

*The potash-soda-felspars. I. Thermal stability.*

(With Plate XVIII.)

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## I. INTRODUCTION.

IN a previous paper (24)<sup>1</sup> the writer discussed the relations between the chemical and physical properties of a number of potash-soda-felspars, mainly of the schillerized or perthitic variety, and the effect of high temperatures upon them. The present paper gives the results of further examination of these and of several additional specimens selected to make the range of composition more complete.

Twenty-six specimens were selected for this investigation. They include two albites, six microclines, and eighteen felspars which have been grouped as an orthoclase-microperthite series. The confused nomenclature of the alkali-felspars makes a choice of suitable names difficult. Alling's classification (1, pp. 253-254) represents a systematic attempt to overcome this confusion, but it seems doubtful whether some of his arbitrary subdivisions (e.g. 'anorthoclase potentially eutectoperthite' and 'microcline eutectoperthite') can exist. The expression 'orthoclase-microperthite series' is used throughout this paper in a strictly limited sense for a continuous series between potash-rich, non-perthitic orthoclase felspar, and the higher-soda, schillerized type with more or less complete exsolution of the soda-component. It is not certain that this series continues unbroken to albite, but it extends to specimens with about 60% soda-felspar.<sup>2</sup> The series includes a number of specimens (J to R, tables I and II) which normally—and by Alling's classification—would be called anorthoclase, but it does not include the glassy, non-perthitic sanidines or anorthoclases of the Haddington, Mt. Kenya, Pantelleria, and Mt. Erebus types, which will be discussed separately. Although the microclines show perthitic structure, they do not belong to this series, nor is it certain that adularia does. The Eifel sanidine and Korea moonstone (specimens G and P) do not strictly belong to the series; they are included to show how, by heat treatment, the properties of the orthoclase-microperthite series may be changed to those of the sanidine-anorthoclase series.

Most members of this orthoclase-microperthite series show a blue or white schiller and a very fine perthitic structure. The perthite belongs in part to Andersen's 'film' or 'string' type (3, p. 149) and in part to Brøgger's 'cryptoperthite' (8, pp. 524-551).

<sup>1</sup> Numbers in parentheses refer to the table of literature on p. 493.

<sup>2</sup> Unless otherwise stated, compositions are expressed in weight, and not in molecular, percentages.

The six pegmatitic microclines also show this 'film' or 'string' perthite, but on a somewhat coarser scale. In one or two of them a still coarser form occurs in association with the 'film' perthite. While it can scarcely be classed as 'film' perthite, it is too fine and regular to belong to Andersen's 'vein' perthite.

Most microclines are too heterogeneous or opaque for accurate optical determination. The six specimens (U to Z) were chosen because of their relative clearness. Their compositions fall within a rather limited range; it is certain that more extreme compositions and physical properties could have been found in the rejected material.

## II. CHEMICAL COMPOSITION.

The analyses of all specimens examined are set out in table I (pl. XVIII) in three groups in order of increasing soda-content. Specimens marked with an asterisk have been previously described; one or two minor corrections, obtained from recent repetitions, have been introduced into their analyses.

It will be seen that all the specimens are relatively poor in lime. The three (O, Q, and R) with the highest lime-content contain minute inclusions of apatite or tourmaline. In the table all the lime present has been calculated as anorthite. Specimens B and G contain appreciable amounts of barium.

In the orthoclase-micropertthite series, the soda-felspar content ranges from about 4% to 52%, increasing by fairly uniform steps. In the microcline series the soda-felspar ranges between the narrow limits of 13% and 22%. The maximum range for all the microclines examined by me was about 8% to 31%; as noted above, many of these feldspars were unsuited for optical measurement. Vogt (27, pp. 29-40) and Andersen (3, pp. 166-167) have also observed a similar limited range of composition.

*Notes on table I.*—Specimens A, C, D, F, H, L, O, Q, and S have already been described (24).

B. Large crystal, about three inches in diameter, with outermost one-eighth inch containing vermicular chlorite. Only clear uniform inner parts were used. St. Gothard, Switzerland.

E. Tabular phenocrysts in garnetiferous granite-gneiss. Railway-cutting near Ombadowla, Kalahandi State, Orissa, India.

G. Probably from a basaltic tuff. Eifel, Rhineland.

I and J. Moonstone from Ambalangoda, Ceylon.

K. From the contact of a pegmatite with limestone. Myo Taung, 3¼ miles north-east of Mogok, Burma.

M. Moonstone from Ambalangoda, Ceylon.

N. With white schiller and fairly coarse microperthite. Oksaung Daung, 3½ miles east-north-east of Mogok, Burma.

P. Small, glass-clear, idiomorphic crystals, twinned on Carlsbad, Baveno, and Manebach laws. Kanchin-do, Meisen-gun, north-east Korea.

R. With deep blue schiller. Contains minute inclusions of tourmaline or apatite. (001) sections show under the microscope a 'lattice' pattern, of the sort figured by Alling as 'incipient microcline-twinning' (1, p. 273 and pl. v). The 'lattice' directions correspond, however, to prism traces, and not to the traces of (100) and (010). Fredriksvärn, Norway.

T. A glass-clear specimen of albite. Portions of the crystal show regularly arranged microscopic solution-cavities that suggest a hydrothermal origin. From the mica-pegmatites of Kodarma, Bihar, India.

U, V, and Z. These three specimens come from the mica-bearing pegmatite of Kodarma, Bihar, India. The first two are almost glass-clear, the third somewhat opaque in thick section. All show medium coarse microperthitic structure of the 'string' or 'film' types.

W and X. From the graphite-bearing pegmatites of Patna State, Orissa, India. These pegmatites border the granite-gneiss intrusions of the Kalahandi area, and may belong to the same period of igneous activity. Both specimens show fairly coarse regular microperthite.

Y. From a quartz-felspar-tourmaline-pegmatite near Ryagada gorge, Orissa, India. The specimen shows two generations of microperthite, one of the fine 'film' or 'string' type, and one distinctly coarser, but just as uniform as the first. The microcline is semi-transparent in fairly thin flakes.

### III. PHYSICAL PROPERTIES.

The refractive indices, optic axial angles, extinction-angles, and specific gravities of the specimens examined are set out in table II (pl. XVIII). The specific gravities were measured by the method previously described (24, p. 352). Optic axial angles were measured on the microscope with a stage goniometer, the crystal plate being immersed in a liquid matching its mean refractive index.

Refractive indices were determined on small specimens whose polished faces were cut parallel to the principal planes of the indicatrix. This preparation was facilitated for many of the potash-soda-felspars by the fact that the cleavage-plane (010) is parallel to one of the planes of the indicatrix. An Abbe oil refractometer was used, and was checked from time to time against known standards.

### IV. RELATIONS BETWEEN COMPOSITION AND PHYSICAL PROPERTIES.

#### (a) *The orthoclase-microperthite series.*

The data given in tables I and II (pl. XVIII) show that, with a few exceptions, a regular progressive relationship exists between the

refractive indices, optic axial angle, extinction-angle, specific gravity, and composition in the orthoclase-microperthite series. The relation between the last three properties and composition has already been described (24, pp. 340-345) for some members of the series.

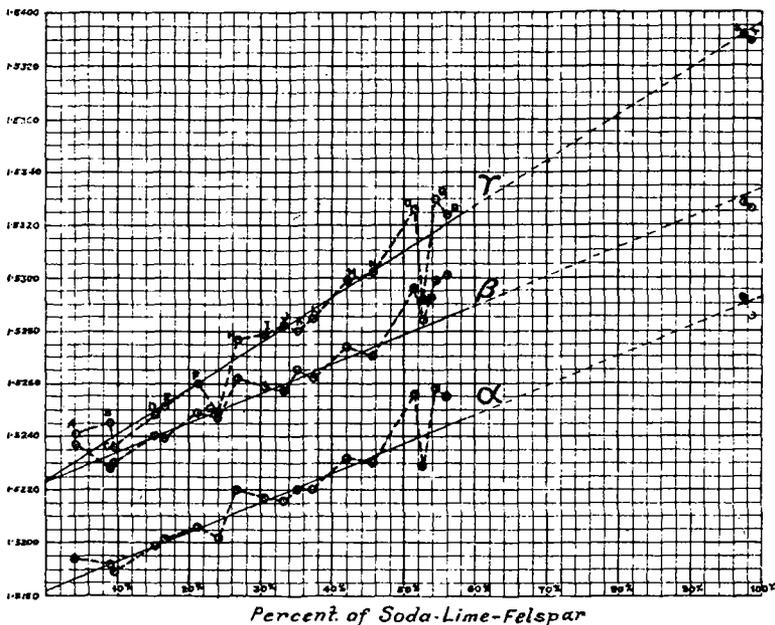


FIG. 1. Refractive indices and chemical composition of the orthoclase-microperthite series.

*Refractive index.*—In general the mean values of  $\alpha$ ,  $\beta$ , and  $\gamma$  increase with increase in the soda-lime content of the felspar;  $\beta - \alpha$  remains sensibly constant throughout. The smoothed curves of fig. 1, when produced, pass close to the plotted indices of albite, showing that the refractive indices of the two felspar components are additive. It will be seen later that this holds only when the exsolution of the soda-component is complete. The points for A, H, O, Q, and R lie above the mean lines; for any one specimen the deviation is approximately the same for all three indices. These deviations are explained by the chemical 'impurities'; H, O, Q, and R contain minute inclusions of highly refracting minerals (probably apatite or tourmaline), while A is comparatively rich in ferric iron. Specimens G and P (sandine) have refractive indices below the mean, with different

deviations for each index. Adularia (specimen B) has  $\gamma$  above and  $\beta$  below the respective means.

*Optic axial angle.*—The upper curve of fig. 2 connects the optic axial angle with composition; the points representing untreated specimens are enclosed in circles. The prolongation of the nearly

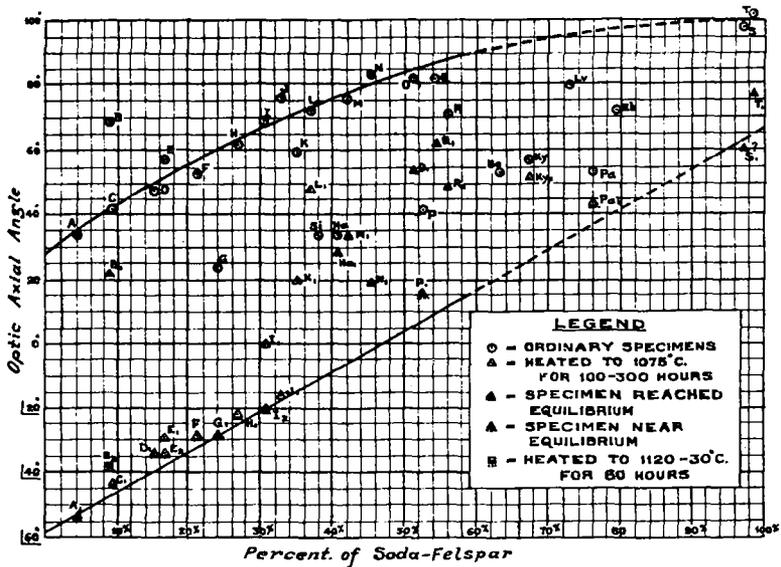


FIG. 2. Optic axial angle and chemical composition: ordinary and after prolonged heating.

linear curve again lies close to the points for albite. As might be expected, the impurities which caused uniform deviations of the refractive indices of A, H, O, and Q do not greatly affect the optic axial angles. The specimens of adularia (B) and sanidine (G and P) do not conform to the curve, while K and R show rather low values.

*Specific gravity and extinction-angle on (010).*—Fig. 3 shows the variations of specific gravity and extinction-angle with composition, in both of which a general increase with increasing soda-content is seen. Deviations from the mean specific gravity curve on the whole resemble those for the refractive index, and have a similar explanation. The deviations of extinction-angle are of the same type as those for the optic axial angle, and, as will be seen, are caused by the special conditions under which the felspars have formed.

In summary, these results for the orthoclase-micropertthite series confirm the relationships brought out in the previous paper (24), and extend them to include the three refractive indices. Two kinds of deviation were again found, namely, (a) those caused by the presence of impurities, which only affect refractive indices and specific

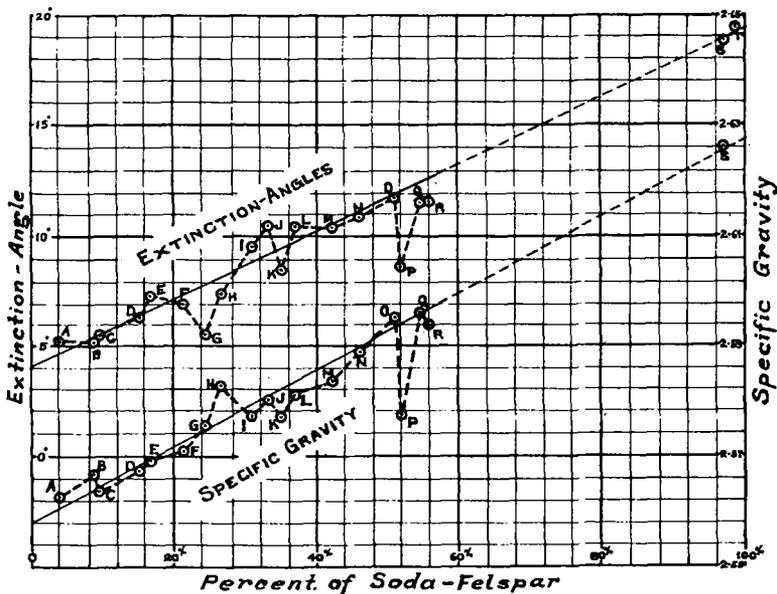


FIG. 3. Extinction-angles, specific gravity, and chemical composition.

gravity; (b) those caused by incomplete exsolution, which affect all the physical properties, but the optic axial angle more than the rest.

The same relationship has been found to hold for many more specimens than could be included in this selected list. In one or two instances where a slight discrepancy was found that could not be accounted for by the factors mentioned, a re-examination proved that either the analysis or the physical determination was at fault. For these reasons the writer would now question any results for potash-felspars that did not conform fairly closely to these relationships, allowing for the types of deviation mentioned above.

While the refractive indices, specific gravities, optic axial angles, and extinction-angles on (010) thus vary proportionately with the

amounts of potash- and soda-felspar present, the same is not true of the extinction on (001), and the inclination of the  $\beta$ -axis of the indicatrix to the crystallographic axis- $b$ . For albite the extinction on (001) is about 4–5°, and the inclination of the  $\beta$ -axis to the  $b$ -axis is about 15°. In orthoclase they are both zero, and remain zero or nearly so in the orthoclase-microperthite series up to 40–50 % of soda-component, whether the albite is present as perthite or not. In a few cases the extinction on (001) is 1–3°, the  $\beta$ -axis of the indicatrix still remaining nearly normal to (010)

(b) *Albite.*

The refractive indices, specific gravities, and optic axial angles, &c., of the two albites call for no special comment. They fall approximately on the extension of the curves for the orthoclase-microperthite series, indicating that exsolution in the perthitic members of this series is fairly complete.

(c) *Microcline series.*

The refractive indices and optic axial angles of the microclines, when plotted against composition, show a considerable deviation from those of the orthoclase-microperthite series, and, in order to avoid confusion, they have been plotted separately on fig. 4, p. 461, with the mean lines of the orthoclase-microperthite series added for comparison. The values for adularia have also been introduced to show how the refractive indices and optic axial angle of this felspar are closer to microcline than to the orthoclase-microperthite series. This similarity is better seen in the heat-treatment experiments.

As indicated on p. 455, these six microclines, chosen for their transparency and homogeneity, may not be truly representative of average microcline-felspar. Although their optic axial angles are distinctly larger than those of corresponding orthoclase-microperthites they are smaller than the axial angles of most microclines. In the latter, which usually show coarser perthite and coarser multiple-twin structures, the axial angle rarely falls below  $2V\ 80^\circ$  and may be as high as  $85\text{--}87^\circ$ .

#### V. HEAT-TREATMENT.

Larsen (18, p. 89) suggested that a knowledge of the crystallization temperatures of rock-magmas might be obtained from the consideration of the unmixing temperature of the microperthite felspars. In view of this possible use of the microperthite transformation as

a 'geological thermometer', it is surprising that so few attempts have been made to determine the temperatures at which these structures go into, and out of, solid solution.

Dittler and Köhler (11) observed the progressive microscopic changes produced in perthitic microcline on heat-treatment. They

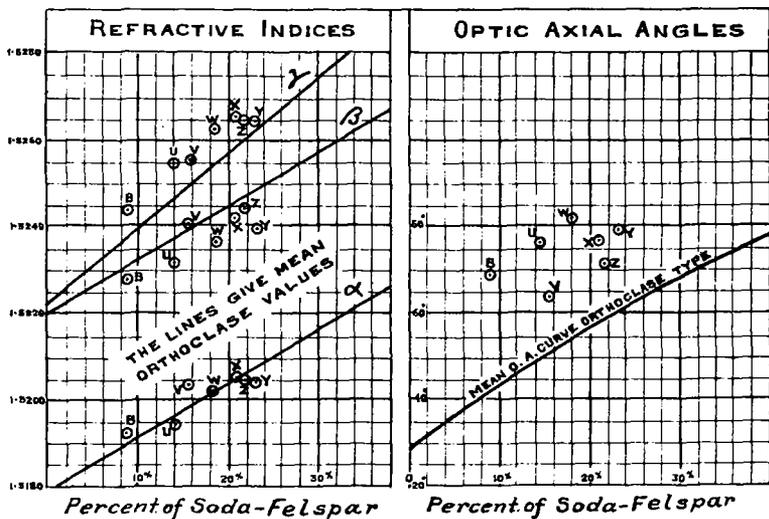


FIG. 4. Refractive indices, optical axial angle, and chemical composition of microclines.

found that the fine micropertthitic lamellae could be dissolved by prolonged heating at 900°C., but that the coarser 'vein' type of perthite required a longer time at a higher temperature for its solution. The chief disadvantage of the microscopic method lies in the difficulty in judging the beginning, the end, or the amount of progressive change.

Kôzu and Endô (13) took Laue photographs of Ceylon and Korean moonstone, both said to be free from micropertthitic lamellae. The pattern, which in the unheated material was double, became single after the specimens had been heated to 700°C. and 1000°C. respectively. On slow cooling down to 700°C., the Laue pattern of the Ceylon moonstone became double once more; no further change took place below 700°C.

The writer (24) showed that the destruction of schiller in Ceylon moonstone was accompanied by a solution of micropertthite and

a reduction in specific gravity. The drop in specific gravity was proportional to the amount of perthite dissolved, up to about 40 % of soda-component. For the majority of the feldspars most of the change took place between 450° C. and 750° C., and was completed in a few minutes. Very little additional effect was noted on long continued heating at any given temperature.

Barth (5) recently carried out long-period heating tests on a number of potash-soda-feldspars, including some perthitic types, mainly with a view to observing changes in optic axial angle and extinction. His results show that these feldspars suffer no change in extinction-angle on prolonged heating at 1000° C. In feldspars with less than 25 % soda-component the optic axial angle is reduced.

Criticizing Dittler and Köhler's results for microperthitic feldspars, Barth says (5, p. 58), 'Determinations of inversions or any change in physical properties of such homogenized perthites have therefore but little significance; they are, at best, only measures of rate of diffusion'. This statement implies that perthitic solution on heating is a relatively slow process, which, if true, would of course make it difficult to ascertain the temperature of solution accurately. It also suggests that changes brought about during or subsequent to heat-treatment are slight and unimportant.

In the following pages the writer shows that solution of perthite in the orthoclase-microperthite series—and to a lesser extent in the microperthitic microclines—is a relatively rapid phenomenon, and that the temperature range of solution is determinable by measuring the accompanying changes in refractive index and specific gravity.

As will be seen later, natural rock cooling conditions must have been far too slow to have retarded the exsolution of perthite in ordinary potash-feldspars with high optic axial angles. Hence all feldspars of this type occurring in nature with more than about 10 % of soda-component must have some soda-feldspar present as microperthite. By heat-treatment this microperthite can be redissolved, usually with little effect upon the optic axial angle. These homogenized high-angle microperthites—not the homogeneous low-angle sanidine and anorthoclase—are the true soda-rich representatives of the naturally homogeneous soda-poor orthoclase. Although the sanidines have attracted most attention because of their susceptibility to change on heating, it is equally necessary to examine the effects of high temperature upon the properties of the homogenized microperthites.

Lack of discrimination in the behaviour toward heat-treatment of the fine 'film' or 'string' types of perthite of exsolution origin and the coarser 'vein' perthite has led to much confusion in estimates of the rate of homogenization. Dittler and Köhler (11, pp. 257-8), however, emphasized that the fine perthite can be taken into solution much more readily than can the 'vein' type. All the perthites that have been used for the tests now to be described belong to the readily soluble micro- or crypto-perthitic types, and are undoubtedly of exsolution origin.

The effects of heat upon these feldspars vary with the temperature, the period of heating, the composition, and the type of feldspar. To simplify description the results have been arranged as follows:—

1. Heating for short periods at progressively higher temperatures up to near the melting-point. The results for each group of specimens are considered for two divisions of the temperature range:

(a) up to 850° C.,

(b) from 850° C. up to near the melting-point.

2. Prolonged heating at 1075° C. The results for each group of specimens are given separately, the orthoclase-microperthite series being divided into:

(a) specimens with less than 30 % soda-feldspar,

(b) specimens with more than 30 % soda-feldspar.

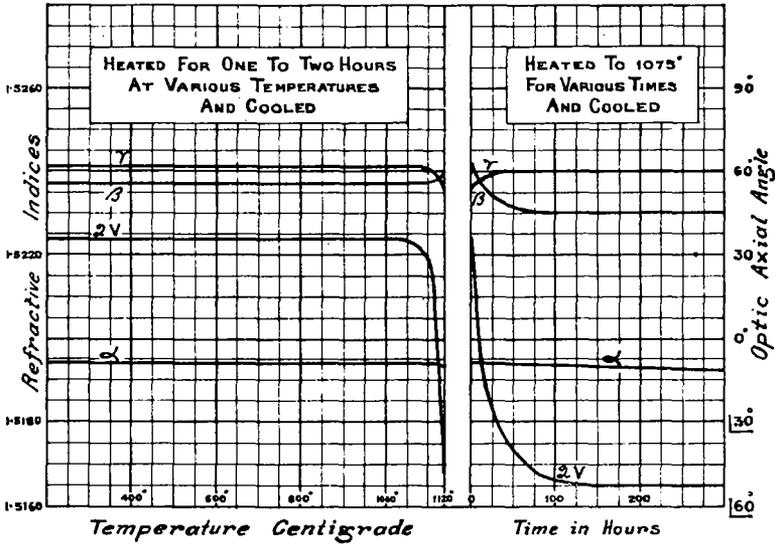
## VI. RESULTS OF PROGRESSIVE HEATING TO 850° C.

Specimens prepared for the determination of refractive index were heated in a small electric furnace, whose temperature was measured by a Pt-Rh thermocouple and millivoltmeter. The period of heating was one hour, after which the specimens were rapidly cooled in air. Where rapid changes took place temperature intervals of 50° C. were used; elsewhere the interval was 100° C. Curves were drawn for each specimen to show the refractive indices and optic axial angle at all temperatures to near the melting-points. Twelve of the most representative of these are shown in figs. 5-16, while the results are briefly summarized below.

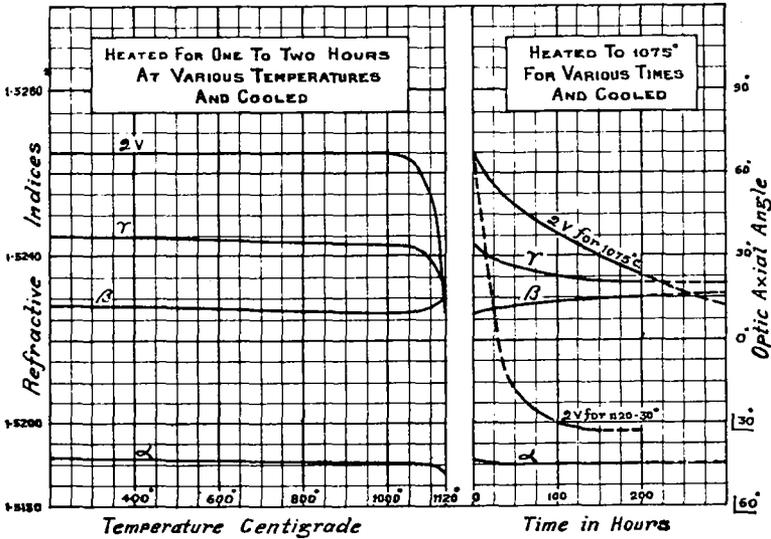
### (a) *Orthoclase-microperthite series.*

*Reduction of refractive index and specific gravity.*—A decrease in refractive index is found on heating all the schillerized perthitic feldspars (specimens D to R) to 850° C. Except in one or two cases

SPECIMEN A. YELLOW ORTHOCLASE FIG. 5.

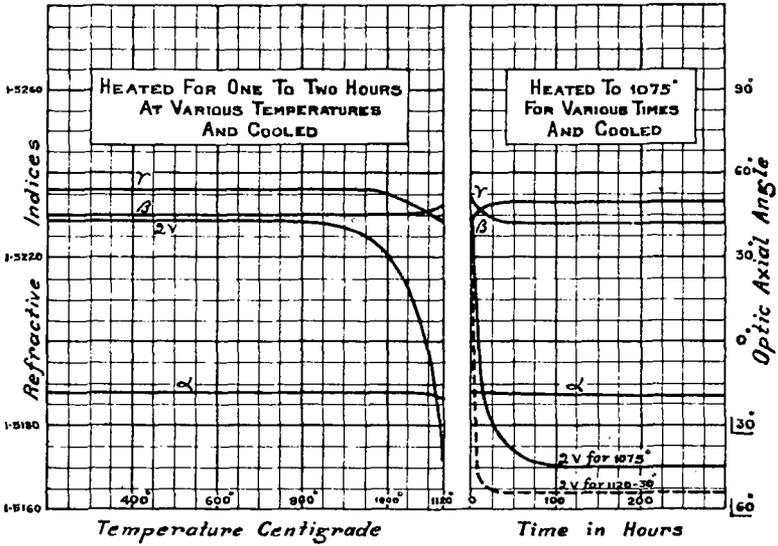


SPECIMEN B. ADULARIA ST. GOTHARD FIG. 6.

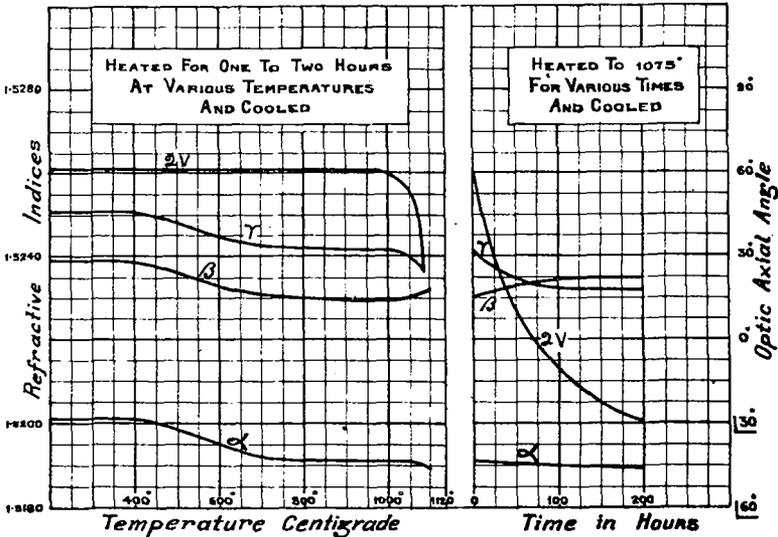


Changes in the optical properties on heating.

SPECIMEN C. BURMA COLOURLESS FIG. 7.

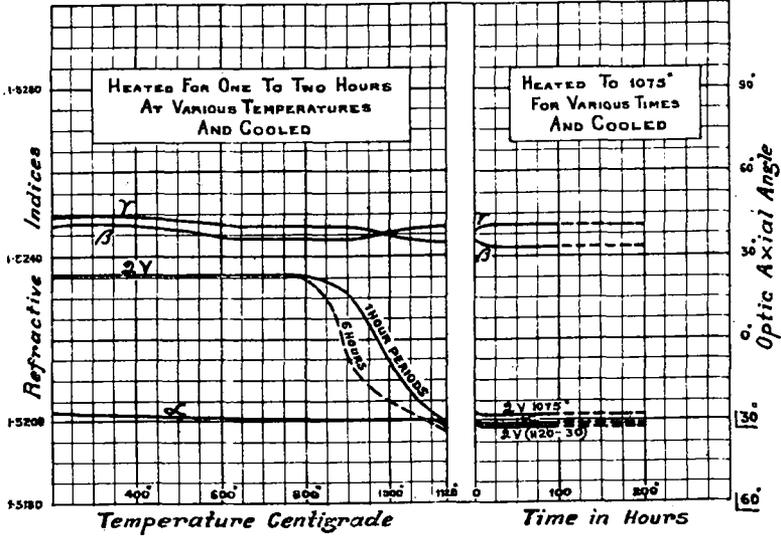


SPECIMEN E. KALAHANDHI ORTHOCLASE FIG. 8.

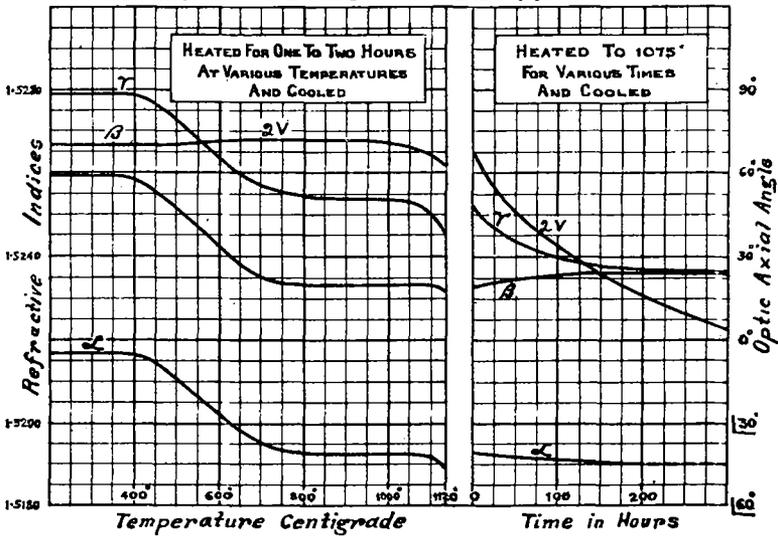


Changes in the optical properties on heating.

SPECIMEN G. EIFEL SANDINE FIG.9.

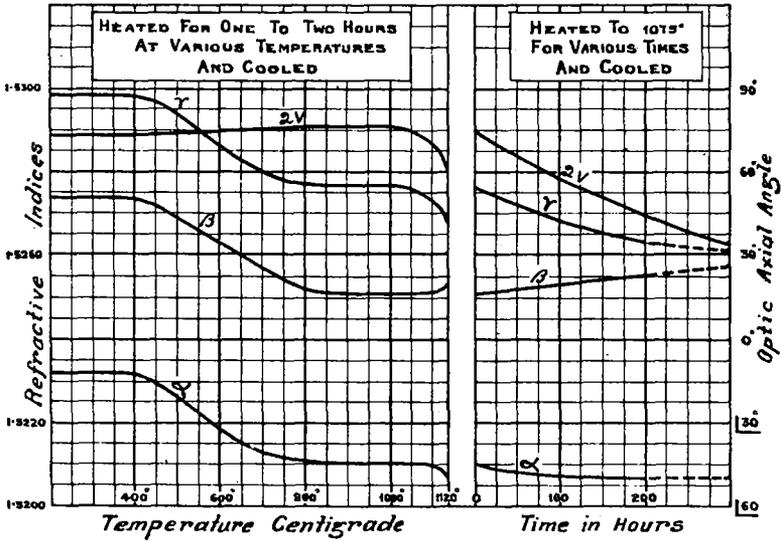


SPECIMEN I. CEYLON BLUE No. I FIG.10.

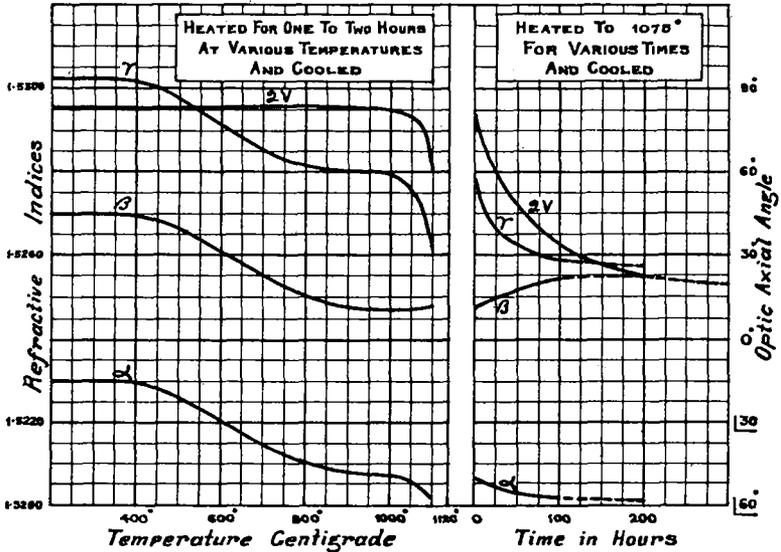


Changes in the optical properties on heating.

SPECIMEN M. CEYLON BLUE No. III FIG. 11.

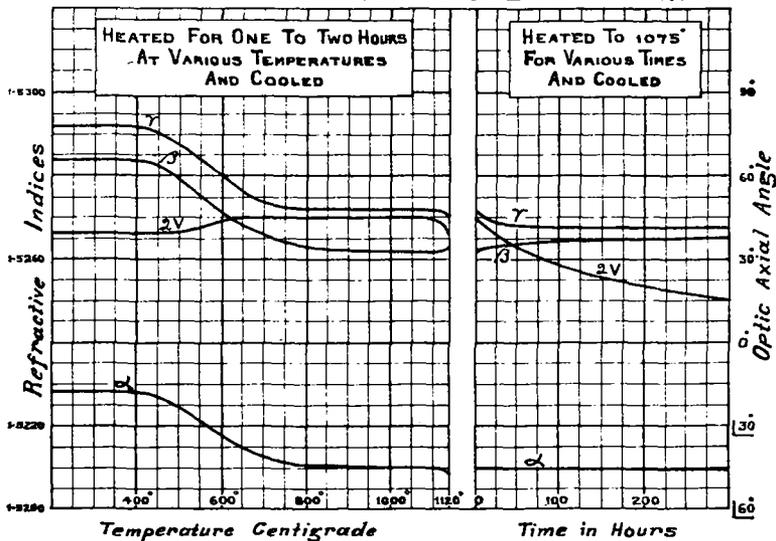


SPECIMEN N. BURMA WHITE No. II FIG. 12.

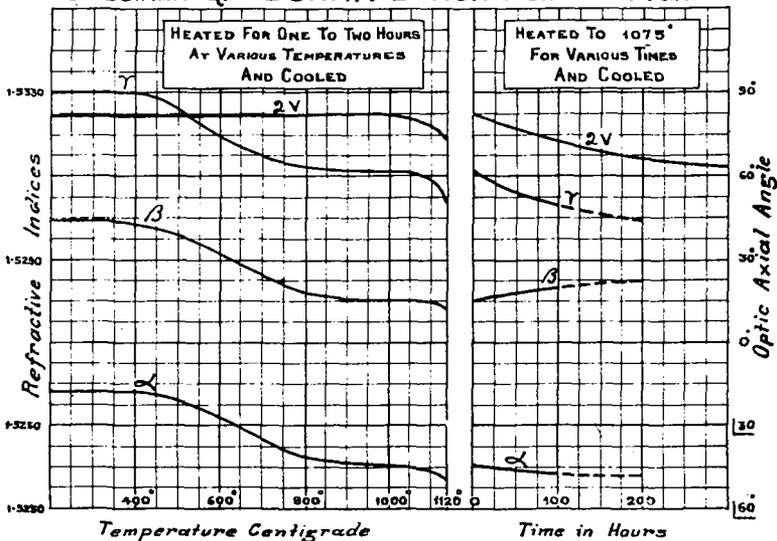


Changes in the optical properties on heating.

SPECIMEN P. KOREA BLUE FIG.13.

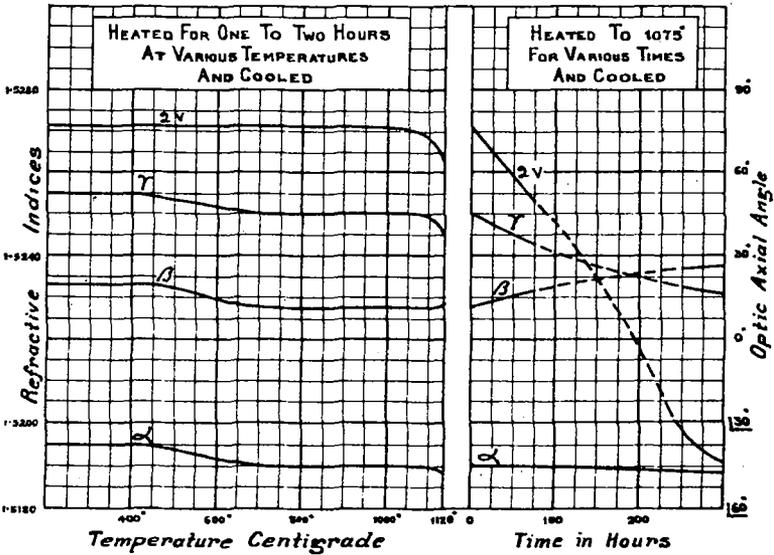


SPECIMEN Q. BURMA BLACK No. II FIG.14.

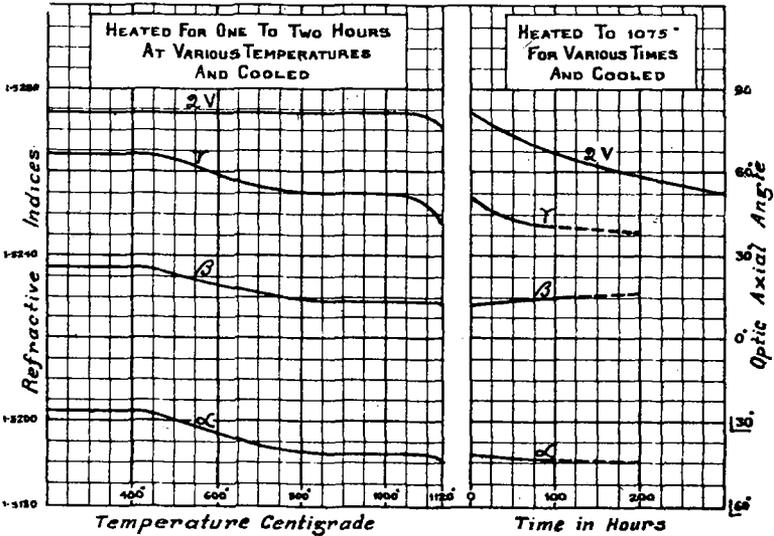


Changes in the optical properties on heating.

SPECIMEN U. KODARMA WHITE MICROCLINE No I FIG.15.



SPECIMEN W. PATNA MICROCLINE No. I FIG. 16.



Changes in the optical properties on heating.

where a change in optic axial angle takes place, the decrease is the same for each of the three indices (see figs. 5-14). The soda-poor, non-schillerized specimens A, B, and C show no such decrease on heating, and the non-schillerized sanidine G, although richer in soda, shows only a slight effect. The changes begin between 350° C. and 450° C., and are completed between 650° C. and 850° C.: the temperature of beginning and end of the alteration is higher in the varieties richer in soda.

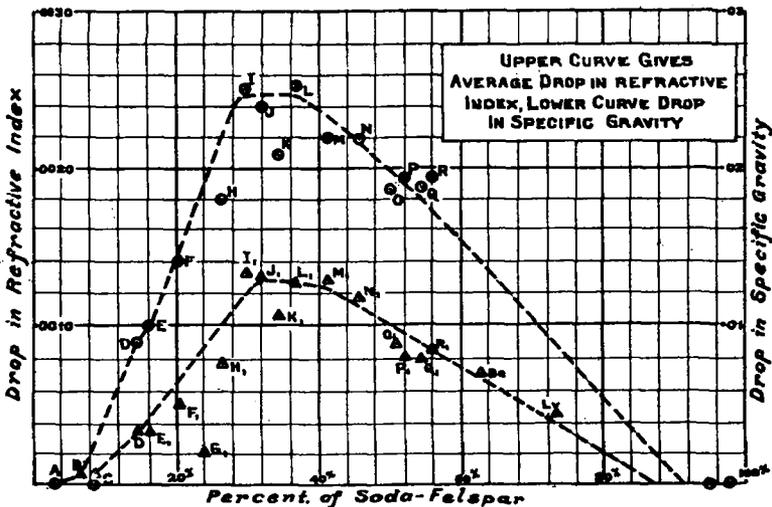


Fig. 17. Drop in refractive indices and specific gravity after rapid cooling from 850° C.

The drop in each of the refractive indices on heating to 850° C. increases nearly linearly with the soda-felspar content between about 8 % and 30%,<sup>1</sup> while between 30 % and about 50 % the drop is proportionately less. These relations are exhibited in the upper curve of fig. 17. Since albite shows no decrease in refractive index after this heat-treatment, the curve is prolonged tentatively towards its plotted indices.

<sup>1</sup> A few specimens within this compositional range show a drop of refractive index and specific gravity less than their composition would suggest. These all have a white schiller and rather coarse micropertthitic structure, which are more difficult to destroy by heating than those of the normal moonstones. The perthitic boundaries are sharper, perhaps owing to the presence of films of air or some mineral, which may be responsible for the greater resistance to perthitic solution.

From these results it may be concluded that a maximum of about 30 % of soda-felspar may be taken into solution in orthoclase at 800°–850° C. A departure either way from this proportion permits less soda-felspar to be taken into solution, and the accompanying drop in refractive index is reduced. Soda-felspar in excess of 30 % may be dissolved slowly by long heating above 850° C. with only a slight further reduction in refractive index, and usually with some decrease in optic axial angle.

It has already been shown (24, pp. 348–358) for many of these specimens that there is a reduction of specific gravity on heating to 850° C., proportional to the soda-felspar content between 10 % and 40 %. The soda-rich specimens now available show that this reduction falls off when the soda-felspar exceeds 40 %, closely paralleling the changes in refractive index. The lower curve of fig. 17 illustrates this.

*Changes in optic axial angle and extinction-angle.*—A few specimens of the orthoclase-micropertthite series show a slight permanent increase in the optic axial angle after heating to 850° C. The increase takes place with the fall in refractive indices and the re-resolution of the pertthite. The phenomenon is displayed by the blue schillerized micropertthite types with 30 % or more soda-component, which have subnormal optic axial angles at ordinary temperatures. The increase is larger the greater the deviation from the normal figure (see figs. 10–14).

Thus the optic axial angle of specimen R (2V 71.5°) is about 10° below the normal and increases 2–3° on heating to 850° C. Several specimens from Ceylon and Burma with optic axial angles 2–6° below the normal showed a rise of 1–2.5°. Specimen P (Korea), phenocrysts in a liparite probably from the same locality,<sup>1</sup> and feldspars from the Sparling Gulch rhyolite previously described (24, p. 337) have optic axial angles before heating of 2V 38–40°. A rise of 4–6° takes place on heating to 800° C.

Kôzu and Suzuki showed that the optic axial angle of moonstones from Korea and Ceylon rose 6° and 2° respectively on heating to 800–900° C.

<sup>1</sup> A brick-red, crumbly liparite probably from Kanchin-do, Meisen-gun, N.E. Korea, contains blue moonstone phenocrysts up to one-eighth inch in diameter, closely resembling those from the rhyolite of Sparling Gulch, Colorado, in composition and physical properties. SiO<sub>2</sub> 66.00, Al<sub>2</sub>O<sub>3</sub> 19.18, Fe<sub>2</sub>O<sub>3</sub> 0.88, CaO trace, MgO 0.10, K<sub>2</sub>O 7.76, Na<sub>2</sub>O 6.06, loss 0.54, total 100.52. Composition Or<sub>45.98</sub> Ab<sub>51.23</sub>. The low summation is caused by the presence of alteration-products.

The changes in extinction-angle on (010), already described for Ceylon moonstone (24, p. 346), have been found to apply to all the medium and soda-rich perthitic felsars with normal optic axial angles. The greater part of the change, however, takes place only on prolonged heating above 850° C., and is associated with the further solution of perthite and reduction of optic axial angle at these higher temperatures.

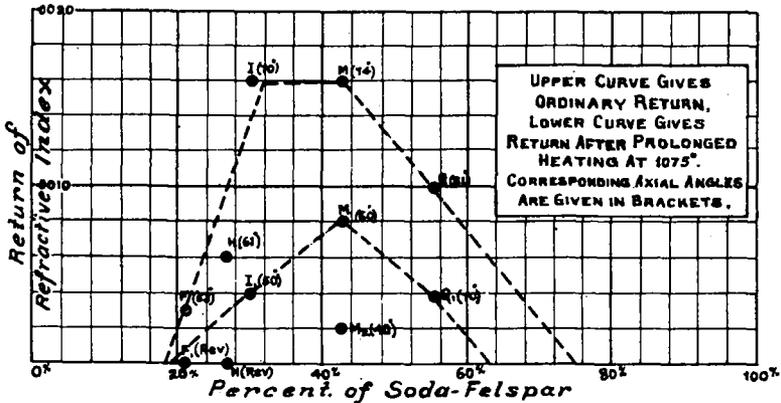


FIG. 18. Refractive indices changes: partial return on slow cooling from 850° C. to 350° C. over 20 days.

(b) *Partial return of the schiller, refractive index, and specific gravity on very slow cooling.*

It has been found that much of the drop in refractive index, caused by heating to 850° C., can be restored by slow cooling in the furnace. Cooling from 850° to 350° C. over 100 hours reduced the refractive index drop of specimens I and M from 0.0025 to 0.0015 and from 0.0024 to 0.0014. Cooling for 500 hours over the same temperature range reduced the drop to about 0.0010 and 0.0009 respectively. For a given rate of cooling the amount of return of refractive index is nearly proportional to the original drop on heating to 850° C. This is shown for various members of the orthoclase-micropertthite series in the upper curve of fig. 18.

The decrease in specific gravity shows a restoration on slow cooling similar to that of the refractive index: the results are set out in the lower curve of fig. 18.

The schiller, which vanishes on heating, can be restored by slow

cooling. Flakes of specimens I and M, cut to show the maximum schiller, were heated for some hours at 1075° C., when the schiller was completely destroyed. Cooling for 500 hours from 800° to 350° C. caused a return of a strong blue schiller and visible microperthitic structures.

(c) *Significance of results.*

The results of these experiments prove that microperthite can be dissolved and re-precipitated from solid solution much more readily than has generally been supposed possible. Most of the solution takes place between the relatively low temperatures of 350° C. and 750° C., and so readily that the rate of cooling of quickly chilled lavas would not prevent complete exsolution, if the rapid cooling affected only that temperature range. The existence of such clear, non-schillerized soda-bearing feldspars as Eifel sanidine cannot be due to rapid cooling through that temperature region.

The results extend the first published experimental evidence of exsolution given by Kôzu and Endô (13), who probably obtained a limited amount of exsolution in the upper temperature region, but who failed (owing to too rapid cooling) to show exsolution below 700° C.

## VII. RESULTS OF PROGRESSIVE HEATING TO 1120° C.

(a) *Changes in the orthoclase-microperthite series.*

Most members of the orthoclase-microperthite series with less than 30% of soda-feldspar show little further change on heating to 1120° C. In general the resistance to change of optic axial angle increases with the soda-feldspar content. The optic axial angle of specimen C begins to decrease at 900–950° C., and becomes zero at about 1050° C. At 1100° C. the angle is nearly 30°, with the optic axial plane parallel to (010). At the same time there is a corresponding change in the indices  $\gamma$  and  $\beta$ .

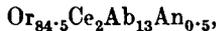
Specimen A (yellow orthoclase, Madagascar), with a smaller soda-feldspar content than specimen C, shows a greater resistance to change. This is probably due to the replacement by ferric iron of some of the aluminium in the atomic framework. The first change begins at about 1060–1070° C. (fig. 5, p. 464); above this temperature the change is rapid. The optic axial angle is about 35° in the symmetry-

plane<sup>1</sup> after 10 hours at 1120° C. These results are similar to those found by Kôzu and Suzuki for this variety of orthoclase (16).

The change in specimen C resembles those found in Eifel sanidine (specimen G), in which the optic axial angle becomes zero at 950–1000° C., and opens out again to about 28° in the symmetry-plane at 1100° C.

The changes in the optic axial angle of sanidine were first described by Des Cloizeaux (9, 10). Kôzu and Suzuki (15) have recently found that the first permanent change begins at about 900° C. They obtained a value 2H 30° as the maximum optic axial angle in the symmetry-plane after heating to 1100° C.

Adularia behaves anomalously in comparison with the other soda-poor members of the series (fig. 6, p. 464) and more closely resembles microcline than orthoclase. The temperature of the first change of optic axial angle varies in different specimens from 900° C. to 1050° C. The change is erratic and sluggish even up to 1100° C. A blue schillerized adularia, with the approximate composition<sup>2</sup>



was found to be equally resistant to change of optic axial angle. Although this specimen lost its schiller on heating to 850° C. (with slight drop in refractive index), the optic axial angle was only reduced from 2V 70° to 58° on six hours' heating to between 1120° C. and 1130° C. This anomalous behaviour of adularia is also suggested by the results of Kôzu's experiments (16, pp. 188–191) and is brought out more strikingly in the long-period heating tests described below.

(b) *Changes in albite.*

No appreciable change in refractive index or optic axial angle could be seen in the two specimens of albite for hourly heatings up to near the melting-point.

(c) *Changes in microcline.*

All six microclines showed a decrease in specific gravity and refractive index on heating to 850° C. For any specimen the same decrease was found for all three refractive indices. The change begins at about 400° C. and is finished at about 800° C. (see figs. 15 and 16, p. 469). The drop is lowest for the specimens low in soda-

<sup>1</sup> Optic axial angles in the symmetry-plane are indicated in the diagrams by a sign L placed against the values of the angles.

<sup>2</sup> SiO<sub>2</sub> 63.88, Al<sub>2</sub>O<sub>3</sub> 19.58, Fe<sub>2</sub>O<sub>3</sub> 0.16, FeO n.d., CaO 0.10, MgO trace, BaO 0.71, K<sub>2</sub>O 13.98, Na<sub>2</sub>O 1.48, loss 0.20, total 100.09. From Zillertal, Tirol.

felspar and increases with increase in soda. The decrease is less than that found for orthoclase-microperthites of corresponding composition. No further changes occur in these specimens on heating to 1000–1050° C. At the latter temperature some specimens show a slight, sluggish reduction in optic axial angle, more clearly seen in the long-period experiments.

### VIII. RESULTS OF HEATING FOR LONG PERIODS AT 1075° C.

The temperature of 1075° C. was chosen for these prolonged experiments as being sufficiently below the melting-point to avoid the formation of glass, whilst being high enough to ensure fairly rapid transformation. N. L. Bowen (7) gives  $1100^{\circ} \pm 10^{\circ}$  C. as the melting-point of albite, and Vogt, quoting Andersen (3, p. 87), states that mixtures of orthoclase with 40–70 % of soda-felspar begin to melt about 30° C. below the melting-point of pure albite. I have not been able to melt specimens with 30–50 % soda-felspar at 1100° C., but flakes or cut plates in contact tend to adhere on prolonged heating at temperatures as low as 1080–1090° C. Such flakes do not lose their crystalline properties, and little glass, if any, is formed. When, at higher temperatures, partial melting occurred, it was always found to begin at the surface or along cracks.

To avoid this adhesion, the specimens were loosely and separately packed in ignited precipitated silica. Albites and soda-rich specimens could be so heated for long periods at 1100–1110° C. without any loss of shape or crystalline structure. The electric furnace was automatically controlled and could be kept within 3° or 4° C. of any temperature up to 1200° C. The pyrometer was checked from time to time at the melting-point of pure copper (1083° C.), pure sodium chloride (794° C.), and pure zinc (420° C.). Specimens were heated for ten-hour periods for the first fifty hours, followed by periods of fifty hours. For most specimens, heating extended to 200–300 hours. As before, curves were drawn for each specimen examined, showing the change of optic axial angle and refractive index, but with time, instead of temperature, as abscissae. Figs. 5–16 (pp. 464–469) show twelve of these curves, and a summary of results is given below.

(a) *Changes in the orthoclase-microperthite series with up to 30 % soda-component.*

*Changes of optic axial angle: the equilibrium angle.*—With the exception of adularia, which strictly does not belong to the series, all

the orthoclase-micropertthites, up to and including J (with 33 % of soda-lime-felspar), were transformed to the abnormal or sanidine type when heated for various periods up to 300 hours. Most of these specimens showed no further change of optic axial angle after the first 100 hours' heating. The size of the optic axial angle in the symmetry-plane decreases with increasing soda-content, while the time taken to attain the final value increases as is shown below.

Specimen.	Optic axial angle 2V in (010) plane.			Time needed to attain equilibrium.		
A ... ..	54°	...	...	90-100	hours	
C ... ..	45	...	...	80-90		
D ... ..	33	...	...	300		
E ... ..	29	...	...	200		
F ... ..	28	...	...	300		
G ... ..	28	...	...	100		
H ... ..	22	...	...	200		
I ... ..	20	...	...	300		
J ... ..	16	...	...	300		

On reheating to still higher temperatures, these specimens gave larger values for 2V. Specimens A, C, and G, on heating to 1120° C. for 12-14 hours, gave respectively 2V 58°, 53°, and 32°. Thus the 'equilibrium angle' for these sanidinized feldspars depends upon the temperature as well as on the soda-content. The 'equilibrium angles' for a temperature of 1075° C. are plotted in the lower part of fig. 2 (p. 458), and lie approximately upon a straight line.

Although the natural Eifel sanidine is comparatively rich in soda it begins to change at a lower temperature than do the medium and soda-rich orthoclases. Its equilibrium angle for 1075° C. is less than those of the orthoclases A and C, and lies in true position on the lower curve of fig. 2. Two other specimens of sanidine from Eifel, of almost the same composition as specimen G, show optic axial angles at normal temperatures of 2V 18° and 24° in the symmetry-plane, but after heating for 10 hours at 1120° C. both show angles of 2V 32°, identical with specimen G.<sup>1</sup>

Changes in dispersion accompany changes in optic axial angle.

<sup>1</sup> A sanidine from Mt. Cimino, Viterbo, Italy, now under examination, has an approximate composition  $Or_{81}Ab_{16}An_3$ . It alters on heating more readily than does specimen G, beginning at 770° C. Heating for 10 hours at 1120° C. changes the optic axial angle from 2V 13° in the symmetry-plane to 2V 34-35° in the symmetry-plane.  $SiO_2$  64.24,  $Al_2O_3$  20.24,  $Fe_2O_3$  0.22, FeO n.d., CaO 0.56, MgO trace, BaO n.d.,  $K_2O$  12.87,  $Na_2O$  1.80, loss 0.50, total 100.43.

In those orthoclase-microperthites in which the optic plane is normal to (010) the dispersion is  $r > v$ , but when the optic axial plane becomes parallel to (010) the dispersion is  $v > r$ .

An attempt was made to find whether slow cooling would affect the value of the optic axial angle. Specimens low in soda, heat-treated to give the largest 'sanidine' optic axial angle, would be most likely to respond. After heating specimens A and G to 1100° C. for 50 hours, the optic axial angles were found to be 2V 54.1° and 32.1° respectively. The specimens were then cooled for 70 hours from 1100° C. to 770° C., after which the optic axial angles were 2V 53.1° and 29.7°. Specimen A was heated again for 150 hours at 900° C., when 2V 43.7°. After cooling specimen G for 500 hours from 800° C. to 350° C. it had an optic axial angle of 28.8°.

These results suggest that slow cooling may to some extent reverse the direction of change of optic axial angle, particularly in the region of 1000–900° C., but they are not conclusive. In any case the changes are sluggish compared with those that accompany perthitic solution and exsolution between 350° C. and 750° C.

*Changes in refractive index.*—Accompanying the changes in optic axial angle, the values of  $\gamma$  and  $\beta$  are transposed, whilst the value of  $\alpha$  remains almost constant, falling at the most 0.002. Usually the fall in the value of  $\gamma$  was found to be greater than the rise in the value of  $\beta$ .

(b) *Changes in the orthoclase-microperthite series with more than 30 % soda-component.*

*Changes in optic axial angle.*—The equilibrium angle in the symmetry-plane falls with increasing soda-content, while at the same time the feldspars become more resistant to change in optic axial angle on heating. Specimen I with 30 % soda-feldspar needed 300 hours at 1075° C. to reduce the optic axial angle to zero, and 100 hours at 1090° C. to reverse it to 2V 20°. Specimen M, with 42 % of soda-feldspar, was only changed from 2V 73° to 34° by 300 hours' heating, and specimen Q, with 54 % soda-lime-component, was only changed from 2V 83° to 62° in 300 hours.

It must be remembered that in all specimens with large optic axial angles (including microcline and adularia) a greater relative change in the indices  $\gamma$  and  $\beta$  is required to produce a given change of that angle than when the angle is initially small. With an angle 2V 10–20°

a relative change of one in the fourth decimal place of  $\gamma$  and  $\beta$  corresponds to a change in the optic axial angle of about  $10^\circ$ , but when  $2V$   $80^\circ$ , the change is only about one degree.

However, the fact that these soda-rich specimens are intrinsically more resistant to change is shown, firstly, by the fact that the equilibrium angle at  $1075^\circ\text{C.}$  falls as the soda-content increases, and secondly, by the resistance to change of specimen P. This has the low initial angle of  $2V$   $38^\circ$ , but requires 300 hours at  $1075^\circ\text{C.}$  to reduce the angle further to  $2V$   $15^\circ$ .

*Changes in refractive index.*—Prolonged heating at  $1075^\circ\text{C.}$  caused changes in the refractive indices of soda-rich microperthites slightly different from those found in the soda-poor forms. In the latter the values of  $\alpha$  remained nearly constant, while the values  $\gamma$  and  $\beta$  change, but in the soda-rich varieties all three refractive indices are slightly depressed, apparently because of solution of excess microperthite. The drop in refractive index is less in proportion to the amount of perthite dissolved than that found during solution in the  $350$ – $850^\circ\text{C.}$  region. If the solution of perthite takes place during the reduction of optic axial angle, the final effect on the refractive indices is a large drop in the value of  $\gamma$ , a smaller drop in the value of  $\alpha$ , and a small rise or drop in the value of  $\beta$ , depending upon the change in the optic axial angle and the amount of perthite dissolved. Specimen P, which is entirely homogeneous above  $800^\circ\text{C.}$ , shows no decrease in refractive index, except for the changes which accompany the reduction of optic axial angle.

*Changes in the extinction-angle.*—The medium- and high-soda members of the true orthoclase-microperthite series show a small reduction in extinction-angle on heating to  $850$ – $900^\circ\text{C.}$ , and a further reduction on prolonged exposure to higher temperatures. This effect has already been described for Ceylon moonstone (24, p. 347). Specimens with extinctions of  $11$ – $12^\circ$  on (010), after heating to  $1000$ – $1075^\circ\text{C.}$  show a reduction to about  $8^\circ$ , and those with extinctions of  $9$ – $10^\circ$  are reduced to  $7$ – $8^\circ$ . This reduction may be caused by those factors which reduce the optic axial angles, but in some cases the change in extinction-angle precedes the change in optic axial angle.

Barth (5, p. 72), from his experiments on the potash-soda-felspars, concluded that the position of the indicatrix in the homogeneous members was unaffected by heat-treatment, but the above easily demonstrable changes in extinction-angle show that the position, as well as the form, of the indicatrix can be modified by heating. As

Barth used adularia, microcline, and anorthoclase, which are not representative of the potash-soda-orthoclase series, any general conclusions drawn from his experiments are likely to be misleading.

(c) *Changes in adularia.*

It has been stated<sup>1</sup> that adularia suffers an irreversible change between 700° C. and 900° C., the optic axial angle decreasing to zero and opening out in the symmetry-plane. This statement is based on the work of Des Cloizeaux (9, 10) and Merwin (21), but it is not supported by the work of Kôzu, Barth, or the writer. Kôzu and Suzuki (16, pp. 187–191) heated specimens of adularia to a temperature of 1100° C., and found that the optic axial angle remained unchanged up to about 900° C., after which it declined irregularly with increase of temperature to about 2V 30°. Barth (5, p. 60) also subjected adularia to prolonged heat-treatment. After 400 hours at 1000° C., he found that the optic axial angle had declined from 2V 61° to 30° without equilibrium being attained.

Similar results have been obtained by the writer for prolonged heating at 1075° C. and higher temperatures. Table II (pl. xviii) and fig. 6 (p. 464) show the results of heating adularia (specimen B) for 200 hours at 1075° C. The optic axial angle was reduced from 2V 68° to 22° without reaching equilibrium. Heating the same specimen for 100 hours at 1120° C. reversed the optic axial angle into the symmetry-plane to 2V 30°, with patchy areas having a lower angle. Tests on further specimens from the same crystal and from others of similar composition showed an even greater resistance to change at high temperature, the optic axial angles being reduced only from 68–70° to 40–50° after 300 hours at 1075° C. In view of the low soda-content this resistance to change is remarkable and is only paralleled by the resistance of microcline and the soda-rich orthoclase-microperthites. The reason for this is undoubtedly connected with the lower temperature of formation.

(d) *Changes in albite.*

The behaviour of the two albites (S and T) towards prolonged heat-treatment was somewhat peculiar. After heating to 1075° C. for 50 hours there was a slight reduction of optic axial angle in specimen S, but no change in specimen T. After a further 50 hours' heating T

<sup>1</sup> See, for example, A. N. Winchell, *Elements of optical mineralogy*. 2nd edit., 1933, pt. 2, pp. 361–362.

showed no change, while the optic axial angle of S was reduced from  $2V\ 100^{\circ 1}$  to about  $80^{\circ}$ . At the same time the extinction-angle on (010) was reduced in a patchy manner. After 300 hours at  $1075^{\circ}\text{C}$ ., specimen S showed a uniform extinction of  $8^{\circ}$  on (010); the optic axial angle was then  $2V\ 35\text{--}60^{\circ}$ , with a change in the direction of the optic axial plane which made it difficult to read the angle accurately. The optic axial angle of specimen T diminished on the same treatment to about  $2V\ 80^{\circ}$ . A (010) section showed a regular mosaic of parts extinguishing at  $8^{\circ}$  and  $18^{\circ}$  respectively. The specific gravity of both specimens fell about 0.006 during the treatment.

It is evident that the changes produced in albite by heat-treatment are quite different from those produced in the orthoclase-micropertthite series. Of the specimens examined, adularia is the only one that tends to behave like albite; it is significant that field-evidence indicates a low-temperature hydrothermal origin for both species, as compared with a high-temperature origin for the orthoclase-micropertthites and an intermediate temperature for the microclines.

(e) *Changes in microcline.*

In comparison with the corresponding orthoclases, the six microclines examined show a characteristic resistance to change on prolonged heating. Thus specimens E and H of the orthoclase-micropertthite series, with approximately the same soda-felspar content as the microclines, show axial angles  $2V\ 29^{\circ}$  and  $22^{\circ}$  in the symmetry-plane after 200 hours at  $1075^{\circ}\text{C}$ . The optic axial angles of the microclines, by the same treatment, drop from  $2V\ 70\text{--}80^{\circ}$  to  $30\text{--}50^{\circ}$ , the optic axial plane remaining normal to (010). Microclines U and V showed unexpected changes after heating for 300 hours at  $1075^{\circ}\text{C}$ .; the optic axial angles were reversed into the symmetry-plane to  $2V\ 44^{\circ}$  and  $16^{\circ}$  respectively. At the same time the fine microcline twinning visible on (001) was destroyed. It is seen that these glassy or semi-glassy microclines are more easily sanidinized than adularia of corresponding composition.

Previous attempts to convert microcline to the homogeneous monoclinic orthoclase form by heat-treatment have yielded conflicting results. Mäkinen (20, pp. 125–127) and previous investigators found that the cross-hatch structure was not destroyed on heating to near the melting-point of the felspar.

<sup>1</sup> In conformity with the orthoclase-micropertthite series, the recorded optic axial angle is that one which includes the minimum axis of the indicatrix.

Dittler and Köhler (11, pp. 250–258) by heating microcline-microperthite for 500–700 hours at 1000° C. found that the cross-hatching disappeared, leaving a mineral with the characters of orthoclase. More recently, Barth (5, p. 63) heated low-soda microcline for 300–600 hours at 1000° C., after which the mineral was still triclinic.

These variable results probably represent the difference in behaviour of different microcline specimens. The writer's results show that the semi-glassy, finely twinned microclines are much less resistant to heat-treatment than the coarsely twinned varieties with 'vein' perthite, especially when the optic axial angle is initially large. There is little doubt that prolonged heating at 1075° C. would convert even the latter into the homogeneous sanidine form. The character of the transformation seems to be more abrupt than that found in the orthoclase-microperthite series, and resembles the changes undergone by albite.

(f) *Effect of slow cooling on 'sanidinized' feldspars.*

It has been suggested on p. 473 that the homogeneity of the natural soda-bearing sanidines cannot be due, as is often assumed, to rapid cooling through the temperature range of perthitic exsolution, since no rock-cooling rates can have been so rapid as those that have been found necessary, in the writer's experiments, to prevent exsolution. The natural sanidines are invariably forms with small optic axial angles. It appears probable that the size of the optic axial angle is a measure of some modification of the atomic framework, which is the cause of the capacity for holding the soda-feldspar in permanent solid solution. In support of this it was found that artificially 'sanidinized' feldspar, on cooling for 500 hours from 850° to 350° C., showed a smaller return of refractive index (indicating less exsolution) than did specimens of the same feldspar that had not been heated above 800° C. and that thus had larger 'normal' optic axial angles.

Fig. 18 (p. 472) shows these results, the upper curve giving the restoration of refractive index on slow cooling for non-sanidinized specimens, the lower curve being for the same specimens on slow cooling after having been converted to the sanidine form. In each case the number in brackets near the plotted point is the optic axial angle. For any specimen, the lower the optic axial angle of the sanidinized form, the smaller is the return of refractive index. Thus the form with the low optic axial angle holds the soda-component in solution during slow cooling through the range of perthitic exsolution.

Sanidine from Eifel (specimen G) with the low optic axial angle of  $2V\ 24^\circ$  shows a drop in refractive index of only 0.0003–4 on heating to  $800^\circ\text{C}$ . Two anorthoclases at present under examination, from Drachenfels, Siebengebirge, Rhine, and Haddington, Scotland, are low-angle specimens with higher soda-contents. Their analyses, together with their approximate compositions, are set out below.

	Siebengebirge.			Haddington.		
SiO <sub>2</sub> ... ..	63.90	%	...	62.85	%	...
Al <sub>2</sub> O <sub>3</sub> ... ..	20.09	...	...	20.43	...	...
Fe <sub>2</sub> O <sub>3</sub> ... ..	0.79	...	...	0.67	...	...
CaO ... ..	0.62	...	...	1.30	...	...
K <sub>2</sub> O ... ..	10.10	...	...	9.83	...	...
Na <sub>2</sub> O ... ..	4.02	...	...	4.02	...	...
Loss ... ..	0.62	...	...	0.74	...	...
	<u>100.14</u>	...	...	<u>99.84</u>	...	...
Composition (Wt. %)	Or <sub>62</sub> Ab <sub>35</sub> An <sub>3</sub>	...	...	Or <sub>59</sub> Ab <sub>35</sub> An <sub>6</sub>	...	...
Symbol on fig. 2 (p. 458)	Si	...	...	Ha	...	...

The refractive index of the Siebengebirge specimen, with an optic axial angle of  $2V\ 33^\circ$ , drops by 0.0003 on heating to  $800^\circ\text{C}$ ., while the Haddington specimen, with  $2V\ 34^\circ$ , shows a drop of 0.0005. Both are free from schiller and perthitic inclusions. It is clear that with these compositions and optic axial angles the saturation point is not appreciably exceeded in the exsolution temperature range.

These anorthoclases are much more resistant to change than the sanidines. Specimen G (Eifel sanidine), after heating to  $1075^\circ\text{C}$ . for 300 hours, showed a change of optic axial angle from  $2V\ 24^\circ$  in the plane normal to (010) to  $2V\ 29^\circ$  in the symmetry-plane. The same treatment reduced the optic axial angle of the anorthoclase by only  $5\text{--}7^\circ$  (fig. 2, p. 458). A similar resistance to change has been noticed in other soda-rich, low-angle anorthoclases.

As the optic axial angle increases, mutual saturation of the two feldspars in the range of  $750\text{--}350^\circ\text{C}$ . is ultimately exceeded, and some of the soda-feldspar separates as perthite. The higher the soda-content, the lower the optic axial angle when this occurs. Interesting examples are specimen P (Korea) and the phenocrysts from the Sparling Gulch rhyolite (24, p. 337). The composition and optic axial angles of these feldspars are such that for temperatures below  $800^\circ\text{C}$ . the saturation point has been exceeded, but at this temperature they both become clear and homogeneous. Orthoclase pheno-

crysts from a riebeckite-trachyte, Berkum, Rhine,<sup>1</sup> have a faint blue schiller that disappears on heating to 850° C., with concomitant drop in specific gravity and refractive index, and a slight rise in optic axial angle.

For feldspars with still higher optic axial angles and high soda-content the saturation point may be exceeded even at a higher temperature than 800° C. Thus specimens J, L, M, and N of the orthoclase-microperthite series all possess lower soda-content than the Korea specimen P, but have higher optic axial angles (72–83°). None of these specimens becomes clear and homogeneous at 800° C., although the changes in refractive index indicate that the greater part of the soda-component has been taken into solution.

(g) *The continuous nature of the changes in the orthoclase-microperthite series.*

An important deduction from the results described above is that the changes brought about by the heat-treatment of members of the orthoclase-microperthite series are continuous, the physical properties, at equilibrium, varying progressively with the temperature.

The sudden change in expansion and other properties observed by Kôzu and Saiki (17) at temperatures of 450–500° C., at 750° C., and at 900–950° C., and the changes observed by Merwin (21) at 900° C., can be included in these general changes. Thus between 500° and 650° C. microperthite begins to go rapidly into solution, and 700° C. is the temperature at which saturation is nearly complete for specimens with up to 30 % of soda-component. The temperature of 900–950° C. is that at which the optic axial angle of many specimens is first affected.

It is possible that some slight change in the atomic structure of the feldspar at or near these temperatures is responsible for the sudden change in the rate of alteration, but, if so, it does not show as a change in the *form* of the indicatrix. Moreover, these temperatures are not fixed, but vary very considerably with the type and composition of the feldspar. Hence the available evidence does not support the belief that an inversion occurs at these temperatures, as Alling (2)

<sup>1</sup> Belyankin (6) described this feldspar as anorthoclase showing 'cross-hatch' twinning on basal sections. My specimen is schillerized and microperthitic. The structure seen on basal flakes is due to microperthite. Belyankin's analysis agrees closely with mine. SiO<sub>2</sub> 64.94, Al<sub>2</sub>O<sub>3</sub> 20.27, Fe<sub>2</sub>O<sub>3</sub> 0.45, FeO n.d., CaO 0.67, MgO trace, BaO n.d., K<sub>2</sub>O 6.12, Na<sub>2</sub>O 6.82, loss n.d., total 99.27.

and Winchell (28) have assumed. Except for a possible break to the microcline type in the formation temperature region of 600–750° C., for adularia at a lower temperature, and for albite at a very high temperature, the evidence points strongly towards a gradual change in physical properties with change in equilibrium temperature or composition.

## IX. X-RAYS AND FELSPAR STRUCTURE.

### (a) *The identical structure of orthoclase and sanidine.*

X-ray examination of orthoclase and sanidine by Schiebold (23) and Taylor (25, 26) fails to show a difference in their structure. Taylor, realizing that some difference must exist to account for their optical dissimilarity, says (26, p. 494): 'A fact of some importance which bears upon this question is that optical examination is much more sensitive than X-ray examination to a change in symmetry and to small distorting forces.'

Kôzu and Suzuki observed the effect of heat upon the optic axial angle of sanidine, but could find no corresponding change in structure by X-ray examination. They concluded that the effect 'is due to changes in the arrangement of the dispersion electrons composing the atoms of the crystals, not to the atomic arrangement' (15, p. 241).

It is unlikely that small changes of the above nature could account for the pronounced differences in permanent solubility for soda-component between the two forms of potash-felspar. Again, the reversal of the optic axial angle in the soda-poor potash-felspars, from about 40° in the plane perpendicular to (010) to about 55° in the symmetry-plane, involves a transposition of the refractive indices  $\gamma$  and  $\beta$ , with a relative change in their values of about 0.0010. This change in the direction of maximum refractive index for the same kind and number of atoms in the framework must mean that some modification of the structure has occurred.

### (b) *The structure of feldspars and its bearing upon perthitic solution.*

From the work of Machatschki (19) and Taylor comes the suggestion that the felspar structure is one of linked chains of tetrahedra of  $\text{AlO}_4$  and  $\text{SiO}_4$ , with the alkali metals distributed as cations in the interstices of the oxygen atom arrangement. According to Taylor (26, p. 479) albite has the same structure as sanidine (orthoclase?) except for a slight rotation and closing up of the chains round the

smaller sodium ions. In perthitic feldspars he suggests that 'The tetrahedron framework may thus be continuous throughout the lamellar crystal, but with regions of greater extension of the chains, and lesser extension, which appear optically as orthoclase and albite lamellae respectively' (26, p. 489).

It is no longer necessary to assume that the whole of the albite or orthoclase molecule migrates during the formation of perthite, only that the sodium and potassium ions undergo translation. On slow cooling, the smaller sodium ions tend to segregate, and when this segregation has reached a certain value, the tetrahedron framework contracts in these areas and rotates a little, and a patch of albite is produced. Re-resolution of the perthite structure on heating would represent a reversal of this process.

It has been shown (24, pp. 298-303) that the micropertthitic structure in soda-rich specimens of the Ceylon or Burma moonstone type is of two kinds: (a) the ordinary fine 'film' or 'string' micro- or cryptopertthite; and (b) a coarser 'shadow' perthite in lenses which lie approximately in the plane (100), and which embrace a number of the finer micropertthitic lamellae. The 'shadow' perthite is generally present in normal members of the series when the soda-content is in excess of 25-30%. It is more difficult to destroy by heat-treatment than the 'film' type of perthite, and often persists after prolonged heating at 1000°C. It seems probable that the 'shadow' perthite represents an early, high-temperature separation into areas richer and poorer in sodium ions. It may be that at temperatures down to 800-850°C. the sodium ions, corresponding to the excess of soda-component over 30%, segregate and form regions in which the structure is a little denser, or nearer albite, than the potash-rich areas. The optical difference between these two forms cannot be great, since they do not produce schiller, and there is only a slight change in optical properties when they are taken into solid solution.

Another peculiarity of the orthoclase series (see p. 460) is that the extinction on (001) tends to be straight, and the obtuse bisectrix tends to remain normal to (010), even in soda-rich specimens. Since albite shows a considerable deviation in both these respects, one would expect that a lamellar mixture of orthoclase and albite would show a proportional deviation. That this is not seen might be explained: (a) by the special manner and direction in which the albite lamellae have separated from solid solution, involving a minimum disturbance to the tetrahedron framework as a whole; (b) by the tetrahedron

framework within the albite lamellae still possessing certain ortho-class characteristics, i.e. shrinkage may have taken place without rotation of the structure.

The latter explanation would account for the ease and rapidity with which these 'film' types of microperthite go into solution as compared with the coarser 'primary' or 'vein' perthite. This variety, most common in the microclines, is generally believed to have crystallized directly from solution, and, as a result, may possess a true albite structure of greater rigidity. These coarse lamellae invariably show multiple albite-twinning, which the writer has not yet found in 'film' perthite of exsolution origin. These facts are in better agreement with the view that perthitic solution and exsolution are caused by a translation of the metallic ions rather than of the feldspar molecules themselves.

#### X. AN ATTEMPTED EXPLANATION OF THE EXPERIMENTAL RESULTS.

An attempt will now be made to review the experimental results described above in the light of the X-ray explanation of the feldspar structure.

##### (a) *Feldspars with 0-30% of soda-component.*

The stable form at high temperatures of the potash-soda-feldspars with less than 30% of soda-component is the sanidine type, with the optic axial plane parallel to (010). For a given temperature, the optic axial angle in this plane decreases with increase in soda-content. Conversely, with a constant soda-content, the optic axial angle decreases with lowered temperature of formation. Both these changes finally cause the optic axial plane to become perpendicular to (010), while further increase in soda-content, or a lowered temperature of formation, increases the optic axial angle towards the albite figure.

In potentially perthitic feldspars this tendency reaches a maximum while the feldspar is still homogeneous. Perthitic exsolution causes only a uniform change in the three refractive indices without affecting the optic axial angle. It may be assumed from this that the sodium ions in the homogeneous feldspars produce the same average distorting effect as they do when separated as perthite lamellae. Exsolution causes no further distortion of the framework, only a uniform shrinkage in the spaces occupied by the separated soda-feldspar

lamellae, which thus acquire the refractive indices and density of albite, without apparently taking on full triclinic symmetry.

If the optic axial angle is not at a maximum just above the temperature of exsolution, some of the soda-felspar will remain in solid solution, even though cooling through the exsolution range is slow. For instance, the homogeneous feldspars of Siebengebirge and Haddington, with optic axial angles of about  $35^\circ$ , hold some 35% of soda-felspar.

(b) *Feldspars with more than 30% soda-component.*

In the high-angle, soda-rich microperthites the temperature of perthitic exsolution is above that at which the optic axial angle attains its maximum. In order to render such feldspars homogeneous, it is necessary to heat them for long periods at a temperature at which the optic axial angle is considerably reduced. These feldspars must have been formed at a higher temperature, with a small optic axial angle, which has increased to its present value by very slow cooling and with exsolution.

That this cooling must be exceedingly slow is shown by the 'sub-normal' optic axial angles of such feldspars as P and K, from hypabyssal rocks. In volcanic rocks, although their cooling is slow in comparison with any experimental rates, the optic axial angle is usually nearer the minimum than the maximum possible.

The changes in the oblateness of the indicatrix which give rise to the changes of optic axial angle are not very great, and any corresponding change in the form of the tetrahedron framework would only be slight. This may explain why X-ray examination has so far failed to distinguish a difference in structure between low-angle sanidine and high-angle orthoclase. Small as these changes are, they control the behaviour of the potash-soda-feldspars in the exsolution temperature region by determining whether the feldspar shall remain homogeneous, with the sodium and potassium ions dispersed evenly throughout the structure, or whether the ions shall segregate and form respectively albite and orthoclase perthite lamellae.

XI. (a) *Diagrammatic representation of the microperthitic field.*

The relations between the optic axial angle, the degree of exsolution, and the soda-feldspar content are indicated by the curves of fig. 19. For a given composition, forms with high optic axial angles

show complete exsolution, but in corresponding low-angle forms exsolution is completely inhibited.

The curve *DCE* shows the optic axial angles of normal feldspars of the orthoclase-microperthite series, and *HI* the probable equilibrium angles of the sanidine-anorthoclase series at a temperature of 1075° C.

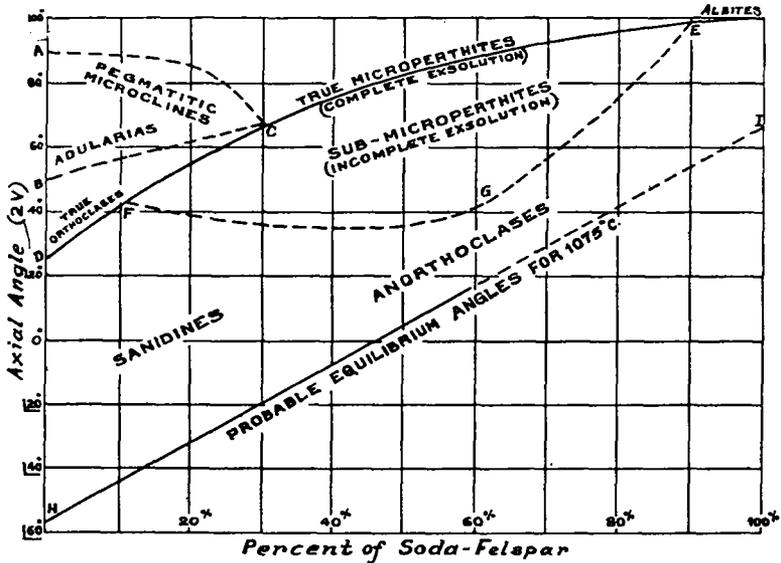


FIG. 19. Optic axial angles and feldspar forms.

The curve *FGE* represents the approximate boundary between complete and incomplete homogeneity; all the microperthitic orthoclase forms fall within the area *FCEG*. The closer the optic axial angle is to the upper line *FCE*, the greater the degree of exsolution and the more complete the perthitic separation.

In the area *ACB* are included the microclines and adularias, whose optic axial angles are all considerably higher than those of the corresponding orthoclase-microperthites. This is probably connected with their lower temperature of crystallization. Perhaps the trend of the orthoclase boundary towards *D* may indicate the inability of the solid phase produced at relatively high temperature to maintain perfect equilibrium of optic axial angle with falling temperatures. If this is true *CD* represents metastable forms; the true stable forms lying close to the line *CB*. It is also possible that the changes in

atomic structure, which must accompany the increase in optic axial angle, favour the formation of the triclinic microcline form. This question will be referred to when discussing the origin of pegmatitic microclines in the second part of the paper.

(b) *A possible discontinuity in the high-soda region.*

In order to draw more precisely the boundary between the homogeneous and perthitic fields in the high-soda region (i.e. the right-hand portion of the curve *FGE*; fig. 19), two specimens described by E. D. Mountain (22, p. 336) have been referred to, and three additional specimens have been examined. The results and analyses are tabulated below.

	1.	2.	3.	4.	5.
SiO <sub>2</sub> ...	60.08	64.80	64.33	64.76	62.79
TiO <sub>2</sub> ...	0.97	—	—	—	—
Al <sub>2</sub> O <sub>3</sub> ...	19.99	21.14	20.94	21.50	22.12
Fe <sub>2</sub> O <sub>3</sub> ...	1.57	0.68	0.20	0.54	0.36
FeO ...	1.68	—	0.58	—	0.41
CaO ...	2.21	1.18	2.01	1.94	3.76
MgO ...	0.72	0.10	—	0.18	—
K <sub>2</sub> O ...	4.45	5.26	4.71	3.88	2.98
Na <sub>2</sub> O ...	7.03	6.94	7.22	7.44	7.35
Loss ...	n.d.	0.20	0.37	0.10	0.26
	98.70	100.30	100.36	100.34	100.03
Comp. (wt. %)	Or <sub>27</sub> Ab <sub>62</sub> An <sub>11</sub>	Or <sub>28</sub> Ab <sub>62</sub> An <sub>10</sub>	Or <sub>24</sub> Ab <sub>66</sub> An <sub>10</sub>	Or <sub>19.5</sub> Ab <sub>61.5</sub> An <sub>19</sub>	
		Or <sub>32.5</sub> Ab <sub>62.5</sub> An <sub>6</sub>			
Optic axial angle (2V) ...	80°	57.5°	51°	53.5°	62°
Symbol on fig. 20	Lv	Ky	Km	Pa	Eb

1. Schillerized feldspar with fine micropertthitic and composite structure; optic axial angle sub-normal. Phenocrysts from larvikite. Oslo area, Norway. Analyst, E. Spencer.

2. Homogeneous non-schillerized feldspar, with sub-normal optic axial angle. Phenocrysts from kenyte, Mt. Kenya, East Africa. Analyst, E. Spencer.

3. Homogeneous non-schillerized feldspar, with sub-normal optic axial angle. Phenocrysts from kenyte, Mt. Kenya, East Africa. Analyst, E. D. Mountain.

4. Homogeneous non-schillerized feldspar, with sub-normal optic axial angle. Isolated phenocrysts. Pantelleria. Analyst, E. Spencer.

5. Homogeneous non-schillerized feldspar, with sub-normal optic axial angle. Phenocrysts, Mt. Erebus, Antarctica. Analyst, E. D. Mountain.

It will be seen that all five specimens are relatively rich in lime, and it appears that orthoclase-micropertthite rich in soda but poor in lime is uncommon. Phenocrysts in the trachyte of Berkum,

Rhine,<sup>1</sup> provide the most sodic, lime-poor specimens that I have yet investigated, with a composition of  $Or_{37}Ab_{60}An_3$ .

E. D. Mountain (22, p. 340) has shown that the felspar phenocrysts from Mt. Erebus and Mt. Kenya can be included in a series ranging between  $Ab_{65}Or_{35}$  and  $Ab_{65}An_{35}$ ,<sup>2</sup> whose end-members are the Berkum anorthoclase and oligoclase-andesine. The series has continuous optical and crystallographic properties. In fig. 20 the line *CD* on

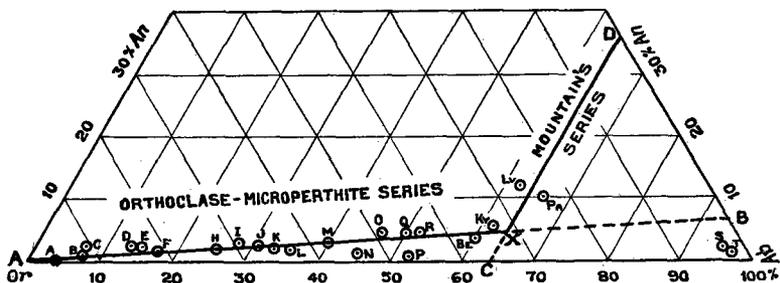


FIG. 20. Orthoclase-microperthites and E. D. Mountain's series.

the compositional triangle represents this series, and the orthoclase-microperthite series is shown by the line *AB*. The intersection of these lines at *X* corresponds approximately to the composition of the Berkum anorthoclase. The three new specimens *Lv*, *Ky*, and *Pa* all lie near *CD*.

Johansson (12), Asklund (4), and Alling (2) have plotted the analyses of a large number of felspars on the Or-Ab-An triangle, and it is noteworthy that the lines *AX* and *XC* of fig. 20 lie approximately in the directions of the maximum density of occurrence of potash-bearing felspars in these diagrams.

These facts support the view that there is a discontinuity in the potash-soda-felspar series above 60% of soda-component, with a deviation towards oligoclase-andesine. It appears that, at the crystallizing temperature of these felspars, the orthoclase structure can accommodate up to 50-60% of soda-component with only a slight distortion towards the albite form, and that the albite structure can accommodate up to 20-30% of potash-component with some modification towards the orthoclase form, but that between these limits, and

<sup>1</sup> See footnote, p. 483, for analysis.

<sup>2</sup> These compositions are expressed in molecular percentages, as given by E. D. Mountain. Those tabulated above are weight percentages.

with the amount of lime usually present in the crystallizing magma, homogeneous potash-soda-feldspars are not produced.

#### SUMMARY.

A series of potash-soda-feldspars of the orthoclase-microperthite type, selected with increasing soda-contents up to 60 %, have been examined and found to exhibit a progressive relationship between chemical composition and physical properties. Albite ( $Ab_{97}An_2Or_1$ ) conforms in physical properties to the soda end-member of the series.

Adularia and microcline do not strictly belong to the series, the optic axial angle  $2V$  and the birefringence  $\gamma - \beta$  being too high. On the other hand, the sanidines and anorthoclase feldspars have lower refractive indices and a lower optic axial angle than orthoclase-microperthites of corresponding composition. This low optic axial angle is the result of relatively rapid cooling through the temperature range of 1050–900° C., and the ensuing modification of the internal structure enables the feldspar to hold the soda-component in complete solid solution on further cooling through the perthite exsolution temperature range (850–350° C.), however slow the cooling through that range may be.

The microperthite of the orthoclase-microperthite series is of the exsolution type, and can be taken into solid solution again by heating for some time to 750–800° C., followed by rapid cooling. At the same time, the schiller is more or less destroyed, and the specific gravity and the refractive indices are reduced, the reduction being roughly proportional to the amount of microperthite taken into solution. Providing that the optic axial angle has not been reduced by prolonged heating at high temperatures, the microperthite may be in part reprecipitated by very slow cooling; the schiller and microperthite structure reappear and the drop in specific gravity and refractive index are in part restored.

In all cases where the optic axial angle is normal and microperthite exsolution complete, the angle remains unaltered during the refractive index changes which accompany the solution of the microperthite on heat-treatment. If the optic axial angle is sub-normal and exsolution of the microperthite is incomplete—as with Korea moonstone, &c.—the solution of the microperthite is accompanied by a slight rise in the axial angle.

Recent X-ray examination of feldspar structures has led to the

suggestion that micropertthitic exsolution represents a local segregation of the sodium and potassium ions within the silica-alumina framework followed by a contraction and slewing of the framework in the areas rich in sodium ions. This view explains the relative ease with which the micropertthitic changes can be brought about on heating.

The optic axial angles of potash-soda-felspars are reduced by prolonged heating at high temperatures. Specimens with less than 40% of soda-felspar can be completely 'sanidinized' or converted into the abnormal type of felspar with the optic axial plane parallel to the plane of symmetry. The equilibrium value of the optic axial angle, for a temperature of 1075°C., depends on the chemical composition, the relationship being approximately linear between  $2V 60^\circ$  (0% soda-felspar) and  $2V 0^\circ$  (40-45% soda-felspar). Microcline can be converted to the abnormal form by heating at 1075°C. for a long period; at the same time the cross-hatch twinning is destroyed.

Attempts to reverse this process and to restore the original optic axial angles to 'sanidinized' felspars, by cooling them very slowly through the high-temperature range, have not given positive results, but the indications are that a part of the change may be reversible in laboratory cooling times.

In conclusion, I wish to thank Professor P. G. H. Boswell for his help and advice and Mr. R. Walls of the Imperial College of Science and Technology, London, for assistance in the preparation of this paper; also members of the Geological Survey of India, especially Sir Lewis Fermor and Dr. J. A. Dunn, for their kind help and criticism; and Messrs. K. B. Sen and B. P. Gupta, of Messrs. Bird & Co., Calcutta, for much help with the chemical analyses and physical determinations.

*Addendum.*—When the MS. was in its final form, the writer's attention was drawn to the recent paper by C. T. Barber (*Min. Mag.*, September 1936, this vol., p. 343). Barber heated plagioclase felspars for long periods at 1000°C., and found that the optic axial angle of albite was not significantly affected by this treatment. It is probable that the low temperature of the experiment was responsible for the negative result. Prof. W. L. Bragg informs me that unpublished investigations on the behaviour of metallic alloy-systems show that the rate of transformation falls off greatly with decreasing temperatures. It is likely that similar effects would be found in the felspars.

From tests that I have made on potash-oligoclase, it seems that the presence of appreciable quantities of lime in the feldspar structure retards the change even on prolonged heating at 1075° C.

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Table I  
CHEMICAL COMPOSITION OF THE  
POTASH - SODA-FELSPARS EXAMINED.  
A. ORTHOCLASE - MICROPERTHITES

SPECIMEN	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	BaO	K <sub>2</sub> O	NH <sub>3</sub> O	Loss	TOTAL	POTASH FELSPAR	SODA FELSPAR	LIME FELSPAR	TOTAL
A ORTHOCLASE *	64.40	18.70	0.62	Tr.	Tr.	-	16.14	0.46	-	100.41	95.39	3.89	-	99.28
B ADULARIA St. Gothard	64.28	19.19	0.09	0.11	0.10	0.11	18.30	0.92	0.36	100.46	90.43	7.78	2.50	99.03
C ZODIACHES *	63.66	19.54	0.10	-	-	-	18.60	0.80	-	100.30	92.20	6.76	2.60	101.46
D BURMA No. I *	65.30	18.84	0.16	-	-	-	14.18	1.82	-	100.44	83.90	13.69	1.70	99.19
E KALAMANDI Orthoclase	63.75	19.10	0.48	-	-	-	13.91	1.74	0.62	99.56	82.21	14.71	1.80	98.72
F BURMA No. II *	65.14	19.60	0.10	-	-	-	13.01	2.20	-	100.56	77.24	18.60	2.25	98.09
G EPEL Sardine	64.70	18.56	0.20	Tr.	Tr.	1.31	12.72	2.46	0.42	100.37	75.18	20.79	2.25	99.17
H WHITE No. I *	64.02	19.53	0.32	Tr.	0.33	0.16	12.12	3.02	0.28	99.83	71.63	25.53	1.65	98.81
J CEYLON No. I	64.66	19.72	0.08	-	0.34	Tr.	11.72	3.42	0.18	100.12	69.27	28.91	1.70	99.88
J CEYLON No. II	65.16	19.01	0.19	-	0.17	0.10	11.07	3.78	0.40	99.88	65.43	31.95	0.85	98.23
K BURMA No. III	64.40	19.80	0.10	-	0.36	Tr.	10.92	4.00	0.50	100.08	64.54	33.81	1.80	100.15
L KANDY No. I *	64.97	19.77	0.23	-	0.20	0.15	10.42	4.24	0.37	100.35	61.58	35.84	1.00	98.42
M WHITE No. II	64.50	20.25	0.47	-	0.48	Tr.	9.60	4.72	0.28	100.30	56.74	39.90	2.40	99.04
N BURMA No. II	65.40	19.89	0.27	-	0.14	Tr.	8.92	5.30	0.30	100.22	52.72	44.80	0.70	98.22
O BURMA No. I *	64.76	19.96	0.08	Tr.	0.84	Tr.	8.12	5.54	0.54	99.84	47.99	46.83	4.20	99.02
P SODA	66.38	18.92	0.40	Tr.	0.10	-	7.50	6.06	0.50	100.36	46.69	51.23	0.50	98.42
Q BURMA No. I *	65.22	19.88	0.08	Tr.	0.84	Tr.	7.64	5.88	0.56	99.80	45.15	49.70	4.20	99.05
R FREDRICHSMN	64.98	19.64	0.64	-	0.84	Tr.	7.33	6.00	0.40	99.83	43.32	50.72	4.20	98.24

B. ALBITES

S AMELIA *	67.24	20.48	0.12	-	0.25	-	0.44	11.43	0.30	100.26	2.60	96.62	1.25	100.47
T KOPARNA	67.10	20.44	0.10	-	0.08	-	0.24	11.62	0.40	99.98	1.42	98.22	0.40	100.04

C. MICROCLINE - MICROPERTHITES

U KOPARNA (White) No. I	64.38	19.50	0.11	-	0.28	Tr.	14.32	1.48	0.28	100.35	84.63	12.51	1.40	98.54
V KOPARNA (Green) No. II	64.38	19.48	0.12	-	0.22	Tr.	14.02	1.72	0.30	100.24	82.86	14.54	1.10	98.50
W PATNA No. I	64.64	19.52	0.13	-	0.08	Tr.	13.58	2.10	0.16	100.21	80.26	17.75	0.40	98.41
X PATNA No. II	64.26	19.72	0.10	-	0.31	Tr.	13.42	2.28	0.18	100.27	79.31	19.27	1.55	100.15
Y RYAGADA	64.20	19.10	0.40	-	0.34	-	12.76	2.60	0.72	100.12	75.41	21.98	1.70	99.09
Z KOPARNA (White) No. II	64.22	18.78	0.66	-	0.31	Tr.	13.16	2.38	0.60	100.11	77.79	20.12	1.55	99.45

Table II  
 PHYSICAL PROPERTIES OF THE POTASH-SODA-FELSPARS EXAMINED.  
 A. ORTHOCLASE - MICROPERTHITES

SPECIMEN	ORDINARY READINGS				EFFECT OF HEATING TO 850°C. AND QUICKLY COOLING.				EFFECT OF PROLONGED HEATING TO 1075°C.				MAXIMUM ANGLE CHANGE AND CONDITIONS									
	REFRACTIVE INDICES		DIFFERENCE (Δ)	EXTINGUISHING ANGLE (θ)	REFRACTIVE INDICES		SPECIFIC GRAVITY	AXIAL ANGLE (α)	AXIAL ANGLE (β)	AXIAL ANGLE (γ)	TIME (Hours)	TEMPERATURE (°C)	TEMPERATURE (°C)	TEMPERATURE (°C)	TEMPERATURE (°C)	TEMPERATURE (°C)	TEMPERATURE (°C)	TEMPERATURE (°C)				
	α	β			γ	α													β	γ	α	β
A ORTHOCLASE	1.5194	1.5237	5241	34.8	33.5	2.0	0047	2	5665	1.5194	1.5192	5230	0045	88	5	24	120	36	SR	Equilibrium	17	11
B AVALARA	1.5192	1.5226	5245	60.4	57.2	3.2	0053	2	5662	1.5191	1.5226	5248	0052	11	2	3000	1075	20	R	Equilibrium	11	11
C KODARA	1.5188	1.5230	5236	43.6	41.3	2.3	0048	2	5652	1.5188	1.5230	5236	0048	16	3	3000	1075	20	R	Equilibrium	11	11
D BORNA No. I	1.5199	1.5240	5246	27.7	26.2	1.5	0048	2	5673	1.5190	1.5231	5236	0049	10	2	3000	1075	20	R	Equilibrium	11	11
E KALAMANDI	1.5201	1.5239	5251	57.6	58.7	1.1	0030	2	5537	1.5193	1.5230	5242	0038	11	2	3000	1075	20	R	Equilibrium	11	11
F ORTHOCLASE	1.5202	1.5247	5249	24.0	23.8	0.2	0047	2	5763	1.5200	1.5244	5246	0043	22	2	3000	1075	20	R	Equilibrium	11	11
G EVELL	1.5220	1.5261	5277	61.5	61.1	0.4	0037	2	5831	1.5208	1.5248	5260	0040	10	2	3000	1075	20	R	Equilibrium	11	11
H BLUE	1.5217	1.5259	5279	63.1	63.9	0.8	0062	2	5778	1.5192	1.5233	5254	0041	7	2	3000	1075	20	R	Equilibrium	11	11
I BLUE	1.5216	1.5257	5282	75.0	75.8	0.8	0066	2	5801	1.5192	1.5233	5258	0041	7	2	3000	1075	20	R	Equilibrium	11	11
J BLUE	1.5220	1.5265	5286	61.4	63.9	2.5	0067	2	5781	1.5193	1.5233	5258	0040	11	2	3000	1075	20	R	Equilibrium	11	11
K BLUE	1.5224	1.5274	5293	73.7	75.0	1.3	0067	2	5848	1.5204	1.5241	5276	0037	15	2	3000	1075	20	R	Equilibrium	11	11
L BLUE	1.5230	1.5270	5302	83.5	83.5	0.0	0072	2	5930	1.5204	1.5241	5276	0037	15	2	3000	1075	20	R	Equilibrium	11	11
M BLUE	1.5232	1.5274	5293	73.7	75.0	1.3	0067	2	5848	1.5204	1.5241	5276	0037	15	2	3000	1075	20	R	Equilibrium	11	11
N BLUE	1.5236	1.5296	5326	82.8	81.6	1.2	0070	2	5930	1.5207	1.5241	5276	0037	15	2	3000	1075	20	R	Equilibrium	11	11
O BLUE	1.5228	1.5284	5292	59.1	64.3	5.2	0064	2	5773	1.5200	1.5243	5272	0036	15	2	3000	1075	20	R	Equilibrium	11	11
P BLUE	1.5258	1.5296	5330	81.7	81.1	0.6	0072	2	5960	1.5211	1.5281	5311	0070	11	2	3000	1075	20	R	Equilibrium	11	11
Q BLUE	1.5255	1.5301	5324	71.3	70.4	0.9	0069	2	5948	1.5215	1.5281	5305	0066	12	2	3000	1075	20	R	Equilibrium	11	11
R BLUE	1.5292	1.5326	5332	88.2	87.8	0.4	0100	2	6266	1.5202	1.5328	5332	0100	11	2	3000	1075	20	R	Equilibrium	11	11
S BLUE	1.5285	1.5326	5339	101.0	102.1	1.1	0104	2	6280	1.5203	1.5328	5339	0101	11	2	3000	1075	20	R	Equilibrium	11	11

B. ALBITES

S ANELIA	1.5292	1.5326	5332	88.2	87.8	0.4	0100	2	6266	1.5202	1.5328	5332	0100	11	2	3000	1075	20	R	Equilibrium	11	11
T KODAMA	1.5285	1.5326	5339	101.0	102.1	1.1	0104	2	6280	1.5203	1.5328	5339	0101	11	2	3000	1075	20	R	Equilibrium	11	11

C. MICROCLINE - MICROPERTHITES

U KODAMA No. I (MINT)	1.5195	1.5232	5255	76.2	76.5	0.3	0062	2	5692	1.5190	1.5228	5250	0060	10	2	3000	1075	20	R	Equilibrium	11	11
V KODAMA No. II (GREEN)	1.5203	1.5241	5256	63.5	64.3	0.8	0053	2	5736	1.5191	1.5235	5251	0055	11	2	3000	1075	20	R	Equilibrium	11	11
W PATNA No. I	1.5202	1.5237	5246	48.1	48.2	0.1	0062	2	5757	1.5201	1.5236	5249	0065	10	2	3000	1075	20	R	Equilibrium	11	11
X PATNA No. II	1.5204	1.5243	5246	76.0	76.7	0.7	0060	2	5747	1.5203	1.5235	5254	0062	11	2	3000	1075	20	R	Equilibrium	11	11
Y RYAGADA	1.5204	1.5240	5245	79.3	79.7	0.4	0061	2	5771	1.5191	1.5228	5245	0061	11	2	3000	1075	20	R	Equilibrium	11	11
Z KODAMA No. II (ROSE)	1.5205	1.5245	5245	71.8	70.6	1.2	0060	2	5708	1.5193	1.5230	5240	0065	11	2	3000	1075	20	R	Equilibrium	11	11