GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 39

GEOLOGY OF THE ILÍMAUSSAQ ALKALINE INTRUSION, SOUTH GREENLAND

DESCRIPTION OF MAP AND STRUCTURE

BY

J. FERGUSON

WITH 38 FIGURES IN THE TEXT
AND 2 MAPS

Reprinted from
Meddelelser om Grønland, Bd. 172, Nr. 4

KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A/S
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CONTENTS

Abstract.

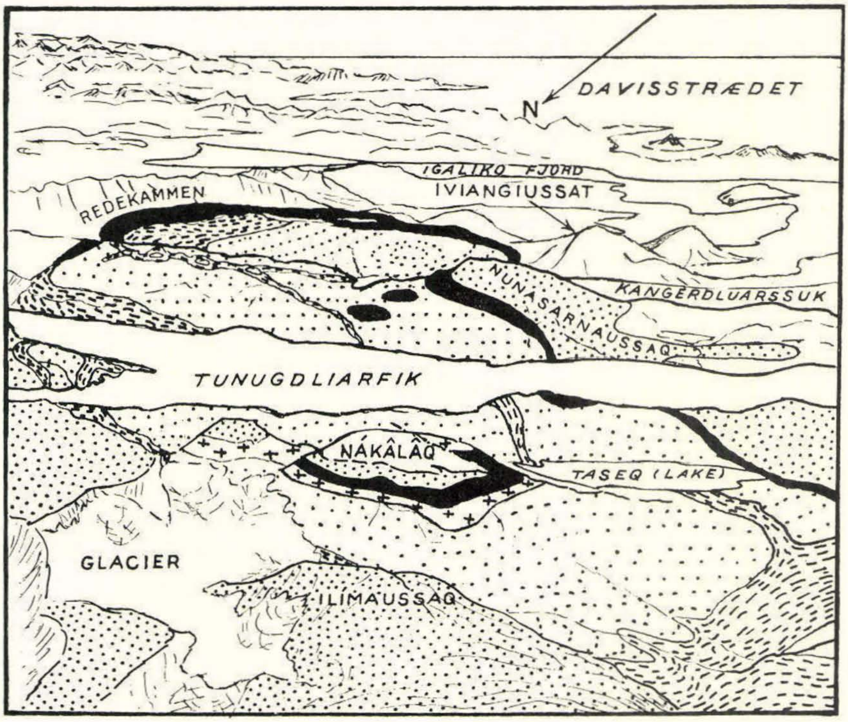
The Ilímaussaq Intrusion forms part of the alkaline province of South Greenland. It is thought that all the alkaline intrusions in South Greenland were emplaced in the basement rocks towards the close of the Gardar period. Rb/Sr age determinations of the Kûngnât and Ilímaussaq rocks give values of 1240 m.y. and 1086 m.y. respectively.

The Ilímaussaq Intrusion intruded into the Julianehåb granite and the overlying sandstones, basalts and trachytes of the Gardar continental series.

The trachytes probably represent an extrusive phase of the Ilímaussaq igneous activity. E.S.E. faulting, initiated in Ketilidian or early Kuanitic time, continued through the Sanerutian into the Gardar period and is thought to be the controlling factor of emplacement for the major alkaline centres.

The earliest magma of the Ilímaussaq Intrusion had an augite syenitic composition. After emplacement this magma proceeded along an undersaturated differentiation trend. The *in situ* undersaturated differentiation was interrupted by an injection of alkali granite into the upper parts of the intrusion. Following this, *in situ* undersaturated differentiation was resumed, and, aided by volatiles, formed a magma of peralkaline composition (agpaitic). Crystallization took place from the roof downwards with simultaneous gravity accumulation on the floor of the intrusion. Finally a residual liquid, rich in volatiles, was trapped between the downward crystallizing naujaite and the gravity accumulating kakortokites. As a result of faulting and/or slumping, the residual crystal mush was injected into the overlying brecciated rocks where it crystallized to form the fissile lujavrites.

Minor syenitic intrusions in the complex probably mark the last phase of igneous activity.



Ilímaussaq batholith as viewed from North-East (oblique aerial photograph used as base)

Legend

Late stage injected lujavrites } *Agpaites*

Banded nepheline syenites } *Agpaites*

Alkali acid rocks

Just undersaturated syenites

Gardar sandstone & diabase

Basement (mostly granites & gneisses)

Scale along Tunugdliarfik 1:100 000 (approx.)

Fig. 1.

I. INTRODUCTION

The Ilímaussaq Intrusion forms a spectacular landmark, the grey weathering of the friable nepheline syenite mountains contrasting markedly with the massive darker country rocks. The north and west margins of the intrusion are bounded respectively by the 61° N parallel and the 46° W meridian. The central point of the intrusion lies 11 km east of the town of Narssaq.

Due to the unusual nature of the rocks, plus the fact that the intrusion straddles the well known Tunugdliarfik fjord, the area has attracted the attention of many travellers and geologists. We owe the first geological record to GIESECKE who visited the area in 1806 and 1809. A number of new minerals from his collection were subsequently described (GIESECKE's diary pub. 1910).

In 1876 K. J. V. STEENSTRUP, G. HOLM and A. KORNERUP carried out a scientific survey in the Julianehåb district (STEENSTRUP 1909). STEENSTRUP followed up this visit with expeditions in 1888 and 1899.

In 1897, FLINK paid a visit to the area, discovering a number of new minerals (FLINK 1898).

BØGGILD and USSING made their first visit in 1900. USSING revisited the area in 1908, and published his classical work on the findings of these two field seasons (USSING 1912).

WEGMANN (1938), in a paper on the geology and structural divisions of Southern Greenland, submitted an unusual metasomatic theory for the origin of the nepheline syenites.

SØRENSEN (1958) summed up past theories and submitted his own modified view of the mode of intrusion of the "batholith". SØRENSEN has followed up this work with a detailed study of the agpaitic pegmatites and late-stage veining in the Ilímaussaq Intrusion (1962).

During the field seasons of 1957 and 1959, HAMILTON carried out a study of the northern half of the Ilímaussaq Intrusion (HAMILTON, in press).

The author, during the field seasons of 1958, 1960 and 1961, mapped the southern half of the intrusion on a 1:10.000 scale and the northern half on a 1:20.000 scale.

This paper deals primarily with the field relations and structure of the Ilímaussaq Intrusion. The general petrography is presented only as an appendix. The detailed petrography and study of the rock-forming minerals, plus the five types of igneous banding, will be submitted in later papers.

II. ACKNOWLEDGEMENTS

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J. FERGUSON

Grønlands Geologiske Undersøgelse,
København, February 1962.

III. REGIONAL SETTING

The Ilímaussaq Intrusion forms part of the alkaline igneous province of South Greenland (see plate II). Other major alkaline intrusions of this province include Kûngnât (UPTON 1960), Grønnedal (EMELEUS in press), Nunarssuit (HARRY and PULVERTAFT 1963), Puklen (PULVERTAFT 1961), Narssaq (STEWART 1960), Igaliko (USSING 1912) and the composite dikes of Tugtutôq (UPTON 1962). That these intrusions are of similar age has been confirmed in two cases using rubidium—strontium age determinations; measurements from Kûngnât and Ilímaussaq gave values of 1240 m.y. and 1086 m.y. respectively (MOORBATH, WEBSTER and MORGAN 1960).

It is thought that these alkaline intrusions were emplaced in the basement rocks towards the close of the Gardar period.

The chronology of the basement rocks of the Ivigtut-Julianehåb district of South Greenland was first outlined by WEGMANN (1938) and modified by later workers (BERTHELSEN 1960).

The following chronology has been established for pre-Gardar time (BERTHELSEN 1960).

4. Gardar period.
3. Sanerutian period.
2. Kuanitic period.
1. Ketilidian cycle.

Three phases of Ketilidian folding have been established; a strong migmatization accompanied the second phase of folding. Between the second and third phase of folding, ultrabasic plugs were emplaced.

The Kuanitic marks a period of tension, during which regional swarms of basic dikes were intruded, each generation with its own trend.

Reactivation of the Ketilidian rocks, in which the Kuanitic dikes were involved, took place during the Sanerutian period.

The Gardar cycle in South Greenland is represented by a supracrustal rock series and a highly varied suite of intrusive rocks which form dikes as well as the alkali intrusive centres. The supracrustal rocks

Fig. 2. Northern part of the Ilímaussaq Intrusion viewed from Kvanefjeld.

comprise a series of continental sandstones, basalts and minor trachytes. Gardar dike rocks are widespread with a dominantly E.N.E. trend. The composite alkali dikes of Tugtutôq (UPTON 1962) belong to this igneous phase.

Major E.S.E. faulting which was initiated in the Ketilidian or early Kuanitic time, continued through the Sanerutian into the Gardar period (HENRIKSEN 1960). BERTHELSEN (personal communication) is of the opinion that these faults are the controlling factor of emplacement of the major alkaline intrusive centres. USSING (1912, p. 288) proposed that the E.N.E. faulting acted as the structural control for the emplacement of the Ilímaussaq "Batholith".

In the case of the Ilímaussaq Intrusion, one of these major E.S.E. faults is seen to be of post-Gardar continental series and of pre-agpaite age.

The Ilímaussaq Intrusion intruded into the Julianehåb granite (product of Ketilidian and Sanerutian plutonic activity) and the later Gardar continental series of sandstones, basalts and trachytes. As suggested by USSING (*loc. cit.* p. 306), there was probably an extrusive phase of

Fig. 3. General view of Ilímaussaq Intrusion north of Tunugdliarfik Fjord.

the Ilímaussaq igneous activity which is now represented by the Ilímaussaq porphyry, occurring within the overlying Gardar continental series.

The Ilímaussaq Intrusion has a gently domed profile and an oval surface plan elongated 17 km along a S.E. axis and measuring 8 km along the shorter N.E. axis.

IV. EVOLUTION AND FORM OF THE ILIMAUSSAQ INTRUSION

General.

USSING (1912, p. 107) divided the Ilímaussaq batholith into an older, unstratified and a younger. stratified division.

Older unstratified division:	*Younger stratified division:*
	(From top to bottom)
arfvedsonite granite	arfvedsonite granite
augite syenite	quartz syenite
nordmarkite	pulaskite
essexite	sodalite foyaite
	naujaite
	lujavrite and kakortokite.

The "unstratified" division, with the exception of the augite syenite, forms separate rock units to the west of the "stratified" division. In this presentation the author uses the terms *Ilímaussaq Intrusion* to cover the "stratified" division plus the augite syenite, and *Narssaq Intrusion* to refer to the "unstratified" division, less the augite syenite.

Recent investigations of the Narssaq Intrusion by J. W. STEWART have led to the subdivision of USSING's "Nordmarkite" into two principal rock varieties, namely, pyroxene syenite and quartz syenite. The Narssaq syenites and the associated alkali granite are generally quite distinct in hand specimen from their petrological equivalents in the Ilímaussaq Intrusion. So far there is no field evidence which fixes incontrovertably the relative ages of the two intrusions. In the Narssaq Intrusion, the alkali granite is distinctly younger than the syenites, in contrast to the Ilímaussaq Intrusion, where the alkali granite occupies an intermediate position between the augite syenite and younger agpaitic syenites.

The Ilímaussaq Intrusion is formed essentially from two magmas, namely, the augite syenite and alkali acid magmas. Aided by volatile enrichment, the augite syenite magma has followed a peralkaline differentiation trend, producing agpaitic rock types. The alkali acid magma was injected into the partially differentiated augite syenite. As a result of mixing between the two magmas, hybrid rocks were developed.

Magmas:	*Hybrids:*	*Differentiates:*
Augite syenite		augite syenite heterogeneous-syenite sodalite foyaite naujaite lujavrites kakortokites
	quartz- syenite pulaskite	
Alkali acid		alkali granite quartz syenite

USSING (1912) has provided excellent petrographical descriptions of these rocks. A summary of the rock units with additional petrographic and optical data is given in section VI.

Genesis of the Ilímaussaq Intrusion.

(refer to figs. 4 & 5 for this section).

The earliest magma of the Intrusion was an augite syenite of just saturated composition. The emplacement of this magma was controlled by faulting and achieved by overhead stoping (USSING 1912, p. 300). The augite syenite magma chilled against the country rocks and consolidated from the margin inwards. Differentiation of the augite syenite proceded along an undersaturated trend giving rise to the more alkaline heterogeneous syenite (USSING's foyaite) which is found as a sheet just below the roof development of the augite syenite "shell".

During this *in situ* differentiation period an injection of alkali granite occurred, which, in one locality, punched through the augite syenite and occupied horizons both above and below the augite syenite roof. To the south of Tunugdliarfik fjord, the alkali acid rocks are preserved only as small stocks and sills within the heterogeneous syenite. Here the roof of augite syenite is thought to have been removed by erosion. Hybrids, namely quartz syenite and pulaskitic rocks, were developed by reaction between the alkali granite magma and the earlier undersaturated rocks. These hybrids occur mostly *in situ*, being marginal to the alkali granite. However, in some cases, before the alkali granite intruded into the roof zone, it mixed with the undersaturated magma and produced similar hybrid rocks, which occur as small separate plugs and sheets. USSING (*loc. cit.* p. 320—321) was of the opinion that a differentiation sequence existed *in situ* with alkali granite at the top

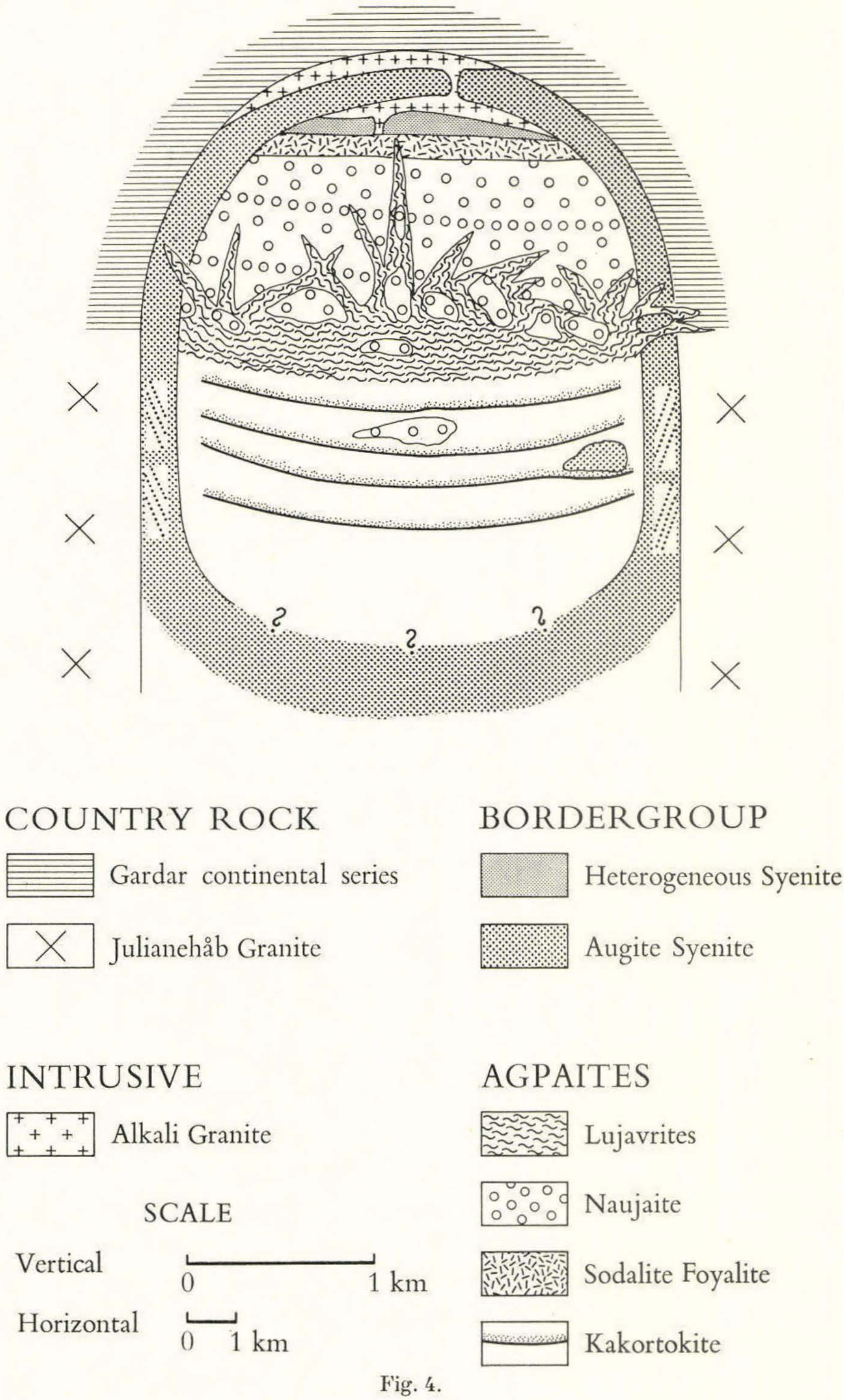
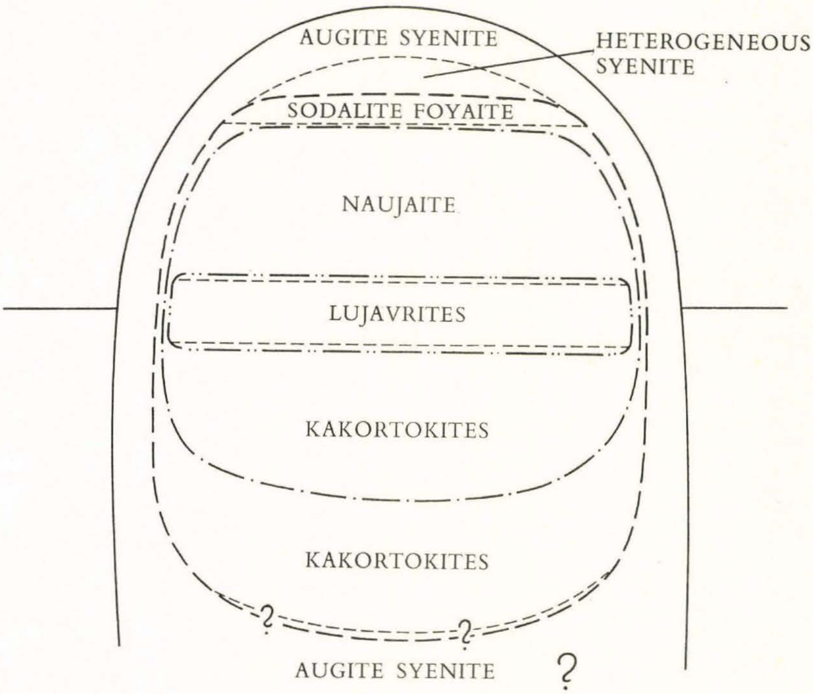

COUNTRY ROCK
Gardar continental series
Julianehåb Granite
BORDERGROUP
Heterogeneous Syenite
Augite Syenite
INTRUSIVE
Alkali Granite
SCALE
Vertical
0
1 km
Horizontal
0
1 km
AGPAITES
Lujavrites
Naujaite
Sodalite Foyalite
Kakortokite

Fig. 4.



OUTER BORDERS OF SUCCESSIVE
AGPAITE DIFFERENTIATES

··——··——··—— Third phase

——·——·——·—— Second phase

— — — — — — First phase

- - - - - - - - - - - Boundaries of rock units

Alkali Granite omitted as it is not part of in situ differentiation

SCALE

Vertical 0 — 1 km

Horizontal 0 — 1 km

Fig. 5.

grading downwards through quartz syenite, pulaskite, foyaite and finally into agpaites. SØRENSEN (1958, pp. 29—30) interpreted the pulaskite as a representative of the primary magma (the composition of the pulaskite is similar to augite syenite), and the quartz syenite and alkali granite as products of reaction with the roof rocks.

After the injection of the alkali granite, undersaturated *in situ* differentiation continued in the central parts of the chamber, forming a series of peralkaline rocks (agpaites). SØRENSEN (1958) and FERGUSON (1962) are of the opinion that a considerable amount of volatiles helped to achieve this superundersaturated differentiation. Sodalite foyaite occurs at the top of the agpaitic sequence, immediately below the heterogeneous syenite.

The remarkable series of banded kakortokites found in the lowermost exposed part of the Intrusion are considered to have been formed by gravity accumulation, deposition taking place during and after the formation of sodalite foyaite in the upper part of the magma chamber. In places, an agpaitic pegmatite forms a buffer between the outer shell of augite syenite and these layered peralkaline rocks.

The pegmatoid naujaite is found above the gravity accumulated kakortokites and immediately below the sodalite foyaite. The naujaite is considered to have been formed by the flotation of 2–3 mm diameter sodalite crystals which were trapped in a downward crystallizing rock, giving rise to the poikilitic texture which characterizes this rock. Sodalite normally makes up 35—45 % of the rock. However, sodalite-rich and sodalite-poor horizons are locally developed in the naujaite. In the former, sodalite may form up to 70—80 % by volume of the rock. USSING (p. 74) refers to these 0,5—5,0 m thick horizons as sodalitites; they are interpreted as having formed during periods of excess sodalite formation and/or efficient flotation processes (e. g. current action).

In further contrast to the normal naujaites, the 10—20 cm thick sodalite-poor horizons lack a poikilitic texture. The minerals in these zones are of a similar pegmatitic size to those developed in the average naujaite. The sodalite crystals, when present, are xenomorphic towards the other minerals in the rock and are also of pegmatitic dimensions. These horizons are thought to have been produced during short periods of arrested sodalite flotation which allowed the magma to crystallize without accumulation of sodalite.

SØRENSEN (1962) is of the opinion that some of the naujaite pegmatites were produced by the accumulation of volatiles in irregularities at the base of the downward crystallizing naujaite. Colour banding is locally produced; only minor textural variations accompany this change (see p. 58). Naujaite comprises the greatest volume of the rocks exposed in the Intrusion.

While the naujaite was forming the kakortokites were steadily accumulating on the floor of the central magma chamber.

Finally, a residual liquid rich in volatiles, was trapped between the downward crystallizing naujaite on top and the gravity accumulating kakortokites below. As a result of faulting and/or slumping, the naujaite, the marginal augite syenite, and, in places, the country rock were brecciated: the residual mush was injected and squeezed into these overlying rocks where it consolidated to form the fissile lujavrites. This interpretation differs from that of USSING (1912, pp. 38, 47 and 177) and SØRENSEN (1958, p. 18), who, although regarding the lujavrites as the latest agpaitic rock, consider them to have originated at a level below the kakortokites. The present vertical juxtaposition of the kakortokites and lujavrites in the south part of the Intrusion is interpreted as being due to a relative upthrow on the S. side of an E.—W. fault contemporaneous with the emplacement of the lujavrites.

The lower lujavrites are green aegirine-rich rocks and the upper lujavrites black and arfvedsonite-rich.

Slumping caused the upper layers of the Intrusion to sag, as indicated by the usual moderate marginal dips and, along the northern border of the Intrusion, the vertical attitude of these layers.

The volatile phase of the lujavrites was squeezed out during crystallization to form late-stage natrolite-analcime veins in the overlying rocks. The petrogenesis of these veins has been described in detail by SØRENSEN (1962).

A small number of alkaline intrusives are found in the agpaitic rocks and probably represent the last phase of igneous activity in the area.

V. CONTACT RELATIONS

Augite syenite - country rocks.

Within a few metres of the contact with the country rocks, the augite syenite has developed a fine-grained chill. This was seen on the N. and S. shore of Kangerdluarssuk, in Narssaq elv and on the top of Nákâlâq. Away from this contact, the rock has developed a coarse-grained facies and is more alkaline. A pegmatitic facies is locally developed near the margin; this was noticed particularly on the N.E. slope of Iviangiussat mountain. Here the pegmatites are approximately 25 cm wide and contain schiller perthites 6—9 cm long; the pegmatites are highly sinuous. The country granite within several metres of the contact is shattered; some quartz-feldspar pegmatites project into it.

The effects of the emplacement of the Ilímaussaq Intrusion on the Julianehåb granite have been observed by J. H. Allaart who has supplied the following information.

The Julianehåb granite has been altered for a distance up to 40 m from the contact with the Ilímaussaq rocks. Near the contact the rocks have been completely fenitized. The plagioclase and microcline have been converted into the chess-board variety of microline which is characteristic of the Ilímaussaq alkaline rocks. The biotite has been converted into soda-amphibole and soda-pyroxene. Quartz has been expelled from the fenitized granite in a zone up to 20 m wide. Quartz and biotite are unaffected 30 m from the contact; however, the feldspars are clouded.

Mylonitic shear zones are found in the Julianehåb granite up to 100 m from the contact. The granite has been completely fenitized for 0,5 m on either side of the mylonites.

1 km S. of the summit of Nákâlâq, a fine-grained chill of augite syenite was seen against the roof pendant of basalt. Apophyses of augite syenite 1 m wide also occur in this block; fine veinlets project from these apophyses.

0,4 km N. of the summit of Nunasarnaussaq two small pipe-shaped diatremes of augite syenite, a few metres in diameter, occur in the basalt country rocks. Along the margins of these diatremes numerous chips

Fig. 6. Alkali granite veining sandstone blocks. N.E. Iviangiussat, at sea-level.

and fragments, up to 1 m diameter, of sandstone and basalt are found in a matrix of augite syenite. Towards the centres of these diatremes, fresh fragments of the underlying Julianehåb granite are found.

Augite syenite-sandstone blocks.

At the foot of Iviangiussat mountain, four sandstone blocks occur in the augite syenite, the largest measuring over 100 m long × 50 m wide. These have been well described by Ussing (1912, pp. 51–54). Another sandstone block of a few cubic metres was noted in the augite syenite, 1,5 km S. of Agpat. As pointed out by Ussing, the sandstone blocks first described must have sunk a distance of a few hundred metres, as the top of the adjacent Iviangiussat mountain is below the lower contact of the continental series, from which these sandstone blocks have undoubtedly been derived.

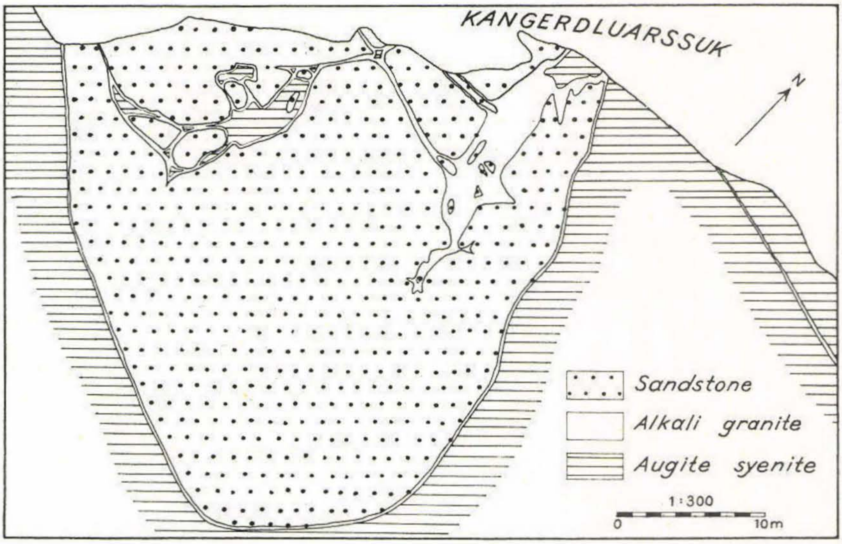


Fig. 7. Map of sandstone block in augite syenite with alkali granite formed as a reaction product.

The main locality is well known for the reaction of augite syenite with sandstone forming alkali granite. The latter rock type occurs in two distinct forms:

i) Reaction *in situ* of sandstone and augite syenite forming alkali granite (fig. 6).

ii) Intrusion of alkali granite veins into sandstone and augite syenite.

The sandstone block occurring at sea-level was mapped in detail as it affords good, clean exposure (fig. 7).

The *in situ* reaction has taken place where the augite syenite veins invade the shattered sandstone block. The reaction product of alkali granite occurs over a width varying between 10 and 18 cm. A reaction rim of soda-amphibole is present along the alkali granite – sandstone contact with the amphibole prisms aligned perpendicular to the contact (fig. 8). There is also a reaction zone of alkali granite produced along the main contact of the augite syenite and the sandstone block.

The alkali granite of the second type intrudes into the augite syenite as fairly large veins. This occurrence of alkali granite must have resulted from a complete reaction of sandstone with augite syenite followed by intrusion into the hot augite syenite. The intrusive alkali granite veins are for the most part coarse-grained to pegmatitic.

Fig. 8. Reaction of augite syenite and sandstone, forming alkali granite; immediate contact between sandstone and alkali granite is marked by a rim of soda-amphibole.

Augite syenite-alkali acid rocks.

The augite syenite is never seen in contact with the main alkali granite intrusives, as a quartz syenite reaction zone is always found between the two rocks. The thickness of the quartz syenite is of the order of 5–10 m with a maximum of 50 m. Due to the friable nature of the augite syenite the immediate contact with quartz syenite has not been seen. Within a few metres there is no change in grain size in either rock. At a height of 1000 m to the S.W. of the Nákâlâq plateau, indistinct inclusions of a rock resembling quartz syenite occur in the augite syenite. 1 km E. of Taseq lake, a network of alkali acid veins and minor pegmatites penetrate the augite syenite.

Augite syenite-naujaite.

The contact between naujaite and augite syenite has been seen in only three localitites. At an altitude of 400 m on the N.E. slope of Nunasarnaussaq the augite syenite and naujaite have a sharp undulating contact with no compositional or textural change in either rock. S.W. of

Taseq lake and on the N. coast of Kangerdluarssuk, the naujaite sends small apophyses into the marginal augite syenite; there is no change in either rock.

The immediate contact between sodalite foyaite and augite syenite was not seen: however, on the N.E. slope of Nunasarnaussaq there is no variation to be seen in these two rock types within 3 m of their contact.

Augite syenite-lujavrite.

Where the lujavrite has intruded into the brecciated augite syenite the contacts are sharp. This is most noticeable in the areas just west of Tugtup agtakôrfia, Narssaq elv, Kvanefjeld and Laksefjeld. In most cases there is a slight concentration of dark minerals in the lujavrite along these contacts, but no change in grain size. On top of Laksefjeld, augite syenite blocks occur in green lujavrite; here the immediate contact is marked by a zone of sugary feldspar, 2 cm wide.

Along the S.E. margin of the intrusion, the marginal augite syenite is separated from the lujavrite by an agpaitic pegmatite 50 m wide.

Augite syenite-kakortokites.

The main contact between the augite syenite and kakortokite is marked by an agpaitic pegmatite 50–100 m wide. The pegmatite pinches out 1 km S. of Agpat. There is no change of grain size in the augite syenite as this contact is approached. The immediate contact of the augite syenite with the pegmatite is marked by vertical veins of fibrous aegirine. Augite syenite also makes an appearance in the kakortokites as block inclusions varying in size from small chips to blocks a few hundred metres in diameter. The contact between these augite syenite inclusions and the kakortokites is marked by a pegmatitic development of agpaitic minerals, 5 cm–3 m wide (average 2 m). In a few instances the immediate contact is marked by a fibrous aegirine zone, 2 cm in width.

Alkali granite-country rock.

The contact between the alkali granite and Gardar basalt was seen on the north slope of the hill 1 km E.S.E. of Nákâlâq peak. The granite becomes fine grained and develops a sugary texture towards the contact. No noticeable change was seen in the basalt.

Alkali granite-undersaturated syenites.

A perfect transition of hybrid rocks exists between the alkali granite and the lower undersaturated rocks. The thick alkali granite sheet underlying the Nákâlâq mountain, grades downwards into a quartz syenite, which has a fairly constant average thickness of 5–10 m and a variable quartz content. At the top of the quartz syenite zone the quartz content is less than 15 % diminishing downwards into a nepheline-bearing pulaskitic rock. The pulaskite is 2–4 m thick in this area. The top of the pulaskite zone is poor in nepheline while the lower part contains approximately 7 % nepheline.

In the small capping of roof rocks to the S. of Taseq lake, an identical relationship exists between quartz-syenite and pulaskite. In this case the absence of alkali granite is accounted for by erosion.

To the S. of Tunugdliarfik fjord, the alkali acid rocks have intruded into the heterogeneous syenite in the form of small plugs and sills. The two plugs of alkali granite measure a few metres in diameter. Surrounding the granite are two narrow zones made up of an inner quartz syenite zone and an outer pulaskite zone. However, this area has a further peculiarity in that quite separate plugs and sills of quartz syenite and pulaskite are found in the heterogeneous syenite. These plugs and sills are interpreted as being hybrid rocks produced by contamination of the alkali granite magma by the undersaturated magma, followed by injection into the overlying consolidated rocks. This contrasts with the more usual formation of these hybrids by *in situ* reaction between the alkali granite magma and consolidated undersaturated rocks.

Heterogeneous syenite-pulaskite.

The heterogeneous syenite, when present, directly overlies the sodalite foyaite. It is developed on the N. side of Tunugdliarfik fjord as a thin sheet with a maximum thickness of 8 m. To the S. of Tunugdliarfik it occurs as two erosional cappings both 1 km wide. The contact with the pulaskite is sharp. There is no change in grain size in either rock.

Sodalite foyaite-heterogeneous syenite.

Towards the overlying heterogeneous syenite, the sodalite foyaite normally becomes slightly finer grained over a 20 cm wide zone and the dark and light anhedra decrease from 2 cm to 1 cm in diameter. The immediate contact is sharp and undulating. Macroscopic olivine becomes noticeable in the sodalite foyaite within this 20 cm wide contact zone.

In the capping of rocks to the S. of Taseq lake the sodalite foyaite-heterogeneous syenite contact is less distinct. Here a mixed rock is present over a 20 cm wide zone.

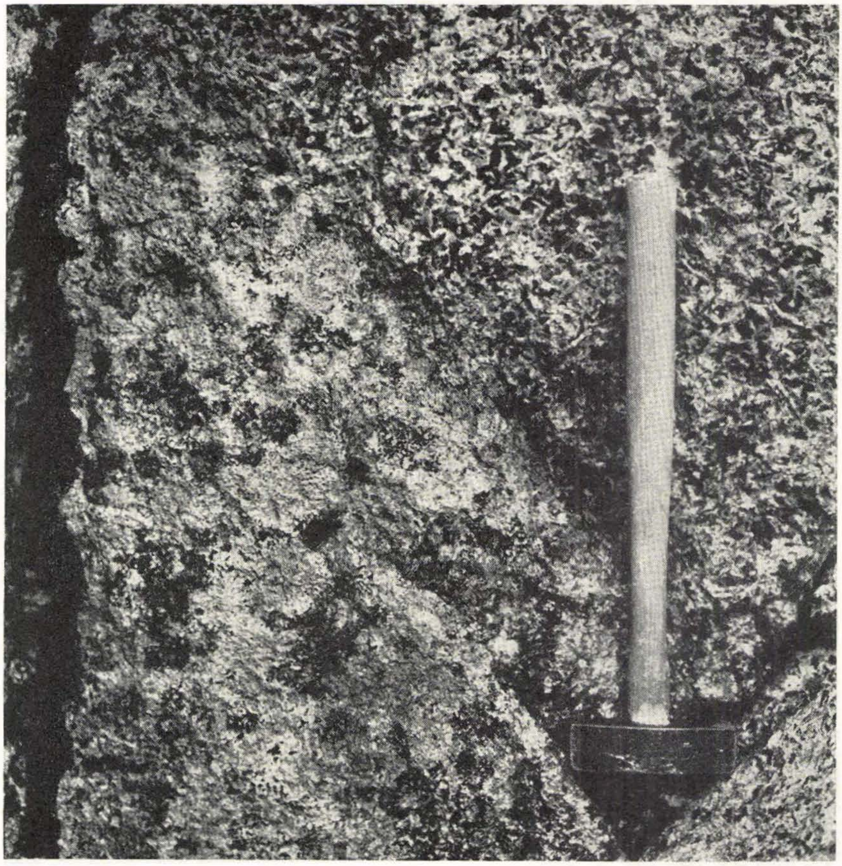


Fig 9. Razor-sharp contact between naujaite and sodalite foyaite. South side of Tunugdliarfik Fjord.

Naujaite-sodalite foyaite.

For the most part there is a perfect transition between these two rock types. In the main sheet of sodalite foyaite to the N. of Tunugdliarfik fjord, the gradual transition of sodalite foyaite into naujaite takes place over a zone approximately 2 m wide. The normal 5–10 cm diameter poikilitic phenocrysts in the naujaite decrease to 0,5–2,0 cm diameter and the euhedral sodalites decrease from 3 mm diameter to less than 1 mm diameter. There is a transition upwards, the sodalite tending to collect interstitially until finally the transition into non-poikilitic sodalite foyaite is complete. S. of Tunugdliarfik fjord this transitional zone can be up to 7 m thick.

In two areas there are notable exceptions to this transitional contact. S. of Tunugdliarfik fjord, over a strike distance of 0,5 km, the western contact between the sodalite foyaite and naujaite sheets is razor

Fig. 10. Breccia zone showing naujaite blocks in lujavrite. North coast of Tunugdliarfik Fjord.

sharp. Here both rocks have normal development right up to the contact (fig. 9).

In the small capping of roof rocks, S. of Taseq lake, the contact between the naujaite and sodalite foyaite is sharp. The sodalite foyaite has only a minor development here, having a maximum thickness of 80 cm and pinching out locally. The naujaite has decreased in grain size, the poikilitic anhedra being only 1 cm in diameter and in the included sodalite 1 mm in diameter.

Naujaite-country rocks.

The contact between the naujaite and country rocks was seen along the N.E. boundary of the Ilímaussaq Intrusion. The marginal augite syenite is absent here and the naujaite comes into direct contact with the country rock basalts. The naujaite is separated from the basalts by a 5 m wide agpaitic pegmatite. The main contact between pegmatite and basalt is sharp and vertical. Small apophyses of agpaitic pegmatite project into the basalt. Heavy natrolization of the agpaitic pegmatite has taken place.

Lujavrite-naujaite.

The lujavrite intrudes into the naujaite. The blocks of naujaite in lujavrite usually have sharp contacts (fig. 10). Small angular chips of

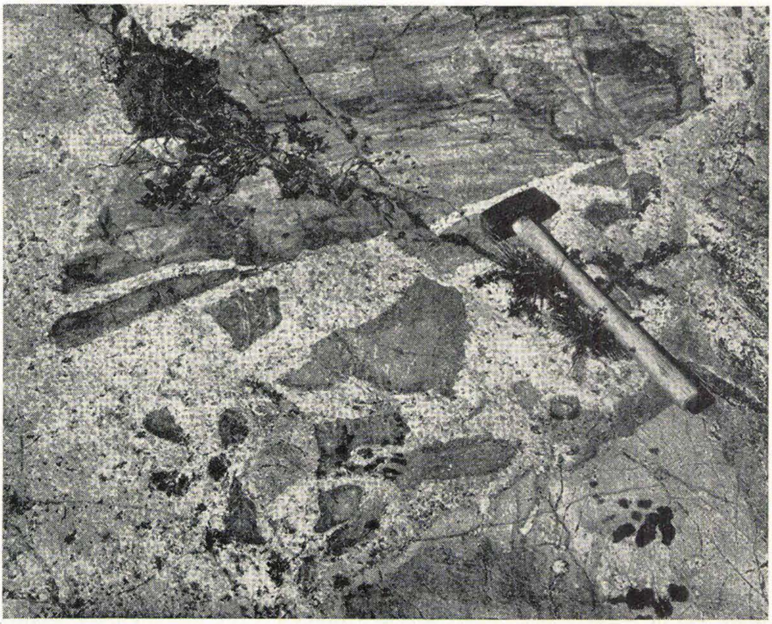


Fig. 11. Remobilized naujaite containing lujavrite fragments. Loc. at 640 m in Narssaq elv.

naujaite, a few centimetres long, are included in the lujavrite and show no sign of alteration. However, in lujavrites rich in zeolites naujaite blocks are digested; this is particularly prevalent in mixed zones of lujavrite, analcime-rich veins and naujaite (see SØRENSEN 1962).

At 640 m in Narssaq elv, an unusual case of remobilized naujaite containing lujavrite fragments was seen (fig. 11).

Black lujavrite-green lujavrite.

The main contact between the black and green lujavrite can be studied over a strike distance of 6 km. The contact is completely gradational over a true thickness of 3 m. The transition rock is characterized by a colour variation from black to grey to green, corresponding to a change in the arfvedsonite/aegirine ratio. There is no change in grain size. Elsewhere sharp conformable colour bands of alternating green and black lujavrite can be seen (fig. 12).

Away from the main black and green lujavrite contact these two rock types can be seen intersecting one another. Inclusions of aegirine lujavrite, a few centimeters in diameter, are present in the black lujavrite (SØRENSEN 1958, p. 38 fig. 17). A rim rich in analcime-nepheline surrounds the aegirine aggregate.

Fig. 12. Sharp conformable bands of alternating green and black lujavrites. South shore of Tunugdliarfik fjord.

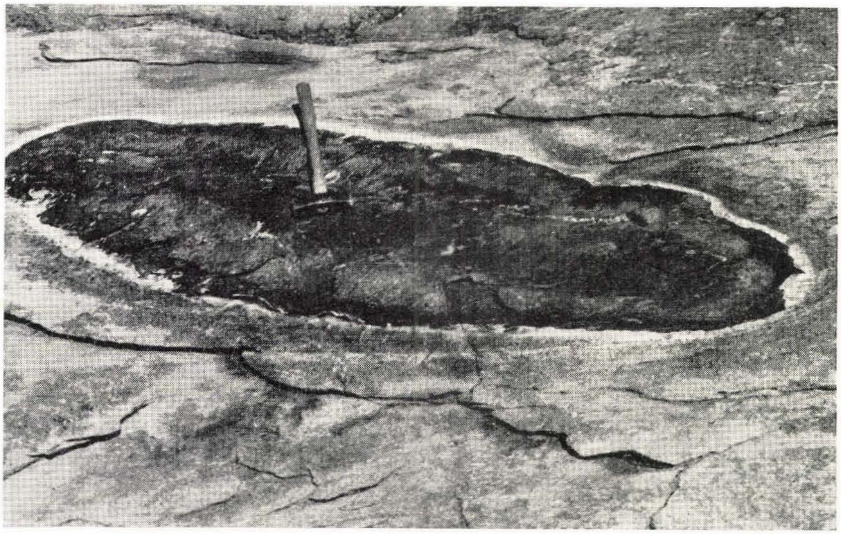


Fig. 13. Lens of "black lujavrite" or lujavritized basalt, in green lujavrite. West end of Nunasarnaq peninsula.

At the west end of the peninsula of Nunasarnaq, lenses of a "black lujavrite" a metre or two long are inclosed in green lujavrite. These lenses may, however, represent lujavritized basalt inclusions (fig. 13).

Fig. 14. Contact of kakortokite and naujaite block (lower right) marked by 5 cm long aegirine and arfvedsonite phenocrysts. Kringlerne plateau at 400 m.

Kakortokite-green lujavrite.

Along the S.E. border of the intrusion in the Laksefjeld area, the green lujavrite overlies the kakortokite. Unfortunately this area has been hydrothermally altered and is further complicated by the presence of large blocks of augite syenite which obscure the kakortokite–lujavrite contacts. It is thought that the kakortokite and lujavrite layering is conformable.

Kakortokite-naujaite.

Naujaite and augite syenite blocks (see p. 24) are found in the kakortokites. Contact relations between the naujaite blocks and the kakortokites vary considerably. Sometimes a narrow pegmatite is present; the contact is however sharp and characterized by arfvedsonite and aegirine phenocrysts of pegmatitic dimensions arranged perpendicular to the contact (fig. 14).

Aĝpaitic dikes.

Along the S.E. border of the Intrusion two eudialyte-sodalite-syenite dikes in the Julianehåb granite have been observed by J. H.

Allaart. These dikes have not been seen cutting the marginal augite syenite; however, the highly weathered augite syenite in this area may obscure the presence of these dikes. To date, no agpaitic dikes have been observed in the country rocks above the level of the agpaitic rocks in the Intrusion.

Syenitic dikes.

i) Augite syenite intrusives having both dike and sill forms were seen at 300 m in the Narssaq elv. These intrusives were noted cutting the lujavrites.

ii) Brown weathered dikes form late stage intrusives and are usually less than 1 m wide. They are found in the northern part of the intrusion, have a E.N.E. strike and are for the most part vertical. Upton (1962, p. 59), is of the opinion that these dikes could possibly be correlated with an E.N.E. striking dike swarm on the island of Tugtutôq to the S.W. of Ilímaussaq. Unfortunately these rocks have undergone heavy sericitization. However, the remnant feldspars appear to be potash feldspars. This is in contrast with the dikes of Tugtutôq which are basic.

iii) Green porphyry syenite intrusions are found in the kakortokites and sparingly in the green lujavrite. These intrusions have both dike and sill developments. In the S.W. and N.E. part of the kakortokites this rock occurs as a sill underlying a red kakortokite horizon. The sills are connected by a series of N.E. striking dikes. A few minor occurrences form small plugs in the green lujavrite on top of Laksefjeld. The intrusive is usually over 3 m thick, and has a 10 cm wide chill with a concentration of dark minerals. Where the intrusive is less than 0,5 m in width there is a complete reaction with the kakortokites which is marked by a pegmatitic zone 1–2 m wide, containing large spherulitic aegirines.

iv) Dikes containing spheroids of feldspathic material 1–3 cm in diameter are found in the southern half of the Intrusion, and strike N.N.E. These dikes rarely exceed 0,5 m in width but can be traced for 1–2 km and maintain a remarkably straight course.

VI. PETROLOGY

Augite Syenite.

Macroscopic features: Typically this rock has a holocrystalline texture and is coarse-grained and equigranular. Feldspars form irregular white anhedra, which are sometimes stained brown. Exceptionally a lath form is developed; occasionally schiller structure can be seen. The augite occurs either as single anhedra or in aggregates of small grains; both forms have a diameter of 2–3 mm. The augite is interstitial to the feldspar. Olivine is difficult to identify macroscopically; it occurs as rounded anhedra 2 mm in diameter. Small amounts of chalky-white feldspathoids are usually present in the coarse-grained rock as anhedra 2–3 mm in diameter.

Microscopic features: The rock-forming minerals are crypto-perthite, augite, olivine and magnetite, and minor amounts of lepidomelane, nepheline and apatite.

Estimated mineral percentages.

	Crypto perphite	Magne-tite	Olivine	Augite & Aegirine-augite	Biotite	Apatite
Fine-grained chill:	65	8	10	15	2	<1
coarse-grained facies:	75	5	5	10	3	2

For the most part the feldspar occurs as crypto-perthite and forms irregular anhedra; exceptionally, a lath form is developed. The anhedra have mutually interfering boundaries. With the exception of the accessory apatite, the crypto-perthites are the first formed minerals in the rock. Coloured and opaque minerals are xenomorphic towards the feldspar. Only occasionally is magnetite enclosed in the periphery of the crypto-perthite anhedra. In the fine-grained chill facies, the cryptoperthite anhedra measure less than 1 mm in diameter. In the coarse-grained facies, these anhedra measure 2–5 mm across and anomalously form laths 3 mm long $\times$0,5 mm wide. In the fine-grained chill, the crypto-perthites are usually concentrically zoned. At times a hair-like twinning is present having two developments at right angles to one another. In all cases crypto-perthites were developed except in two anomalous occurrences where multiple twinned albite and crypto-perthite were present as zones in individual anhedra.

Magnetite was the next mineral to crystallize after the feldspar and forms subhedral grains. In the fine-grained chill rocks these grains measure 0,5 mm in diameter, and in the coarser rock facies, 1 mm in diameter. Usually they are surrounded by a narrow corona of lepidomelane, even when included in perthites, olivine and augite.

Olivine appears to be the next mineral to have crystallised. In the fine-grained chill rock it is not enclosed in augite, but is sometimes included in the augite of the coarser-grained rocks. The olivine usually forms rounded grains, varying in size from less than 0,5 mm diameter in the fine-grained chill to 2 mm diameter in the coarser-grained facies. Normally, iron-oxide is present along cracks in the olivine and also rims these grains. These olivine aggregates are sometimes surrounded by a green alteration product of antigorite which is in turn surrounded by lepidomelane. The composition of the olivine varies from the fine-grained chill to the more alkaline coarse-grained facies.

Fine-grained chill:	Coarse-grained facies:
2Vx = 60° (range 58°–61°)	2Vx = 52° (range 50°–55°)
Fa = 89	Fa = 100
	(composition according to the method of Poldervaart 1950 p. 1073)

Augite was the last of the rock-forming minerals to crystallize; frequently it is poikilitic. Magnetite, olivine, lepidomelane and apatite can be included. There is quite a marked difference in the augite from the two facies of this rock.

The augite in the fine-grained rock is homogeneous, has a neutral buff colour and is not pleochroic. Moreover, diallage twinning is developed in 20–30 % of the augite anhedra from this zone and is never present in augite of the coarse-grained facies. The augite in the fine-grained zone forms anhedra less than 1 mm in diameter. In the coarse-grained facies, the augite makes up 2–3 mm anhedra which usually display a concentric zoning. The centres are neutral buff augite, grading into pale-green pleochroic margins of aegirine augite.

Fine-grained chill:	Coarse-grained facies:
2Vz = 56° (range 54°–58°)	cores 2Vz = 60° (range 58°–62°)
z:c = 49° (range 48°–51°)	z:c = 56°
twinning on (100) twin axis	
co-incident with c (diallage)	rims 2Vz = 80°

Lepidomelane is always present, usually forming coronas around magnetite and, less commonly, around olivine and augite. Anomalously the lepidomelane forms separate anhedra 2–3 mm long. Pleochroism varies from colourless to deep red brown.

Nepheline is not present in the fine-grained chill but occurs in the coarse-grained rock. Natrolite pseudomorphs after nepheline are frequently present.

Apatite occurs as water-blue hexagonal prisms which form quite abundant accessory grains and are included in all the other minerals of the rock. The prisms are usually $<0,5$ mm diameter $\times 1$ mm long.

Quartz is anomalously present, never in the fine-grained rock, but only in the coarse-grained rock near acid inclusions. In the few cases noted the presence of quartz appears to be due to contamination.

At times this rock undergoes extreme alteration. Fibrous natrolite, fluorite and albite attack and completely replace the crypto-perthites and nepheline. The augite is converted into crystals having kataphoric hornblende centres and riebeckite margins, plus small amounts of associated neptunite, calcite and natrolite. Olivine is converted into iron-oxide and antigorite.

Average **chemical analyses** of augite syenites (HAMILTON 1964).

	Chilled augite syenite (Nos. 1–2–3)	Coarse-grained augite syenite (No. 6)
SiO_2	53,5	57,5
Al_2O_3	16,2	17,1
Fe_2O_3	3,7	1,8
FeO	6,3	6,9
MnO	0,2	0,2
MgO	2,0	0,9
CaO	4,6	1,9
Na_2O	5,8	5,8
K_2O	4,7	5,1
TiO_2	1,6	1,1
P_2O_5	0,4	0,4
H_2O	0,5	0,5
Total	99,5	99,2

Textural and compositional variations: The augite syenite occurs texturally and compositionally as a highly variable rock type but behaves as a structural unit.

A notable variation of the more normal augite syenite is developed in the Narssaq elv and Kvanefjeld areas. Here the feldspar is 2 cm long and purple in colour with a narrow white to green rim.

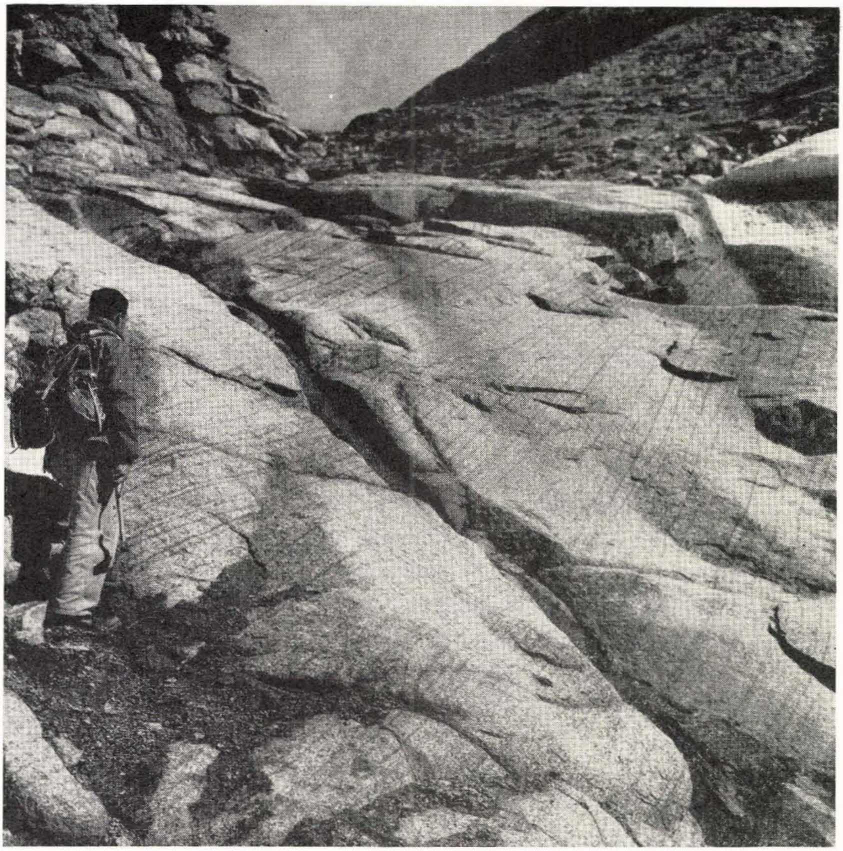


Fig. 15. Steep banding in augite syenite at 100 m on south side of Kangerdluarssuk fjord.

Pegmatites are developed locally, particularly near the major contacts (p. 20).

Locally the augite syenite develops banding. This banding is confined to the lower 500 m of the ca. 1500–2000 m exposed part of the outer shell of augite syenite. Banding is well developed in the augite syenite on the north and south shore of Kangerdluarssuk (fig. 15). It is also developed sporadically from sea-level up to 500 m in the zone adjacent to the kakortokites. The banding is most prominently developed in a medium to coarse-grained rock over a 100 m wide zone situated 200–300 m in from the margin. The banding, where noted, has a strike roughly parallel to that of the outer margin of the intrusion. Dips are always inward and rather steep except when they are disturbed by inclusions of country rocks. The range of dip angles varies from 50°–75° inward, averaging 60°.

The banding is entirely due to concentrations of magnetite, augite and olivine. These form layered concentrations 1–3 cm wide, separated by lighter bands of normal augite syenite 2–30 cm wide (fig. 15). These bands wedge out laterally, marginally against the fine- to medium-grained rock and inwardly against the coarse-grained facies of augite syenite. On the whole, however, they maintain a remarkably constant thickness; anomalously they can merge up-dip.

Heterogeneous Syenite.

Macroscopic features: This rock is characterized by its heterogeneous grain size. Typically, pockets of coarse-grained rocks are enclosed in pegmatitic rocks. There is very little mineralogical difference between the pegmatitic and coarse-grained varieties, and they will accordingly be described together.

In the pegmatitic rock the feldspars average 6 cm long × 1 cm thick (range 2–8 cm × 0,5–2,0 cm). This contrasts markedly with the feldspars from the coarse-grained pockets which are quite regular measuring 0,5–1,0 cm long × 1 mm thick. In the crudely sheeted pegmatitic rock the feldspars tend to be aligned perpendicular to the contact. By contrast the coarse-grained rocks have no preferred orientation of the feldspars. In both rock facies all the other minerals in the rock are xenomorphic towards the feldspars; only in exceptional cases are pyroxenes and amphiboles semi-poikilitic. In the pegmatitic rocks the amphiboles and pyroxenes make up 0,5–2,0 cm diameter anhedra with an average diameter of more than 1 cm. In the coarse-grained rocks the interstitial anhedra are less than 0,5 cm diameter. Olivine is locally quite abundant occurring as 2–4 mm diameter anhedra. The size of nepheline varies considerably in the pegmatitic and coarse-grained rock. In the former rock they occur as irregular anhedra 2–3 cm diameter, whereas in the coarse-grained rocks they form anhedra 2–3 mm diameter.

Microscopic features: In both facies of this rock group the feldspars develop perthitic textures. The exsolved albite lamellae develop fine multiple twinning parallel to (010); in one case an exsolved albite lamella was noted to have twinning developed on (001). In all cases the microline host possesses the usual albite chessboard twinning. The average ratio of Mi:Ab = 60:40. In the case of the coarse-grained rocks, but not in the pegmatitic, a homoaxial rim of albite surrounding a core of perthite is present in 50 % of the sections examined. In both facies of the rock small, less than 0,5 mm, albite laths are usually present. These usually project at random into the margin of the perthite laths and can be seen lying within the latter. In the case of the pegmatitic feldspars, these small albite laths are frequently aggregated along the centres of the perthites. Microlites of arfvedsonite, and, less commonly, aegirine, are always included in the perthites. These acicular inclusions tend to be aligned parallel to the *c* axes of the perthites.

The pyroxenes and amphiboles have a strong concentric zoning. The acmitic pyroxenes show the strongest development of this feature. In the majority of aegirine anhedra the pleochroism of the centre is in lighter greens than that of the margins. This darkening towards the margin is completely gradational.

Cores:	Margins:	
aegerine bearing augite	aegirine-augite	aegirine
2Vz = 74° (range 60°–88°)	2Vx = (range 50°–88°)	
2Vz = 60°	2Vz = 88°	2Vx = 82°
	x : c = 22°	x : c = 10°
Nx = pale-green	Nx = green	Nx = dark green
Ny = pale grey-green	Ny = pale green	Ny = light green
Nz = neutral brown	Nz = pale yellow-green	Nz = light yellow-green

According to Larsen (1941), these values correspond to a core of aegirine-bearing augite grading into aegirine-augite which is surrounded by an outer rim of aegirine. As can be seen from the range of core values, aegirine-bearing augite is sometimes absent, and in these cases the cores consist of aegirine-augite. As many as three centres of aegirine-bearing augite may be present in a single aegirine anhedron. Acmitic alteration is frequently present along the margins and in some cases has penetrated along fractures. In a few cases incomplete rims of homoaxial arfvedsonite surround the zoned pyroxene anhedra. (100) parting is rather common in the acmitic pyroxenes. In a few instances twinning can be seen on (100) crystal faces. The twin axes are parallel to (100) and are nearly coincident with the *c* crystallographic axes. In the aegirine-augite, and more particularly in the aegirine zones, small bubble inclusions of fluorite are present. They are conspicuously absent in the zone of aegirine-bearing augite. Infrequent anhedra of aenigmatite are at times present in the outer margin of aegirine. Aegirine is frequently seen as a fringe surrounding magnetite.

Homoaxial growth of arfvedsonite around pyroxene is quite common. In these instances nepheline is included in the arfvedsonite. The arfvedsonite is usually zoned. In the centre of the arfvedsonite anhedra there is a lighter blue-green-purplish colour than along the margins.

The zones are not gradational but rather sharp and with angular boundaries. The darker margins have the following optical characteristics:

$2\,Vx = 66°$
Ny = blue-green
Nz = pale green-blue.

Aenigmatite is usually present and has a core of magnetite which is in turn often surrounded by arfvedsonite.

Fluorite blebs and apatite prisms are scattered through the arfvedsonite, aenigmatite and olivine crystals. Infrequent biotite flakes and neptunite are usually present along contacts between aenigmatite and magnetite and along contacts of olivine and iron oxide.

Olivine occurs as 2–4 mm dia. anhedra and usually has a narrow rim of iron oxide which also penetrates along cracks in the olivine. These aggregates are invariably surrounded by a fringe of arfvedsonite. Optical determinations of olivine gave:

$$2\ Vx = 48°$$

corresponding to Fa 100.

Nepheline is xenomorphic towards the feldspar and only occasionally is there an interference between these two minerals. Nepheline can be included in the arfvedsonite. Heavy zeolite replacement of nepheline is quite common. When the two zeolites analcime and natrolite are found together the latter usually serves as a buffer between the analcime and nepheline. Sodalite appears to be of secondary origin occurring in and along the nepheline border. Arfvedsonite microlites are sparingly included in the nepheline.

Chemical analysis of heterogeneous syenite. (Anal. M. MOURITZEN).

Spec. no. GGU 40124

SiO_2	55,07
TiO_2	0,56
Al_2O_3	14,05
Fe_2O_3	6,20
FeO	5.80
MnO	0,26
MgO	tr.
CaO	3,07
Na_2O	8,44
K_2O	4,76
P_2O_5	0,10
H_2O+	1,39
$H_2O÷$	0,13
Cl	0,04
ZrO_2	0,27
rare earths	0
total	100,17

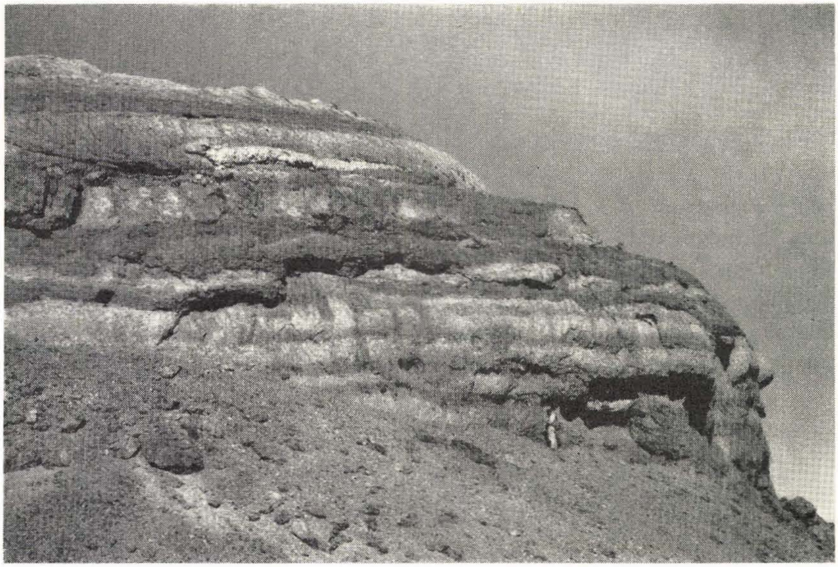


Fig. 16. Banding in heterogeneous syenite. 1 km north-east of Nunasarnaussaq.

Fig. 17. Close up of banding seen in fig. 16.

Banding in heterogeneous syenite. This rock unit is characterized by its heterogeneous grain size; coarse-grained facies alternate with pegmatitic facies. Both rock facies have a similar mineralogical composition: the rock-forming minerals are perthite, soda-pyroxene, soda-amphibole, olivine and nepheline.

In the pegmatitic rock the feldspars average 6 cm long × 1 cm thick and tend to be aligned with the long axes perpendicular to the contacts. The feldspars from the coarse-grained rock measure 1 cm long × 1 mm thick. Banding is sporadically produced by alternations of coarse-grained layers approximately a metre thick, with the lighter-coloured near horizontal sheets of pegmatitic rock up to a metre thick. The higher olivine content in the coarse-grained bands has further emphasized the banding due to "rust" weathering (figs. 16 and 17). Fragments of the coarse-grained rock, 20–30 cm diameter, are often included in the pegmatitic rock, particularly where the latter is slightly transgressive.

This rock unit is considered to have crystallized from the roof downwards. The pegmatitic bands might be best explained by repetitive water and volatile accumulations at the base of the downward crystallizing rock.

Alkali Granite.

Macroscopic features: The alkali granite is holocrystalline, medium to coarse-grained, and has a hypidomorphic texture. Opaque green feldspar makes up stout laths 1 cm long × 3 mm thick. Quartz and coloured minerals are xenomorphic towards feldspar. Quartz is usually clear and glassy making up rounded grains 2 mm in diameter which often group into clusters 1 cm across. The arfvedsonite occurs as prisms 1–2 cm long × 2–3 mm thick. In a few localities, fibrous red elpidite crystals 1–2 mm long can be seen making up 2–3 % of the rock.

Microscopic features: The rock-forming minerals are perthite, quartz, arfvedsonite, aenigmatite and aegirine. Accessory minerals include pyrochlore, elpidite and zircon. Secondary minerals are specularite, hematite, fluorite, calcite, neptunite and riebeckite.

Estimated mineral percentages:

Perthite	Quartz	Arfvedsonite	Aenigmatite	Aegirine
70	15	12	2	1

The feldspars are micro-perthites, occasionally with crypto development. The microcline has albite chessboard twinning and the albite has fine multiple twinning. At times there is a tendency for albite to rim the perthites. The green colouration of the feldspars is due to inclusions of aerigine and a few arfvedsonite microlites. Occasionally thin quartz stringers are present along the margins of the feldspars. In addition a myrmekitic to graphic intergrowth is developed between these two minerals. Numerous minute fluid cavitites are present in the quartz.

The arfvedsonite displays patchy pleochroism. The margins of these anhedra have a pleochroism browner in colour than the more usual arfvedsonite. Frequently there is an intergrowth between the arfvedsonite and aenigmatite. Acmite and/or riebeckite alteration is common along the margins of arfvedsonite. Neptunite grains are sometimes associated with this break-down of arfvedsonite. Occasionally separate aegirine anhedra with acmite margins are found.

Minute grains of zircon, pyrochlore and acicular elpidite are often included in feldspar and quartz.

Chemical analysis: Average value of alkali granite (Hamilton 1964).

SiO_2	72,32
Al_2O_3	10,27
Fe_2O_3	2,71
FeO	3,50
MnO	0,23
MgO	0,16
CaO	0,67
Na_2O	5,17
K_2O	3,92
TiO_2	0,33
P_2O_5	0,18
H_2O	0,54
Total	100,00

Textural and compositional variations: The alkali granite occasionally displays a textural variation. The rock becomes medium grained and the dark minerals tend to concentrate in stringers. In addition the normally green feldspar can be blue. This colour variation is due to inclusions in the feldspar of arfvedsonite microlites in place of aegirine.

Occasional quartz veins occur and are usually parallel to the N.60°E. joint direction. These vary in width from a few millimetres to 5 cm. Alkali granite pegmatites 5–10 cm wide are sparingly present; the arfvedsonite prisms which are 4 cm long tend to parallel the margins of the pegmatites.

Quartz Syenite.

Macroscopic features: This rock is holocrystalline, medium to coarse-grained and has a hypidomorphic texture. There is a great similarity between the quartz syenite and the alkali granite; the essential difference is the lower quartz content in the former rock. The feldspars are usually an opaque pale green, forming either stout laths or having a granular habit. The laths measure 3 mm long × 1 mm thick and the granules 2 mm across. The amount of quartz varies from < 15 %–0 % as a result of this rock being a hybrid. In many cases the quartz syenite has undergone extreme alteration.

Microscopic features: The rock-forming minerals comprise perthite, quartz, soda-pyroxene and arfvedsonite. Accessory minerals include apatite, magnetite and riebeckite. Secondary minerals are hematite, calcite, fluorite and iron oxide.

Estimated mineral percentages:

Perthites	Quartz	Soda-pyroxene	Arfvedsonite
60–75	0–15	10	5

The feldspar is a micro-perthite, around which a margin of multiple-twinned albite is sometimes seen. The microcline has the usual albite chessboard twinning. Aegirine microlites crowd the perthites. The coloured minerals and quartz are xenomorphic towards the feldspar.

The soda-pyroxenes and amphiboles have usually undergone heavy replacement, with the formation of acmite and riebeckite.

The quartz is usually clear but can have a rim of iron oxide.

Textural and compositional variations: Infrequent 1 m long pegmatitic zones occur in this rock. The minerals in these are essentially the same as those of the quartz syenite but with a dimension greater than 1 cm diameter.

Narrow arfvedsonite veins, up to 5 cm width, cut the quartz syenite. Quartz veins of a similar size are also to be found.

Narrow banding is locally developed and is particularly well-developed in a 2 m thick sill seen to the S. of Tunugdliarfik fjord. The banding is due to 0,5–1,0 cm wide concentrations of arfvedsonite separated by 2–3 cm wide bands of feldspar. The sill is banded throughout its entire thickness. Lamination is never present. In one case the bands develop a discordancy in the central part of the sill (fig. 18).

Fig. 18. Banding in quartz syenite sill with slight discordancy near the centre. 1 km northeast of Nunasarnaussaq.

Pulaskite.

Macroscopic features: The feldspars form stumpy grey-white laths 4–6 mm long × 2–3 mm wide. The 0,5–1,0 cm diameter pyroxenes and amphiboles are semi-poikilitic; at times the feldspar is included in these minerals. Chalky-white and dull bluish-grey feldspathoid anhedra usually measure 2–3 mm in diameter.

Microscopic features: The rock-forming minerals comprise perthite, acmitic pyroxene, arfvedsonite, aenigmatite and nepheline. Accessory minerals comprise fluorite, apatite, magnetite, olivine, sodalite, and biotite. Secondary minerals include analcine, natrolite, stilbite, sericite and katapleite.

Estimated mineral percentages:

Antiperthite	Aegirine	Arfvedsonite	Aenigmatite	Nepheline
70	13	5	5	7

The large feldspars are antiperthites and are the first-formed minerals in the rock, with the exception of microlites of aegirine and arfvedsonite which are included in the feldspars. The antiperthites generally have a ratio of Ab:Mi = 70:30. The normal albite comprises fine, multiple-twinned lamellae; the exsolved microline is elongated parallel to c and has the usual chessboard albite twinning developed. In some cases the exsolved microcline tends to be concentrated towards the centre of an antiperthite anhedron. The albite along the borders tends to develop coarser twin lamellae than the albite in the centre of the phenocrysts. These albite "overgrowths" on the predominantly perthitic core are probably related to a second generation development of albite. Large simple (010) and occasional (001) twins, are frequently seen passing through the antiperthite and in a few cases there appears to be an oblique twin plane. Small, less than 1 mm long, second generation albite laths are usually seen randomly included in the antiperthites. Occasionally they have grown homoaxially with the antiperthites. In areas there is some albite alteration; here distinctly secondary albite occurs, usually at the intersections of the antiperthites, and in some cases replaces the perthites. These secondary albite aggregates are cloudy and form matted aggregates.

Microlites and small grains of aegirine, and, to a lesser extent, arfvedsonite, are always included in the antiperthites. The microlites have a strong tendency to parallel the c direction of the perthites. Clear water-blue apatite prisms are always present in the antiperthites but in varying amounts; they, too, tend to parallel the c direction of the antiperthites.

Analcime replacement of antiperthites is sometimes seen.

Amphibole, pyroxene and aenigmatite anhedra are xenomorphic towards the feldspar. In some cases all three of these minerals include the feldspar laths. Minute grains and microlites of aegirine and arfvedsonite are, however, included in the feldspar and nepheline, indicating two ages for these minerals. A concentric zoning is frequently present in the acmitic pyroxenes. The centres are lighter green in colour than the margins. There is usually a completely gradational darkening towards the margin; however, at the periphery there is often an abrupt change to a very narrow dark green rim.

The following optical properties have been determined:

Cores:	*Margins:*
Avge. 2Vz = 70° (range 60°–98°)	2Vx = 82° (range 72°–90°)
Pleochroism	
Nx = pale green	Nx = apple green
Ny = pale grey-green	Ny = light apple green
Nz = neutral brown	Nz = brownish-green

These average values correspond to a core of aegirine-bearing augite, grading into aegirine-augite enclosed by an aegirine rim (LARSEN 1941). Frequently there are narrow, interrupted arfvedsonite margins to these zoned acmitic pyroxenes. In the larger aegirine anhedra, as many as three aegirine-bearing augite centres are present in a single anhedra. Frequently, acmite alteration is present along the boundaries of the pyroxene and amphibole anhedra. Small fluorite blebs are commonly scattered through these acmitic pyroxenes, as well as minor grains of apatite, biotite, aenigmatite and olivine. The arfvedsonite anhedra usually also display a crude concentric zoning. The centres are a light brownish-purple as compared to the blue-green margins. This zoning is not completely concentric but rather patchy; however, the general tendency is towards light centres and dark margins. A dark rim is also present around inclusions in the arfvedsonite. The following optical measurements have been made on a zoned arfvedsonite:

$$2Vx = 72°–98° \text{ (core-margin)}$$
$$x:c = 56°$$

Pleochroism

Cores:		*Margins:*
Nx = light brownish-purple	—	brownish-purple
Ny = light olive-green	—	olive-green
Nz = blue-green	—	dark blue-green

The arfvedsonite and aegirine have interference growth; on occasions, arfvedsonite includes aegirine anhedra. The usual aegirine-arfvedsonite relationship is homoaxial arfvedsonite growing interruptedly along the margin of the zoned aegirine. In some cases acmitic breakdown of arfvedsonite is quite advanced and only small remnants of arfvedsonite remain in predominantly acmitic anhedra.

Aenigmatite occurs as frequently as arfvedsonite in this rock suite. Usually a core of magnetite is surrounded by a patchy pleochroic, deep red-brown aenigmatite. Aegirine and aenigmatite are frequently in association; the aegirine is usually marginal to the aenigmatite. Except for minute flakes of arfvedsonite enclosed in the aenigmatite, these two minerals are rarely associated. Like the aegirine and arfvedsonite, the aenigmatite can enclose feldspar; however, laths of the latter usually project deeply into the aenigmatite. A few biotite flakes are also usually associated with the aenigmatite. Small amounts of fluorite "blebs" and apatite prisms can be included in the aenigmatite. The nepheline anhedra are xenomorphic towards the feldspar, the latter projecting deeply into the nepheline and on occasions included in it. Microlites of aegirine and arfvedsonite are always present in the nepheline, and, less commonly, small anhedra of these two minerals plus magnetite, aenigmatite, olivine and "blebs" of sodalite. In only a few instances is the pulaskite free of nepheline, but in these cases there is always a high zeolite content in the rock, which probably represents a total pseudomorphing of the nepheline. Birefringent analcime with complex twinning commonly replaces the nepheline. In the cases of complete nepheline replacement, sericite is often associated with the analcime. In only a few cases is a vermicular texture present between analcime and the nepheline host. Natrolite is also quite commonly present as a pseudomorphing zeolite; four varieties are found. Minor stilbite has also been found as a zeolite replacing nepheline. Only in three cases was eudialyte or its pseudomorphs found in the pulaskite; in all three cases the specimens came from the lower part of this rock suite. The eudialyte is interstitial to the feldspar laths. In only one case was the eudialyte not completely pseudomorphed by an aggregate of katapleite plates and analcime.

Chemical analysis of pulaskite (anal. M. MOURITZEN).

	Spec. no. G.G.U. 40102
SiO_2	59,91
TiO_2	0,38
Al_2O_3	16,14
Fe_2O_3	3,24
FeO	3,99
MnO	0,15
MgO	0,06
CaO	1,64
Na_2O	8,46
K_2O	4,88
P_2O_5	0,06
H_2O^+	0,48
$H_2O^÷$	0,10
Cl	0,03
ZrO_2	0,37
rare earths	tr.
Total	99,89

Textural and compositional variations: On the S. side of Tunugdliarfik fjord, where the pulaskite occurs in small plugs and sills, it characteristically develops banding. On the N. side of the fjord banding was noticed only at one locality, 1,7 km E. of Taseq lake. The banding is due to a concentration of arfvedsonite and small amounts of olivine giving rise to dark bands averaging 1 cm thick. Feldspar concentration is responsible for the broader, 2–3 cm wide, light coloured bands (fig. 19). In the thin sheets banding can be developed throughout the entire thickness and may have a lateral extent of 100 m before wedging out into the normal rock.

Fig. 19. Banding in pulaskite. 1 km north east of Nunasarnaussaq.

Sodalite Foyaite.

Macroscopic features: The feldspars usually form laths 1–1,5 cm long × 2–3 mm thick and show no signs of a foyaitic texture. The feldspar laths project deeply into 1–2 cm diameter anhedra of eudialyte, aegirine, arfvedsonite and aenigmatite. Poikilitic texture is displayed by the coloured minerals but rarely by feldspar. 0,5 cm squarish nepheline and 2–3 mm diameter sodalite crystals are included in the coloured minerals and at a few horizons sodalite is included in feldspar.

Microscopic features: The rock-forming minerals comprise perthite, acmitic pyroxene, soda-amphibole, aenigmatite, eudialyte, sodalite and nepheline. Accessory minerals comprise olivine, magnetite, rinkite, astrophyllite, neptunite and fluorite. Secondary minerals are natrolite, analcime, stilbite, monazite, katapleite and sericite.

Normally the feldspars develop a perthitic texture, which is usually micro- and, less frequently, crypto-perthitic. It is thought that all the feldspar was perthitic but interpretation is complicated by the selective analcime replacement of exsolved albite. The separate microcline twin lamellae are elongated parallel to the (010) composition plane and have developed the usual albite chessboard twinning. In addition to this twinning of the microcline there are often large simple twins developed parallel to the (010) composition planes; in one case a large twin was present along the (001) compositional plane. These twins accord with the albite and manebach laws respectively. Hence the microcline can show a double albite or albite-manebach twinning. A maximum of three of these large simple twins was seen in a single lath. The exsolved albite is multiple twinned; the exsolution lamellae are parallel to the (001) direction; usually the microcline:albite ratio is 65 : 35.

Secondary albite is sparingly present; infrequently granules of albite are found at the intersections of perthite laths. Sometimes small albite laths less than 1,0 mm long are found along the (001) crystal edge of the perthites with their c axes making small angles to that of the perthite or else homoaxial with them. Microlites of aegirine and arfvedsonite are always present in the perthites as well as occasional fragments of these two minerals. The prismatic microlites have a strong tendency to be parallel to the c axes of the perthites. Analcime is the commonest zeolite replacing the feldspars. As remarked earlier, the analcime has a preference for albite, as can be seen from the selective replacement of exsolved albite in the perthites. In rare cases there is total pseudomorphing of feldspar by analcime. Natrolite is not as common a replacing mineral in the perthites, but is occasionally present as a narrow fringe at the intersection of two perthites. It is usually present as a fringe along the contact margins of the sodalite and nepheline. The most striking texture developed between the soda-amphibole and acmitic pyroxene in the sodalite foyaite suite is a concentric growth pattern. In the cores a concentrically zoned pyroxene occurs having a neutral brown to pale green pleochroism grading into a pale greenish, barely pleochroic margin. This core is surrounded by a markedly pleochroic dark green rim and finally the whole is surrounded by arfvedsonite. The core corresponds to aegirine-bearing augite (Larsen 1941). Variations between the central core and the margin are:

$$2\,Vz = 64°–74°$$
$$x:c = 32°–40°$$

The homogeneous green pleochroic belt surrounding the aegirine bearing augite core is comprised of a narrow inner transition rim of aegirine-augite enclosed in aegirine. In this latter zone the following determinations have been made (from inner to outer part of belt):

2V x = 92°–74°
Nx = apple green
Ny = pale green
Nz = olive green

Within the outer dark green fringes of aegirine-augite and aegirine minute "bubble" inclusions of fluorite occur and continue a short distance into the arfvedsonite zone, where the fluorite inclusions are larger (0,1–0,2 mm dia.). Outside of this poikilitic zone only occasional large fluorite inclusions occur. Prisms and small irregular crystals, of aegirine project into the outer arfvedsonite zone. The outer arfvedsonite zone is usually markedly pleochroic in patches, tending to be darker along the margin and around inclusions. This is quite a standard pattern for this rock type. Aenigmatite can also be present, projecting into the outer arfvedsonite margin together with sodalite and nepheline; sometimes these two latter minerals are included in arfvedsonite. As many as four centres of aegirine-bearing augite have been seen in a single arfvedsonite anhedron. Occasionally arfvedsonite contains fluorite blebs and is surrounded by a partly homoaxial acmite rim. In other instances aegirine, aegirine-augite and arfvedsonite can be seen with an interference growth; the contacts are frequently marked by an irregular orientated acmite fringe. More commonly aegirine and arfvedsonite form separate small anhedra 2–5 mm in diameter. To a lesser extent aegirine-augite and aegirine bearing augite also form small separate anhedra. In most cases these anhedra show concentric or patchy zoning. Aenigmatite and minor iron staining is often associated with the acmite breakdown. Sometimes minute fluorite inclusions are present along the margins. Arfvedsonite fragments are occasionally seen projecting into the aegirine margins. Olivine, with a rim of magnetite, is sometimes also included in the aegirine. Acmite as a purely secondary mineral also occurs in turbid prism aggregates, which, together with other minerals, pseudomorph eudialyte. The eudialyte, when fresh, is clear and has an irregular patchy birefringence usually outlined by linear boundaries. Occasionally an anomalous blue birefringence is displayed. Minor katapleite is usually present, lining small fractures in the eudialyte. Usually the eudialyte shows heavy alteration. This alteration generally forms an aggregate of katapleite plates, acmite, analcime and specks of fluorite. For the most part sodalite forms phenocrysts having a pseudo-hexagonal outline, (probably dodecahedral); this is the cross-section most frequently seen. Occasional hexagonal prisms occur usually less than 1 cm long × 2–3 mm diameter; these are infrequent. Sodalite phenocrysts, although sparingly enclosed by perthites, are frequently included in the acmitic pyroxenes, amphiboles and eudialyte. The included sodalite is smaller than the interstitial variety in the rock. Between nepheline and sodalite there is an unusual relationship, with irregular small blebs of sodalite lying within the nepheline. Microlites, and less commonly small fragments, of aegirine and arfvedsonite crowd the centres of the sodalite giving the mineral a "dirty" core. In one instance a small clear apatite was seen lying in the sodalite.

Sodalite is usually altered, if only to a small degree, and total pseudomorphing is quite common. The three replacing zeolites are natrolite, analcime and stilbite. When analcime replacement of sodalite occurs, a narrow natrolite fringe often separates the two minerals. In a few cases aggregates of short fibrous stilbite have totally replaced sodalite and nepheline. In these instances natrolite veins can be seen passing through the stilbite. Nepheline forms rectangular to squarish phenocrysts 0,5 cm wide. The nepheline forms inclusions in the acmitic pyroxenes, soda-amphiboles and eudialyte but is only sparingly enclosed in perthites. In exceptional cases perthite projects into the nepheline. Sodalite "blebs" are frequently found enclosed in the nepheline. These "blebs" are rounded, small and irregular, not at all like the euhedral sodalite found elsewhere in the rock. Along the marginal parts of the nepheline a vermicular to micro-graphitic texture is frequently encountered, developed between analcime and the nepheline host. This texture appears to be of secondary origin as it is usually confined to the marginal parts of the anhedra and is only present when the analcime content of the rock is high. Nepheline usually displays natrolite, analcime and less frequently stilbite alteration.

Chemical analysis of sodalite foyaite (USSING 1912, p. 141 No. 5)

SiO_2	49,38
TiO_2	0,63
ZrO_2	0,61
Al_2O_3	17,31
Fe_2O_3	4,20
FeO	5,25
MnO	0,08
MgO	0,53
CaO	2,23
Na_2O	13,87
K_2O	2,55
H_2O	1,46
Cl	1,68
SO_3	–
P_2O_5	–
	99,78
Cl = O	0,38
Total	99,40

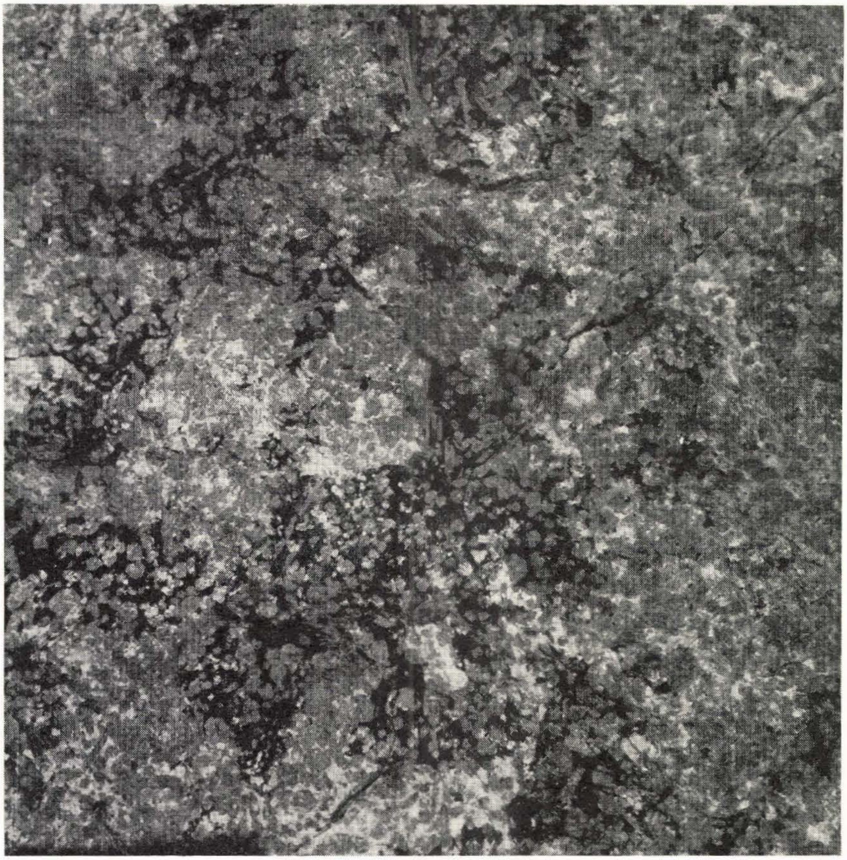


Fig. 20. Poikilitic texture of naujaite. Approx. scale 1:2.

Textural and compositional variations: Eudialyte has an erratic distribution, impoverished and enriched horizons are present.

Pegmatites are rather scarce. Two very coarse conformable pegmatite sheets have been observed on the S. side of Tunugdliarfik fjord. These pegmatites are less than 0,5 m thick and of small lateral extent. Feldspar and aegirine form 10–15 cm long phenocrysts; eudialyte and sodalite form 3 cm diameter phenocrysts. Li-mica is present as 1–2 cm diameter books.

Naujaite.

Macroscopic features: Naujaite is characterized by a poikilitic texture. Poikilitic aegirine, arfvedsonite, feldspar and eudialyte of pegmatitic dimensions have 2–3 mm diameter sodalite inclusions (fig. 20). On an average sodalite forms 35–45 $^0/_0$ of the rock; however, sodalite-rich and sodalite-poor horizons are locally developed (see p. 18).

Microscopic features: The rock-forming minerals comprise perthite, aegirine, arfvedsonite, aenigmatite, eudialyte, sodalite and nepheline. Accessory minerals include monazite, schizolite, apatite, rinkite, li-mica, biotite, pyrrhotite and pyrite. Secondary minerals include natrolite, analcime, britholite, sericite, ussingite, fluorite, katapleite, grossularite, chlorite, mesodialyte, eucolite, neptunite and villiaumite.

An approximate modal analysis was carried out in the field on the naujaite. A tape was used and point counts taken every 1 cm. Six runs were made giving a total length of 5 m.

Dark minerals	Eudialyte	Feldspar	Nepheline	Sodalite
20	4	23	14	39

The dark minerals comprise aegirine, arfvedsonite and aenigmatite and are usually indistinguishable in the field. In all the thin sections examined these three dark minerals were seen to occur in approximately equal amounts. However, frequently one of these three minerals occurs to the exclusion of the other two.

The perthite usually forms large laths 4–5 cm long × 1–2 cm wide; 2–3 mm wide sodalite crystals are usually included in the perthites. In all cases a perthitic texture is developed in the alkali feldspar and varies from micro-perthitic to crypto-perthitic. The proportion of microcline to albite is 70:30. In the perthite the exsolved albite has developed multiple twinning parallel to (010). The long axis of the exsolved albite parallels the (010) direction of the microcline host. The microcline in turn has an albite twinning resulting in a chessboard pattern. The micro- and crypto-perthitic varieties are found towards the top of the naujaite zone. It must be noted, however, that perthite can also be present in the top part of the naujaite zone. The micro- and crypto-perthite varieties do not appear to be present in the lower naujaite zone (i.e. breccia horizon).

Secondary multiple twinned albite is occasionally present, occurring as prisms less than 1 mm in aggregate form. However, it is often found along the margins of the perthites paralleling the (010) direction in the latter, but can occur making small angles to this direction.

The perthites usually display some secondary alteration; in extreme cases there can be total replacement by natrolite and, less frequently, by analcime. The perthites contain many microlites of aegirine and minor arfvedsonite which have a strong tendency to parallel the (010) direction of the feldspar. A cloudy alteration product of the exsolved albite is sometimes present forming quite distinct patches in the perthites.

The arfvedsonite, aegirine, and, in some cases, aenigmatite, make up large poikilitic phenocrysts 5–10 cm wide. Sodalite crystals 2–3 mm in

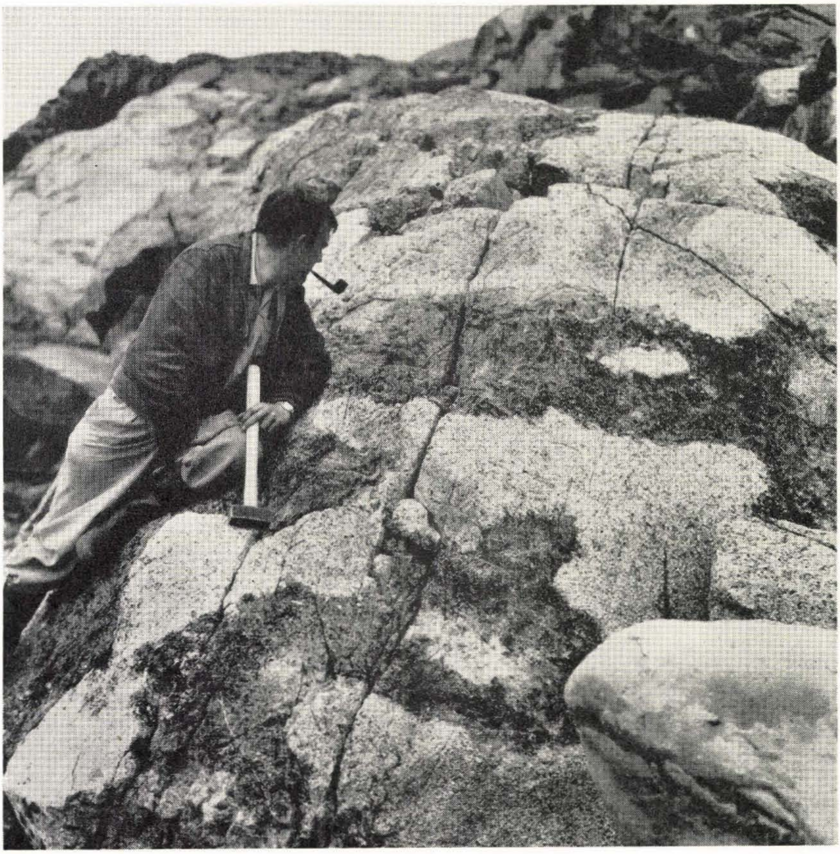


Fig. 21. Giant crystals 1–2 m long developed in naujaite.
South coast of Nunasarnaq.

diameter and sometimes rectangular nepheline phenocrysts are included in these amphiboles and pyroxenes. The anhedra of aegirine usually have patchy pleochroism and a corresponding patchy birefringence. The areas with different pleochroism usually have linear boundaries which make small angles to the (110) cleavage. The colour variation is marked: in darker zones the range is from dark to apple green, while in lighter areas it is from pale green to neutral brownish green. These coloration zones are acmite and aegirine-augite respectively. This breakdown to acmite, or more rarely, aegirine-augite, is probably paulopost and is always homoaxial. The more advanced stages of acmitic break-down are concentrated along the margins of the aegirine. Here the aegirine has been altered into a non-pleochroic neutral brown acmite. In these more extreme cases of acmite breakdown small flakes of aenigmatite (?), minor neptunite and black "dust" are also in association.

The anhedra of arfvedsonite usually have homogeneous pleochroism, often accompanied by concentric birefringent zoning. In some cases, however, the deep olive green to blue-green pleochroism is diluted to a pale blue-green to pale violet brown; this variety is kataphoric hornblende. Kataphoric hornblende, when present, usually has rims and veinlets of arfvedsonite passing through the anhedra. Within the kataphoric hornblende a marked concentric pleochroism is present becoming lighter towards the centre.

In a few extreme cases narrow parts of the arfvedsonite have been locally acmitized leaving only separate remnants of arfvedsonite in the acmite. Minor aenigmatite and neptunite anhedra are associated with this breakdown but can also occur in unaltered arfvedsonite.

The aenigmatite appears to grow at the expense of aegirine and arfvedsonite. The aegirine and arfvedsonite occur as separate remnants, in optical continuity with one another, lying within the aenigmatite. The pleochroism of the aenigmatite, when not entirely opaque, varies from dark brown-red—opaque. In a few cases a very patchy pleochroism was noted in the aenigmatite; alternating areas of dark brown and red-brown occur, both of which become opaque in the Nz position.

At the locality of Sdr. Siorarssuit aegirine and/or arfvedsonite has been converted to ilvaite with associated grossular garnet. Also in this area the aegirine and/or arfvedsonite has been locally converted to chlorite (probably pennine), and in one case a piedmontite aggregate replaces either the amphibole or pyroxene.

(Piedmontite 2Vx = 70°–72°)

The commonest form of aegirine has the following optical properties:

2Vx = 67°	Nx — deep apple green
	Ny — olive green
z:c = 79°	Nz — pale brown to olive green

This corresponds to aegirine (Sabine 1950). Aegirine-augite is sparingly developed. Of the 20 phenocrysts tested for acmite and aegirine-augite, only two phenocrysts proved to be aegirine-augite, and have the following optical properties:

2Vz = 84°	Nx — brown
z:c = 73°	Ny — pale brown
	Nz — pale brown

In two cases optical measurements of aenigmatite were made.

2Vz = 42°	
2Vz = 46°	
z:c = 37°	(Nx — opaque)
	(Ny — opaque)

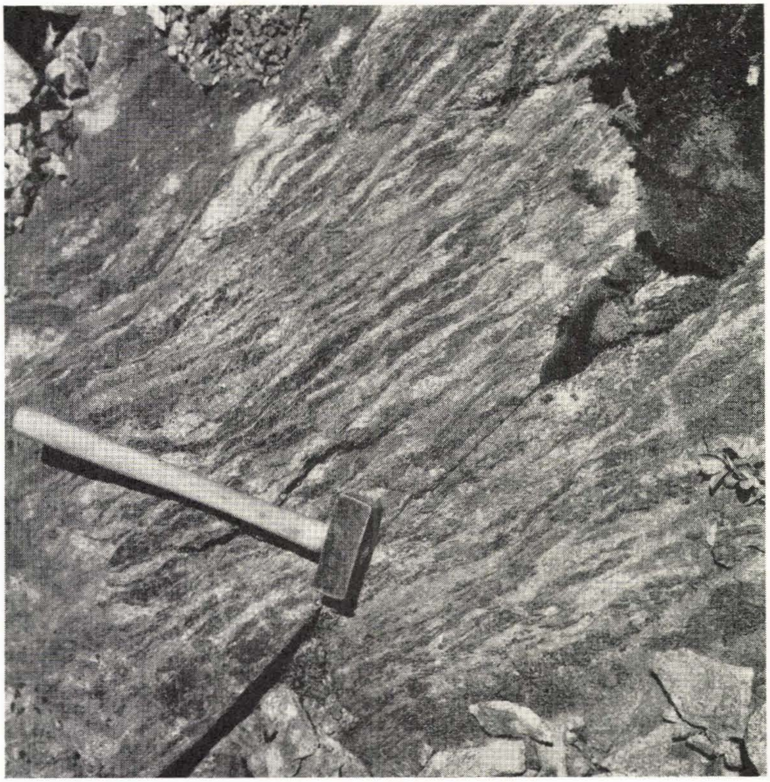


Fig. 22. Stretched naujaite. N.W. of Taseq lake.

Neptunite.

2Vz = 64°	Nx — deep clear red
	Ny — bright orange red
z:c = 7°	
2Vz = 56°	Nx — deep clear red
	Ny — clear brownish red

The eudialyte, in the naujaite, normally makes up large irregular anhedra 5–10 cm wide containing sodalite crystals 2–3 mm in diameter. The unaltered eudialyte is characterized by a light pink colour, particularly if the section is a little thick; otherwise it can be clear. Typically it has a highly irregular fracture pattern and displays patchy or zoned birefringence, sometimes with an anomalous blue interference colour. The zoned birefringence is gradational and usually concentric; the more usual anomalous birefringence is angular. Frequently narrow lines run parallel to the sides of the grains. In a few cases mesodialyte and, in one occurrence, eucolite was seen. Mesodialyte has two forms; in the less usual it is developed at the centre of the eudialyte phenochrysts, the concentric birefringent zoning becoming darker towards the centre with an isotropic core. In the more usual occurrence a dendritic pattern is developed in the eudialyte. The veins comprise the isotropic mesodialyte.

Veins of arfvedsonite microlites are quite common in the eudialyte, having an approximately parallel attitude to one another. These stringers are independent of fracture directions in the eudialyte. Small flakes of arfvedsonite and aegirine are also present as inclusions. These textures appear to be primary.

There are many minerals pseudomorphing the eudialyte. The commonest of these, which is usually present, is katapleite, which is found as thin plates along the numerous fractures in the eudialyte. Katapleite rarely attains a length greater than 1 mm and is usually of microlitic size. Other common replacing minerals which often occur in aggregates are acmite, aenigmatite, monazite, rinkite, britholite, steenstrupine, schizolite, natrolite, analcime and brown dust. Natrolite, analcime and, in one case, a yellow pleochroic mineral (neptunite?) form veins or vugs along fractures in the eudialyte.

Aegirine prisms are frequently crowded along the margins of eudialyte crystals.

Frequently minor mica rosette aggregates occur along or near eudialyte/sodalite contacts, in either of the two minerals.

Accessory schizolite was found to have the following optic axial angle:

$$2V_z = 50°–51°.$$

The usual form of sodalite is 2–3 mm dodecahedrons; occasionally pseudo-hexagonal prisms 2–3 mm thick × 1 cm long are present. These sodalites are included in alkali feldspar, eudialyte, aegirine and arfvedsonite (fig. 16). In exceptional cases a different form occurs in nepheline. In the latter mineral the sodalite has a "corrosive" contact towards nepheline where it penetrates the margin of the latter and is found as "bleb" inclusions in the nepheline. The hexagonal variety of sodalite has not been seen included in nepheline.

Usually microlites of aegirine and arfvedsonite crowd the sodalite, having a tendency to concentrate towards the centre, giving the core a "dirty" appearance. Also commonly present are grains of aegirine, arfvedsonite and, in rare cases, aenigmatite. Occasionally a narrow stringer of aegirine passes through the sodalite. In a few cases, fine aegirine veining demarcates the border of the sodalite.

Fluorite is sometimes present in the sodalite as rounded bodies less than 1 mm in diameter. It is not certain whether these are of primary or secondary replacive origin. It must be noted that when fluorite is present in the sodalite it is usually found in most of the other minerals of the rock. Minute fluid inclusions frequently form stringers in the sodalite.

There are a number of breakdown products of sodalite; it is exceptional to find entirely fresh sodalite. The commonest of these replacing minerals is natrolite. There are a number of forms of the latter. They attack the margin and work towards the core; frequently replacement is complete. The usual form of the natrolite is a dirty brown fibrous aggregate. Sometimes at the periphery of the pseudomorph a narrow fringe of clear natrolite is present. This latter variety of natrolite is made up of plates showing distinct (110) cleavage. In the occurrences where natrolite replacement is ancillary there is a border fringe replacement and also a fine hair veining by natrolite along fractures in the sodalite, and, in some cases, along the cleavage directions. Natrolite is usually present as a narrow buffer between the sodalite and the host mineral. Analcime also replaces sodalite but is less common than natrolite. As in the case of natrolite, analcime replacement first takes place along the margin. When sodalites are in juxtaposition analcime is present along the contact and also penetrates along fine veins into the interior of the sodalite. In many instances a narrow fringe of natrolite separates the sodalite from the replacing analcime. In one section ussingite was seen totally pseudomorphing sodalite. In another it can be seen along the margin and penetrating along narrow fractures in the sodalite. Ussingite is also usually present as a fringe around the fluorite included in the sodalite. Occasionally fine stringers of a colourless mica are also present in the sodalite. Monazite can be seen included as small grains in the altered sodalite.

Nepheline usually makes up irregular to rectangular phenocrysts 0,5–1,0 cm in size. Usually small anhedra of aegirine, arfvedsonite and exceptionally aenigmatite, are present, as well as microlites of the two former minerals. There is only a slight tendency for these minerals to concentrate towards the centre of the grain. At times aegirine and arfvedsonite grains crowd along the margin of the nepheline. Sometimes sodalite is seen corroding the nepheline along the margin but can also occur entirely within the boundary of the nepheline.

In cases where the nepheline is only of minor importance it frequently projects into the perthite.

Not infrequently a peculiar vermicular texture is developed between the nepheline and analcime (or sodalite?). In extreme cases this texture is distinctly micro-graphic. It is difficult to know whether this is a primary or secondary texture. The micro-graphic texture is confined to one margin of one large nepheline grain. However, in the more normal cases where the texture is a little more coarse-grained there is no preference for this intergrowth to take place along the margin. It must be noted that this texture is present when the analcime content of the rocks is high.

As in the case of sodalite the nepheline is subject to alteration, particularly by analcime and natrolite. There is a form of natrolite replacing nepheline which differs markedly from the varieties found replacing sodalite. Along the border of the nepheline a brick red, barely birefringent natrolite is found; this border rarely exceeds 2 mm in thickness.

Analcime replacement is frequently quite severe in the nepheline. Isolated, optically continuous nepheline remnants often lie in a matrix of complex, twinned, birefringent analcime.

Britholite and monazite can at times be seen in and near the margins of the nepheline.

Chemical analysis of naujaite. Anal. M. Mouritzen.

spec. No. G.G.U. 48004

SiO_2	45,43
TiO_2	0,36
Al_2O_3	22,48
Fe_2O_3	3,41
FeO	2,69
MnO	0,12
MgO	0,06
CaO	2,56
Na_2O	16,20
K_2O	3,52
P_2O_5	0,03
H_2O^+	0,66
$H_2O^\div$	0,09
Cl	2,79
ZrO_2	0,15
$\div O_2$ (for Cl)	$\div$0,63
Total	99,92

Discussion on naujaite banding: Banded horizons have been observed throughout the ca. 1000 m of exposed naujaite. The commonest banding seen in the naujaite is produced by compositional variation which is usually associated with textural change. The usual banded sequence is formed of dark bands of aegirine/arfvedsonite concentration, 60 cm–1 m wide alternating with thicker feldspar rich bands (figs. 23 and 24). An occasional 5–10 cm thick eudialyte band can be interspersed in a repetitive sequence of dark and light bands. The poikilitic texture of the normal naujaite is retained in these bands, however; the aegirine/arfvedsonite anhedra usually have different sizes in the two bands. In the dark

Fig. 23. Banding in naujaite. East of Igdlúnguaq.

bands the aegirine/arfvedsonite forms the usual 10 cm diameter anhedra found in the normal naujaite but in the light bands the aegirine/arfvedsonite forms prisms 2–3 cm × 1 cm.

Alternations of aegirine/arfvedsonite concentrations 20–30 cm thick with normal naujaite layers 1 m thick is also a common banding phenomenon. The aegirine/arfvedsonite in the dark bands forms prisms 2–3 cm × 1 cm; the other minerals have a size development similar to that in the normal rock.

Sodalite-rich and sodalite-poor horizons are developed locally in the naujaite. The sodalite-rich bands vary from 0,5–5,0 m thick; the sodalite may form up to 70–80 $^0/_0$ of such bands which have been termed sodalitites by Ussing (*loc. cit.* p. 74). The remaining minerals in the sodalitites can be any of the usual naujaite minerals but only have a skeletal appearance due to the excessive amount of sodalite inclusions. The sodalite is usually of the same dimensions as that occur-

Fig. 24. Close-up of naujaite banding seen in fig. 23.

ring in the normal naujaite, but can be finer grained. Often these sodalitites form isolated horizons within the normal naujaite. However, sodalite-rich bands can alternate with light bands of poikilitic feldspar and eudialyte concentrations; these bands are 20–30 cm thick.

The sodalite-poor horizons occur singly within the normal naujaite and have a non-poikilitic texture. The minerals in these bands are of similar size to those developed in the normal naujaite with the exception of the occasional xenomorphic sodalite crystals which measure a few centimeters in diameter. These bands are 10–20 cm thick.

Lenticular pegmatites less than 1 m thick are sporadically found in the naujaite having conformable relations to the banding. These pegmatites lack a poikilitic texture and can develop crystals 20–30 cm long. Assymmetrical zoning is a common feature of these pegmatites. Eudialyte is concentrated along the lower margin, followed by an intermediate zone of aegirine/arfvedsonite and finally a feldspar-rich zone at the top. In some pegmatites the upper zone is free of eudialyte.

As the naujaite and kakortokites are considered to have had simultaneous crystallizing periods, only at different levels, in the same magma chamber, both rock units must have been subjected to similar pressures. To account for the layered sequence of the kakortokites a rhythmic pressure variation was postulated which must similarly affect the crystallization history of the naujaite. The naujaite banding is interpreted as a manifestation of this pressure variation which was locally influenced by current action.

The commonest banded sequence of dark and light bands with minor associated red bands is interpreted as having formed due to pressure variation. However, the sodalite-rich bands could have been formed during periods of excess sodalite formation and/or efficient flotation processes. Efficient flotation processes could be produced either by strong current action or pressure increase which would increase the density of the volatile-rich magma allowing the sodalite to rise more rapidly. Conversely the sodalite-poor bands could have been produced during short periods of arrested sodalite flotation which allowed the magma to crystallize without the addition of cumulus sodalite. This latter condition may correspond to periods of low pressure or lack of current action in the magma chamber.

The banded naujaite pegmatites have been interpreted by SØRENSEN (1962) as having formed by the accumulation of volatiles in irregularities at the base of the downward crystallizing naujaite.

The naujaite thus represents an example of a flotation cumulate.

Late-stage veining: In the higher part of the naujaite zone natrolite solution-ways are often very noticeable. In the southern half of the intrusion these are particularly well developed in a N.N.W. direction in 10–30 cm wide vertical zones. These natrolizing solutions have also percolated along conformable partings in the naujaite. The sodalite and most of the nepheline in these zones is natrolized. These solutions are probably derived from a volatile phase expelled from the underlying lujavrites.

Kakortokites.

Macroscopic features: The kakortokites are the layered agpaitic rocks exposed in the lowermost part of the Intrusion (fig. 25). The layering comprises rhythmic compositional alternations developed through an exposed thickness of more than 400 m. Black, red and white kakortokites correspond to concentrations of arfvedsonite-aegirine, eudialyte and feldspar respectively.

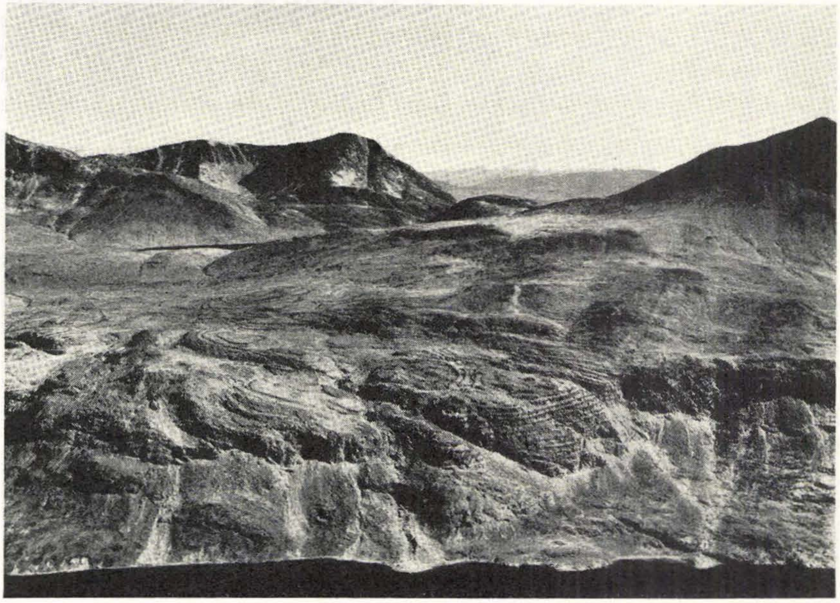


Fig. 25. Kakortokites viewed from Nunasarnaussaq.

There are approximately 25–30 units in the exposed part of the kakortokites. Each unit consists of a black kakortokite layer, overlain by a red kakortokite layer which passes upwards into a white kakortokite layer. This compositional sequence is never varied although the red bands may be inconspicuous. The average thicknesses of the black, red and white kakortokite layers are 1,5 m, less than 1,5 m and 8–12 m respectively.

The layers are considered to have been originally horizontal but, due to slumping, are now gently undulating; they are very persistent laterally and have a constant thickness. A single band can be traced through the whole of the exposed area of kakortokite. The bands maintain their thickness to within 50 m of the margin where they rapidly wedge out into a coarse-grained rock. Where inclusions of older rocks are found in the kakortokites, the underlying layers are compressed. In one instance the layers were seen to be compressed to a depth of 15–20 m and thinned by approximately $^1/_3$ of their original thickness (fig. 27). The overlying layers conformably enclose the inclusions without any thinning on the crests.

The black kakortokites and, to a lesser extent, the white kakortokites, possess a marked lamination. The finer-grained red kakortokites tend to have a sugary texture. The lamination in the kakortokites is produced by the elongated crystals lying in a common plane. There is no lineation in the plane of lamination. The feldspars have a platy habit and are

Fig. 26. General view of kakortokites on Kringlerne plateau.

Photo: F. L. JACOBSEN

Fig. 27. Compression of kakortokite layers due to weight of inclusion. (Reproduced from H. SØRENSEN, 1958)

4 mm long × 1 mm thick in the black and white kakortokites, but tend to be smaller in the red kakortokites. Arfvedsonite and aegirine usually form prisms 4 mm × 1 mm. Eudialyte forms stumpy hexagonal plates, 2 mm × 1 mm, which have a weak tendency to parallel the lamination; in the red kakortokite the eudialyte tends to be granular measuring 0,5 mm in diameter.

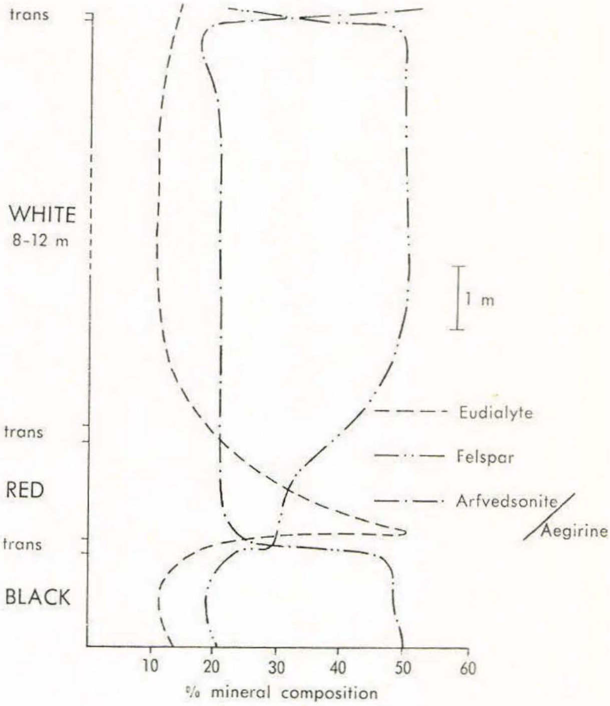


Fig. 28.

In all three types of kakortokite the nepheline content is constant. The interchange of the other rock-forming minerals, for a typical layered sequence, is shown in fig. 28. The transition from white to black kakortokite is quite abrupt, usually taking place over 5–10 cm; in one instance only was a razor sharp contact observed between these two rock types (fig. 29). The mineral proportions within the black kakortokite are constant but there is sharp increase in the amounts of eudialyte and feldspar in the 15–25 cm wide zone transitional into the red kakortokite. In the red and white kakortokite the arfvedsonite/aegirine content remains constant. Eudialyte concentrates towards the base of the red kakortokite layers and the amount varies inversely to the feldspar content on transition into the white kakortokite.

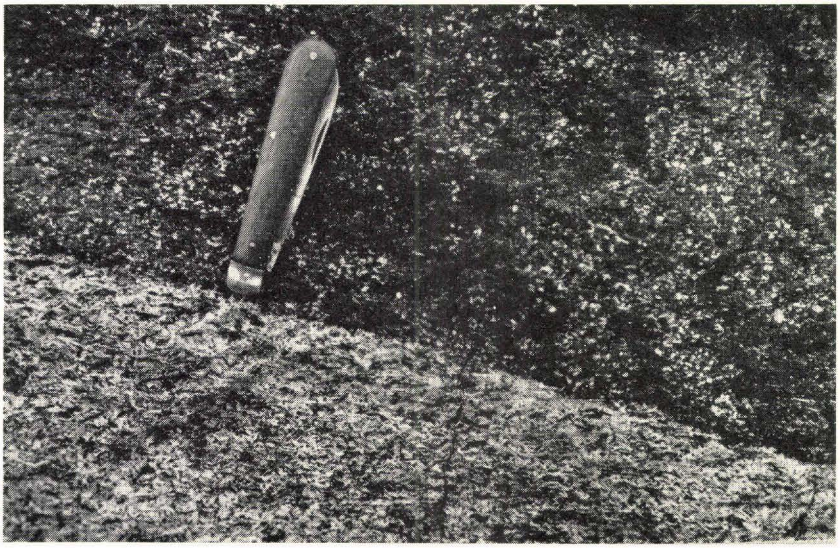


Fig. 29. Unusual razor-sharp contact between black and white kakortokite. Loc. Kringlerne plateau.

Opaque yellow prisms of rinkite are frequently seen as accessory minerals in all three kakortokite types. Disseminated specks of galena with associated pyrrhotite are of common occurrence.

Microscopic features: Estimated mineral percentages. (secondary alteration omitted)

	Perthites	Aegirine	Arfvedsonite	Eudialyte	Nepheline
White kakortokite	50	9	13	10	18
Red kakortokite	36	6	12	29	17
Black kakortokite	18	13	40	11	18

The alkali feldspars in the kakortokites form perthites. The amount of exsolved albite appears to be slightly higher in those perthites from the black and red bands as compared to those from the white kakortokites. In a few cases microcline appears to be completely absent in the black kakortokites. The average exsolution ratio is Ab:Mi = 25:75 in the microcline-perthites. The microcline has developed albite chessboard twinning. Sometimes the microcline texture is further complicated by large simple twinning developed on the (010), or more rarely on the (001), composition planes. A maximum of four of these twins have been observed passing through the length and breadth of a single lath. These twins correspond to the albite and manebach laws respectively. Hence, the microcline can show a double albite or albite-manebach twinning. It is noteworthy that the double twinning of the microcline perthites only occurs if the exsolved albite makes up less than 20 % of the anhedra. However, it does not follow that double albite twinning occurs if there is less than 20 % albite. The optic axial angle for microcline ranges from 78°–84° averaging 2Vx = 81°. The exsolved albite is always multiply twinned. Albite and albite-ala twinning have been measured. The average optic axial angle for the exsolved albites of the white kakortokites is 2Vz = 80°. There is a tendency for albite to concentrate along the peripheral parts of the perthites.

The perthites are included in aegirine and arfvedsonite in the white and red kakortokites and project into nepheline in all three varieties of kakortokites. Microlites of aegirine and arfvedsonite are always present as inclusions in the alkali feldspar.

In addition to the 4 mm long perthites there are common occurrences of fine laths and granules of feldspar which show multiple twinning. They appear to be made up chiefly of albite with a minor scattering of microcline. Aggregates of these fine laths and granules occur at the intersections of the perthites; this suggests a cataclastic origin for their formation.

Occasionally analcime and natrolite marginally replace the feldspars or penetrate along cleavage and fracture directions.

The arfvedsonite and aegirine are non-poikilitic in the black kakortokite but develop poikilitic textures in the white and red kakortokites. In the latter two rock types the arfvedsonite and aegirine contain inclusions of eudialyte, nepheline and perthite. Minor included accessory minerals in arfvedsonite and aegirine in all three kakortokite varieties are microlitic laths of albite and specks of fluorite and aenigmatite. The arfvedsonite and aegirine display a marked patchy pleochroism but homogeneous birefringence.

Arfvedsonite.

Nx = Berlin blue.
Ny = dark blue/brown.
Nz = dark blue/green.
x:c = 45,5° (average).

The optical properties of the aegirine display very little variation.

x:c = 5° (average).
2Vx = 68° (average).

Twinning is not very common in the aegirine and arfvedsonite. Homoaxial acmite is a common alteration product, attacking the arfvedsonite more readily than the aegirine. The acmite tends to align itself parallel to a preferred direction in the host mineral. Usually associated with this breakdown are minute flakes of brown-green biotite.

Aenigmatite is usually included in arfvedsonite, and occasionally in aegirine, occurring as small highly pleochroic (red → opaque) anhedra. Nowhere does it make up more than 5 % of the rock. The red kakortokite is richer in aenigmatite than the other two kakortokite types. In one instance aenigmatite can be seen enclosing nepheline. At certain levels in the intrusion aenigmatite enrichment occurs in the kakortokites.

The eudialyte makes up euhedral to subhedral hexagonal plates averaging 1–1,5 mm diameter in the white and black kakortokite and 0,5 mm diameter in the red kakortokite. The fresh eudialyte is usually clear in thin section or in some cases has a faint pinkish tinge. The eudialyte is included in the aegirine and arfvedsonite of the white and red kakortokite; in the black kakortokite it usually shows an interference growth towards these two minerals, rarely it is included. The high proportion of eudialyte in the red kakortokite has resulted in an interference growth between the perthite and eudialyte producing strongly indented margins in the former. The included eudialyte is usually smaller than the interstitial variety of eudialyte. Towards the nepheline the eudialyte has an interference growth but is rarely included in this mineral; this applies to all three rock types. The eudialyte frequently displays a patchy birefringence and in a few instances strong concentric zoning is present.

The eudialyte has often undergone heavy pseudomorphing but the euhedral outline is usually maintained. The replacing minerals frequently make up a matted aggregate having the following order of abundance: acmite, katapleite, analcime and fluorite. The pseudomorphing is highly selective, fresh and totally replaced eudialyte can occur side by side. This pseudomorphing is most common in the black kakortokite.

The following No determinations are the average values for the eudialyte from the three respective kakortokite rock types.

Black	*Red*	*White*
1.6133	1.6136	1.6092
	(range 1.6018–1.6218)	

Nepheline is always present, usually occurring as phenocrysts of interstitial habit and having a roughly rectangular outline with sides 1 mm long. However, in the white and red kakortokites some of the nepheline is included in aegirine and arfvedsonite; this form is usually half the size of the interstitial variety. Towards the perthites the nepheline is strictly xenomorphic. The nepheline is crowded with microlites of aegirine and arfvedsonite. The alteration products include analcime, natrolite, muscovite and very occasionally cancrinite (?).

Sodalite is infrequently present in the kakortokites having irregular form and appearing to be of secondary origin.

Primary fluorite appears to be present in the black kakortokites, having an interstitial habit. Normally fluorite is found replacing eudialyte.

Rinkite makes up pale brownish-yellow prisms that occur interstitially to other minerals in the rock.

Chemical analyses of kakortokites. (USSING 1912, p. 182 Nos. 13, 14 & 15).

	White kakortokite	Red kakortokite	Black kakortokite
SiO_2	51,62	49,39	48,90
TiO_2	.44	.49	n.d.
ZrO_2	1,70	4,89	1,96
Al_2O_3	15,63	10,39	7,85
Fe_2O_3	6,06	4,31	11,46
FeO	4,98	7,72	13,32
MnO	.33	.97	1,11
MgO	tr.	–	.38
CaO	3,13	5,11	1,95
Na_2O	10,09	11,45	7,40
K_2O	4,19	2,62	3,23
H_2O	2,12	1,46	1,80
Cl	.17	.51	.03
P_2O_5	–	–	–
F	n.d.	.75	n.d.
Total	100,46	100,36	99,39

Discussion on kakortokite banding: In the white and red kakortokite, alkali feldspar, eudialyte and nepheline constitute the cumulus minerals and poikilitic arfvedsonite and aegirine are the intercumulus minerals (WAGER et al. 1960). In the black kakortokite the lack of a poikilitic texture suggests that all the minerals are cumulates.

With the exception of the slight tendency for the perthites to have albite rimming and the rare zoning of eudialyte, the minerals in the kakortokites lack lower temperature compositional zones. A slight cryptic layering (WAGER and DEER 1939) is indicated by the nepheline with a maximum variation of $^0/_0$ $KAlSiO_4$ = 9,6–18,5; there is a decrease of the K molecule towards the top of the kakortokites, no phase layering (HESS 1960 p. 132) occurs.

Some idea of the maximum size of the original cumulus minerals in the red and white kakortokites can be gained from the poikilitic texture. The nepheline and, less commonly, the eudialyte crystals which are included in the arfvedsonite and aegirine are approximately half the size of their interstitial equivalents. As the perthites are only partially included in the arfvedsonite and aegirine the interstitial variety does not show any obvious size difference. In the black kakortokite the lack of zoning and poikilitic texture make it impossible to determine the amount of post-depositional growth the cumulus minerals have undergone.

If the lack of compositional zoning of the kakortokite minerals is taken as an indication of adcumulate growth, the diffusion of magma material and intercumulus liquid must have taken place, at least locally, through a depth of 15–20 m. This is the depth of unconsolidated mush as indicated by the compression of the bands by the weight of a foreign inclusion (see p. 62).

Ussing (1912) advanced the following hypothesis for the formation of the kakortokites ..... "the simplest supposition is perhaps that the recurred layers have originated in consequence of repeated variations of pressure" (p. 361). Experimental work by Yoder (1954) on the system diopside-anorthite-water has demonstrated that such a mechanism can produce layering. Trachytes in the overlying Gardar continental series probably represent an extrusive phase of the Ilímaussaq igneous activity (Ussing *op. cit.* p. 306), indicating that this is probably a high-level intrusion. Intermittent pressure release could then take place by access to the surface through fractures or volcanic conduits. Diatremes have been observed in the Gardar Continental Series.

A small change in position of the eutectic so that arfvedsonite/aegirine crystallized out first would account for the excellent black-red-white layered sequence of the kakortokites, as the minerals are also density layered. Upton (1961, p. 12) considers that the black kakortokites have formed during periods of flow that have been sufficiently strong to retain much of the cumulus feldspar in suspension. As sodalite has floated and feldspar has sunk the density of the magma must lie between the densities of these two minerals. In the agpaitic magma which has a high volatile and water content there would be a density increase with increasing pressure. Rather than magma flow, the sinking rate of the minerals could be retarded by a density increase in the magma; as the feldspar is the lightest of the gravity cumulate minerals its sinking rate would be impeded the most.

Outwash channels or other evidence of the strong convection currents or turbulence which are thought to be responsible for gravity banding in some layered igneous rocks is lacking in the kakortokites.

UPTON (1961, p. 25) claims to have observed small-scale "incipient trough banding" and minor disconformities in the kakortokites, but these were not observed by the writer. Conditions allowing undisturbed accumulative settling appear to have been operative on the floor of the magma chamber. This is in contrast to the Skærgaard Intrusion where strong convection currents operated in most localities, hence the similarity to the kakortokites is not as close as WAGER and DEER (1939, p. 289) have inferred.

The structure of the kakortokites is very analogous to that of the layered series of Rhum (BROWN, 1956), in both cases the marginal wedging out of the bands is evident. In order to account for the absence of structural change on approach to the marginal rock, as recorded from Skærgaard, BROWN has proposed that the layered series was moved upwards into its present position along ring-shaped fractures, lubrication being afforded by the structureless marginal gabbro.

The writer proposes that the banding in the kakortokites was produced by intermittent change in water vapour pressure, release taking place by access to the surface through fractures and volcanic conduits. The periodicity of the water vapour pressure caused displacements of the eutectic of the system with the early formation of arfvedsonite and aegirine at the beginning of each crystallization sequence. The density increase of the volatile rich agpaitic magma with increase in pressure allowed the cumulate minerals to settle slowly and possibly kept the feldspars in suspension long enough to produce the density layering of the kakortokites. Magmatic currents appear to have been of minor importance on the floor of the intrusion but winnowing effects due to current action may have been operative at higher levels in the magma chamber.

Lujavrites.

The lujavrites of the Ilímaussaq Intrusion make up a group of the youngest agpaitic rocks. These rocks are finer grained than the other nepheline syenites of the intrusion, and are further contrasted by developing a strong fissility (fig. 30).

On the basis of mineral composition and texture, they can be divided into 2 main groups and 2 sub-divisions:

Main groups	green aegirine lujavrite
	black arfvedsonite lujavrite
Sub-divisions	"murmanite"[1]) lujavrite
	naujakasite lujavrite

[1]) This mineral probably belongs to the series epistolite-murmanite-lomonosovite but may be a new Nb mineral.

Fig. 30. Typical lujavrite displaying a strong fissility. North of Lakseelv at 400 m.

Macroscopic features: The green lujavrite is a fine- to medium-grained rock with a groundmass comprised of felted aegirine needles measuring 2 mm long. Arfvedsonite needles are usually present in minor amount having a similar size to the aegirine. However, in some horizons arfvedsonite phenocrysts up to 1 cm long occur (fig. 31). If the arfvedsonite exceeds the aegirine content, the rock is termed a black lujavrite. Feldspar usually makes up small plates 2 mm long × 0,5 mm thick. These also display a parallel arrangement. Eudialyte commonly makes up small hexagonal plates, 0,5–1,0 mm in diameter, which are usually a vitreous translucent brown and make up 5–10 % of the rock. Nepheline and sodalite occur as rounded grains commonly 2 mm wide. The weathered sodalite forms bluish "eyes" and nepheline is chalky-white.

Where the 0,5–3,0 cm poikilitic arfvedsonite phenocrysts occur, they enclose all the other minerals of the rock. These phenocrysts appear to post-date the fissility of the rock. Frequently arfvedsonite and aegirine have been altered into a brown acmite.

The black lujavrite is the arfvedsonite-rich rock and has a very similar habit to the green lujavrite. The colour change can vary from dark grey to light grey to grey-green, corresponding to the arfvedsonite

Fig. 31. Green aegirine lujavrite with arfvedsonite nodules.

to aegirine proportion. The arfvedsonite usually makes up needles 2–3 mm long which display a marked foliation but only weak lineation. Minor aegirine needles are usually present in the black lujavrite. The feldspars occur as small plates 1–2 mm long and have their long axes in planar arrangement with the arfvedsonite needles which produces a fissility in the rock. Translucent, brown eudialyte occurs as grains 0,5 mm in diameter. This mineral is often pseudomorphed by a "dirty" aggregate. Feldspathoid occurs as grains averaging 2 mm in diameter. Earthy orange-yellow monazite is disseminated throughout the rock. Acmitization of the arfvedsonite occurs quite frequently.

The "murmanite" lujavrite is found in abundance on Kvanefjeld. This rock is stretched and sharply contorted. The rock is fine-grained and dense with the minerals tending to form stringers. The weathered surface is characterized by streaks, knots, swirls and other compositional irregularities. A few recognizable stretched naujaite and country rock inclusions are present. Aegirine-rich zones measuring a few metres wide are present in this rock. The main mineral characteristic of this rock is "murmanite" in silver-pink rhombs measuring 0,5 cm long × 1 mm thick. Usually there is a yellow star aggregate mineral associated with the murmanite rock, having an average diameter of 1 cm and a maxi-

Fig. 32. Fissile lujavrite folded around naujaite block.

mum of 3 cm. This "star" mineral usually lies in a plane of fissility. Semi-quantative spectrographic analysis of this mineral indicates a high Nb content; the "star" mineral may then be a pseudomorph after "murmanite". The "murmanite" lujavrite is usually present along the margins of basalt inclusions.

The naujakasite lujavrite is quite common on Kvanefjeld where it forms minor horizons rarely wider than 50 m and usually only 5–10 m wide. It is characterized by 1 mm rhombs of shiny silver naujakasite occurring in an acmitic lujavrite. The rock is always highly altered, very schistose, friable, and subject to clayey weathering; the naujakasite is however always fresh and shiny.

Microscopic features: The rock-forming minerals include microcline, albite, arfvedsonite, aegirine, acmite, nepheline and eudialyte, and less commonly "murmanite" and naujakasite. Accessory minerals include monazite, sodalite, mesodialyte, eucolite and steenstrupine. Secondary minerals include biotite, ilvaite, grossularite, analcime, natrolite, muscovite, fluorite, villiaumite, cancrinite (?), katapleite, britholite and schizolite.

Estimated mineral percentages:
(Secondary alteration has been ignored).

	Microcline	Albite	Aegirine	Arfvedsonite	Eudialyte	Nepheline	Sodalite
Black lujavrite	18	13	5	30	9	24	1
Green lujavrite	25	15	28	8	10	13	1

In contrast to the other agpaites the microcline perthites are absent in the lujavrites; here microcline and albite form separate laths. The microcline makes up stouter laths than the albite, having a length: width of 4:1, whereas the equivalent ratio for albite is 8:1. These two feldspars frequently project into the normal arfvedsonite anhedra and are included in the large "nodular" arfvedsonites. The microcline has developed albite chessboard twins as well as occasional double albite and, more rarely, albite/manebach twins. The albite is always multiple twinned; a few determinations indicated albite-carlsbad.

Microcline	Albite
2Vx = 77,5 (average)	An = 3 % (Reinhard curves)

Albite is more readily replaced by analcime than is microcline; in many cases it is completely pseudomorphed. This often makes identification of albite pseudomorphs impossible, hence the figure quoted in the mineral percentage is probably lower than it should be.

Aegirine generally forms very narrow prisms 0,5–1,0 mm long, which tend to form stringers along the boundaries of other anhedra. Sometimes these prisms are bent around phenocrysts through 90°, this bending has been accomodated by fracturing at right angles to the long axes of the prisms.

Arfvedsonite normally tends to form elongated anhedra or stumpy prisms 1–2 mm long. In some of the green lujavrites, arfvedsonite forms distinct poikilitic nodules 0,5–3,0 cm in diameter, enclosing all the minerals of the rock. Thus the arfvedsonite is the last mineral to crystallize in the rock irrespective of whether it is a green or black lujavrite. Twinning is quite frequently seen in the aegirine and, to a lesser degree, in the arfvedsonite. The following optical constants have been determined.

Aegirine	Arfvedsonite
Parallel twinning on (110)	x:c = 41°
2Vx = 63°	
x:c = 11°	

Many secondary replacement minerals of the arfvedsonite and, to a lesser extent, of aegirine are found. The arfvedsonite is frequently partly or wholly altered into brownish acmite. Minor biotite flakes are often associated with this breakdown. In the more extreme zones of alteration the arfvedsonite can be completely replaced by ilvaite whilst the aegirine is unaffected. Grossularite garnet is always in association with the ilvaite.

Nepheline makes up squarish phenocrysts 2 mm in diameter. The surrounding aegirine bends around them, suggesting a rotation of the nepheline during crystallization. Occasionally twinning is displayed by the nepheline. Inclusions in the nepheline are made up of aegirine, and arfvedsonite microlites plus occasional small feldspar laths. Rarely is nepheline entirely fresh. The abundant secondary replacing minerals comprise analcime and natrolite; the latter is almost always present even if only making up narrow rims around the nepheline. More usually, however, replacement is complete. Cloudy replacement by fine muscovite is infrequently present.

The eudialyte in the lujavrites is always shattered and has strain extinction. It commonly comprises phenocrysts 1 mm in diameter varying from euhedral hexagonal to rounded in form, the latter appears to be due to cataclastic action. In a few instances the eudialyte shows strong birefringent zoning and has a pale buff colour. Mesodialyte development takes place in a few of the lujavrites. This latter texture occurs when birefringent eudialyte phenocrysts are shot through by an intricate veining of isotropic to near isotropic mesodialyte. Occasionally a few aegirine and arfvedsonite microlites are included in the eudialyte. There are many alteration products of eudialyte, acmite and katapleite being the most common. The acmite commonly makes up a fibrous cloudy aggregate interspersed with platy katapleite; analcime and fluorite can also accompany this breakdown. Isotropic steenstrupine is found especially in rocks in which the eudialyte is either strongly altered or totally lacking (Buchwald and Sørensen 1961 and Sørensen 1962).

Sodalite is not often encountered in these rocks. Usually it has been subjected to analcime replacement, hence identification can be difficult to impossible. Analcime and natrolite can form a very high content of these rocks; they appear to be secondary after the light minerals.

Fig. 33. Banded green and black lujavrite truncated by auto-intrusion of inhomogeneous lujavrite. Loc. Sarfánguaq.

Discussion on lujavrite banding: The lujavrites form an irregular unit having a total thickness of approximately 200 m. The green lujavrite occupies the lower half of this unit and the black lujavrite the upper half. Banding is concentrated at the boundary of the two lujavrite types in a mixed zone approximately 50 m thick. The lujavrite banding is usually due to compositional change, rarely is there a textural difference. The compositional banding of the lujavrite is produced by arfvedsonite, aegirine or feldspar enrichment. The bands are lens-shaped and may have marked pinch and swell structures. Auto-intrusion has resulted in banded lujavrites being truncated by cross-cutting inhomogeneous lujavrite dikes.

The following rhythmic banded alternations have been observed:

i) Arfvedsonite lujavrite bands in aegirine lujavrite.
ii) Aegirine lujavrite bands in arfvedsonite lujavrite.

Fig. 34. Banding due to alternations of aegirine and arfvedsonite lujavrite.

iii) Feldspar-rich bands in either black or green lujavrite.
iv) Feldspar-rich bands in coarser-grained aegirine lujavrite.

The bands vary in thickness from 1 cm to 15 m, averaging 10 cm. Banded sequences are normally not developed over thicknesses exceeding 30–40 m and are commonly found only within 2–5 m thick zones.

Banding due to alternations of aegirine and arfvedsonite involves no textural variation or density stratification. The contacts are sharp and strictly conformable to the fissility of the rock. At Sarfánguaq these bands are truncated by an inhomogeneous 50 cm wide black lujavrite (fig. 33). In addition to the normal 10 cm thick banding, examples of gneissic structure have been observed.

The banding produced by alternations of dark and light minerals in the lujavrites, does not show any textural inhomogeneities, but displays density stratification. At the base of each dark band with a 10 cm thickness there is a 3–4 mm concentration of pure arfvedsonite; upwards, there is a progressive increase in light minerals (figs. 35 & 36). The dark bands occasionally grade into an overlying white rock with little or no demarcation line; more often, there is a distinct break.

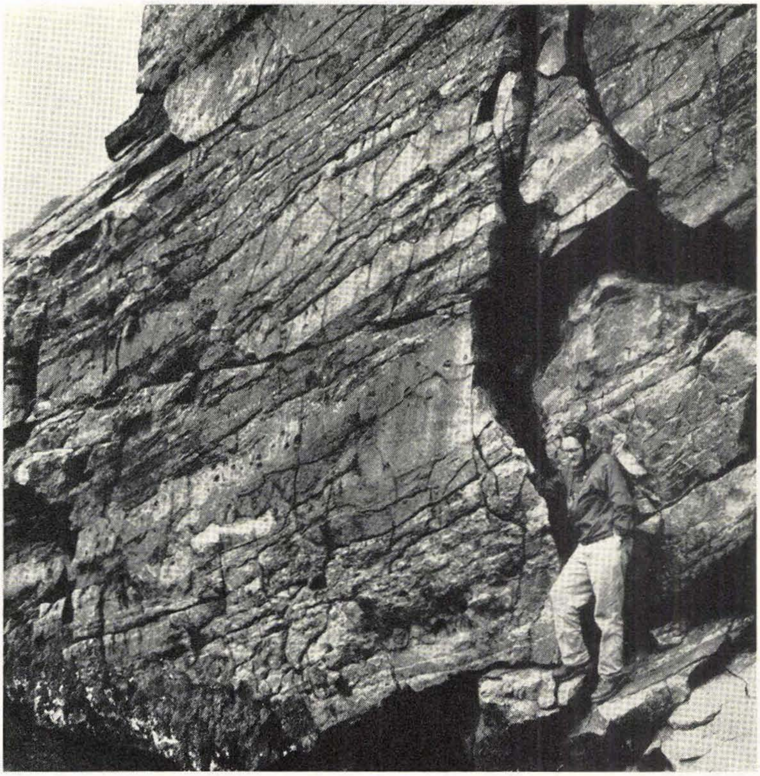


Fig. 35. Banding in black lujavrite produced by alternations of dark and light minerals, at Tugtup agtakôrfia.

Only one example of compositional and textural banding was seen in the lujavrite, occurring 1 km S.W. of Agpat. This occurs in a green lujavrite containing an even distribution of arfvedsonite nodules 0,5–1,0 cm in diameter. Within this nodular lujavrite are light feldspar-rich bands, 50 cm thick, which contain incipient bands of less than 1 cm thickness comprised of arfvedsonite needles, 2–3 mm long (fig. 37).

It is postulated that aegirine, feldspar, eudialyte and nepheline formed cumulus minerals in the residual volatile enriched magma, and gravity accumulated on the floor of kakortokites. The intercumulus areas are thought to have had a high volatile content which kept the floor cumulates in a fluid state. Lack of poikilitic texture and zoning in the crystals give no indication of the amount of post-depositional growth that these minerals have undergone.

After half of this volatile-enriched magma had gravity accumulated, arfvedsonite began to replace aegirine as the dominant cumulus mineral. Alternations in the formation of these two minerals produced arfved-

Fig. 36. Close-up of part of banding seen in fig. 35 showing density layering. Note concentration of dark minerals at base of the black bands.

sonite and aegirine enriched bands. Finally arfvedsonite completely replaced aegirine as the dominant cumulus mineral.

Yagi (1953) inferred that the order in which aegirine-augite or arfvedsonite crystallizes out in a magma depends on the presence of volatile components, especially water, which favour the crystallization of arfvedsonite. The hypothetical stability relations of the hydroxyl and fluorine-bearing amphiboles by Fyfe et al. (1958 p. 162–3) show that at high water pressure hydrous amphiboles are stable. These hypotheses are in excellent agreement with conditions in the lujavrite magma, where an increase in volatiles and pressure presumably takes place in the late residual magma. The density layering could have been produced by variation in water vapour pressure combined with winnowing effects due to magmatic currents.

As a result of faulting and/or sagging, this accumulated crystal mush was compressed and injected into the overlying brecciated rocks

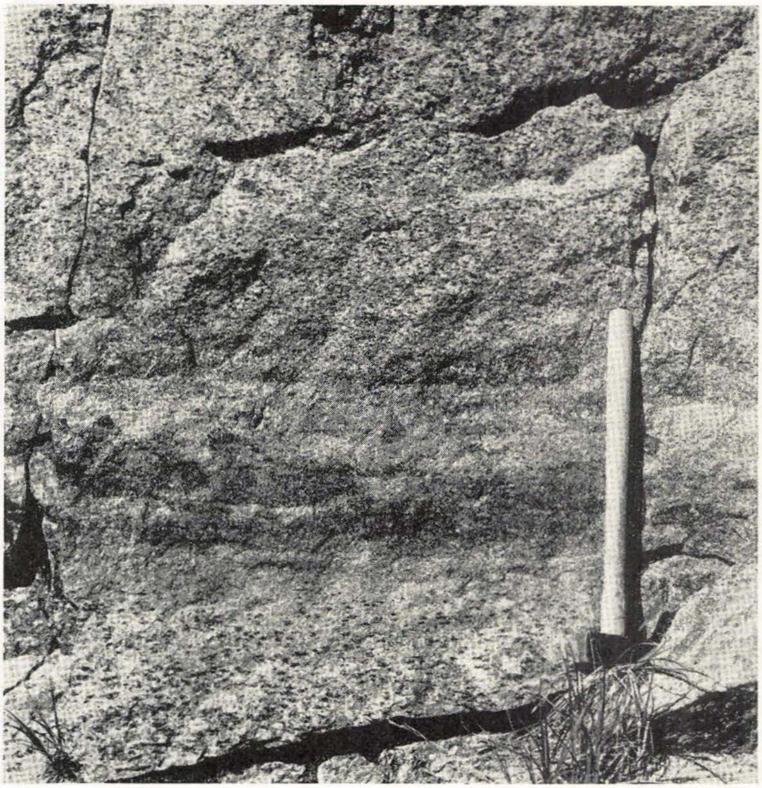


Fig. 37. Compositional and textural banding in nodular green lujavrite.

with final crystallization forming the fissile lujavrites. At least two periods of movement occurred, as indicated by auto-intrusion in the lujavrites. The volatile phase was squeezed out during crystallization to form the late-stage natrolite-analcime veins in the overlying rocks. The minerals in the lujavrites show strong fracturing as a result of this deformation. Aegirine and arfvedsonite can be bent through 90° with zeolites forming fracture fillings.

Numerous inhomogeneities were present in the lujavritic mush due to the compositional fractionation, and the later assimilated inclusions from the overlying brecciated rocks. During deformation, these inhomogeneities have been stretched, particularly in the highly deformed marginal parts of the Intrusion and in the breccia zones. This has resulted in banded gneissic structures in the most deformed areas as well as flow layering. The textural banding is thought to have been produced by size sorting during flowage, a mechanism subscribed to by WILSHIRE (1961).

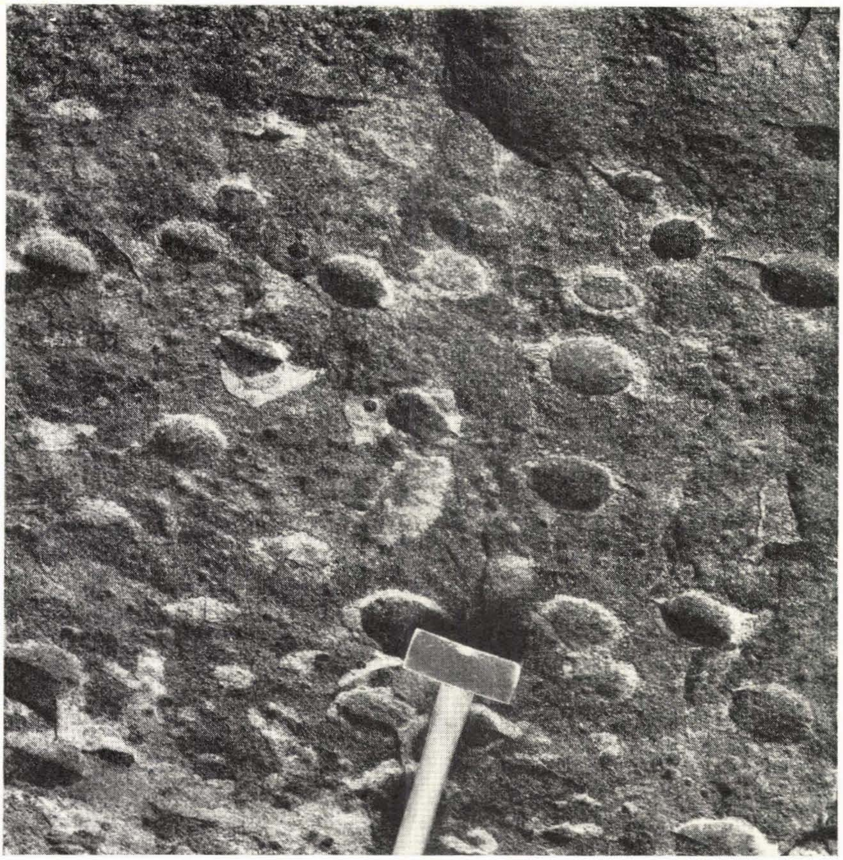


Fig. 38. Analcime nodules with acmite rims, in black lujavrite at Igdlúnguaq.

Nodular structures: At Igdlúnguaq, Tugtup agtakôrfia and Kvanefjeld a peculiar nodular texture was noticed in the black lujavrite. These nodules average 4–8 cm in diameter (maximum 20 cm). They are slightly flattened parallel to the fissility. A pale 1 cm wide corona of acmite and analcime surrounds these readily weathered nodules. The cores of these nodules are made up of analcime plus arfvedsonite needles. These nodules are distinctly ellipsoidal when seen in three dimensions (fig. 38). (See Ussing 1912, p. 82 and Sørensen 1962).

Another type of mottling occurs in the black lujavrite. This is particularly well developed east of Nákâlâq near the border of the Intrusion, where "balls" of feldspar 10–15 cm diameter are set in the more normal lujavrite. These "balls" are probably of secondary origin as the foliation of the rock passes directly through them without bending or distorting.

On the south side of Taseq lake in the river bed, an augen texture was encountered in lujavrite dikes. This was caused by grey/black nodules of lujavrite set in a fine-grained network of black lujavrite. It appears that this augen texture has been a result of movement at the time of emplacement. There is a heavy shearing parallel to the walls of the dikes, as well as a streakiness.

Agpaitic Dikes.

These rocks are fine-grained and dense. The feldspars have been seen to form micro-perthites, microcline (with chessboard twinning) or albite (multiply twinned). Two feldspars co-exist.

Soda-pyroxene, soda-amphibole and aenigmatite are intergrown.

Sodalite is quite abundant, forming larger anhedra than the rest of the minerals.

Nepheline forms small irregular anhedra.

Eudialyte can make up 5 % of the rock and has usually undergone katapleite replacement.

Natrolite veinlets are sometimes present and purple fluorite alteration is common.

Green Porphyry Syenite.

The groundmass is fine-grained and appears to be made up of granules of albite plus abundant acicular aegirine needles. The phenocrysts are micro-perthites.

Augite syenite intrusives.

This rock is fine-grained and there appears to be a development of two feldspars, namely microcline and albite. Augite and neptunite are xenomorphic towards the feldspars; neptunite makes up approximately 5 % of the rock.

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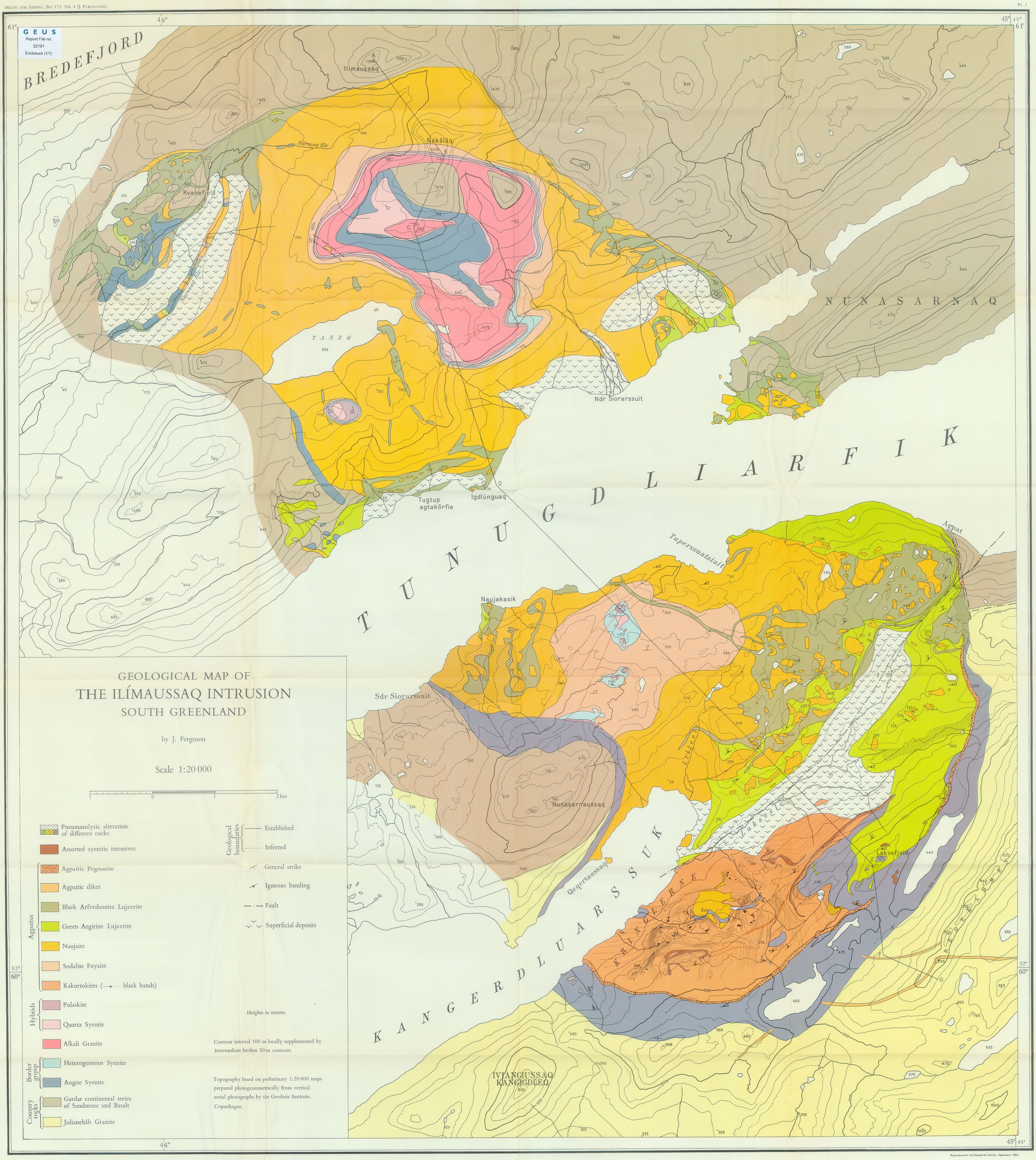
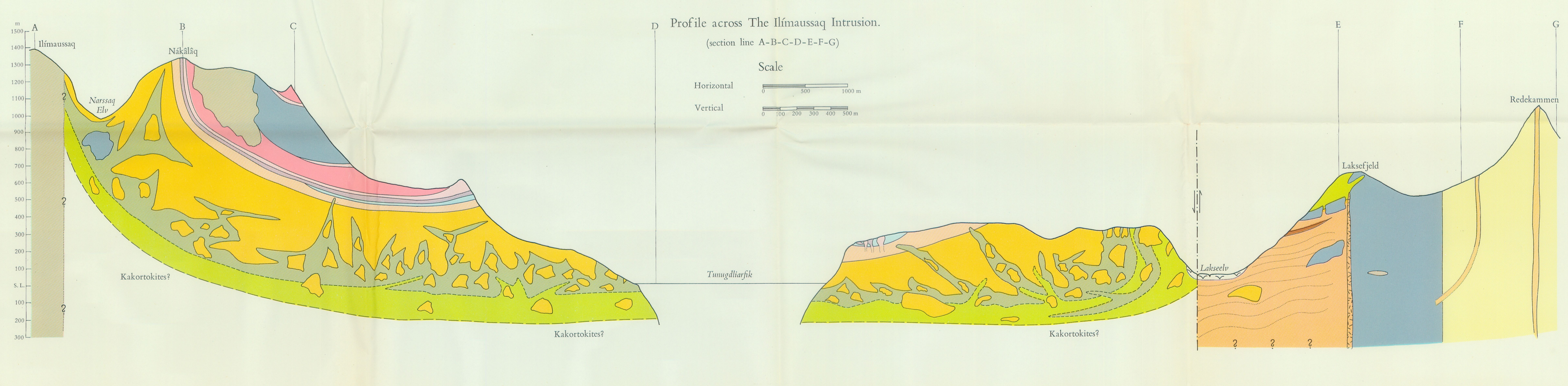
GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

Medd. om Grønl. Bd. 172. Nr. 4. (J. Ferguson). Pl. 1





Profile across The Ilímaussaq Intrusion.
(section line A-B-C-D-E-F-G)
Scale

GRØNLANDS GEOLOGISKE UNDERSØGELSE

THE GEOLOGICAL SURVEY OF GREENLAND