 54½        | 62        | 51         | Albite-Ala B      | -80  |
|         | P   | 69         | 55½       | 40½        |                   |      |
|         | T   | 34         | 58        | 84         | Ala B             | —    |
|         | P   | 71         | 52        | 40         |                   |      |
|         | T=P | 73         | 48½       | 42         |                   |      |
| 5.      | T   | 67½        | 32½       | 67         | Albite-Carlsbad A | -74  |
|         | P   | 51         | 71        | 47         |                   |      |
|         |     |            |           |            | and               | -80  |
|         | T=P | 51         | 50        | 58         | Manebach          | —    |
| 6.      | T=P | 68         | 61        | 38         | Albite            | -78  |
| 7.      | T=P | 60         | 70        | 36         | Albite            | -78  |
|         | T=P | 50         | 64        | 50         | Manebach          | —    |
| 8.      | T=P | 55         | 60½       | 45         | Manebach          | -78  |
| 9.      | T=P | 76         | 56        | 34         | Albite            | -78  |
| 10.     | T   | 38         | 81        | 50         | Carlsbad A        | -78  |
|         | P   | 53         | 68        | 47         |                   |      |
|         | T=P | 61         | 59        | 42         | Albite            | —    |
|         | T=P | 53         | 62        | 49         | Manebach          | —    |

\* T = pole of twin-axis, P = pole of twin-plane.

When these results are plotted the points fall quite close to the twinning curves given by Duparc and Reinhard,<sup>1</sup> usually at between 70 % and 80 % anorthite, the slight discrepancy found being due, no doubt, to the unusual composition of the felspar with which we are dealing.

The following types of twinning have thus been recognized :

| Normal hemitropy. | Parallel hemitropy. | Complexes.        |
|-------------------|---------------------|-------------------|
| Albite            | Carlsbad A          | Albite-Carlsbad A |
| Manebach          | Ala B               | Albite-Ala B      |
|                   | Pericline           |                   |

Of these the albite and the albite-Ala B twinning types were a good deal more abundant than the others. A feature of this felspar is that the albite lamellae are usually very narrow.

<sup>1</sup> L. Duparc and M. Reinhard, *Mém. Soc. Phys. Hist. Nat. Genève*, 1924, vol. 40, fasc. 1, plate 9. [Min. Abstr., vol. 3, p. 34.]

The optic axial angle ( $2V$ ) was found to vary from  $74^\circ$  to  $82^\circ$  in various examples, with an average value of  $78^\circ$ . The optic sign is negative. Dispersion is very weak with  $\rho < v$ .

By a fortunate chance one crystal measured was oriented normal to the zone [(001) (010)]. The following data, obtained on the universal stage, could then be plotted directly on to a stereographic projection normal to the above zone:

|                                    | Circle $A_1$ . | Circle $A_2$ . |
|------------------------------------|----------------|----------------|
| Axis $A_4 \parallel \gamma$ ... .. | $0^\circ$      | $0^\circ$      |
| „ $\parallel \alpha$ ... ..        | $90$           | $34$           |
| „ $\perp$ cleavage (010) ...       | $216$          | $0$            |
| „ $\perp$ „ (001) ...              | $129$          | $0$            |

$\beta$  could then be plotted, and the average value of  $-78^\circ$  was taken as the distance between the optic axes. The results are shown in fig. 2 together with similar data for certain normal plagioclases.<sup>1</sup>

The indices of refraction were obtained on the universal stage, using Kinzo Nakashima's method,<sup>2</sup> and also from grains, using the immersion method. The two sets of results are compared below:

|                   | Universal stage. | Immersion method. |
|-------------------|------------------|-------------------|
| $n_\alpha$ ... .. | —                | $1.571 \pm 0.002$ |
| $n_\beta$ ... ..  | $1.579$          | $1.580 \pm 0.002$ |
| $n_\gamma$ ... .. | $1.585$          | $1.585 \pm 0.002$ |

Amongst the other optical properties, the maximum extinction-angle on symmetrical albite lamellae was found to be  $40^\circ$ . The inclination of pericline lamellae to the (001) cleavage was  $18^\circ$ . Extinction-angles on cleavage flakes gave  $-26^\circ$  on (001) and  $-40^\circ$  on (010). The values calculated from a stereogram by Fresnel's construction were  $\alpha' : (010) = -27^\circ$ , and  $\alpha' : (001) = -41^\circ$  respectively.

Turning now to the physical properties, the (010) and (001) cleavages are both well developed. In many cases the (010) cleavage is more perfect than that following (001). The cleavage angle is approximately  $94^\circ$ . The specific gravity of this felspar was found to be 2.872 at  $17^\circ C$ . The felspar is insoluble in concentrated hydrochloric acid.

It is thus evident that we are here dealing with a plagioclase felspar, but one whose properties do not agree with those of any

<sup>1</sup> Data for other plagioclases from Duparc and Reinhard, loc. cit., p. 18, fig. 7.

<sup>2</sup> K. Nakashima, Journ. Geol., 1926, vol. 34, pp. 235-247.

previously known variety. In the subjoined table a comparison is made between this felspar and some basic plagioclases: <sup>1</sup>

|                       |     | The barium<br>plagioclase. | Labradorite<br>(Ab <sub>45</sub> An <sub>55</sub> ). | Bytownite<br>(Ab <sub>25</sub> An <sub>75</sub> ). | Anorthite<br>(Ab <sub>0</sub> An <sub>100</sub> ). |
|-----------------------|-----|----------------------------|--|--|--|
| Specific gravity      | ... | 2.872                      | 2.69   | 2.72   | 2.76   |
| Solubility in HCl     | ... | Insoluble                  | Insoluble  | Dissolves<br>slowly                                | Dissolves<br>readily                               |
| Optic axial angle     | ... | 78°                        | 74°  | 86°  | 77°  |
| Optic sign            | ... | Negative                   | Positive   | Negative   | Negative   |
| $n_\alpha$            | ... | 1.571                      | 1.557  | 1.5645   | 1.5755   |
| $n_\beta$             | ... | 1.580                      | 1.560  | 1.5693   | 1.5832   |
| $n_\gamma$            | ... | 1.585                      | 1.566  | 1.5735   | 1.5885   |
| $n_\gamma - n_\alpha$ | ... | 0.014                      | 0.009  | 0.0090   | 0.0130   |
| Dispersion            | ... | $\rho < v$                 | $\rho > v$   | $\rho < v$   | $\rho < v$   |

A portion of the rock was crushed and the heavy minerals separated from the quartz and plagioclase by means of bromoform. Quartz was then separated from the plagioclase by diluting the bromoform until the grains of plagioclase sank, whilst those of quartz floated. The separation was repeated several times. Finally, the plagioclase thus obtained was hand-picked until as pure as possible a concentrate remained. This was subjected to analysis with the following results:

|                                  | I.    | II.   | III.  | IV.   | Mol. ratios<br>of IV. |         |
|----------------------------------|-------|-------|-------|-------|-----------------------|---------|
| SiO <sub>2</sub>                 | 46.0  | 46.0  | 43.3  | 44.6  | 0.743                 |         |
| TiO <sub>2</sub>                 | 0.6   | 0.6   | 0.4   | —     | —                     |         |
| Al <sub>2</sub> O <sub>3</sub>   | 30.7* | 30.2* | 31.8  | 33.0  | 0.324                 |         |
| Fe <sub>2</sub> O <sub>3</sub> † | 2.2   | 1.8   | 1.2   | —     | —                     |         |
| CaO                              | 13.3  | 12.9  | 14.1  | 14.0  | 0.249                 | } 0.326 |
| BaO                              | 5.4   | 5.3   | 5.5   | 5.7   | 0.037                 |         |
| Na <sub>2</sub> O                | ...   | ...   | 1.9   | 2.0   | 0.032                 |         |
| K <sub>2</sub> O                 | ...   | ...   | 0.7   | 0.7   | 0.008                 |         |
| P <sub>2</sub> O <sub>5</sub>    | ...   | ...   | 0.3   | —     | —                     |         |
| H <sub>2</sub> O                 | ...   | ...   | 1.0   | —     | —                     |         |
|                                  | 100.8 | 99.4  | 100.2 | 100.0 |                       |         |

\* Includes P<sub>2</sub>O<sub>5</sub>. † All Fe as Fe<sub>2</sub>O<sub>3</sub>.

I. Analysis on 50.2 mg. by Na<sub>2</sub>CO<sub>3</sub> fusion. Ba and Ca separation based on relative insolubilities of the sulphates. (E.G.Z.)

II. Analysis on 65.8 mg. by the Berzelius method. Ba and Ca separation here based on insolubility of Ba(NO<sub>3</sub>)<sub>2</sub> in fuming HNO<sub>3</sub>. (E.G.Z.)

III. Average of two analyses on a second sample. Total weight of samples used, 0.3392 gram. (E.G.Z.)

IV. Analysis III calculated to 100% after allowing for included sphene and apatite and omitting Fe<sub>2</sub>O<sub>3</sub> and H<sub>2</sub>O.

<sup>1</sup> Data taken from Winchell's Elements of optical mineralogy, 1927, pt. II, pp. 279, 292, 293.

It is found that there is not quite enough silica present to combine with the whole of the soda to form albite, and consequently some of

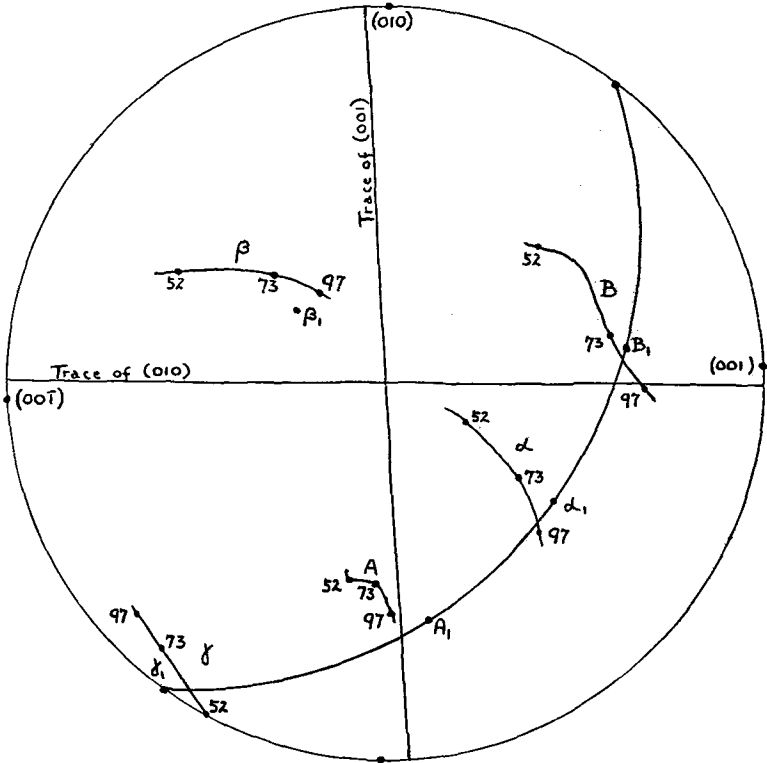


FIG. 2. Stereographic projection on the plane normal to the zone [(001) (010)] plotting the optic axial plane, ellipsoidal axes ( $\alpha_1, \beta_1, \gamma_1$ ), and the optic axes ( $A_1$  and  $B_1$ ) of the barium plagioclase. The ellipsoidal axes and optic axes for certain normal plagioclases (An 52, 73, and 97 %) are included for comparison.

it must be calculated as carnegieite. The composition of the feldspar is then as follows (column I):

|  | I.   | II.   |
|--|------|-------|
| Orthoclase ( $\text{KAlSi}_3\text{O}_8$ ) ... ..                     | 3.9  | 3.48  |
| Albite ( $\text{NaAlSi}_3\text{O}_8$ ) ... ..                        | 8.9  | 36.16 |
| Anorthite ( $\text{CaAl}_2\text{Si}_2\text{O}_8$ ) ... ..            | 69.2 | 53.78 |
| Celsian ( $\text{BaAl}_2\text{Si}_2\text{O}_8$ ) ... ..              | 13.9 | —     |
| Carnegieite ( $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8$ ) ... .. | 4.0  | 5.58  |

The feldspar has thus the approximate composition  $\text{Or}_4\text{Ab}_9\text{Cg}_4\text{Ce}_{14}\text{An}_{69}$  and may be described as a barium 'anemousite' or, more

appropriately, as a barium anorthite. The composition of a typical anemousite taken from Washington and Wright's paper<sup>1</sup> is given in column II for comparison. Although our felspar is a more basic variety, yet the amounts of the carnegieite molecule present are not very different. Both Washington and Wright and, more recently, Barth<sup>2</sup> believe that the carnegieite is in solid solution with the plagioclase; while Beljankin<sup>3</sup> suggests the presence of an alkali aluminate in solid solution. As far as the anorthite molecule is concerned experimental evidence is against any appreciable amount of solid solution with carnegieite, and recent work on the structure of the felspars suggests that solid solution is probably not the true explanation, and we are much indebted to Dr. W. H. Taylor for the more probable interpretation now given. The felspar structure is an open one, and it seems likely that the deficiency of silica found in our analysis is due to the replacement of a certain amount of Si by Al

|                                    | Partial Analysis<br>of rock (B. 222).<br>(E. G. Zies.) |     | Analysis of<br>rock (B. 222).<br>(H. P. White.) |     |
|------------------------------------|--|-----|---|-----|
| SiO <sub>2</sub> ...               | 62.5   | ... | 55.12   | ... |
| Al <sub>2</sub> O <sub>3</sub> ... | 19.1   | ... | 20.72   | ... |
| Fe <sub>2</sub> O <sub>3</sub> ... | 1.3*   | ... | 0.75  | ... |
| FeO ...                            | —  | ... | 0.36  | ... |
| MgO ...                            | —  | ... | nil   | ... |
| CaO ...                            | 8.9  | ... | 10.08   | ... |
| BaO ...                            | 4.8  | ... | 9.23  | ... |
| SrO ...                            | —  | ... | trace   | ... |
| Na <sub>2</sub> O ...              | 1.0†   | ... | 1.13  | ... |
| K <sub>2</sub> O ...               |  | ... | 0.39  | ... |
| H <sub>2</sub> O+ ...              | 1.5  | ... | 1.36  | ... |
| H <sub>2</sub> O- ...              |  | ... | 0.22  | ... |
| CO <sub>2</sub> ...                | —  | ... | trace   | ... |
| TiO <sub>2</sub> ...               | 0.6  | ... | 0.65  | ... |
| P <sub>2</sub> O <sub>5</sub> ...  | 0.3  | ... | 0.25  | ... |
| MnO ...                            | —  | ... | trace   | ... |
|                                    | 100.0  |     | 100.26‡   |     |
| Sp. gr. ...                        | —  | ... | 2.887   | ... |

\* All Fe as Fe<sub>2</sub>O<sub>3</sub>.

† Alkalis by difference.

‡SO<sub>3</sub>, Cl, F, Cr<sub>2</sub>O<sub>3</sub>, NiO, CoO,

V<sub>2</sub>O<sub>5</sub>, Li<sub>2</sub>O, ZrO<sub>2</sub>, CuO absent.

<sup>1</sup> H. S. Washington and F. E. Wright, Amer. Journ. Sci., 1910, ser. 4, vol. 29, p. 59.

<sup>2</sup> T. F. W. Barth, Journ. Washington Acad. Sci., 1930, vol. 20, p. 60. [M.A. 4-398.]

<sup>3</sup> D. Beljankin, Centr. Min., Abt. A, 1931, pp. 356-364. [M.A., 5-70.]

(with co-ordination number 4) in the fundamental Si-Al-O framework. The extra sodium may then be present in the form of sodium atoms filling up some of the unoccupied spaces in the felspar structure. This is equivalent to suggesting that some of the calcium atoms in the felspar structure may be replaced by two sodium atoms as is the case in some of the zeolites.

The barium content in our analyses of the felspar shows a large discrepancy when compared with that found for the rock as a whole in the analysis made by H. P. White. On the other hand, there does not seem to be a sufficient quantity of any other mineral in the rock to bring the total up, even if we assume that mineral to be rich in barium. To make certain of this point we have made a partial analysis of the rock itself. Our result is given opposite together with H. P. White's analysis.

The norm of our partial analysis, assuming all the alkalis to be Na<sub>2</sub>O, is given below together with that of H. P. White's analysis :

|                     | E. G. Z. Analysis. |         | H. P. W. Analysis. |              |         |
|---------------------|--------------------|---------|--------------------|--------------|---------|
| Quartz ... ..       | 35.64              | ...     | ...                | 22.38        |         |
| Orthoclase ... ..   | —                  |         |                    | 2.22         |         |
| Albite ... ..       | 8.38               | } 58.94 | }                  | 9.43         | } 67.82 |
| Anorthite ... ..    | 38.92              |         |                    | 33.64        |         |
| Celsian ... ..      | 11.64              |         |                    | 22.53        |         |
| Wollastonite ... .. | 0.46               | ...     | ...                | 5.68         |         |
| Haematite ... ..    | 1.28               | ...     | ...                | 0.80         |         |
| Apatite ... ..      | 0.67               | ...     | ...                | 0.37         |         |
| Sphene ... ..       | 1.57               | ...     | ...                | 0.59         |         |
| Ilmenite ... ..     | —                  | ...     | ...                | 0.91         |         |
|                     | <u>98.56</u>       |         |                    | <u>98.85</u> |         |

The norms of the two may be seen to differ considerably. The norm of our analysis contains a good deal more quartz, almost half the amount of celsian and less than one-twelfth the amount of wollastonite found in the norm from White's analysis. The amount of wollastonite is, of course, an index of the deficiency in alumina required to make all the K<sub>2</sub>O, Na<sub>2</sub>O, CaO, and BaO into felspar molecules. In our analysis this deficiency equals 0.41 % Al<sub>2</sub>O<sub>3</sub>, in White's analysis the deficiency equals 4.39 % Al<sub>2</sub>O<sub>3</sub>. Our analysis is, admittedly, only a partial one, but the alkalis are the only important constituents not directly determined and these cannot be much greater or less than 1 %. The fact that we have assumed the total alkali content to be Na<sub>2</sub>O when making the norm actually makes our deficiency of Al<sub>2</sub>O<sub>3</sub> appear greater than it really is. This



slight deficiency is probably due to the fact that a little of the lime is present in the rock itself as clinozoisite instead of anorthite, but the deficiency of  $\text{Al}_2\text{O}_3$  in White's analysis can hardly be accounted for in this manner. As a matter of fact the amount of clinozoisite needed to take up the deficiency can easily be calculated. The amount necessary is 3.63 %. The deficiency of  $\text{Al}_2\text{O}_3$  in White's analysis cannot be accounted for in this way as calculation shows that in order to take up the deficiency of  $\text{Al}_2\text{O}_3$  in clinozoisite more lime would be required than is present in the analysis.

Finally, our analysis shows an amount of BaO compatible with the hypothesis that it is all in the feldspar, whereas White's analysis demands the presence of another barium-bearing mineral which, if it carries the same percentage as the feldspar, should be almost as abundant. It is thus probable that the rock varies in composition and that another barium-bearing mineral such as sanbornite was present in the sample analysed by White. We hope to undertake further work on this interesting material and see if we can establish the presence of another such mineral.

#### *Comparison with other Occurrences.*

Both the rock and the plagioclase feldspar described appear to be unique. The highest content of BaO recorded in a rock analysis up to the present is 1.1 % in some highly potassic rocks from Wyoming.<sup>1</sup> There seems to be only one record of a previous barium plagioclase, which comes from an unknown locality.<sup>2</sup> Its composition was very different from that of the present example, having  $\text{SiO}_2$  55.10,  $\text{Al}_2\text{O}_3$  23.20,  $\text{Fe}_2\text{O}_3$  0.45, BaO 7.30, CaO 1.83, MgO 0.56,  $\text{Na}_2\text{O}$  7.45,  $\text{K}_2\text{O}$  0.83, volatile matter 3.72 = 100.44; specific gravity 2.835. It was biaxial negative with an extinction-angle  $\alpha'$ : (010) of  $5^\circ$  on (001) cleavage plates and  $\alpha'$ : (001) of  $7^\circ 30'$  on (010). According to Eskola,<sup>3</sup> the binary system  $\text{CaAl}_2\text{Si}_2\text{O}_8$ – $\text{BaAl}_2\text{Si}_2\text{O}_8$  has been investigated by Ginzberg,<sup>4</sup> but we have been unable to see the latter's paper. He found that the triclinic anorthite could take up limited amounts of barium feldspar in solid solution, whereby the optic axial

<sup>1</sup> H. S. Washington, Journ. Franklin Inst., 1920, vol. 190, p. 767. [M.A. 1-160.]

<sup>2</sup> A. Des Cloizeaux, Tschermak's Min. Mitt., 1877, pp. 99-100.

<sup>3</sup> P. Eskola, Amer. Journ. Sci., 1922, ser. 5, vol. 4, p. 365. [M.A. 2-153.]

<sup>4</sup> A. S. Ginzberg, Ann. Inst. Polytech. Pierre le Grand, Petrograd, 1915. [M.A. 2-153.]

angle diminishes. This would also seem to be the case with the natural plagioclase, since our barium plagioclase has a lower axial angle than that of the normal plagioclase (between 70 % and 80 % An) to which it most closely corresponds with respect to the position of its optic plane, optic axes, &c., and to the positions of the poles of its twin-planes and axes for the various types of twinning found.

The authors wish to express their best thanks to Professor W. R. Browne, of Sydney University, who, through Professor C. E. Tilley, provided the material, and one of them (S. R. N.) to Dr. F. C. Phillips for first introducing him to the use of the universal stage.

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