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## MINERALOGY OF THE ADIRONDACK FELDSPARS


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### I. PLAGIOCLASE

1. OCCURRENCE. The principal constituent of the Adirondack anorthosites is plagioclase, and the associated gabbros, syenites, and intermediate rocks also contain plagioclase as an important

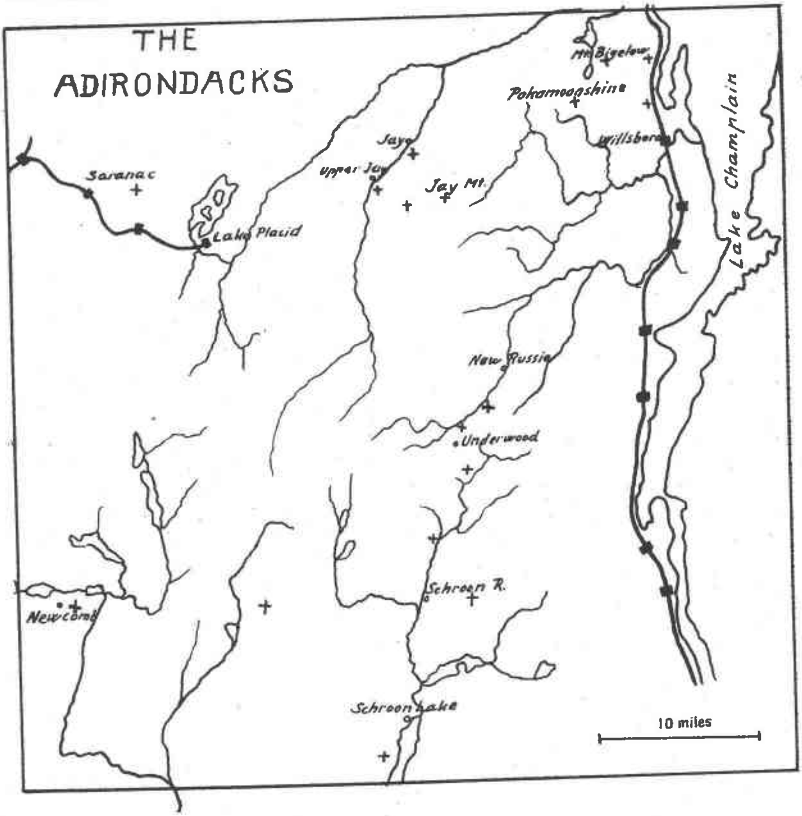



FIG. 1. Sketch map of the Adirondack Mountains. The small crosses indicate where material was collected.

Explanation to Plate I

FIG. 1. Inclusions in plagioclase. (The photograph is about 1/3 mm., across.)

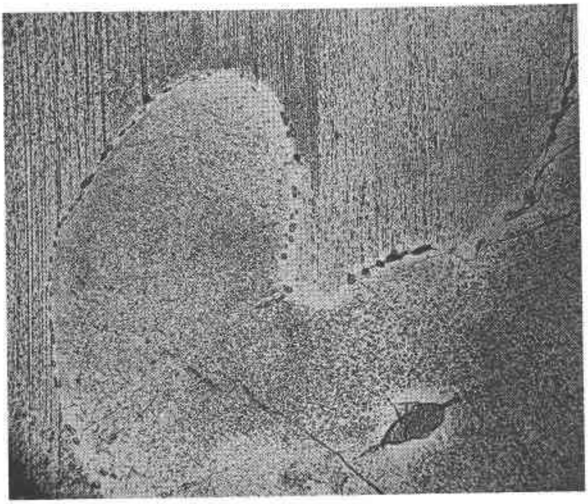
FIG. 2. Guttate perthite. (The photograph is about 1/3 mm., across.) The potash feldspar forms the groundmass and is the same as that occurring in the other perthites.

The plagioclase forms small drop-like spots, which usually are less than 0.02 mm. across. When these spots are studied under high magnification they are resolved into a multitude of very thin disc-like plates or films, one behind the other like the leaves in a book. These leaves are roughly parallel to (100).

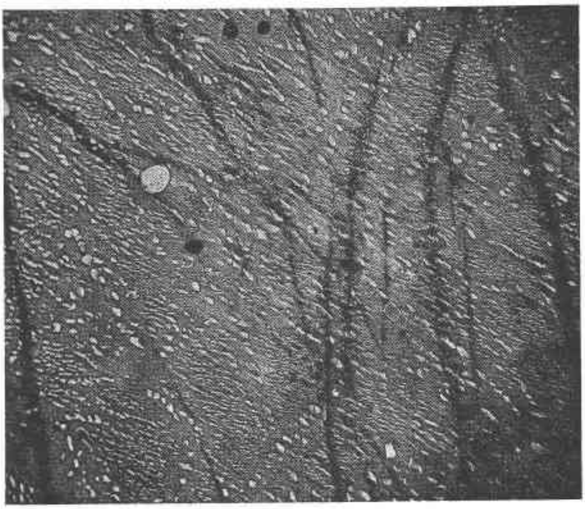
The indicatrix of the perthitic spots has almost the same position as that of the potash feldspar. On basal cleavage fragments the index of refraction of the fastest ray was determined to be $\alpha'(001)=1.540$. These measurements indicate that the perthitic substance is an oligoclase of about An 23. The amount of this oligoclase varies from 0 per cent to 40 per cent of the whole feldspar.

This type can grade into a more vein-like type, the drops then grow larger and more compact, developing simultaneously a lens-like shape, often approaching 0.1 mm. in length, and thus displaying textural features similar to vein perthite.

The orientation of the perthitic sheets parallel to the contraction cracks of the feldspar (*cf.* O. Andersen, *l.c.*, p. 128), the great variability of the amount of oligoclase, and the passing into the vein perthite type, make it difficult to think of this perthite as formed by exsolution of a homogeneous mixed crystal. Probably these drops represent small nuclei of the oligoclase magma trapped by the crystallizing potash feldspar. The nuclei were thereby caused to assume a drop-like form, and were in a later stage partly squeezed out along contraction cracks (vein perthite).



1.



2.

PLATE 1.

mineral. A study of the plagioclase is, therefore, essential to a knowledge of the Adirondack rocks.

2. Inclusions. The *oligoclase* is frequently associated with potash feldspar, thus forming different kinds of perthites and antiperthites and also twofold perthites, *e.g.*, plagioclase with antiperthitic inclusions of potash feldspar that in turn contains perthitic inclusions of plagioclase.

The *andesine* and *labradorite* form large, idiomorphic crystals with sharp and straight twin lamellae. They are always filled with inclusions of various kinds. A small amount of antiperthite and irregularly distributed grains of pyroxene, amphibole, ilmenite and probably spinel are always present. Occasional grains of pyrite, scapolite and garnet are regarded as secondary inclusions.

More conspicuous are, however, the dustlike particles of pyroxene that fill all these plagioclases. This dust is arranged in bands parallel to (010), occasionally also parallel to (001) of the plagioclase. At the contact of two crystals, however, the regularity is lost and the individual dust grains become much larger (see plate 1).

It is worth noting that such plagioclase crystals loaded with pyroxene will have a high density. Taking an actual case for example: It has been observed that in a sodic labradorite (density = 2.68) the amount of pyroxene inclusions is about 30 per cent. As the density of this pyroxene can not well be lower than 3.3, the density of the whole crystal is consequently 2.87. It ought not to be difficult for a crystal of that density to sink in a magma which is in equilibrium with a sodic labradorite.

3. Optical properties. There has been much discussion as to whether or not the Adirondack plagioclase contains potash in solid solution. In this section facts will be presented that prove the non-existence of an admixture in solid solution of potash feldspar (as well as of carnegieite).[1]

[1] Chemical studies of these feldspars are rendered difficult by the presence of perthites and other intergrowths that make it impossible to get pure material for an analysis.

Through a combination of chemical and geometrical analyses of plagioclases of the St. Urbain anothosites Mawdsley was able, however, to demonstrate the non-presence of potash in the molecules of these plagioclases. This statement finds confirmation in the present optical measurements. (F. B. Mawdsley, St. Urbain Area, Charlevoix District, Quebec. *Canada Geol. Surv. Mem.*, **152,** 1927.)

With the Fedorow universal stage it is possible to determine the value of the axial angle and the position of the indicatrix of a plagioclase.

In Fig. 2 the results of the measurements of 15 different, well developed crystals from various parts of the Adirondacks are

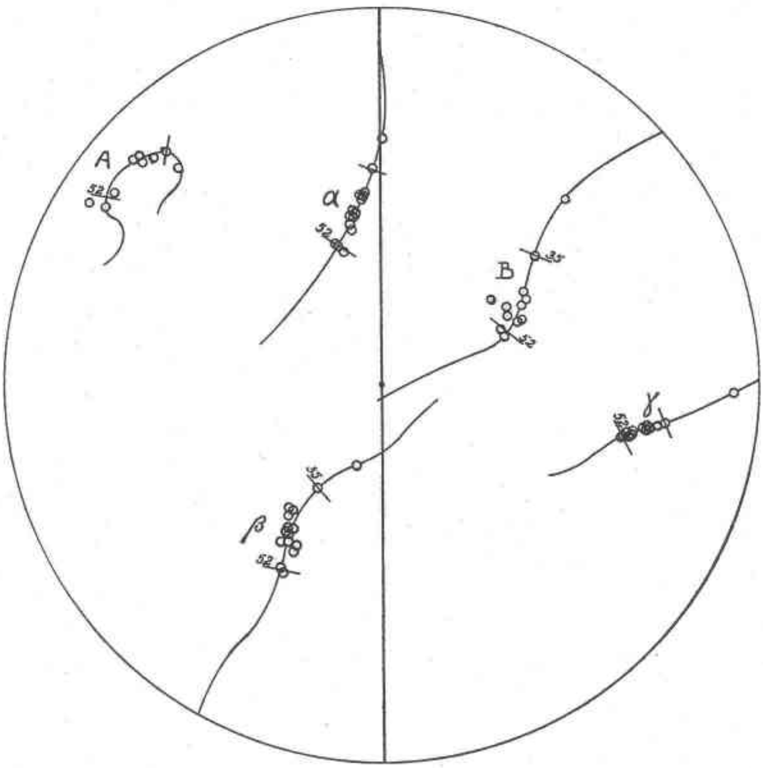



Fig. 2. Stereographic projection of the optical elements of different plagioclases on a plane ⊥ to *c* axis. The measurements are plotted as small circles. The curves indicate the positions of the optical elements in the normal plagioclase series (according to Duparc and Reinhard). The positions of plagioclases consisting of 35 and 52% An are especially indicated. It is seen that most of the Adirondack plagioclases contain from 40 to 50% An.

plotted and compared with the position of the indicatrix of the "normal" plagioclase. All the measurements agree with the curves for the normal plagioclase within the limits of error. It is highly improbable that an appreciable amount of either the potash feldspar or carnegieite would not cause an observable alteration of the shape of the indicatrix, and throw it far out of its normal position.

The following measurements show how the different optical determinations check each other.[2]

1. Phenocrysts in syenite, Aiden Lair (Newcomb).

| | |
|---|---|
| Position of indicatrix: | 51 An |
| $2V_\gamma=79°$: | 48 An |
| $\alpha'(001)=1.554$: | 50 An |
| $\gamma'(001)=1.561$: | 51 An |

2. Phenocrysts in gabbroid anorthosite, Moody Pond (Saranac).

| | |
|---|---|
| Position of indicatrix: | 46 An |
| $\left.\begin{array}{r}2V_\gamma\text{, red light } (670\mu\mu)=86° \\ 2V_\gamma\text{, green light } (510\mu\mu)=85°\end{array}\right\}$ | 42 An |
| $\alpha'(001)=1.557$: | 54 An |
| $\gamma'(001)=1.563$: | 54 An |

3. Phenocrysts in anorthosite, quarry on the highway N.E. of Shingle Bay (Saranac).

| | |
|---|---|
| Position of indicatrix: | 51 An |
| $2V_\gamma=77°$: | 50 An |
| $\alpha'(001)=1.555$: | 51 An |
| $\gamma'(001)=1.561$: | 51 An |

4. TWINNING. It is a remarkable fact that the large phenocrysts are frequently untwinned, whereas the smaller crystals usually show much twinning. Simple albite twins and combined albite and pericline twinning are most commonly met with, although simple pericline twins are by no means rare. This holds true for all plagioclases from 20 to 60% An.

No accurate relation could be established between the chemical composition of the feldspars and the position of the rhombic section of the pericline twins. For plagioclase of 40–50% An $\mathfrak{S}=-4°$ seemed to be an average value. ($\mathfrak{S}$=angle between the rhombic section and the base.) But not infrequently the value of $\mathfrak{S}$ was found to be zero; in fact, various feldspars in the range from 20 An to 55% An exhibited pericline twins with $\mathfrak{S}=0°$. Probably these twins ought to be regarded as Aclin A-twins.

It is worth recording that a small plagioclase crystal of 50% An (in anorthosite from Shingle Bay), in addition to pericline twinning also showed the very rare complex twin of the albite-Ala B

[2] The determination of the position of the indicatrix and of the axial angle were made with a Fedorow stage. The determination of the refraction on basal cleavage pieces was made by the immersion method, (the tables of Tsuboi were used for interpretation).

type. But except for this case, only albite and pericline twins have been observed.

It should also be mentioned that not infrequently only an approximate realization of the twin laws has taken place.

Such a case may be rather accurately established with the Fedorow stage. If, namely, the principal optical elements of one twin individual are not symmetrical relative to the elements of the other individual, it would mean that the twin did not comply perfectly with the law.

If the crystal is twinned according to the albite law a very good check can be made by mounting the twin with its (010)-face

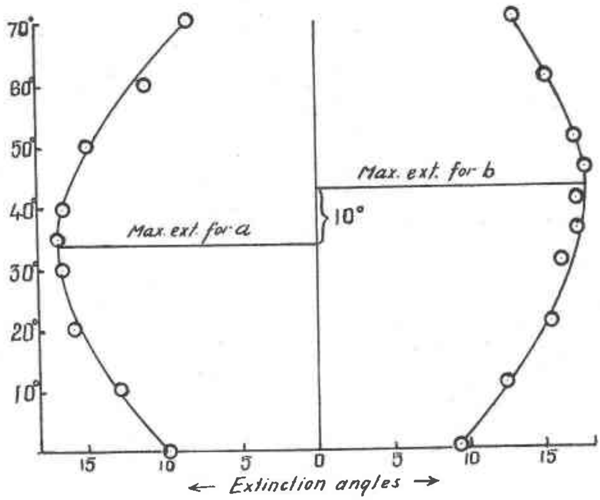



FIG. 3. Graphical representation of the extinction phenomena in the zone ⊥ to (010) of the andesine twin from Split Rock Falls.

Abscissa: extinction angles of the two individuals.

Ordinate: directions in the plane of (010) (twinning plane).

vertically, adjusting the trace of (010) parallel to or symmetrical with the directions of the nicols, and rotating about the axis ⊥ to (010). During this rotation the ideal twin will exhibit an equal illumination, whereas an incomplete adjustment of the individuals in twin position will cause marked differences in the illumination. A deviation of less than one degree is easily observed in this way. The actual amount of deviation is, however, most accurately found by measuring the difference between the positive of maximum extinction between the two individuals in the zone ⊥ to (010).

Quoting an actual example, afforded by an andesine of the anorthosite of Split Rock Fall will make this procedure clear.

The twin concerned consists of two individuals, *a* and *b*, polysynthetically twinned according to the albite law.

Determinations with the Fedorow stage show a relative displacement of 10° of the optical elements of each individual; the twin does not display an equal illumination in the positions just described; and the difference between the positions of maximum extinction for the two individuals in the zone $\perp$ to (010) is 10°. (See Fig. 3).

In this case the same thing has thus been indicated by so many single observations that there can be no doubt about the twin individuals having their *c*-axes, *ca.* 10° apart in the plane of (010). The revolution about the twin axis has thus been 190° (or 170°) instead of 180°.

## II. POTASH FELDSPAR

1. Occurrence. Although the principal constituent of the anorthosites is a calcic plagioclase, potash feldspar is also present, both interstitially, and accumulated in small pegmatitic nests which represent a somewhat larger part of the magmatic mother liquor that has been trapped by the crystallizing magma. These nests, very irregular in size and outline, consist of *oligoclase*[3] and a little *quartz* in addition to *potash feldspar*.[4]

These three minerals may be found as individual grains, and also as perthitic, antiperthitic, and myrmekitic intergrowths, the compositions of the individual minerals of which remain remarkably constant regardless of texture and proportions of the constituents.

Consequently it should be emphasized that only two individual feldspars occur in these pegmatitic nests, *viz.*, a comparatively pure potash feldspar and a pure oligoclase of about 23% An.

2. Perthitic intergrowths. Various types of association of feldspars have been studied and classified by Olaf Andersen.[5] He has developed what he calls "a tentative scheme of classification, based on textural features only." As he has shown, however, the textural features undoubtedly indicate the mode of formation

[3] $An_{23}$; $2V_\gamma = 84°$.

[4] Both triclinic and apparently monoclinic; $a{:}\alpha' = 7°$ in (010); $2V_\alpha = 67-76°$.

[5] Olaf Andersen, Genesis of Feldspar from Granite Pegmatites: *Norsk. Geol. Tidsskr.*, **10**, 116, 1928.

of the perthites, and his classification thus becomes genetical as well as physiographical. In order to save space reference is hereby given to his descriptions and illustrations, and the names introduced by him will be adopted without further explanations.

The perthites of the Adirondack rocks belong to the following types:

1. Guttate perthite, very common.
2. Vein perthite, not characteristically developed.
3. Patch perthite, not rare.
4. Interlocking perthite, common.

The guttate perthite has not been described by Andersen. The name is, therefore, introduced for a new textural type, essentially different from all the nine types contained in Andersen's classification. A description of it is given as text to plate 1. The other types are directly comparable with those described by Andersen.

Every proportion of potash feldspar to oligoclase has been observed. If one begins with a potash feldspar of 100 per cent purity, one can go continuously through the guttate perthites, patch- and interlocking perthites, ending with a pure oligoclase.

3. Genesis of the perthites. The Adirondack perthites are either due to secondary unmixing, simultaneous crystallization, or replacement.

The following facts are supposed to be against the theory of an unmixing.

1. The basicity of the perthitic substance.

2. The fact that the interlocking perthite—which has been formed through a simultaneous crystallization of both feldspars (*cf.* O. Andersen, loc. cit. p. 181)—grades into the other types.

3. The fact that all the plagioclases in the pegmatitic nests are of the same composition (which indicates that they all have been deposited from the same liquid, at about the same time).

4. The great variability in the proportions of the individual phases of the perthites.

In the writer's opinion these perthites have been formed simultaneously with the other minerals of the pegmatites; they have all been precipitated from a liquid with which both potash feldspar and plagioclase were in equilibrium, generally speaking. They have separated out in part as larger homogeneous crystals of microcline and oligoclase, in part as a rhythmical crystallization (interlocking perthite!) and the crystallizing potash feldspar in some instances has hemmed in tiny drops of oligoclase (guttate perthite!).

In the concluding stages some mutual replacement has taken place (patch- and vein perthites!).

## Some Conclusions

In the anorthosites of the Adirondacks two clearly separated stages of crystallization can be distinguished.

During the first stage a potash-free, homogeneous andesine-labradorite was formed, and as no zoning occurs it must be assumed that the labradorite during a very long period had been in equilibrium with a magma (mother liquor) consisting essentially of (molten) oligoclase and potash feldspar.

During the second stage the mother liquor froze, forming potash-free oligoclase and comparatively pure potash feldspar.

The pure labradorite melts somewhat below 1300°, and the perthitic potash feldspar at about 1000°.

The temperature of crystallization of the feldspathic magma is, however, difficult to state, as that would vary with the amount of mineralizers present.

If it be assumed that the anorthositic mother liquor was poorer in mineralizers than the magma of an ordinary granite, it would mean that the potash feldspar formed at, or somewhat above 700°,[6] would be unable to take up any considerable amount of oligoclase in solid solution, and *vice versa*.[7]

4. Optical properties of the potash feldspar. The potash feldspars associated with the Adirondack anorthosites may, according to common practice, be classified in part as orthoclase, and in part as microcline, the difference being that microcline shows an inclined extinction, whereas orthoclase, being a monoclinic mineral, is supposed to show parallel extinction in the zone normal to (010). As a matter of fact most of the so called orthoclase from different types of rocks does not display perfect parallel extinction. According to my experience, the deviation, though small, usually varies from 1° to 3°.

Such is also the case with the potash feldspars from the Adirondacks. Some of them do have parallel extinction, but usually

[6] E. S. Larsen, The Temperature of Magmas: *Am. Mineralogist*, **14**, 81, 1929.

[7] The crystallization of the potash-free andesine has obviously taken place at an appreciably higher temperature.

small deviations may be observed, and even on one and the same crystal different areas will exhibit different values for the extinction angle; indeed, within one crystal consisting principally of orthoclase, even the "quadrille" structure so characteristic of microcline may be observed here and there. The extinction angle on the base may have any value between zero and fifteen degrees. If, however, the extinction angle exceeds 4°–5°, usually the "cross-hatching," due to the microscopic lamellar twinning of the microcline, will appear. The axial angle of the orthoclase is about 70°, that of the microcline is usually slightly larger.

From these properties it is, however, difficult to state whether the potash feldspar is pure, or whether it is an anothoclase, carrying the soda feldspar in solid solution.

A determination of the indices of refraction for different wavelengths was therefore undertaken in order to determine whether the feldspar was anorthoclase. The principles of this improved method for studying powdered minerals have been given by Merwin, and later by Tsuboi, and others, and it is claimed, if care is exercised, the experimental error may be reduced to about two units in the fourth decimal place.

Large crystals of perthitic potash feldspars from a pegmatitic nest in the anorthosite of the south-eastern slope of Pokamoonshine Mt. were used. The crystals may be said to consist mainly of orthoclase, although the extinction angle on (001) is rarely zero, usually varying from 1°–3°. Also here and there the "quadrille" structure of microcline appears, and at such places the extinction angle on the base will vary from 4° to 15°.

For the orthoclase the values shown in table 1 were obtained.

TABLE 1.

| | $486\mu\mu$ | Na-light | $656\mu\mu$ |
|---|---|---|---|
| $n_p$ | 1.5278 | 1.5230 | 1.5198 |
| $n_m$ | | 1.5270 | |
| $n_g$ | 1.5338 | 1.5288 | 1.5255 |

For sodium light, $n_g - n_p = .0058$; $n_m - n_p = .0040$; $n_g - n_m = .0018$.
The dispersion of $n_p$, $F-C = .0080$; that of $n_g$, $F-C = .0083$.
The axial angle, $2V_\alpha = 68°$, no visible dispersion.

A microcline of the same crystal shows the following properties: Extinction angle on (001) is $=15°$, the axial angle $2V_\alpha = 75°$. The refractive indices for sodium light are:

$$n_p = 1.5225$$
$$n_m = 1.5268$$
$$n_g = 1.5293.$$

As essentially the same data are given for other potash feldspars it may be concluded that the investigated feldspars are comparatively pure species. It is, however, worth noticing that there do occur potash feldspars, especially orthoclases, with considerably lower indices of refraction, and although our feldspar is far from being anorthoclase it, nevertheless, may contain small amounts of albite in solid solution.

5. THE TWINS. Usually these potash feldspars are untwinned, and megascopically visible twins were in no case observed. A microscopic lamellar twinning of extreme thinness may, however, often be seen.

It is especially noteworthy that simple twinning acording to the albite law has been observed, the extinction angle on the base of these twins is very small, only about 1°, it must be assumed that the orthoclase variety of the potash feldspar in exhibiting this type of twinning, indicates that it is really triclinic with a very close approach to the monoclinic symmetry rather than truly monoclinic.

A simple twinning of the triclinic potash feldspar is very uncommon. Miss Reynolds[8] has, however, observed a very similar lamellar twinning on (001) in the case of authigenic potash feldspar of the Leicestershire marl, and a triclinic adularia exhibiting simple twinning of the acline B-law, and Carlsbad twins of simple microcline are also on record.[9] But these cases furnish probably the only known examples of simple twinning of triclinic potash feldspars.

In all other cases the multiple-twinning causing the well known "cross-hatching" has been observed. It is hard to understand why the microcline, if twinned, always shows two sets of lamellar twinning, but it is a fact that also holds true for the Adirondack feldspars.

The microcline of this area looks however, a little different from ordinary microcline as the twinning bands are usually very narrow and short. The twins are visible only with a high-powered objective, and many areas which with a medium magnification

[8] D. L. Reynolds, *Geol. Mag.*, **66**, 390, 1929.

[9] T. Barth, *Zeitschr. f. Krist.*, **68**, 473, 1928; *Chemie der Erde*, **4**, 119, 1928.

seem homogeneous, are resolved into numerous small twins when a higher magnification is used; one can hardly get rid of the impression that if it were possible to use still higher magnifications other areas of the orthoclase would reveal tiny (submicroscopic) twins. It would therefore be interesting to calculate the properties of a mineral which would be formed if the Adirondack microclines were really made up of submicroscopic twins.

6. THE EFFECT OF SUBMICROSCOPIC TWINNING. The optical phenomena produced by the superposition of small crystalline lamellae have been mathematically discussed by Mallard.[10]

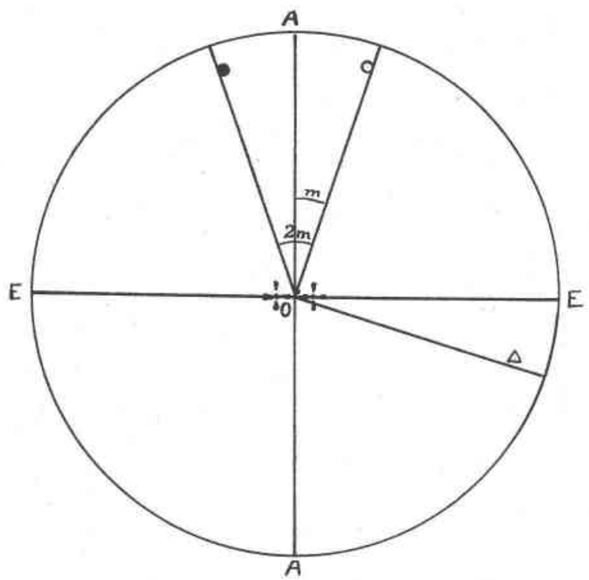



FIG. 4. Stereographic projection of the optical elements of a microcline twin on a plane symmetrical with the $\beta$-directions. o $=\alpha$, $+ = \beta$, $\Delta = \gamma$, $A-A$ = twinning plane.

It can be shown that the optical properties of a packet of small crystalline lamellae can be always represented by Fresnel's ellipsoid, the shape and dimensions of which are independent of the order in which the lamellae is packed, depending only on the nature and the relative proportion and orientation of each lamella.

In a submicroscopically twinned microcline the twins presumably belong to the albite and pericline types. In the former

[10] E. Mallard, *Bull. Soc. Min. France*, **4**, 71, 1881; *Traité de cristallographie*, II, Paris, **1884**, p. 263.

the axis ⊥ to (010), in the latter the $b$ axis, is the twin axis. As these two directions are only a few minutes of arc apart,[11] in the following calculations they will be regarded as coinciding.

If one constructs the indicatrix ellipsoid of every one of the small twins, giving each of them a value of $\epsilon/E$ ($\epsilon$ = the thickness of the twin, $E$ that of the whole packet), and along each direction draw a line equal to the sum of the radius-vectors corresponding to the direction, a certain surface is obtained, which can be shown to be the indicatrix ellipsoid of the whole packet. For the purpose of finding the properties of the resulting ellipsoid it is expedient to consider the propagation of light along a direction corresponding to the $b$ axis of orthoclase.

Fig. 4 is a stereographic projection of the optical elements of the described microcline twin on a plane normal to said direction. The extinction angle of the microcline in this plane is

$$m = 17°,$$

referred to the trace of the twinning plane. Such a twin corresponds thus to a packet of two identical lamellae crossed at an angle equal to $2m$. The faster of the two rays propagating through the microcline along this direction has an index of refraction $n_p'$, almost equal to $n_p$ of the microcline = 1.5225. The slower ray has an index of refraction $n_g'$, that is slightly lower than $n_g$ of the microcline. Calculations show that $n_g' = 1.5292$.

The two indicatrices corresponding to the positions of the two twin individuals are identical and are symetrically placed with reference to the twinning plane (the bisector of the angle $2m$). The resulting indicatrix that determines the optical properties of the packet admits thus the twinning plane and a plane normal to this, E-E, as symmetry planes, see Fig. 4. Or the axes of the resulting indicatrix will lie at A, E, and O of Fig. 4.

This result was arrived at by Mallard[12] and Michel-Lévy[13] 50 years ago. But we may now also determine the lengths of the axes of the ellipsoid.

If $N_p$ and $N_g$ indicate the values of the resulting refractive indices corresponding to the axes at A and E, respectively, it can be shown that approximately:

[11] T. Barth, *Fortschritte der Mineralogie*, etc., **13**, 31, 1929.
[12] E. Mallard, *loc. cit.*
[13] A. Michel-Lévy, *Bull. Soc. Min. France*, **2**, 135, 1879.

$$N_p = \frac{n_p' + n_g'}{2} - \frac{n_p' - n_g'}{2} \cdot \cos 2m,$$

$$N_g = \frac{n_p' + n_g'}{2} + \frac{n_p' - n_g'}{2} \cdot \cos 2m.$$

The value of the third axis $N_m$ may be found in the same way by considering the propagation of light along a direction corresponding to the $a$ axis of orthoclase.

Table 2 contains the calculated values compared with the observed values for the Adirondack orthoclase.

TABLE 2.

| Calculated | Observed | Diff. |
|---|---|---|
| $N_p = 1.5231$ | 1.5230 | −.0001 |
| $N_m = 1.5269$ | 1.5270 | +.0001 |
| $N_g = 1.5286$ | 1.5288 | +.0002 |
| $2V_\alpha = 67.5°$ | 68° | +.5° |

This table shows clearly that the differences fall within the limits of error and that the observed optical properties of the Adirondack orthoclase are readily explained as a result of twinning of submicroscopically small microcline individuals.

The small deviation from parallel extinction in most of the orthoclases can easily be explained through the assumption that one of the twin systems predominates, a condition which, of course, frequently exists; also the variation of the axial angle is a necessary consequence of this phenomenon.

ACKNOWLEDGMENTS

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