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GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 7.

PETROGRAPHY OF A GROUP OF
ALKALI-TRACHYTIC DYKE ROCKS FROM
THE JULIANEHAAB DISTRICT,
SOUTH GREENLAND

A CONTRIBUTION TO THE ALKALI FELDSPAR PROBLEM

BY

J. BONDAM

WITH 6 FIGURES IN THE TEXT AND 2 PLATES

Reprinted from
Meddelelser om Grønland, Bd. 135, No. 2

KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A/S
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PREFACE

The present paper is a result of observations made during the geological mapping of the area around Tunugdliarfik fiord, Julianehaab district, South Greenland, in the summer of 1951.

I am much indebted to Professor ARNE NOE-NYGAARD, Director of the Mineralogical Museum at Copenhagen, who made my working in this area possible and who placed at my disposal the excellent facilities of the Geological Institute of Copenhagen. Under his inciting leadership I had the opportunity of presenting the result of my work to a critical auditorium, where a discussion of the alkali feldspar problem has contributed much to the elaboration of this paper.

I wish to thank Mr. H. PAULY, M. Sc., for his friendship and inspiration during our fieldwork together. Under the difficult conditions prevailing during the season due to an epidemic among the Greenlanders, we could not have been so successful, if the organisation of our trip had not been placed in the hands of Mr. M. MAAG, who also kept our boat in fine condition.

My best thanks are due to my colleagues Mr. H. SØRENSEN, M. Sc., Mr. K. ELLITSGAARD RASMUSSEN, M. Sc., and Mr. A. BERTHELSEN, M. Sc., who through their lively interest in my work, have supplied me with valuable information.

Miss M. MOURITZEN, C. E., kindly undertook the chemical analyses of two samples.

The microphotographs have been taken by Mr. C. HALKIER.

Mrs. HARRIET OPPENHEJM has revised the English language of the MS.

Mr. C. A. JENSEN prepared the thin sections.

The outline map, fig. 1, has been made based on maps kindly placed at our disposal by the Geodetic Institute of Copenhagen.

Copenhagen, January 1954.

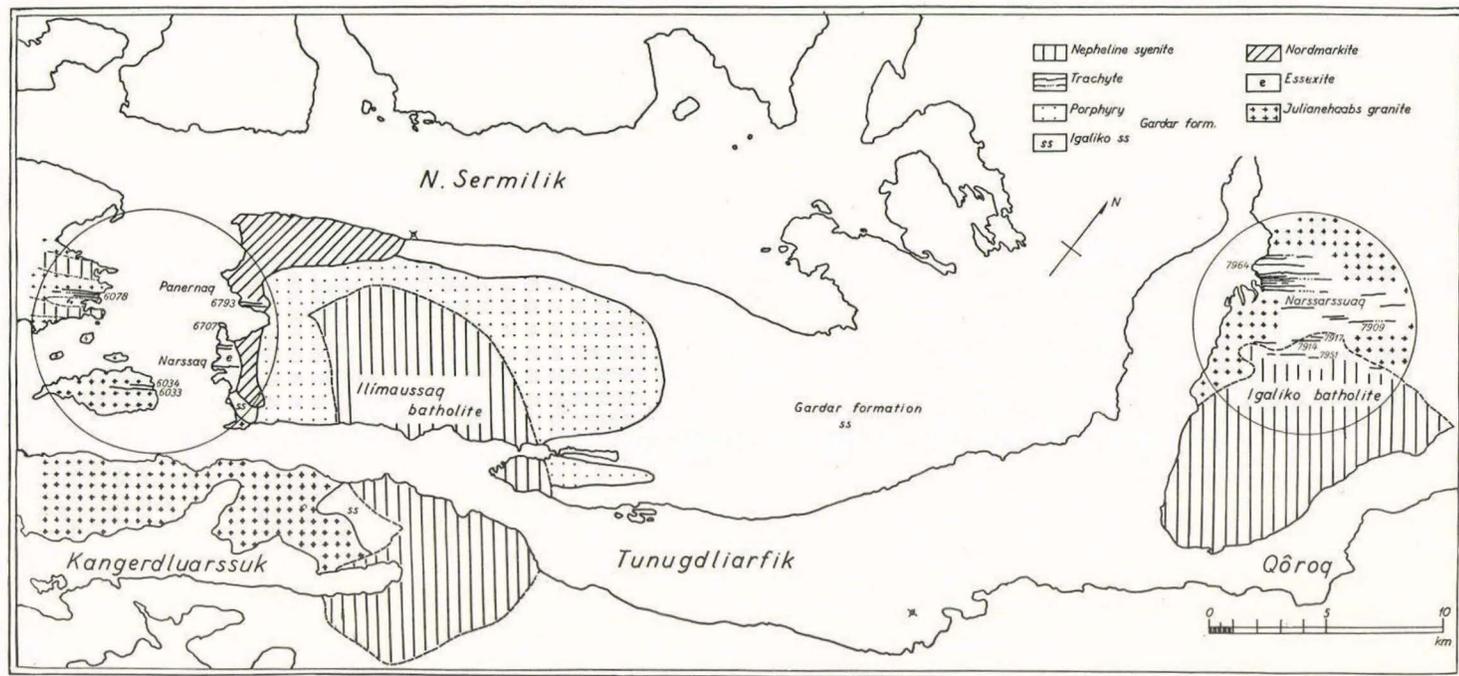


Fig. 1. Geological outline map of the area around Tunugdliarfik fiord.
 The island on which the samples no. 6034 and 6033 have been collected, is called Igdlutalik, while sample no. 6078 has been taken on Tugtutôḡ.

INTRODUCTION

In the course of the fieldwork of the Greenland Geological Survey during the summer of 1951, a number of alkali-trachytic dykes were met with in the area around Tunugdliarfik fiord, the Julianehaab district, South Greenland.

The samples used in the present paper have been collected in two distinct parts within the region—see the encircled areas on the outline map, fig. 1—.

1) The area around the Narssarsuaq valley, at the head of the Tunugdliarfik fiord, forms the northernmost borderzone of the so-called Igaliko batholite (USSING, 1912). The country rock of this batholite consists mainly of a foyaitic nepheline syenite. To the north are found Ketillidian basement rocks containing numerous signs of Upper Gardar volcanic activity (WEGMANN, 1938).

The trachytic dykes are chiefly concentrated in a swarm just north of the valley.

2) The area around the settlement of Narssaq includes a great variety of hypabbysal and metamorphic rocks. The occurrence of a nordmarkite (alkali syenite) subvolcano with its hypabbysals is found just north of Narssaq on the Panernaq peninsula¹⁾, and northwest of the settlement. The subvolcano intersects the strata of the Gardar formation, Igaliko sandstone at the bottom, porphyries on top. Narssaq itself is surrounded by essexite gabbro, which is an earlier differentiate of the magmatic cycle of the Gardar formation.

The island of Igdlutalik consists of basement rocks which, like the basement of the Narssarsuaq area, have been subject to a lively volcanism.

Finally the northern part of Tugtutôq has been visited. Here rocks belonging to the nepheline syenite kindred are met with, they do not, however, seem to have any batholitic dimensions, but form a row of small lenticular massives striking NE and intersecting Ketillidian base-

¹⁾ Previously called the Kusinga (: Kugssanga) peninsula.

ment in the same manner as the batholites. The structural relations in this part of the area are rather complicated and not yet understood. The syenitic members consist mainly of a sodalite foyaite and augite syenite.

The occurrences of dykes and other signs of volcanic activity are numerous and have long attracted the attention of various explorers and scientists; they were first mentioned by PINGEL (1843). USSING (1912) has described several of these rocks, recognising the importance of the dykes in relation to the stratigraphy of the area. WEGMANN (1938) has later again pointed out their usefulness as stratigraphical indicators.

It lies beyond the scope of the present investigation to describe all the different kinds of dyke rocks, ranging from true dolerites over intermediate stages to trachytes, mainly because so far no study has been made of the stratigraphy of the porphyry series of the Gardar formation.

Previous observations and investigations in the Julianehaab district.

During the 19th century and in the beginning of the 20th, the geological activity in Greenland has mainly been focussed on the area around Julianehaab.

GIESECKE (1910) started the geological exploration of the country as early as 1806, in which year he visited the southern parts. He mentioned a number of localities of mineralogical interest which later have attracted widespread attention.

PINGEL (1843) was the first after GIESECKE to describe a few porphyritic dykes in the neighbourhood of the settlement of Igaliko. He describes macroscopically three types of dyke rocks, a red one, a black one, and a green one, their habitus, strike and surroundings, without going into details.

At the close of the 19th century an important era of investigation of the syenitic massives around Tunugdliarfik fiord begins with the expedition to the Julianehaab district in 1876, in which K. J. V. STEENSTRUP, A. KORNERUP and G. HOLM (1881) took part.

The first geological map of the area was published at that time.

The main object of investigation became there after the study of the mineralogy of the syenitic rocks, which is of peculiar character. Mineralogists as LORENZEN, FLINK, USSING and BØGGILD have contributed much to the knowledge of a large group of rare minerals, but the genetic relations had not been dealt with. An excellent review of the alkali feldspars, among other minerals of the Greenlandic nepheline syenites, has been given by USSING (1898).

The first attempt to correlate structural and petrographical evidence was made by N. V. USSING (1912). After his death, the work was carried on by O. B. BØGGILD, K. CALLISEN and R. BØGVAD. Their studies were mainly of a mineralogical and petrographical nature.

In 1926, H. ØDUM visited the country around Igaliko and published a sketchmap of this area. (H. ØDUM, 1930).

No general outline of the geology of South Greenland had been made, until WEGMANN's investigation in 1938. His outstanding explanatory description of the structural relations in South Greenland, has contributed much to the understanding of the genesis of the main rock types. His paper has served as a basis for my own work. The hypothesis of the metasomatic origin of the syenitic massives has been used by me as an explanation of the occurrence of the meta-trachytes in the area around Narssarssuaq valley.

The alkali trachytic hypabbysals.

Among the many dyke swarms which intersect the country rock, the group of alkali trachytic dykes occupies an outstanding place. They form a fairly homogeneous group easily recognisable in the field. A subvolcano is known and well described by USSING as a nordmarkite. Obviously they represent a late stage of volcanic activity, as the subvolcano cuts through the lower part of the porphyry series.

From both parts of the area (cf. outline map) a number of samples have been selected, covering the whole trachytic series. Macroscopically they can be divided into a subgroup with hypautomorphic texture (7977); with small hornblende crystals giving a whole-crystalline appearance, they do not contain alkali feldspar phenocrysts. Well represented as another sub-group are the porphyritic types (7964, 7909) with large alkali feldspars. Dense rocks have occasionally been found (6078).

The colour of the trachytes is usually of a dark red shade, but it is not a constant feature; a slight increase of the dark constituents makes them violet to nearly black.

Mineralogically they form a unit mainly carrying alkali feldspar in the phenocrysts as well in the groundmass. A green soda-hornblende is a common constituent of all types; further some are carrying subordinate pyroxenes. Quartz is often found interstitially.

A number of dykes, intersecting the nepheline syenite massive at Narssarssuaq are known. In accordance with WEGMANN, who believes the syenitic massives to be of metasomatic origin, these dykes have been called metatrachytes, to emphasize the fact that they have been re-activated during the formation process of the syenites. Their genesis is discussed elsewhere in this paper (p. 25).

The mode of intrusion of the dykes in some cases shows a peculiar feature. The dykes look as if they were composite in character, the borderzones are dark coloured, the inner zone, often with a sharp contact towards the outer zones, is on the other hand red. The concentration of green hornblende towards the borders is conspicuous. It explains why violet coloured to nearly black trachytes are found within this group, while it shows only a slight change in the mineral composition towards the dark component.

It is suggested that selective devitrification is the main cause of the "saalband" phenomenon. The dykes have been chilled as a trachytic glass, with phenocrysts both of alkali feldspar and soda-hornblende. Crystallites of alkali feldspar have, as a matter of fact, been the centres of devitrification, which in some cases is clearly shown by the radiating growth of the alkali feldspathic groundmass. The hornblende has been dissolved and partly absorbed during the formation of the alkali feldspar of the groundmass. Only on the borderzones fixation seems to have been definite, and a glass with other physical properties was formed; probably the glassy chilling has made it impossible to form crystallites in sufficient amount to start a thorough devitrification. Selective absorption has not taken place and the relative amount of hornblende is therefore larger than in the inner zone (p. 23).

The trachytes, described in this paper, stand in close relation to the nordmarkite body, as described by USSING (1912). The dykes only occur in a zone about two miles wide in the direction NE—SW, which runs across the nordmarkite occurrence at Panernaq.

Short description of the samples.

Narssarssuaq:

- 7909: A porphyritic trachyte dyke of "composite" character, intersecting the Julianehaab granite (reactivated Ketillidian basement). The feldspar phenocrysts consist of a clear alkali feldspar with small sphenes. The main dark mineral is a green soda-hornblende; further some phenocrysts of a diopsidic augite have been found. The trachytic groundmass consists chiefly of alkali feldspar with some interstitial quartz. Apatite has been observed in small amounts, as well as magnetite.
- 7914: A hypautomorphic dyke rock, intersecting the borderzone of the Julianehaab granite towards the foyaite. The feldspar of the groundmass has a microperthitic appearance, the dark mineral is a green soda-hornblende, with an olivegreen core and a bluishgreen reaction rim around it. Quartz is found interstitially.
- 7917: A dense rock, free from phenocrysts, intersecting a red foyaite. It carries no dark anisotropic minerals, but is throughout pigmented by magnetite. The groundmass consists mainly of a spherulite shaped, microlitic alkali feldspar and magnetite. In the rock are found dark spots, the outer parts of which consist of finegrained magnetite; the core may be feldspathic groundmass

or an aggregate of zeolites, mainly analcite. No quartz has been observed. Its petrogenesis is of some interest with regard to the genesis of the foyaite and is discussed elsewhere in this paper (p. 25).

- 7951: A porphyritic trachyte intersecting the red foyaite. The phenocrysts show microperthitic texture. The groundmass, too, consists mainly of alkali feldspar, its texture is trachytic, with a tendency towards spherulitic grouping. As in 7917 no hornblende nor pyroxene have been observed, instead the rock is pigmented by ferrous oxides and magnetite. An interesting feature is the occurrence of fluorite, enclosed in some of the phenocrysts.
- 7964: A dyke which intersects the Julianehaab granite. The rock belongs to the same hypautomorphic type as 7914.

Narssaq:

- 6033: A porphyritic dyke intersecting the Julianehaab granite. The rock carries faintly microperthitic feldspar phenocrysts. The groundmass is built up of alkali feldspar in a much altered condition. As in 7917, only small cubes of magnetite have been observed as a dark constituent. No quartz.
- 6034: A hypautomorphic dyke rock, very similar to 7914 and 7964; the only difference is that the soda-hornblende does not show a reaction rim.
- 6078: A porphyritic trachyte showing "composite" intrusion, intersecting the Julianehaab granite. The rock carries small clear feldspar phenocrysts. The only case of twinning, a Carlsbad twin, has been found in this rock. One of the phenocrysts shows signs of selective de-albitisation and is easily mistaken for a reverse zoned plagioclase. The red central part of the dyke is unusually poor in soda-hornblende. The latter is concentrated towards the borderzone. Quartz, pyrite and apatite have been observed in small quantities.
- 6707: A porphyritic trachyte of "composite" character intersecting essexite gabbro. It contains small, much worn feldspar phenocrysts of a faint microperthitic appearance. The dark mineral is as usual a soda-hornblende. The groundmass has been much altered, an unusual amount of epidote is found which might have some connection with the large amount of this mineral in the alteration products of the essexite gabbro.
Apatite occurs occasionally, no quartz has been observed.
- 6793: A porphyritic trachyte, intersecting the nordmarkite body. The feldspar phenocrysts are usually clear.
Besides the soda-hornblende, aegirite-augite ($2V_{\gamma} = 45-50^{\circ}$, $\gamma:c = 52^{\circ}$) occurs as a dark mineral. The groundmass consists as usual of alkali feldspar. Quartz and apatite have been observed in small quantities.

All the dyke rocks are more or less stained with iron oxides.

Alkali syenites of the nordmarkite kindred are well-known from the alkaline province near Oslo. Nordmarkite has been defined by BRØGGER (1906) as a rock consisting of 80 % alkali feldspar, 15 % hornblende and 5 % quartz.

Recently the alkaline rocks of the Oslo region have been reexamined by BARTH (1944), OFTEDAHL (1948), and SÆTHER (1947). Barth regards nordmarkite as a member of the series kjelsåsité, larvikite, nordmarkite,

ekerite. OFTEDAHL has submitted the feldspars to a thorough investigation, while SÆTHER describes the field relations in the Bærum cauldron area, where two types of nordmarkite can be distinguished. Here sub-volcanos (or cauldrons) have been dealt with. The same applies to the nordmarkite, described by USSING. USSING places the nordmarkite in the "unstratified transitionzone" between the separately intruded arfvedsonite-granite, and the intrusive nepheline syenite series, called the agpaïtes (USSING, 1912, pp. 339, 340). This transitionzone is supposed to be produced by interaction between the younger granite and the agpaïtic magma (p. 341).

WEGMANN places the nordmarkite in an intrusive series: essexite, nordmarkite, arfvedsonite-granite, while he considers the nepheline syenite batholites to be of metasomatic origin, with the parallels essexite-naujaite, porphyry series—lujavrite. It seems, however, illogical to separate the essexite gabbro and the nordmarkite from the porphyry series: there are several known instances where the endmembers of a normal continental eruptive province are alkali trachytic.

It is unlikely that the alkaline magma was formed through absorption of limestone, (already WEGMANN drew attention to the scarce occurrences of limestone in the area), a point of view which has been favoured by several scientists (DALY, RITTMANN, SÆTHER a. o.).

The problem of the origin of the trachytic magma is left open here.

I. The alkali feldspars.

I. Classification.

The mineralogical classification of the alkali feldspar series, as for instance given by ALLING (1923) and WINCHELL (1925), has since the experiments of SPENCER (1938) undergone a considerable change.

Studies by OFTEDAHL (1948), LAVES (1950) and LAVES and CHAISSON (1950), and the discovery of high albite (BOWEN and TUTTLE, 1950), have contributed to a renewed classification of the different members of this series.

An extensive compilation of previous investigations within the alkali feldspar group has been given by CHAISSON.

Mention should be made of the studies of KÖHLER (1941), concerning the transitional optics between high- and low-temperature modifications. Transitional optics and transitional changes in internal properties within the feldspar group have repeatedly been observed and reported by various authors. (OFTEDAHL, 1948, NICKEL, 1948, VAN DER KAADEN, 1951, and SCOTT MACKENZIE, 1952).

LAVES (1952, A) has recently published an outline of the symmetry relations in the alkali feldspar group, in which he recognizes two stable modifications:

- 1) a high temperature modification: sanidine — analbite series¹).
- 2) a triclinic low temperature modification: microcline — albite series.

The former is a continuous series, the second shows discontinuity.

WM. SCOTT MACKENZIE (1952) has lately demonstrated that high temperature soda-rich feldspars show a gradual convergence of the (111) and ($\bar{1}\bar{1}\bar{1}$) reflections of the X-ray spectogram with rise of temperature. In other words a continuous change of the triclinic symmetry of the feldspars towards a structure with monoclinic symmetry.

According to the graphical representation of the supposed phase relations, as given by LAVES in a more recent contribution to the alkali feldspar problem (LAVES, 1952. B, fig. 9), the relationship in the high temperature series has been modified in accordance with the investigations of W. S. MACKENZIE (1952). Thus the high temperature series has been modified to a sanidine — barbierite series²) in stable solid solution until about 80 ab.

The classification of LAVES is undoubtedly the most adequate one so far to account for the latest crystallographic and structural investigations in the alkali feldspar series, as it suffices to explain the variation of the different modifications. It must, however, be kept in mind that ultimately, under natural conditions, only low temperature modifications can be considered stable. For petrographical reasons therefore a division into several units, as proposed by TUTTLE (1952), is more suitable. For the same reason OFTEDAHL (1948) thought it necessary to establish an intermediate temperature series, the cryptoperthite-anorthoclase series, which may represent the cryptoperthite-orthoclase series proposed by SPENCER (1938).

For reasons mentioned below the high temperature series must be classified as meta-stable cryptoperthites of the sanidine group as done by LAVES — pseudostable sanidine. This group contains the natural sanidines, as found in surface rocks of the rhyolitic and trachytic kindred. The natural boundary for this group must be the inversion temperature

¹) Formerly called disalbite (LAVES, 1950).

²) Note that the nomenclature as given by WINGHELL, has been partly restored by LAVES. Barbierite, previously discarded as a nonexisting form of albite, has been proposed as a name for the soda-rich monoclinic feldspar, found by W. S. MACKENZIE.

at which the optical plane changes from // (010) into its natural position \perp (010), according to SPENCER's experiments.

2. Genesis of the perthites.

With regard to the development of perthitic and cryptoperthitic arrangement of the components of the alkali feldspar group two alternatives are open:

1. the arrangement is the result of an "exsolution", i. e. adjustment of homogeneous high temperature forms to a stable (or meta-stable) low temperature modification. In this sense OFTEDAHL (1948) distinguished the cryptoperthite series, the group of modifications which LAVES called quasi homogeneous.

2. the micro- to coarse perthitic pattern is the result of crystallization or re-crystallization in the low temperature region. Devitrification of alkali glasses or metasomatic processes have been the active mechanism of the formation of this kind of perthite. They form the true microcline — albite series of LAVES and part of the orthoclase — cryptoperthite series of TUTTLE.

The ultimate stable modification under a continuous genesis is according to the phase relations, the microcline—albite series, as especially developed in low temperature pegmatites. This stage can never be reached from pyrogenetic feldspars unless chemically active constituents or catalysators have taken part in the process.

The phenocrysts, here described, have originally crystallized as high-temperature sanidines. Due to later transformation processes, they have developed to low-temperature forms.

The alkaline groundmass has crystallized at low-temperature conditions and thus forms perthites of the second order.

Normally the adjustment towards the metastable modification ends at the cryptoperthitic stage. Only when special circumstances as moderate temperature decrease, selective de-albitization, and chemical action of active constituents prevail, a faint perthitic pattern may develop. Sometimes an albitic schiller accompanies the perthitization of the phenocrysts, especially in the quartz-bearing trachytes.

The formation of a shadow perthite (SPENCER, 1938, p. 485) has only occasionally been observed in some phenocrysts of 6793. In another thin slide (6078) a zoned sanidine phenocryst has been found.

It is assumed that selective regrouping, or zonal de-albitization caused by devitrification of the groundmass (see p. 23) might be the cause of the development of these shadow perthites. The extinction,

or zoning, is rather irregular and does not seem to follow any definite pattern. Only in a phenocryst of 6078, a zoning was more conspicuous.

The formation of true micro-perthites, which must be regarded as a lower grade of adjustment, has only been observed in special cases; coarse micro-perthites are met with in the phenocrysts of some meta-trachytes (7951).

As already mentioned, the common ultimate stage of adjustment in most phenocrysts is the formation of cryptoperthitic alkali feldspars. It might be justified to conclude that the tendency to form perthites is constantly working.

Phenocrysts at the lowermost stage of adjustment to other physico-chemical conditions show optical behaviour in the "sanidine" sense. They are all clear feldspars with a small optical angle and an extinction angle ($a:\alpha$) of the same magnitude. The optical plane is normal to (010). Examples have been furnished by 6078 and 7909¹⁾ with respectively

$$\begin{aligned} n\alpha &= 1.525, n\beta = 1.529, n\gamma = 1.530, 2V_\alpha = 9^\circ, a:\alpha = 9^\circ \text{ and} \\ n\alpha &= 1.524, n\beta = 1.529, n\gamma = 1.530, 2V_\alpha = 9^\circ, a:\alpha = 7^\circ.^2) \end{aligned}$$

TUTTLE (1952) calls this group of feldspars sanidine — anorthoclase cryptoperthites. They are low temperature forms.

In accordance with SPENCER's experiments and in the light of X-ray data, CHAO a. o. (1939), DONNAY (1952), LAVES (1950), an inversion of the optical plane into the "normal" position, \perp (010), from the position \parallel (010) in heated specimens, marks the "stable" low temperature stage of the homogeneous alkali feldspars. Simultaneously the optical angle decreases. In other words the cryptoperthitic stage is practically defined by the position of the optical plane. TUTTLE (1952) distinguishes between clear cryptoperthites, detectable by X-ray methods and a group which does not show mixed patterns. This does not seem necessary (see also LAVES, 1952. B).

So far the development of cryptoperthites in phenocrysts of alkali feldspar composition has been explained as the result of exsolution by solid diffusion, an explanation which is generally accepted.

Recently IVAN ROSENQVIST (1952) has outlined a theory on the solid diffusion of alkali ions in alkali feldspars. Although no experiments with isotopes of the alkali group could be made, due to their low half-life value, ROSENQVIST supposed that the behaviour of sodium and potassium might be compared with that of Ra and Pb. The radioactive isotopes of these two elements were used as tracers in a series of diffusion

¹⁾ The composition of 7909 has been found to be or 37 ab 54 an 9 (Analyst Miss M. MOURITZEN, C. E.).

²⁾ These data have been plotted in figs. 2—4, which represent a part of the diagrams suggested by TUTTLE (1952).

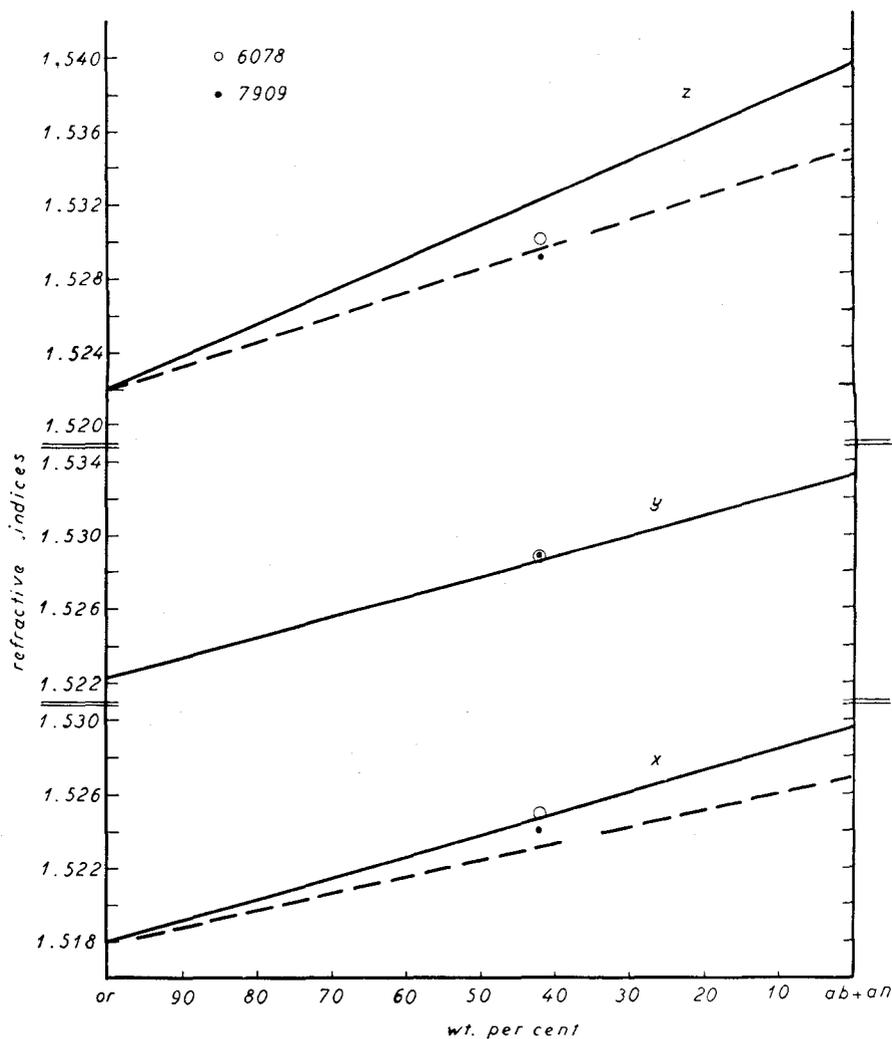


Fig. 2. Refractive indices of alkali feldspars, according to TUTTLE (1952, p. 559, fig. 2). For data see page 17.

experiments with microcline and albite. The result of these experiments showed a marked anisotropy in the rate of diffusion.

The rate of diffusion can be expressed by a revolution ellipsoid, which may degenerate to a sphere as the sodium activity decreases with the temperature.

The different types of perthites, as described by O. ANDERSEN (1929) a. o. are supposed to be the result of temperature differences during the crystallization process. It must be kept in mind that only low temperature forms have been described in his paper. With decreasing tem-

perature ROSENQVIST proposes the following succession: homogeneous feldspars, string perthite, film perthite and/or vein perthite, patch perthite.

ROSENQVIST notes the existence of three ways of perthite formation:

- a. exsolution by solid diffusion
- b. rhythmic crystallization
- c. replacement

In a recent paper (R. BAKKER and I. ROSENQVIST, 1953) the stability relations of the alkali feldspars have been discussed on the basis of adsorption-experiments, the stable and metastable modifications at room temperature have been listed.

The existence however of alkali feldspar mothercrystals as phenocrysts in the trachytes, which nevertheless have not been able to exsolve to such an appreciable extent as to form true perthites, must accordingly be considered in the light of the chemical medium, in which the phenocrysts can or cannot react with their immediate surroundings.

Homogeneous high temperature alkali feldspars are the products of a pyrogenetic crystallization in a melted glass. They are not stable at natural low temperature conditions, but reach a metastable homogeneous stage, (quasihomogeneous according to LAVES (1952, B)), only in a "dry" medium, when frozen in their high temperature state. At other conditions of lower temperature, pressure, or by wet diffusion, low temperature forms will be obtained.

The metastable character of the homogeneous high temperature feldspars is clearly demonstrated in the case of a dyke, which intersects the nordmarkite subvolcano at Panernaq peninsula. (6793).

The subvolcano and the dyke are both of pyrogenetic formation and of the same kindred. The dyke is supposed to have intruded the subvolcano towards the close of its magmatic action, rather in its auto-metasomatic stadium. In other words in an active medium.

The nordmarkite proper and its feldspars have been described by USSING (1912, p. 193). They resemble much those of 6793.

Involved in the process of crystallization at low temperature conditions, the phenocrysts of the dyke,—originally high temperature forms,—have developed a microcline pattern within the normally monoclinic "sanidine" crystal (Pl. 1, fig. 1). It is of interest to note the hypothesis set forth by LAVES (1950), that the microcline pattern originates in the monoclinic system.

This dyke does not in any other respects differ from the other trachyte dykes.

Besides this perthitic development of some phenocrysts, others remain clear or show patches of microperthite. The clear ones vary

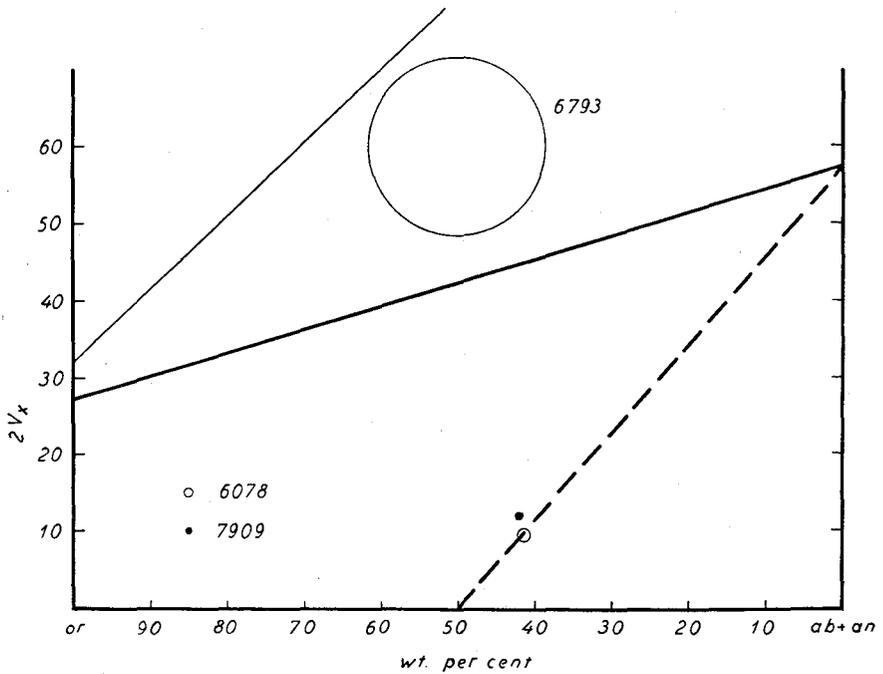


Fig. 3. Diagram showing the relation between the optic angles and the composition in weight per cent. The position of the optic plane is normal to (010). (TUTTLE — 1952, p. 557, fig. 1, partly).

——: Orthoclase cryptoperthite series.

-----: Sanidine-anorthoclase cryptoperthite series.

.....: Heated natural. The same signature is used in fig. 4.

The measured values of 6078 and 7909 correspond more closely with the curve for heated specimens, than with the one of the group to which they belong — sanidine series. The diagram is only tentative in this interval and the scatter of the plotted values in TUTTLE's representation, large. The composition of 6793 is not known, therefore it is confined to an encircled interval, to show the approximate position in the diagram. The orthoclase cryptoperthite stage has obviously not yet been reached. The variation in optic angles of different phenocrysts of 6793 is large.

appreciably as to their optical properties. Four of these, from the same thin slide, were measured:

$2V_{\alpha}$	48	72	60	48
$a:\alpha$	13	13	10	15

The orientation of the optical plane is normal to (010). Compared with the variation diagram as given by TUTTLE (1952, p. 557, fig. 1), the same scattering of $2V$ values is shown in what TUTTLE calls the orthoclase cryptoperthite series. In connection with what has been said above about the genesis of the perthites it is obvious that this series represents a more advanced transition from the high temperature series to the low temperature modifications without being final. In a diagram,

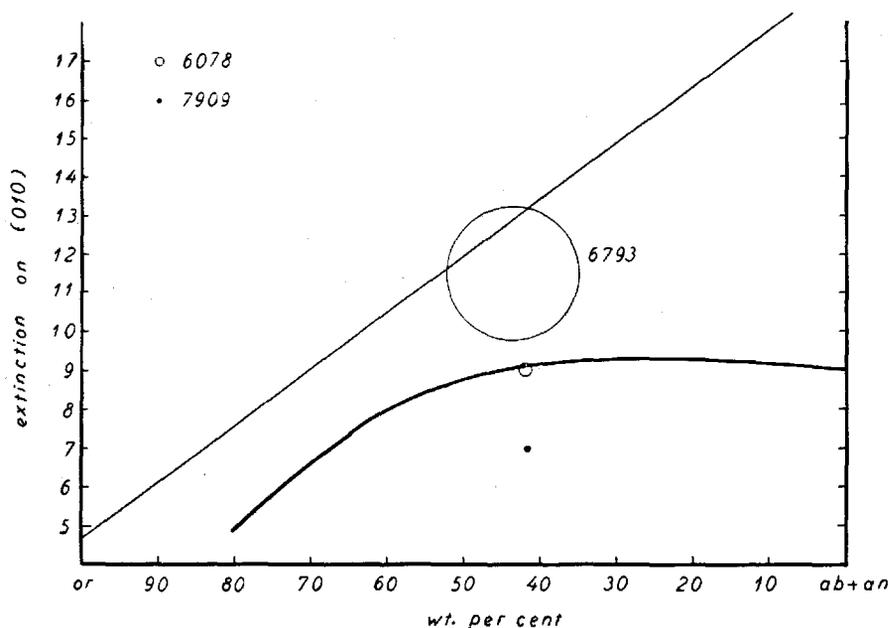


Fig. 4. Diagram showing the relation between extinction on (010) and composition. (TUTTLE — 1952, p. 563, fig. 3).

The extinction of 6793 has again been drawn tentatively. Also in this case it seems probable that the phenocrysts are in an intermediate stage of adjustment between the high-temperature sanidine series and the low-temperature orthoclase cryptoperthite series.

which shows the extinction on (010) (TUTTLE, 1952, fig. 3), a slightly lower value as found in the phenocrysts of 6793, is given for the same interval of composition.

TUTTLE mentions (p. 558) the variation in Ca-content as a possible source of scattering of the $2V$ -values. Since the scattering in this case occurs in the same thin slide, it is hardly thinkable that only the amount of Ca can be of influence on the value of the optical angle. It is suggested that also the stage of adjustment can have some influence on the optical properties. This has already previously been demonstrated by SPENCER (1938). Obviously, even under favourable conditions, the rearrangement of the alkali ions is a very sluggish, and possibly a selective, process as not all high temperature phenocrysts have reached the same stage of transition.

It must be expected that these phenocrysts have a larger K-content than those of the dykes outside the area of plutonic autometasomatism, the ultimate stage of equilibrium in a low temperature trachytic (or syenitic) medium appears to be more potassic, (cf. composition of perthitized phenocrysts — 7951).

Also with regard to contact metamorphic phenomena the conception of alkali transition, as described above, can be applied.

Sanidinites, as such, are always directly connected with volcanic activity and found as xenolites in trachytic lava, as is the case with the sanidinites from Laacher See¹) or embedded in tholeite (Mull²)). In other words their origin is pyrogenetic. Moreover they are always associated with waterfree minerals, such as hypersthene, sillimanite, corundum, spinel or cordierite. Chemical equilibrium is seldom attained, and relics from other facies are common.

Since glass is often found the xenolite must have been in a state of fusion. Under those conditions sanidine is readily formed as has already been shown by SPENCER's experiments. The sanidine formation is a true crystallization and contrary to that of the specimens, which SPENCER used, at least metastable.

3. The feldspars of the groundmass.

The formation of the alkali feldspar crystals of the groundmass is principally the same as that of the perthitic phenocrysts; the development has, however, been different.

The groundmass must be regarded as the ultimate devitrification product of a trachytic glass and evidently crystallized under low temperature conditions.

The first stage of crystallization seems to be represented by the albite lattice. The feldspar laths show the typical plagioclase form with vague signs of twinning according to the albite law. The twinplane is blurred; this results in a kind of hourglass extinction. (See fig. 4, pl. 2.

The potash feldspar was formed later, partly independent of the existing albite lattices, but in most cases it entered the albites, resulting in a micropertthitic pattern.

Prof. A. NOE-NYGAARD has kindly lent me some thin slides of liparitic glasses from Iceland, which show small lath shaped plagioclase microlites in the glass, orientated in lines. At a later stage of devitrification small spherulites of K-feldspar have been formed. (NOE-NYGAARD, 1952, p. 17).

The radiate growth of the groundmass has also been observed in the trachytes, though it is always micropertthitic.

Although at the present time no exact physico-chemical data can be given of the difference in rate of crystallization between the albite

¹) R. BRAUNS — Die kristallinen Schiefer des Laacher See-Gebietes und ihre Umwandlung zur Sanidinit. Stuttgart, 1914.

²) H. H. THOMAS — On certain xenolithic Tertiary intrusions in the island of Mull. Geol. Soc. London Quart. Jour., vol. 78 1922.

and the potash feldspar, it is clear from the above-mentioned observations that exactly this rate of crystallization must be decisive for the formation of the "albite" perthites and the radial growth of the perthite pattern in the groundmass¹).

Summarized: The perthitization is secondary to the formation of the pure components, the latter determine the shape of the perthites in a devitrified trachytic glass.

II. The amphiboles.

Belonging to the riebeckite series the amphiboles often show a peculiar difference in pleochroism between the rim and the core. Also along cracks a difference in pleochroism has been observed. The pattern which thus appears resembles the perthitic "exsolution" pattern. (See fig. 3, pl. 2).

The extinction angle $c:a$ varies slightly between 0° and 5° ; the angle of the core being usually a little less than that of the rim. The variation however is small and lies within a few degrees in most cases. Other data: $n_\beta = 1.694$, $2V_\gamma = \text{ab. } 70^\circ$.

From observations it is clear that the amphiboles are not stable in the alkali-rich, low temperature surroundings. The flakes are clearly subject to assimilation and show a typical ragged outline. Ultimately the amphibole is completely absorbed, to make place for iron oxides, as shown in 6033 and the metatrachytes 7917 and 7951. The first example has been chosen to emphasize the "low metamorphic" character of the absorption process. Dyke 6033 intersects basement rock and lies well beyond the reach of the scope of the immediate alkali supply of the syenitic massives. It is suggested that the need of alkalis of the devitrifying groundmass, an alkali-Si-Al-glass, causes the decomposition of the existing alkali (mainly sodium) sources, in casu the amphiboles. Absorption starts of course at the easily assailable places, rim and cracks. Absorption of the sodium by the groundmass is not necessarily ultimate, but it depends on the demand how far the displacement of the amphibole-glass equilibrium proceeds. Only when particular differentiates have been poor in amphibole (6033), the process of absorption has been final. It may proceed so far that the phenocrysts lose some of their alkalis.

In view of TERZAGHI's studies (1949) concerning devitrified lavas from the Central Plateau in France, an enrichment in alkalis is alto-

¹) Experimentally the rate of crystallization is defined by K in the equation:

$$-\frac{dx}{dt} = K \cdot x \quad \begin{array}{l} x = \text{molar proportion} \\ t = \text{time.} \end{array}$$

gether common. The mechanism of the enrichment is disputable, but as the source of alkalis is so close at hand, no special mechanism but absorption or diffusion suffices to explain the relative enrichment of the alkali feldspar groundmass in comparison with their mode (see also HIGAZY, 1950). The digestive mechanism is in full harmony with the observations made, in the trachytes as well as in the meta-trachytes.

III. Accessories.

Pyroxenes:

Occasionally some phenocrysts of an augitic pyroxene have been found. Aegirite augite, $\gamma:c = 52^\circ$, $2V_\gamma = 45-50^\circ$, has been observed in sample no. 6793. A much corroded pyroxene occurs in 7909, its extinction angle is $c:\gamma = 30^\circ$; due to the small amount no refractive index could be measured.

The pyroxenes are not of any petrographic importance. Obviously they are relics in the alkalic surroundings, belonging to an earlier phase of differentiation. Their existence is completely inferior compared to the abundance of amphiboles which marks the equilibrium in the trachytic magma. The mafic-group minerals have crystallized completely into soda-amphiboles previous to eruption.

Others:

Sphene and apatite are minor constituents of the alkali trachytic rocks. They have been found enclosed in the phenocrysts.

Further it should be mentioned, that sample no. 6078 carries up to 0,2 % cubes of pyrite, about one mm in diameter.

IV. Secondary minerals.

Calcite has sometimes been found enclosed in clear alkali feldspars (6793), though detectable only by very high magnification. Otherwise calcite occurs sporadically only as an alternation product in the groundmass.

Epidote and chloritic material are found as alteration products of both alkali feldspar and hornblende. The epidote is a ferriferous variety: $c:a = 10^\circ$, $2V_\alpha = 55^\circ$ (sample no. 6707).

Sericite possibly occurs as a secondary aggregate in the alkali feldspars, though in inferior quantities. Its presence could therefore not be ascertained. Possibly the cloudy mass, which fills part of the phenocrysts of alkali feldspar should be interpreted as a sericitic aggregate. It might however be expected that these alteration products are rich in iron.

Analcite and fluorite have been observed in some metatrachytes. The analcite has been found in an aggregate of zeolites (7917) where it occupies the main part.

Fluorite occurs in small lenses, surrounded by a rim of alkali feldspar, which very likely has been replaced, or as small dots in the phenocrysts. It is undoubtedly of later origin and its genesis can probably be explained by the lively fluorine activity in the whole "Post Gardar" area (WEGMANN, 1938), together with a preference for Ca, which is likely to be found as a component of the feldspar. The amount of fluorite is small, which is in accordance with the fact that no plagioclase has been observed, the amount of secondary calcite is negligible too.

V. Metatrachytes.

A few trachytic dykes have been found intersecting the foyaitic rocks near Narssarsuaq. Due to their special character, which in my opinion stands in close relation to the formation and mise-en-place of the batholites, these occurrences call for special attention.

WEGMANN suggested that the whole complex should be interpreted as basement rock (Ketillidian gneis) which has been syenitized. (WEGMANN, p. 81). It is too early to settle the question—the field investigations have not yet revealed features, which justify a conclusive decision in this matter. It seems, however, beyond doubt that the dykes are older than the syenites. The advanced perthitization of the phenocrysts which have resulted in a coarse micropertthite (7951 — pl. 1, fig. 2) has only been observed in the metatrachytes. They have been submitted to low-temperature metamorphism or rearrangement of the alkalis under low temperature conditions.

A discussion of the processes of "pneumatolytic" metamorphism, and the following increase of volume, has been presented by WEGMANN (pp. 74—83).

The micropertthitic pattern might under the prevailing conditions, have been formed in two ways:

1. by introduction of alkalis,
2. by a slowly generated complete alkali reaction within the phenocrysts towards equilibrium.

Both processes have undoubtedly been in action simultaneously. The separation $Ab + An/Or$ has been completed, or nearly so. An introduction of alkalis has resulted in an increase of the K — content, relative to the content of Na.

The composition of the phenocrysts of 7951 is Or 50 Ab 40 An 10¹). Compared with 7909, in the same area but outside the scope of syenitization, the Ab + An-content has dropped by 38 %, while the An-content is nearly the same.

No nepheline was observed in the meta-trachytes. This might be due to the fact that the bulk composition of the trachytes corresponds with that of the syenites. A possible explanation is that the dykes may be regarded as open systems in the process of syenitization, in other words the diffusion is free. The uniaxial properties of nepheline cause that the monoclinic and triclinic lattices of the alkali feldspar are not suited for Na-adsorption. The formation of nepheline is therefore restricted to those places, where its hexagonal lattice is more apt to be composed. The alkali-enrichment in the process of syenitization has acted as nephelinization on the surroundings, but missed its effect on the trachytes. The fact that the trachytes already are in a state of saturation with regard to the alkalis, further minimizes the total effect of the alkali supply.

For that purpose the question is raised why no albitization of the phenocrysts has taken place. Contrary to what one should expect the process of perthite formation has obviously been a de-albitization. The ratio between the alkalis might depend on the metasomatic process in such a way that the trachytic, pyrogenetic alkali ratio is changed towards a paragenetic equilibrium, depending on the surroundings. As the need of sodium is extreme in the surroundings, for the reasons explained above, the relative K/Na ratio has been displaced towards the potash member.

Another possibility is furnished by the suggestion made by WEGMANN, who supposed the pre-foiyatic rocks to be of granitic parentage. In these rocks the stable dominant potassium tectosilicate is microcline (or its monoclinic equivalent). The feldspathoitic pendant of nepheline, —kaliophyllite—, is not stable in quartzofeldspathic environment, nor is leucite. Thus only potash feldspar can be formed. As this is already abundant in the pre-foiyatic rocks, there is no reason to believe that a migration of K would have any effect. The only thinkable way of K-enrichment is a replacement of Na by K in perthitic feldspars.

As a summary a satisfactory explanation of the relative increase of the K/Na ratio can be given by supposing a replacement of Na by K. Na migrates to the quartzbearing surroundings in order to form nepheline.

¹) M. MOURITZEN C. E. anal.

Conclusions.

The following may be regarded as a supplement to LAVES' extensive compilation (1952), and may add some suggestions to the problem of the stability relations within the alkali feldspar group.

Accordingly there exist three "different" modifications of mixed crystal-phases in the alkali feldspars.

1. A homogeneous "high-sanidine" phase, only stable at high-temperature conditions, above 700° C and below the solidus curve. The axial plane is parallel to (010). Disorder exists in the AlSi_3O_8 -framework.
2. A pseudo-homogeneous "low-sanidine" phase, metastable at natural conditions. It includes a wide range of different cryptoperthitic variations (TUTTLE, 1952), further adularia. The angles of optic axes increase downward to the more stable forms, of a lower degree of perthitization (= stabilization). Order prevails with regard to the AlSi_3O_8 -framework, incomplete order with regard to the Na^+ - K^+ -distribution.
3. A heterogeneous perthite phase which is stable below its homogenization interval (BOWEN and TUTTLE, 1950). Transformation—by heating—to a homogeneous phase is always reversible.

The low-sanidine phase is metastable only in a dry medium. In a wet medium, metasomatic, hydrothermal or autometamorphic, this phase becomes unstable. Conversion from high-sanidine to low-sanidine by cooling is supposed to be instantaneous and always reversible. It can be compared with the transition from α - to β -quartz. The conversion from the low-sanidine phase to the heterogeneous perthitic phase cannot directly be carried through from high temperature to low temperature as a matter of course.

It is suggested that the AlSi_3O_8 -framework is influenced by temperature in a dry medium, in such a way that the reaction only depends on a different configuration of the bond energies within the framework. Na^+ and K^+ , which are present as active ions, are tied at random to the existing AlSi_3O_8 -framework, under casual conditions. Only by regulated, wet processes, for instance selective solution and transportation of cations (ROSENQVIST, 1952), Na^+ and K^+ might occupy a fixed position in the framework in a stable configuration. The formation of the stable, low-temperature AlSi_3O_8 -framework, with triclinic symmetry, might account for the energetic level of the process. The latter is sufficiently sluggish to establish a complete separation of the pure phases.

Thus the AlSi_3O_8 -framework is determined by the energetic level, by strong covalent bonds, while the position of the cations is set by a selective process, the nature of which for the present is unknown.

Adularia (= orthoclase) is a low temperature form with unfixed cation position in the extreme K-field of the phase diagram. The suggestion made by CHAISSON and LAVES (1950) that rapid crystallization is the cause of the monoclinic form while otherwise the triclinic is stable has been demonstrated by their investigations, in so far as the mono-

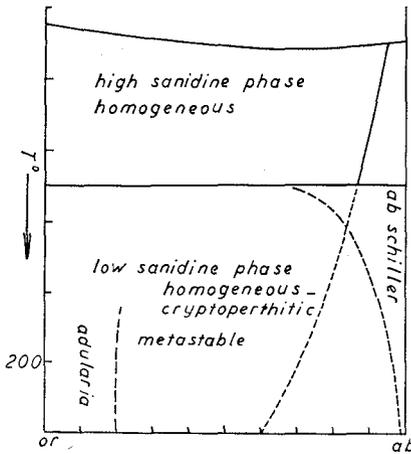


Fig. 5.

Fig. 5. Products of pyrogenetic genesis.

The temperature is falling.

NB. Adularia does not belong to the pyrogenetic series: its interval of formation, below 350°C , has been drawn to accentuate its metastable character.

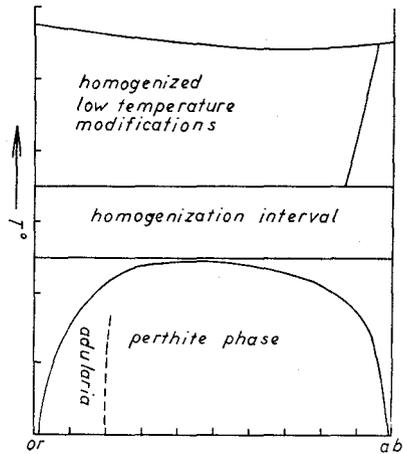


Fig. 6.

Fig. 6. Products of metasomatic origin, and the effect of heating.

The temperature is rising.

clinic lattice is being replaced by a triclinic one. On the other hand, the free three dimensional crystallization, as distinct from the bounded crystallization, sometimes forms crystals of unstable high temperature forms, as for example cristobalite in cavities of volcanic rocks, and wurtzite crystals in cavities and cracks in lead-zinc ores.

The views expressed here are best represented by a phase diagram in the recent paper by F. LAVES (1952 B, p. 557, fig. 9). The "stable diagram", p. 561, fig. 12, same paper, includes all the stable phases at their temperature level. A fairly similar view is expressed in the diagrams published by R. BAKKEN and I. ROSENQVIST (1953). As perthitization, sensu stricto, is exclusively a low temperature genesis, perthites can only be formed as products of devitrification from an alkalifeldspar glass or as the result of action of a flux on preexisting homogeneous alkali feldspars and, finally by wet metasomatic processes under natural conditions, for instance in pegmatites.

Figures 5 and 6 present some tentative diagrams which show the different phases mentioned above.

The transition from the low-temperature to the high-temperature fields is not the same in the two diagrams. Heating and homogenization in both cases is reversible, but resulting from different low-temperature phases. The question whether the internal properties of the material are decisive for the re-transition by cooling (memory) or whether the homogenized components are different in internal structure, or chemical bonds, is yet left open.

Chemical analyses of alkali feldspar phenocrysts.

	7909	7951
SiO ₂	65.60	63.89
TiO ₂	—	tr.
Al ₂ O ₃	18.50	18.61
Fe ₂ O ₃	0.81	0.13
MgO.....		tr.
CaO.....	1.00	1.42
Na ₂ O.....	7.00	5.36
K ₂ O.....	7.24	10.74
H ₂ O ⁺	} 0.19	0.16
H ₂ O ⁻		
	100.34	100.31

7909: Porphyritic trachyte — Narssarssuaq.

7951: Meta-trachyte — Narssarssuaq.

Anal. M. MOURITZEN.

Correction has been allowed for interspersions with riebeckite and alteration products. The composition for 7909 has been found to be or 37 ab 54 an 9, and for 7951, which actually consists of separated phases, as or 50/ab 40 an 10.

Appendix.

Attention is drawn to a new paper by Wm. Scott Mackenzie, "The orthoclase-microcline inversion", which recently has been published in *Min. Magazine*, vol. XXX, 1954, p. 354—366. The conclusions arrived at by Scott MacKenzie from studies of the inversion from the monoclinic (orthoclase) lattice to the triclinic (microcline) lattice, on a rather pure K-feldspar from Bearpaw mts, bear an important evidence of the nature of this transition. Heat of formation measurements on this material might give further useful information.

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Plate 1.

Fig. 1. Spec. no. 6793. Panernaq peninsula. Microcline formation within a monoclinic alkali feldspar phenocryst. The visible crystal faces are (100) and (110).
34 ×. Crossed nicols. C. HALKIER phot.

Fig. 2. Spec. no. 7951. Igaliko batholite. Coarse micropertthite in phenocrysts of a metatrachyte. 34 ×. Crossed nicols. C. HALKIER phot.



Fig. 1.

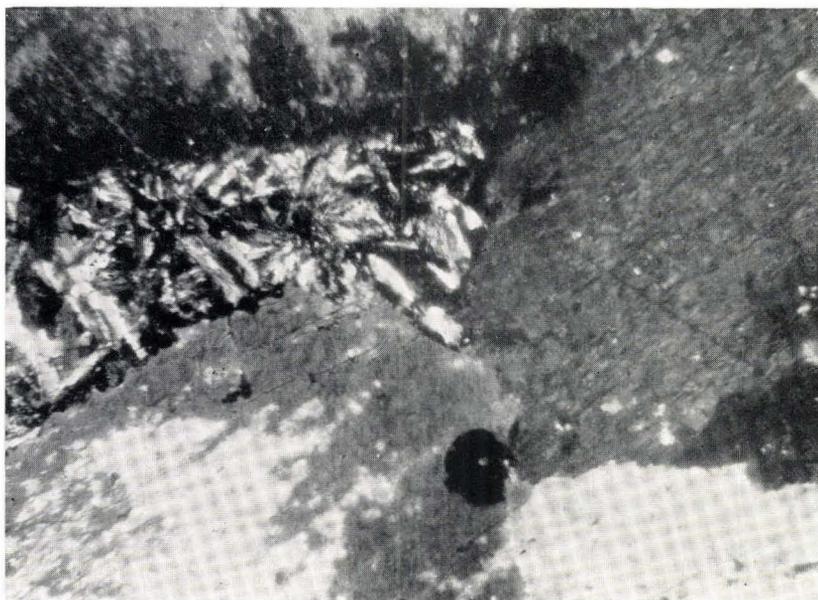


Fig. 2.

Plate 2.

Fig. 3. Spec. no. 7964. Narssarssuaq. Phenocryst of riebeckite in a trachytic groundmass, showing a conspicuous difference in pleochroism, due to selective absorption of the amphibole. $117\times$. 1 nicol. C. HALKIER phot.

Fig. 4. Spec. no. 6034. Near Narssaq. Groundmass, showing a perthitic pattern in an albite-oligoclase lath. Note the faint, "corroded" twin plane. $67\times$. Crossed nicols. AUTHOR phot.

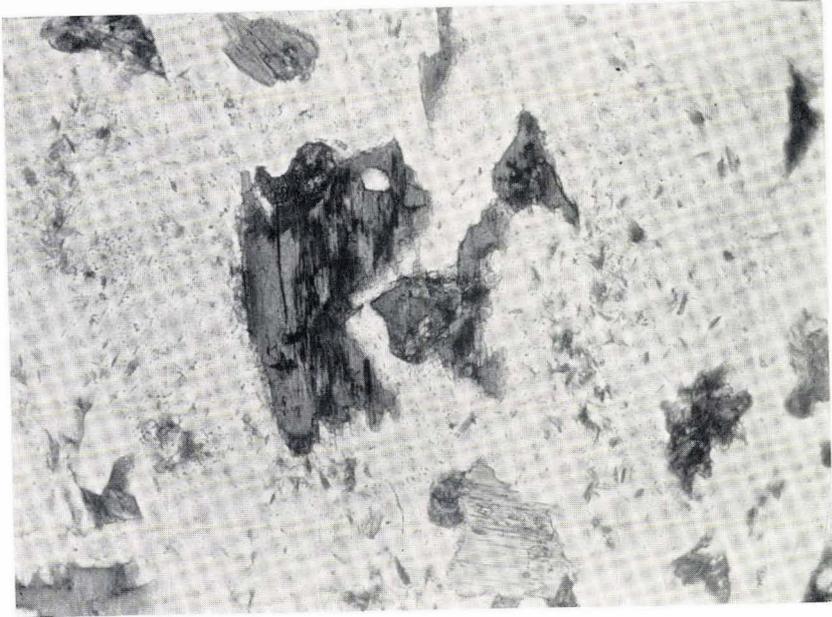


Fig. 3.



Fig. 4.