The geology of Qaersuarssuk Julianehaab district south Greenland

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T H E   G E O L O G Y   O F   Q A E R S U A R S S U K

J U L I A N E H A A B   D I S T R I C T

S O U T H   G R E E N L A N D

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Abstract

An area of Precambrian basement with later dyke intrusions is described.

The area is predominately of granite which has been intruded by later basic dykes. Following the intrusion of these dykes there has been reactivation of the granite. This reactivated granite locally shows intrusive features. Gneiss and a little meta-sediment also occur in the area.

Some textural features in the granite are described and interpreted as the result of potash metasomatism leading to the formation of large potash feldspar porphyroblasts in a granodioritic matrix.

The basic dykes (discordant amphibolites) are described in some detail and comments are made on their use for the division of the basement.

The later dyke rocks consist of a variety of types including dolerites, trachy-dolerites, nepheline - micro-syenites, alkali - micro-syenites, camptonites and a single example of a spherulitic soda-rhyolite. Noteworthy among the dykes are a group which contain numerous, large feldspar crystals (up to 50 cm in length) and feldspar aggregates (up to 1.5 m across). Some of these big feldspar dykes are composite with margins of alkali - micro-syenite. As most of the dykes with alkaline affinities are sub-parallel a division is made on their relations to movements along wrench faults. With the exception of the earliest types this gives an intrusion sequence opposite to that expected from alkaline magmas formed by successive stages of fractional crystallization.

Later than all other dykes and all faulting is a dolerite dyke that is characterized by its vertical banding.

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PART I

INTRODUCTION

The field work for this thesis was carried out in the summers of 1959 and 1960 while with the Geological Survey of Greenland. It formed part of their programme of systematic mapping on a scale of 1:20,000 in the Julianehaab District. The island of Qaersuarssuk was allocated to the writer because it would form a suitably shaped unit on a map for a thesis. It was expected to be granite since it lies within the area marked as Julianehaab granite on Ussing's (1912) and Wegmann's (1939) geological maps of southern Greenland.

Accessibility and Location

In Greenland all transport is by boat with the exception of two helicopters used by the Geological Survey for reconnaissance, transportation of supplies to the field camps and the moving of these camps.

The mapping is done in teams of two - a geologist and an assistant - who camp on the area. These field camps are visited about every seven to ten days by a Survey boat or helicopter with food supplies and the opportunity is usually taken to move the camp.

The island of Qaersuarssuk (map 1) lies on the north side of Bredefjord at its seaward end in the district of Julianehaab in southern Greenland. It lies $60^{\circ}59'$ N and $46^{\circ}45'$ to $47^{\circ}00'$W which is the same latitude as the northern part of the Shetland Islands or slightly further north than Bergen in Norway.

The nearest habitation is a group of six houses on Qârusuarssuk 2 kilometres to the west, and the nearest village is Qagssimiut (6 kilometres to the west) which has a population of 180.

The total area of Qaersuarssuk is about 212 sq. km of which about 190 sq. km is land surface. About five months was spent on the area, just over half the area being mapped during the first season.

The exposure is good over the whole area but inland all outcrops are heavily lichen covered though the highest ground around lake 230 is freer. The coastal exposures are excellent and the coast, though a little steep and narrow in places, is well dissected by fjords and islands. Owing to the heavy lichen cover inland almost all the relationships between the rock types are interpreted from exposures on the coast.

Climate

The climate is oceanic being wet and mild during the summer. At Julianehaab the mean July temperature is 7.4°C and at Ivigtut 9.9° while a maximum of 30° has been recorded at Ivigtut. The mean annual precipitation at Ivigtut is 1128 mm of which September is the wettest month of the year with 147 mm while July is the driest summer month with 78 mm. In August the seaward end of Bredefjord has a good deal of fog though it usually clears later in the day.

Flora and Fauna

The vegetation is that characteristic of low arctic oceanic regions and that of sub-arctic regions in the more sheltered localities. The plant cover is normally complete between the lichen (crustaceous species) covered rock surfaces. Low woody plants are the most common - *Empetrum hermaphroditum*, *Vaccinium uliginosum* and *Betula glandulosa* while various species of *Carex* are characteristic of the wet hollows and *Salix herbacea* together with mosses forms a mat in the hollows where snow lies longest into the spring. In the more sheltered hollows there are

Salix spp. to knee height.

The birds seen in the area are not appreciably different to those seen in western Scotland except for the addition of the Lapland bunting (*Calcarius lapponicus groenlandicus*). Ptarmigan (*Lagopus mutus*) and Black guillemots (*Uria grylle*) are both very common and in the northern part of the area there is an eyrie of the White tailed eagle (*Haliaëtus albicilla*). The mammals known are the Arctic hare (*Lepus arcticus*) and the Arctic fox (*Alopex lagopus*), while pike whale (*Balaenoptera acuto-rostrata*) are occasionally seen in the fjords. The larger and faster flowing rivers have 'salmon' (*Salvelinus alpinus*) and cod occur in the fjords.

Acknowledgements

I wish to thank the board of the Geological Survey of Greenland (Grønlands Geologiske Undersøgelse) for the opportunity of working with the Survey in Greenland, Professor K. C. Dunham of the Durham Colleges in the University of Durham and to professor, dr. phil. A. Noe-Nygaard of the Mineralogisk-Geologiske Institut, København for the laboratory facilities in which the work for this thesis was carried out. I also wish to thank Dr. C. H. Emeleus and professor, dr. phil. A. Berthelsen who supervised the work in Durham and Copenhagen respectively, and to the staff and research students at Durham and the staff of the Mineralogiske Institut and Grønlands Geologiske Undersøgelse in Copenhagen and Greenland who at all times have been most helpful. To all I wish to express my sincere thanks.

I also gratefully acknowledge the receipt of a Danish Government Scholarship for the academic year 1959-60 while engaged on the work in the Mineralogiske Institut in Copenhagen.

The Physiography of Southern Greenland

Around southern Greenland there is a coastal strip of ice-free land. It varies much in width: on the east it is only a few kilometres wide (5-15 km) but on the west it is much broader (about 70 km) from Kap Farvel to Julianehaab bay where it is even wider (100 km). North of the bay it is narrower (40 km).

The grain of the country is strongly marked by the fjords which run in two dominant directions: on the east approximately W.N.W.-E.S.E., on the west N.E.-S.W. in the Julianehaab bay area, swinging to N.N.E.-S.S.W. further south. At the southern tip of Greenland the intersection of the two fjord systems has resulted in the formation of a large number of islands.

There is also a large number of islands in the Julianehaab bay area where the dominant N.E.-S.W. fjord direction has been cut across at right angles by faulting.

The relief of the Julianehaab area varies from an alpine morphology to relatively rounded hills, the area being divisible into strandflat and various plateau heights most of which are independent of the geology. At the head of the longest fjords there are a number of nunataqs of considerable height (Aputaiuitsoq and Niviarsiat are both about 2300 m). To the east the land is entirely buried under the ice. The highest peaks of west Greenland occur in the area to the north of Kap Farvel while the areas of lowest elevations are limited to the outer islands.

Morphology of Qaersuarssuk

Qaersuarssuk is classed as 'strandflat and lowermost plateau' by Weidick (1962). The highest point on the island is 435 m but a considerable part of the area is plateau at about 200 m. The island is divided into two by a N.E.

fjord that penetrates two-thirds of the way across the island and is parallel to Bredefjord. Across the northern part of the island there is a long lake, W.N.W.-E.S.E. which follows a fault line. From its eastern end towards Patdlît (fig.1) there is an excellent example of a glaciated valley. The N.N.W. fault system also has a marked effect on the morphology forming fjords and lakes. At the seaward side the islands are formed by the intersection of the two main fjord directions.

Early Geological Investigations in Southern Greenland

Serious geological investigations in western Greenland were initiated by the German geologist K.L. Giesecke in the period 1806-1813. During this time he traversed the whole of the colonized coast with the object of collecting minerals and gathering information on the economic potential of the country. He visited the southern parts of Greenland twice, once in 1806 and again in 1809. His diary was published unabridged in 1910 by K.J.V. Steenstrup, and apart from its importance as a source of information on the history of mineralogy, it is the only detailed travel book comprising the whole of western Greenland.

In 1828 C. Pingel visited Julianehaab and Igaliko and described the red sandstone with its porphyry dykes (Pingel, 1843). In 1876 Dr. K.J.V. Steenstrup, together with Lieut. G. Holm and A.N. Kornerup were commissioned to traverse a specified part of the Julianehaab district and to undertake geological and geographical research (Steenstrup, 1881; Steenstrup and Kornerup, 1887).

In 1900 N.V. Ussing, accompanied by O.B. Bøggild, examined the eruptive rocks younger than the red sandstone and in 1912 Ussing's classic account of the geology and mineralogy of the Ilímaussaq batholith was published.

No extensive work was then carried out in southern Greenland until the summer of 1936 when C.E. Wegmann made a thorough reconnaissance of the area from north

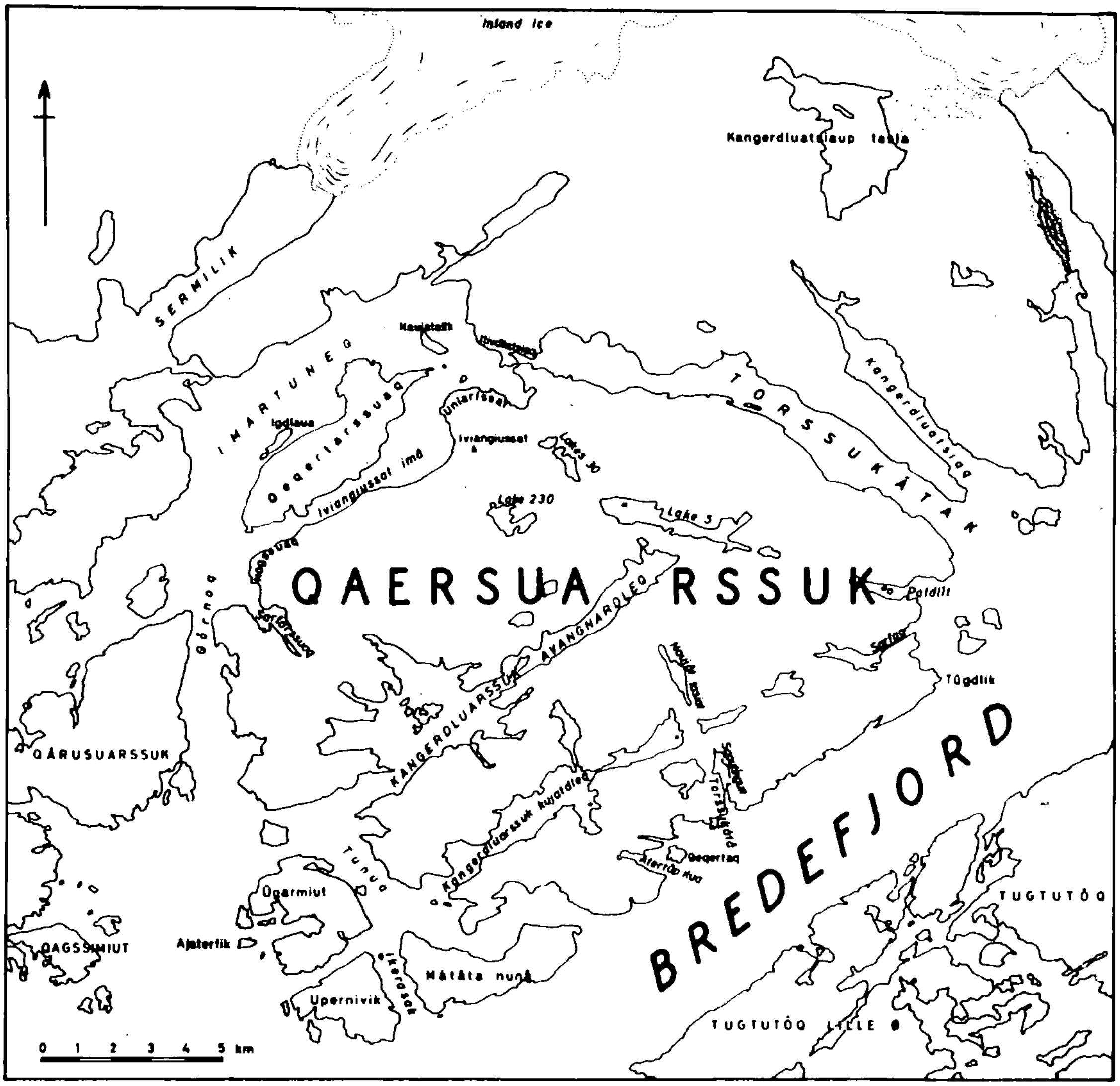

Fig.1. Toponymic map of Qaersuarssuk and its immediate surrounds.

of Arsuk to Frederiksdal. He divided the area into a number of divisions and introduced most of the terminology that is now in use for the different geological periods and series (Wegmann, 1938).

The Second World War naturally put a stop to scientific expeditions to Greenland. Since the war there has been a great deal of scientific activity over the whole of Greenland. The Geological Survey of Greenland (Grønlands Geologiske Undersøgelse) was formed in 1946 and since 1954 has concentrated its activities in west and south-west Greenland. It carried out reconnaissance mapping in the Ivigtut region in 1954-55, followed by regional mapping at a scale of 1:20,000 which was extended into the Julianehaab region in 1958. These investigations have led to our present knowledge of the geology of southern Greenland.

Early Geological Descriptions Pertaining to the Area

It was probably on the 3rd August 1809 that K.L. Giesecke sailed past Qaersuarssuk on his way between Tugtutôq and Qagssimiut. His geological descriptions are very brief and it has not been possible to tell where he examined the rocks. His description - "Die Gebirgsart dieser Inseln ist Granit, in Syenit übergehend, mit Gängen von porphyrartigem Grünstein" - might apply to anywhere in the district (Giesecke, 1878 p.176 & 1910 p.221).

In 1908 N.V. Ussing sailed on Sunday, 5th July from Narssaq to Qagssimiut and passed Ûgarmiut (Tuneĸ), Upernivik and Mátâta Nunâ (Apokatak) and mentions them as being of Julianehaab granite with dolerite dykes (Ussing, unpublished diaries).

A Sketch of the Geology of South-west Greenland

The whole of southern Greenland is structurally an eastwards extension of the Canadian shield. Kranck (1939) pointed out that there are similarities between south-west Greenland and the east coast of Labrador though not all his correlations are now tenable. Recently Berthelsen (1961a) has attempted a more general correlation of western Greenland and eastern Canada.

Wegmann (1938) divided the Precambrian rocks of southern Greenland into two periods, the Ketilidian and the Gardar which are separated by a long period of time, the Gardar deposits being laid down on a deeply eroded Ketilidian basement.

Wegmann divided the supracrustal rocks at the base of the Ketilidian into a lower sedimentary (Sermilik) series and an upper volcanic (Arsuk) series. In the Arsuk Ø and Kobbermine Bugt area (Map 1) this division is still valid, but in the Syd Sermilik area, which is the type area for the sedimentary Sermilik series, the supracrustal rocks are somewhat different and there is no evidence that the two areas are contemporaneous. Since the Sermilik series is named after the southern group of rocks (Wegmann, 1938 p.16) and later redefined (Wegmann,1948) in the southern area the terms Arsuk and Sermilik will not be used in order to avoid confusion. Instead the supracrustal series will simply be referred to as the sedimentary and volcanic series at the base of the Ketilidian.

At the base of the Ketilidian in the Arsuk Ø and the Grænseland areas there is a thick series of sedimentary rocks (Muller and Froidevaux, 1957; Bondesen, 1962) overlain by agglomerates, tuffs, lavas (including pillow lavas and plagioclase porphyrites with intercalated banded semi-pelites and conglomerates and intruded by gabbroic sills (Muller and Froidevaux, 1957; Wegmann, 1938 p.23-30).

Between the meta-sediments, which trend E.N.E. on the south side of Kobbermine Bugt, and the geneisses of Kangek is the area of Julianehaab granite. Most of the granite was formed during the Ketilidian by granitization and migmatization of the supracrustal rocks; green schist and amphibolite enclaves are found in all stages of digestion and replacement by the granite.

Four periods of basic dyke intrusion are recognized in the basement prior to the Gardar dykes. The first of these has only been recognized in the meta-sediments of Kobbermine Bugt and may be contemporaneous with the aerial volcanic rocks. The others are intruded into granite; the second being granitized by a later reactivation of the country rock granite (the Senerutian reactivation). The third period is cut by aplite and pegmatite dykes while the fourth is later than them and has only been metamorphosed.

While most of the Sanerutian reactivation in the area of the Julianehaab granite is slight and only recognized as veining of the second period basic dykes elsewhere it has the form of granitic intrusions. These include the granites of western Sánerut, Storø, Tigssaluk etc. A recent age dating (Moorbath, Webster and Morgan, 1960) on a granite from Julianehaab which has probably been affected by this reactivation gave an age of 1590 ($\pm$ 70).10^6 years.

The Ketilidian was followed by a long period of peneplanation before the initiation of the Gardar sedimentation.

The Gardar comprises 2500 m of continental sandstones (Igaliko sandstone) and basaltic lavas accompanied by dykes and plutons. The dykes are developed on a regional scale as far north as Frederikshaab glacier.

The dykes are abundant and particularly wide (200-800 m) around Ivigtut, Nunarssuit and Tugtutôq. These are also the sites of upper Gardar plutonic centres.

The dolerite dykes are the most widely developed but there are also lamprophyres, trachy-dolerites and alkaline trachytes. In the giant dykes, which run in a N.E. direction, gabbro and syenitic types are found. The strictly plutonic rocks include gabbro, augite-syenite, nepheline-syenite with associated carbonatites, foyalite-granite, soda-granite and 'rapakivi' - granite in addition to the agpaitic rock types of Ilímaussaq (Ussing, 1912).

The faulting, in the region between Sermiligârssuk and Igaliko Fjord, is mainly Gardar and movement continued throughout this period as is seen from the relations of the various dykes with the fault movements. The larger E.S.E.-W.N.W. to S.E. faults may show a total sinistral displacement of up to 25 km showing that there was considerable east-west stretching.

Younger than all the Gardar dykes are the igneous complexes of Kûngnât (Upton, 1960), Nunarssuit (Harry and Pulvertaft, 1963) and Ilímaussaq (Ferguson, 1963; Ussing, 1912). Of these the Nunarssuit intrusion is possibly the largest, though the size of the Igaliko intrusion to the east is not known and may be larger. Isotope dating has been carried out on rocks from upper Gardar intrusions and this gave an age of $1300\text{-}1100.10^6$ years (Moorbath, Webster and Morgan, 1960).

In the coastal districts dolerite dykes occur parallel to the coast, these cut all the Gardar rocks and are unaffected by faulting. They are generally confined to the seaboard and dip seawards. A Tertiary age has been tentatively proposed for them (Berthelsen, 1961b). If a Tertiary age for these dykes is substantiated there is a considerable time gap between the Gardar and the post-Gardar dykes as the former are well in the Precambrian. Apart from these few post-Gardar dolerite dyke intrusions no other geological activity is recognizable in south-west Greenland after the Gardar until the Quaternary glaciation and its subsequent affect on the landscape.

PART II

THE BASEMENT

Introduction

The basement rocks of Qaersuarssuk are principally granites and gneisses. These were formed from supracrustal rocks and possibly some reactivated pre-Ketilidian rocks during an orogenic period that has been termed the Ketilidian.

The Ketilidian period, named by Wegmann (1938) after Ketilsfjorður, the Norse name for Tasermiut "... where the old folds are comparatively well exposed ..." (p.13), affected the whole of southern Greenland.

Supracrustal rocks are represented on Qaersuarssuk by a small thickness of meta-sediments. The area is too small to be able to say where it fits into the chronology of the sedimentary and volcanic series at the base of the Ketilidian.

In the Ivigtut area the Ketilidian orogeny is divisible into three phases of which the latest is the most easily traceable and possibly the most important (Berthelsen, 1960, 1961b) with axes trending N.E.-S.W. The meta-sediments and gneisses on Qaersuarssuk have this trend.

Following the orogenic period and the formation of the syn-kinematic granites and gneisses there was a period of basic dyke intrusion. A number of generations and possibly periods are present on Qaersuarssuk but later reactivation of the granite has metamorphosed the dykes and, in places, partly replaced them. A reactivation of the granite following the emplacement of basic dykes (called the Kuanitic dykes) has been called the Sanerutian period of reactivation (Berthelsen, 1960). Since it has not been possible to trace with certainty the Kuanitic dykes of the Ivigtut area southwards into the Kobbermine Bugt area a more precise definition of the Sanerutian is required. Watterson (1963) redefines it as that granitization and reactivation of the granite which affected the second period of discordant amphibolites in the Kobbermine Bugt area. The division of the discordant amphibolites and the redefinition of the Sanerutian appears to be applicable further east including Qaersuarssuk.

Meta-sediment

A strip of semi-pelitic meta-sediment about 0.5 km wide forms the promontory of Uniaríssat in the north-west part of Qaersuarssuk (map 2). On the most western nose of the promontory it is a well bedded meta-sediment striking about 055° with a dip of 70° to the S.E. The beds are very regular, from a few millimetres to 15 mm in thickness, of various shades of grey and green depending upon the epidote content. Some of the darker beds are more competent than the others and form lens-shaped boudines (fig.2) which frequently contain epidote nodules at their centres.

On the south side of the nose to the promontory, within the area of the semi-pelitic meta-sediment, there are two concordant beds each about 20 m thick of meta-arenite.

In the bedded meta-sediment there is an example of what is either a sedimentary discordance or a small shear bringing together horizons of slightly different lithology at different attitudes. The discordance is about 20°. A thin pegmatite vein follows the contact for part of the way; the rest is sharp (fig.3). If it is an original sedimentary feature it will give the 'way-up' of the beds, but there is no other evidence to corroborate the interpretation and small shears are very likely to occur in this type of metamorphosed terrain. If it is a sedimentary discordance the younger beds are to the S.E.

To the east of the meta-arenite beds, at the base of the nose to the promontory, there is a hornblende-magnetite schist with small folds which plunge about 12° in a direction 076°. The folds have quartz-feldspar segregations in their hinges which were formed, therefore, at the time of folding. But in this same schist there are lenses of quartz-feldspar that are set diagonally across the foliation in the schist (figs. 4 & 5). These are most marked on the vertical surfaces while on the horizontal surface they are nearly at right angles to the foliation. They are probably due to a horizontal couple (cf. Wilson, 1951) producing

Fig.2. Boudins in the meta-sediment at Uniarı́ssat.

Fig.3. A discordance between two horizons of meta-sediment at Uniarı́ssat. Pegmatite follows the discordance for part of the way; the rest is sharp. If it is an original sedimentary discordance the horizon to the S.E. (with the hammer on it) is the younger.

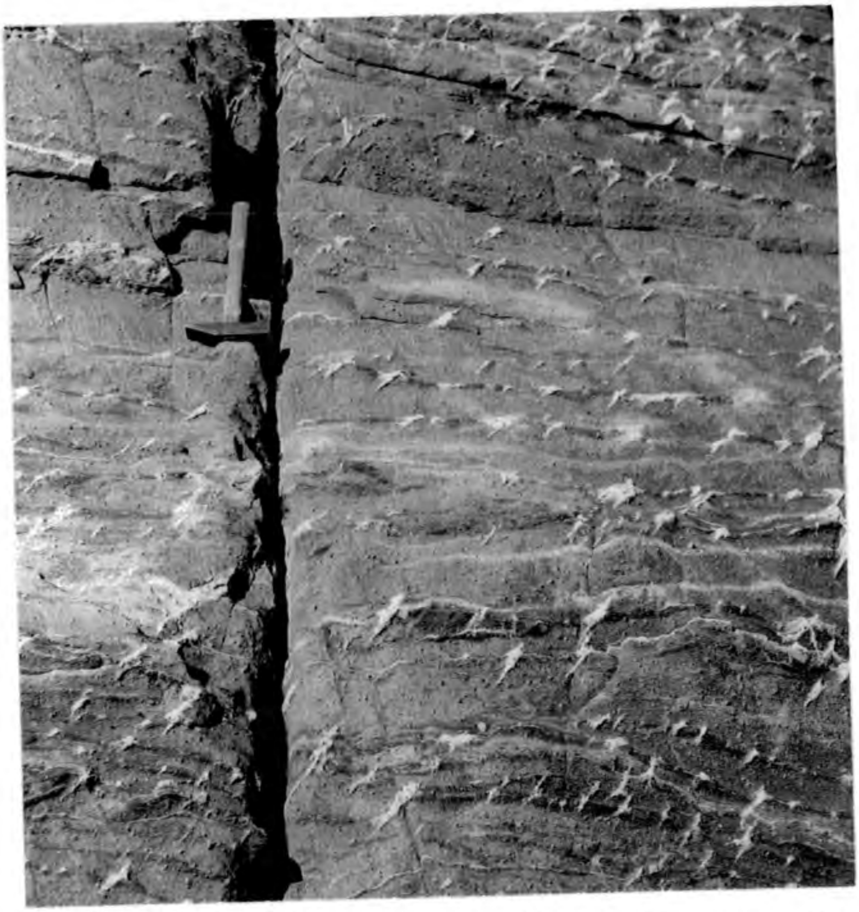

Fig.4. Quartz-feldspar lenses diagonally across the foliation of the hornblende schist. Vertical surface near the top of the photograph, horizontal surface in the bottom half of the photograph. Uniaríssat.

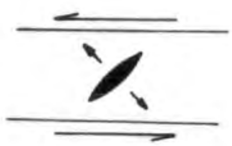

Fig.5. Diagram of the orientation of tension cracks in relation to the couple producing them.

small tension cracks.

On the northern side of Uniaríssat there is a sharp contact against granite. Most of the contact appears to be sharp but on the point at 01/580029 there is a 15-40 cm zone that is intermediate in composition between the granite and the meta-sediment (q.v. p.80).

Along the coast from a point about one kilometre west of the outflow from the lakes 30 there is poorly exposed meta-sediment.

At 01/582029 there is locally a possible conglomerate but the 'pebbles' are very sheared and there is abundant epidote; some of the 'pebbles' could possibly be explained as epidote nodules. Another possible conglomerate or agglomerate is found on the west coast by Qôrnoq (00/507955). Here there are vertical 'lenses' elongated vertically of finer grain and darker grey than the more granitic groundmass. There is a strong vertical foliation throughout.

Approximately one kilometre to the S.E. of Uniaríssat there is a second strip of meta-sediment 1.5 km long which at its western end is 200 m wide but tapers out in an E.N.E. direction. Much of it is a deep green in colour, parts are banded like the meta-sediment at Uniaríssat, parts are amphibolitic. Epidote nodules and hornblende porphyroblasts are common and it is veined by a pink pegmatite and later cut by fine epidote-filled shear planes. To the south the contact against the siliceous gneiss is quite sharp; to the north it is vague.

Between the two areas of meta-sediment there is a weakly banded siliceous gneiss. To the south of the southern of the two meta-sediment bands the siliceous gneiss becomes more granitic with the presence of occasional small feldspar porphyroblasts. It is suggested that the siliceous gneiss has been a more massive rock and richer in quartz than the bedded meta-sediment and that on feldspathization it became more granitic in appearance. The bands that can be distinguished in it have a similar orientation as the banding in the meta-sediments.

Although the meta-sediments are best displayed at Uniaríssat it is not the only area. At 00/572984, on the high ground between Kangerdluarssuk avangnardleq and Iviangiussat imâ, there is a strip of meta-sediment, elongated in a N.N.E.-S.S.W. direction, isolated in the streaky gneiss. At its northern end it is a bedded sediment (fig.6) with occasional boudins and showing distinct traces of migmatization; towards the southern end it is amphibolitic (fig.7). There is a fairly constant orientation of the beds, ca.025/35NW. Just as in the meta-sediment at Uniaríssat the more competent layers are boudinée while pegmatitic segregations are common throughout the rock. In the southern amphibolitic part the streaks in the amphibolite have a similar strike but a steeper dip. It is fine grained, grey in colour with pegmatitic veins accentuating the foliation in the amphibolite.

By the inland ice an enclave of bedded meta-sediment distinctly shows three episodes of deformation: first a strong foliation followed by a shearing that merely crinckled the foliation along the line 2 (see figs. 8 & 9) and finally an apparent sinistral shearing along the line 3 with an important vertical component accompanied by pegmatite along the shear planes. In this enclave the foliation is parallel to the original lithological layering as amphibolitic bands (a in fig.9) are parallel to the foliation. Elsewhere there is a marked foliation of the meta-sediment followed by boudinage of the more competent layers with the accompaniments of pegmatite, and this becomes a migmatite (cf. fig.6) when the meta-sediment is more completely broken up.

The bedded meta-sediment at Uniaríssat is cut by dilation dykes of pegmatite. These were presumably emplaced after the formation of the boudins in the meta-sediment and discordant amphibolites (q.v. p.85) as they do not show signs of boudinage structures. But there are a few granitic veins that are boudinée. The quartz-feldspar filled tension cracks were possibly formed at the same time

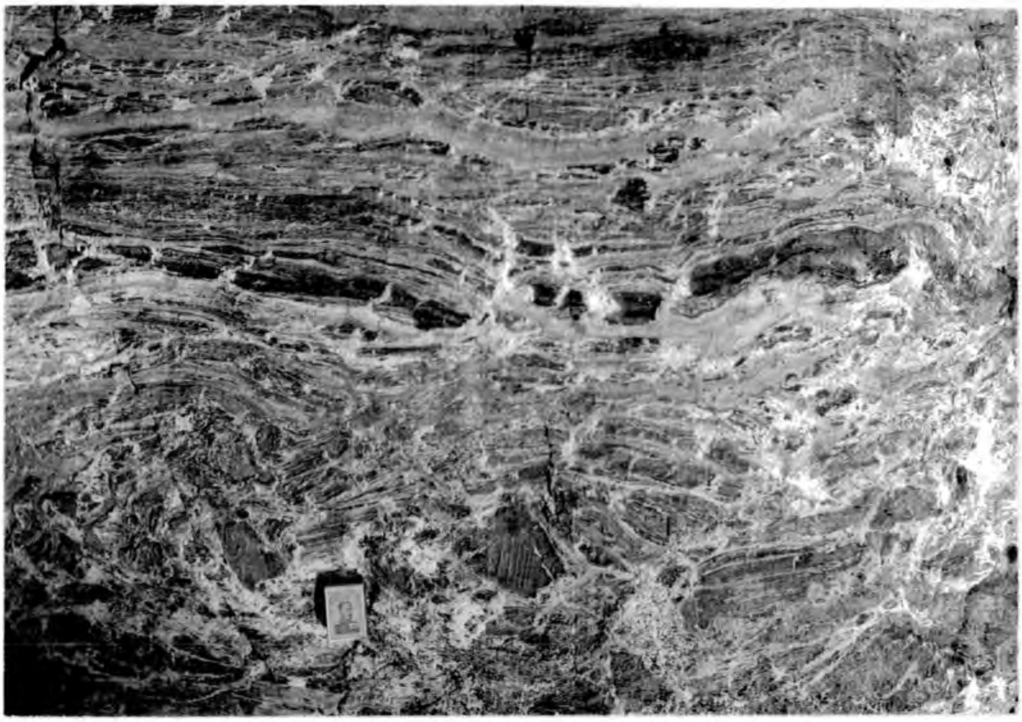

Fig.6. Bedded meta-sediment at the northern end of the strip of meta-sediment at 00/572984 showing migmatization.

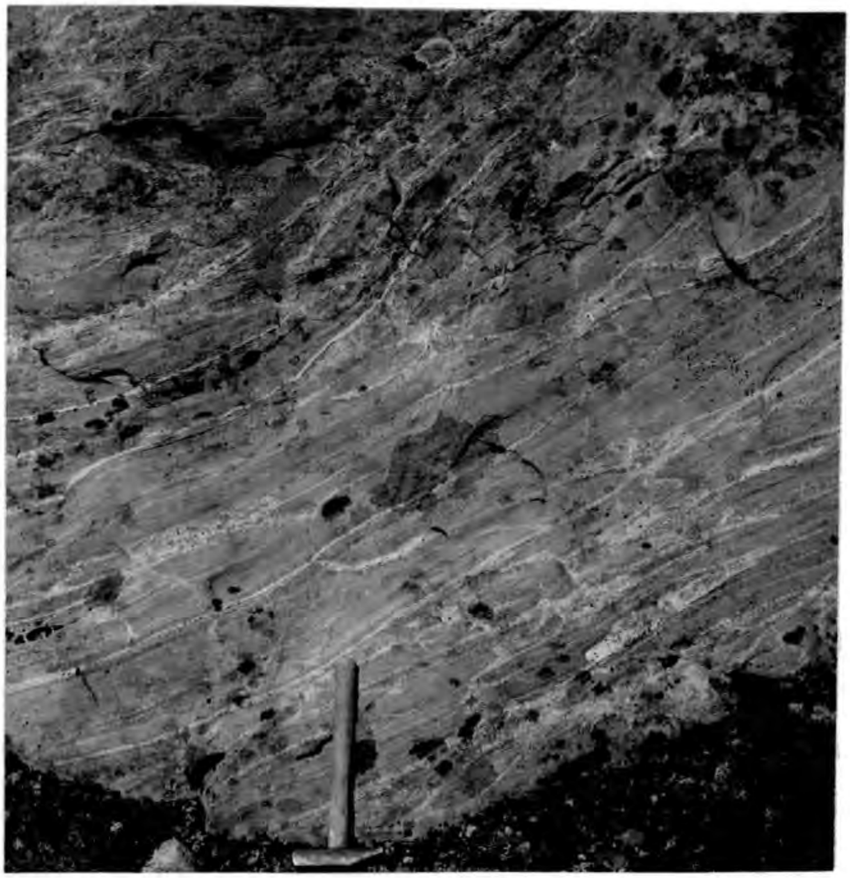

Fig.7. Amphibolitic meta-sediment at the southern end of the strip of meta-sediment at 00/572984.

Fig.8.

Figs.8 and 9. A block of bedded meta-sediment by the inland ice showing three episodes of deformation - see text p.16.

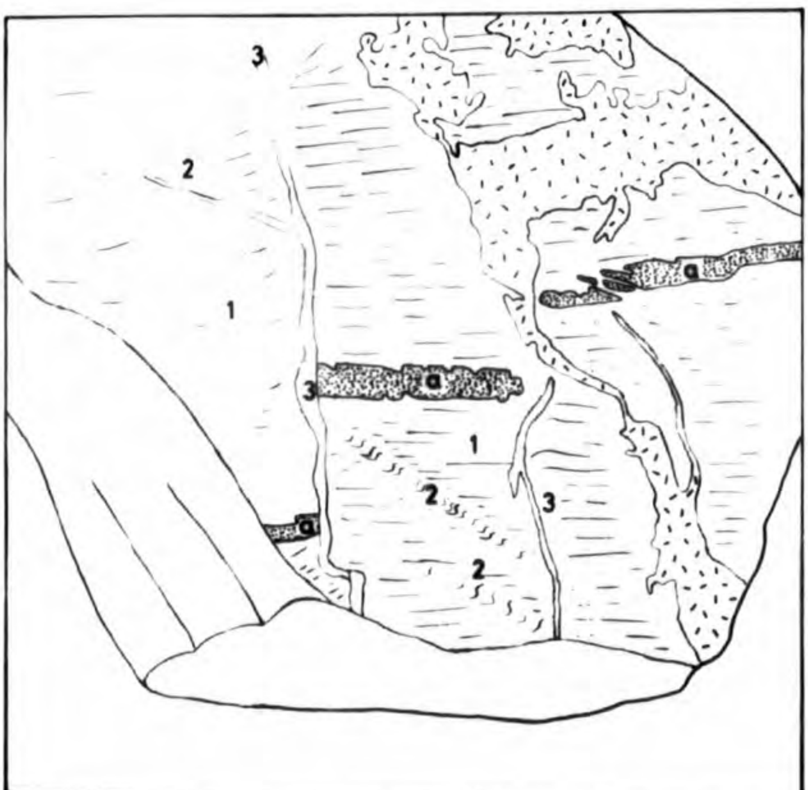

Fig.9.

as the boudins in the beds.

A number of tiny isolated examples of meta-sediment are known from various parts of the area, notably from Ûgarmiut and its associated islands. Here, on the island of Ajaterfik there are three disoriented pieces of bedded meta-sediment in a homogeneous granite. Other occurrences are such as those illustrated by fig.10 where there has been an apparent rotation of the fragments. In fact, a very large number of the dioritic, amphibolitic and biotite schist enclaves found in the granite throughout the island are probably the remains of supracrustal rocks. The presence of a skarn zone with garnet in inner Sarfarssuaq is also indicative of a sedimentary origin.

The meta-sediment at Uniarı́ssat is only one of a number of small areas of meta-sediment that occur within the area of the Julianehaab granite. They are similar, though not identical, to the meta-sediment at Kobbermine Bugt (Watterson, 1963) and Arsukø (Muller and Froidevaux, 1957). A feature of interest is that at Kobbermine Bugt, Uniarı́ssat and at Sortø (an island in the Pârdlît group between Hollænderø and the Julianehaab peninsula) the beds are all younging south-eastwards. The evidence for this at Uniarı́ssat is based on only a single relationship but at the other two localities the relationship of the older and younger beds is well established. All the occurrences have a similar strike, the typical N.E.-S.W. Ketilidian trend. The regularity of the spacing of these isolated areas suggests troughs between granite cores of folds about a N.E.-S.W. axis (Allaart, personal communication).

Petrography

The bedded meta-sediment consists of semi-pelitic, psammitic and amphibolitic horizons. They have been subject to metamorphism of almandine-amphibolite

Fig.10. An enclave, with the appearance of banded meta-sediment, within the banded gneiss in the south-west of Ûgarmiut (00/524868), which shows a clockwise rotation.

Fig.11. Granitic gneiss with dictyonitic structure.

facies (Fyfe, Turner and Verhoogen, 1958 p.218) and migmatization.

The semi-pelites at Uniarissat (cf. sample 45341*) are made up of layers consisting mainly of quartz and plagioclase with microcline, biotite and hornblende together with accessories of sphene and opaque material while epidote is confined to certain layers.

G.G.U. 45341	a. (bed without epidote)	b. (bed with epidote)
Quartz	† 31%	4%
Feldspar	30	56
Hornblende	18	32
Biotite	11	0.5
Opaque material	8	1
Sphene	2	2
Epidote	0	5
	100%	100.5%

The plagioclase occurs in grains about 0.1 to 0.5 mm across and has a composition of oligoclase-andesine. Myrmekite on a pedestal of plagioclase forms lobes into microcline (cf. Oyawaye, 1959).

The hornblende frequently occurs as small grains (0.2 mm) but may form large poikilitic grains up to 0.5 mm. It is pleochroic with α pale yellow-green, β green and γ deep apple green. The biotite flakes lie parallel to the bedding planes. It is pleochroic with α very pale yellow to γ olive green. The presence of epidote in certain beds indicates a difference in the calcium content. Much of the epidote has probably been derived from the sericitization of the plagioclase.

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* The numbers refer to samples in the possession of Grønlands Geologiske Undersøgelse.
† All modal analyses are expressed as volume per cent.

The presence of epidote is probably also indicative of retrogressive metamorphism.

In the horizons of meta-arenite the mica is mainly phlogopite with a random arrangement. The biotite shows alteration to a colourless mica and excess iron is present as opaque grains along its cleavage. Since the arenaceous layer is more competent than the semi-pelites it shows much more the effects of shearing with sericite along the shear planes. It has the following mode:

G.G.U. 45403

Quartz	55%
Microcline	29
Plagioclase	2
Micas	14
Opaque material	0.2
	100%

The grain size and proportion of quartz to microcline varies in different bands. Most of the grains are small and equidimensional (0.1 mm) but the coarser parts, which are almost entirely of quartz, are larger (0.5 mm) and intergrown with one another. Most of the quartz shows undulose extinction and many grains show slight dusting but none have clear outer rims showing later additional growth (cf. Coombs, 1950, p.374).

On the east coast of Qeqertarssuaq, opposite to Uniaríssat, there is a meta-arkose of very similar texture to that of the meta-arenite at Uniaríssat. It has not been affected by late shearing and has a pronounced lineation of the mafic minerals, mainly biotite (with alteration to chlorite (including penninite) and prehnite) together with a little colourless mica. The grains are equidimensional (0.2 mm) with a tendency for the quartz grains to be rounded.

A very similar rock occurs on the southern side of the outflow from the lakes 30. It is tinted pink, probably due to hæmatite, with a very faint banding. This is presumably also a meta-arkose though no sign of the original texture now remains. The grains are equidimensional with highly sutured boundaries.

The semi-pelite from the enclave within the streaky gneiss is of particular interest as a more detailed history can be read from it. It has a foliation imparted by the horne-blende grains and parallel to this there are veins of microcline-quartz - the effect of migmatization. This was followed by the growth of biotite flakes with various orientations indicating that here they have grown after a relaxation of the early stress conditions though elsewhere these stress conditions appear to have continued since the biotite has a strong foliation. Further diaphthoresis resulted in saussuritization of the plagioclase with the growth of epidote and sericite - the necessary calcium being derived from the plagioclase and the iron probably from the biotite, the latter being altered to chlorite and prehnite. Then late stress conditions resulted in small scale shearing with calcite and epidote veins.

G.G.U. 45441

Sedimentation

Deformation and Metamorphism (amphibolite facies)

Stress

Recrystallization and growth of hornblende

Schistosity

Migmatization - granitic veins

Growth of biotite

Saussuritization - epidote - sericite growth

Diaphthoresis

Cold stress

Shearing with chloritization and calcite along shear. Elsewhere epidote along shears.

The amphibolite from the same meta-sediment enclave as sample 45441 just described is in general agreement with this interpretation; it too shows biotite of various orientations.

The amphibolite of Iviangiussat has clots of hornblende which are elongated to give a faint foliation. The clots (ca. 3mm) have small amphibole grains (0.1 mm) of a pale green colour associated with numerous small (0.01 mm) disseminated opaque grains surrounded by a rim of larger grains of hornblende free from opaque grains.

Beside the granite at 01/580029 the meta-sediment has been recrystallized to a hornfels with approximately equal amounts of hornblende and plagioclase, and with veins of hornblende.

Age of the Meta-sediment

In the area of Kobbermine Bugt and Arsuk Ø, Wegmann (1938, p.16-30) divided the low metamorphic supracrustal rocks of the Ketilidian into a lower sedimentary series with quartzites, conglomerates and breccias overlain by argillaceous sediments, and an upper group, a predominantly volcanic series with tuffs and lavas, together with intercalated banded semi-pelites intruded by gabbroic sills (Wegmann, 1938; 1939 p.205; 1948 p.11; Berthelsen, 1961b p.331). The area of meta-sediment on Qaersuarssuk is far too small to place it within the chronology of the supracrustal rocks.

The Gneiss and Granitic Rocks

Introduction

The granitic rocks of the Julianehaab district cover a minimum area of 8000 sq. km. In this area at least two periods of activation of the basement are recognized; these are frequently referred to as the Ketilidian and Sanerutian. If there are granites, gneisses or other rock types in the granite area belonging to a pre-Ketilidian basement, with the possible exception of basic masses at Ilorra to the west, they have not been recognized as such and have been classified with the Ketilidian rocks. The Ketilidian granites are the result of transformation and granitization of sedimentary and volcanic deposits of geosynclinal dimensions. These are still seen on Arsuk Ø, at Grænseland and in Kobbermine Bugt. The Sanerutian is largely a period of reactivation of these older granites together with the metamorphism and migmatization of an earlier set of basic dykes which separate the two periods. The greater part of the rock series to the east of Qagssimiut appears to have been affected by this later recrystallization and locally intrusive contacts are demonstrable.

The main period of granitization was probably the Ketilidian accompanied by folding and the extensive formation of gneisses. The nebulitic gneiss along the Bredefjord coast was probably formed at this time and possibly also the banded gneiss on Ûgarmiut. The nebulitic gneisses and the non-granitized meta-sediments by Uniaríssat both have what is recognized as a Ketilidian trend (N.E.-S.W.). The Sanerutian was probably more in the nature of a static granitization and homogenization of the Ketilidian granites and gneisses. This may be demonstrated by lack of folding of the intervening basic dykes.

Gneiss and gneissose granite occur in a number of places within the area mapped. The greatest areal extent is the granitic gneiss between Kangerdluarssuk avangnardleq and Iviangiussat imâ. Small areas of agmatite and veined gneiss occur scattered throughout the whole of the granite area. Inland exposure is poor so that frequently the varieties and variations have only been identified on the coastal sections. In the majority of cases the small areas of gneiss have been too scattered to build a pre-granite structural picture of the area and in a number of places there has been later mobilization that has disturbed the structure. Elsewhere there was considerable plastic deformation which locally alters a regular structural pattern.

No sharp contacts between different types have been seen and only over one short length has a contact been mapped between granite and the gneiss on the northern side of Kangerdluarssuk avangnardleq.

Small areas of micro-granite are known in a few places.

Microcline megacrysts occur in certain areas but there is no fundamental difference between the ground mass of those granites with and those without megacrysts.

Nomenclature

A rather arbitrary distinction has been made between granite and gneiss. When the rock has recognizable bands or layers of different composition it has been termed a gneiss. When the composition becomes appreciably granitic but there is still a marked structure to the rock it has been termed a granitic gneiss. When the rock is dominantly granitic but there is still a discernable structure it is a gneissose granite. When there is a marked foliation of the mafic minerals it is a foliated granite. The term granite itself is used *sensu lato* in the sense of Read (1943, p.65; 1957, p.48). With this usage an augen gneiss is a gneissose granite with augen, and a homogeneous gneiss, if it is of granitic composition, is a granite.

Amphibolite is a hornblende rock with plagioclase, and when more leucocratic it may be termed a quartz diorite.

Dark Enclaves in the Granite and Gneiss

Enclaves of biotite- and hornblende-schist and mafic schlieren are patchily common throughout the granite and gneiss, as well as remnents of feldspathic gneiss and fine grained quartz-diorite in the granite. In some examples these dark enclaves are undoubtedly the granitized remains of old amphibolite dykes; in most their origin is unknown though it is very likely that they are the remains of the original supracrustal rocks. Within a supracrustal series the basic volcanics (amphibolites) may retain their identity and resistance to granitization longer than many other rock types even though they have been strongly deformed.

Enclaves of hornblende-schist are particularly common in the area above Nûgssuaq (Iviangiussat imâ) where they have various orientations though some of them, in the order of a few metres in length, lie elongated approximately north - south which is not the main trend of the known occurrences of supracrustal rocks.

In general throughout the entire area the orientation of many of these fragments appears to follow a pattern, but without a great deal more information no interpretation is proposed. Most of the structural pattern was probably impressed upon the granites during the Ketilidian but may have been locally changed during the Sanerutian.

The Granitic Gneiss

The largest area (very approximately 20 sq. km) of granitic gneiss forms the high ground to the east and south of the lake 230, with the exception of an east-west band of pale pink aplitic granite that crosses the highest point. The granitic gneiss is a fine grained, grey, streaky to homogeneous rock with a weak foliation (fig.11). The foliation is invariably only seen as a striation on a smooth weathered surface. It is rarely seen on a vertical surface so that it is difficult to measure. Occasionally it appears to be a lineation rather than a foliation. Feldspathization is seen in places as small feldspar megacrysts, commonly aligned parallel to the foliation but quite frequently at an oblique angle to it. The feldspathization therefore appears to be later than the shearing which produced the foliation in the gneiss. Dictyonitic structure (Sederholm, 1907) is comparatively common and becomes more pronounced towards Kangerdluarssuk avangnardleq where the gneiss merges into the grey granite. The megacrysts are only seen in quantity in the vicinity of the granite where, presumably, feldspathization was most intense. Small enclaves of biotite and hornblende schist and schlieren occur throughout the area of the gneiss and a long strip of meta-sediment occurs within its boundaries though it is enclosed by the pale pink aplitic granite (q.v. p.68).

On the southern coast of Iviangiussat imâ the gneiss extends from Uniarîssat southwards right round the bay. Amphibolite sheets, concordant to the low angled southerly dip of the gneisses, are comparatively common along the coastline of the bay. At the western end of the bay the gneiss is clearly banded with a weak foliation parallel to the bands. Some of the bands are epidote coloured and there are epidote-rich nodules within the bands. Some of the finer structures are very reminiscent of sedimentary structures so that the gneiss here appears to have been very little deformed. The stretch of coast on Qeqertarssuaq opposite the bay is very similar but the extent of the gneiss inland is not known.

Fine grained granitic gneiss also occurs along the southern shore of Torssukátak between the island (01/6502) westwards to within 1.5 km of Itivdliatsiaq. Here dictyonitic structure is common (fig.13) and in places there are small feldspar megacrysts mostly parallel to the foliation, but a few are oblique to it. In parts it is a gneissose granite to foliated granite. Inland the nebulitic granite appears to extend very much further westwards than it does on the coast. There is no definite boundary against the nebulitic granite; the granitic gneiss grades through a gneissose granite. The encleves of amphibolite and quartz-diorite that occur within the granitic gneiss may be agmatitic and there are rare traces of skarn. The enclaves have a similar orientation to the gneiss in which they are found which, in general, is approximately E.N.E. with a moderate northerly dip. This, it will be noted, is similar to the orientation of the more southerly of the two bands of meta-sediment.

Similar gneiss occurs in the southern part of the island of Naujatalik where it is extensively veined by quartz-feldspar. There is a comparatively sharp junction against the granite to the north. Within the gneiss there is a wedge of hornblende schist three metres in width which is conformable with the structure of the gneiss. The hornblende schist is partly agmatitic and is veined by quartz and feldspar and there are occasional small megacrysts.

Between the two bands of meta-sediment there is gneiss. To the north it grades into recognizable meta-sediment and to the south there is a comparatively clear distinction between the gneiss, which is here banded, and the semi-pelitic rocks of the banded meta-sediment. Undoubtedly this area has also been part of the supracrust but it has suffered more extensive granitization so that its original sedimentary character has now been lost and must of it is now granitic. There are amphibolitic 'layers' parallel to the foliation of the gneiss which are sheathed by granitic material. The amphibolite may be early dykes but there is no evidence to support the interpretation.

Gneissose Granite

Between the outflow river from the lakes 30 and Torssukátak there is gneissose granite. It is more granitic than the rocks found slightly further to the east on the southern and upper part of Torssukátak, but contains more enclaves, some of considerable size, than the granitic gneiss. The enclaves, mainly amphibolitic to quartz-dioritic in composition, have a distinct E.N.E. orientation and a northerly dip. Granitic veining of the enclaves is abundant and the presence of dictyonitic structure is common (fig.12). At Itivdliatsiaq it is granite.

A veined gneissose granite is also present on Qeqertarssuaq (fig.13). There is a small occurrence due west of Uniaríssat which is partly a lineated quartzite, the rest a gneissose granite with agmatitic quartz-diorite. A similar occurrence lies about a kilometre to the north in the bay on the northern coast.

The northern shore of the inner part of Sarfarssuaq shows considerable evidence of its original sedimentary character. There is a marked foliation and some banding which has a strike about 170° and a steep dip to the west. Fold axes are recognizable in folded amphibolite bands one of which (fig.14) shows refolding. There is a narrow band of skarn (a garnet-quartz-?wollastonite rock) and there is also a possible conglomerate (with foliation present only in the 'pebbles') as well as enclaves of psammitic material. Within the gneissose granite there are small megacrysts parallel to the foliation. The amphibolitic schist enclaves are seen to taper out into darker bands and schlieren in the granite before they are disseminated in the general matrix of the rock.

At the entrance to the inner part of Sarfarssuaq there are bands of medium and coarse grained granite, the medium grading into the coarser, then a

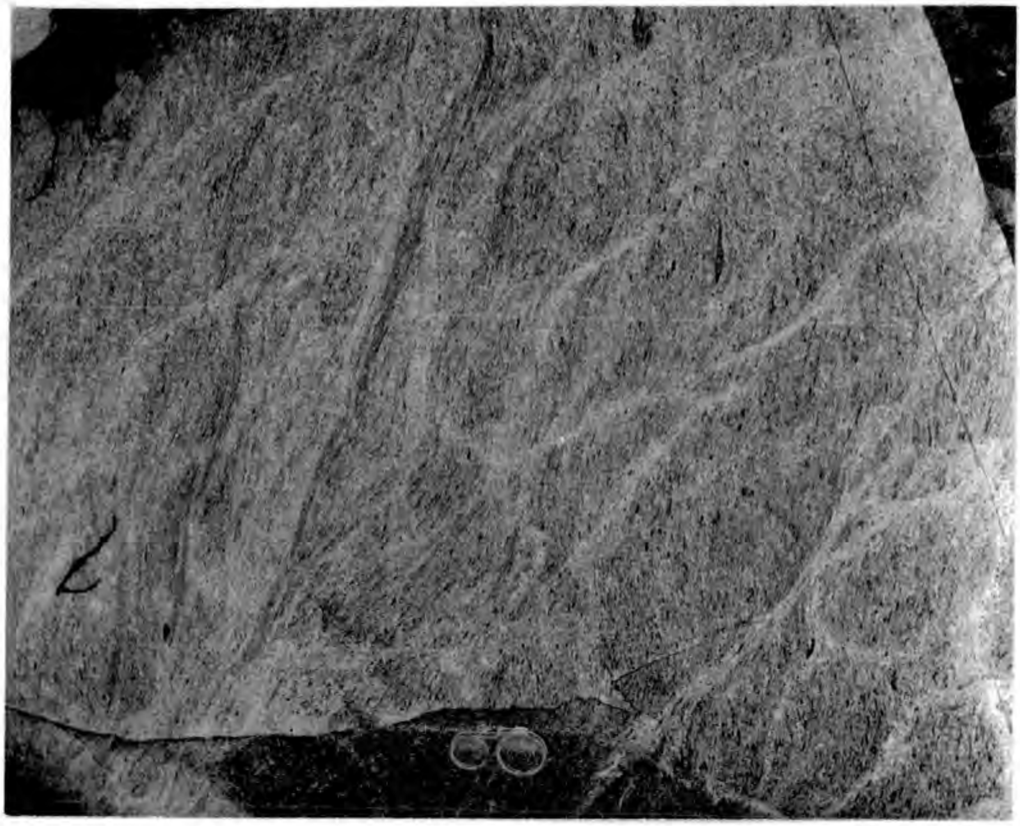

Fig.12. Gneissose granite with dictyonitic structure.

Fig.13. Veined gneissose granite.
Extreme north tip of Qeqertarssuaq.

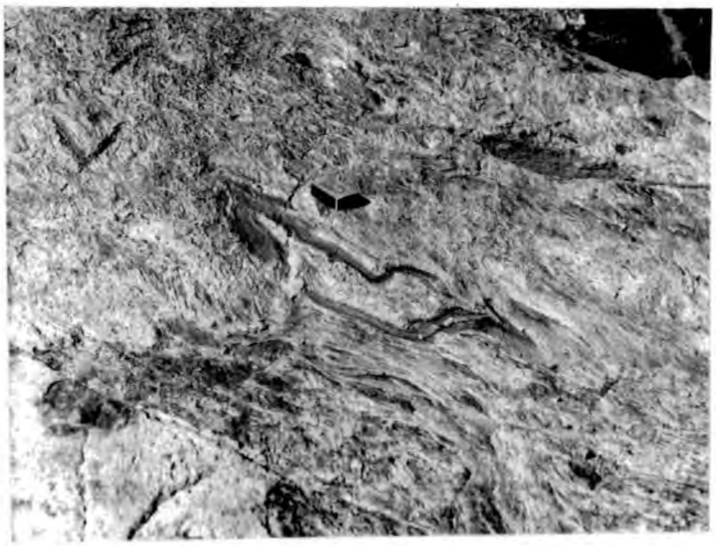

Fig.14. A relict amphibolitic band that shows refolding. Inner part of Sarfarssuaq. 00/523960.

Fig.15. A slab of migmatite. Qeqertarssuaq. x 0.3. Photo G. Wilson.

sharp cut off against medium grained granite, giving rise to a number of contacts all of which are approximately vertical and have a strike of 128°. This has been interpreted as a possible reflection of the original supracrustal rock which had bands of markedly different composition and texture.

Migmatites

In places the metatect (the granitic part of the rock) has increased so that it becomes the dominant part, or is equal in amount to the gneiss. It has thus become a migmatite (fig.15) (Sederholm, 1907).

Nebulitic Gneiss

Nebulitic gneiss is prominent along the Bredefjord coast and occurs in patches on Mátâta nunâ. A large part of the area between the long lake 5 and Torssukátak is also nebulitic gneiss.

On the Bredefjord coast it forms regular bands (fig.16) with a strike N.E. to E.N.E. and a moderate dip north-westwards. The banding is due to layers of different grain size and mafic mineral content. Foliation of the mafic minerals is pronounced in some layers and may be absent in others. The aplitic layers are practically devoid of mafic minerals. Conformable to the banding there are occasional lenses of biotite-hornblende schist which have parallel mineral layering. Some of the coarser grained layers have numerous large feldspar megacrysts with an apparent random orientation. These bands are similar to the big feldspar granite.

On the southern side of Bredefjord, on Tugtutôq and Tugtutôq Lille Ø, there is nebulitic gneiss with the same strike and dip but across Tugtutôq Lille Ø to the S.E. the dip changes to south-eastwards (Upton, 1962 p.10).

Fig.16. Nebulitic gneiss on the coast of Bredefjord. Note the presence here of lenses of hornblende-biotite schist with mineral layering that are conformable to the coarse grained and to the leucocratic fine grained granitic bands.

Fig.17. Nebulitic gneiss in which there is very regular banding together with sheared out schistose and mafic enclaves. There has then been later shearing along vertical planes which show sinistral movement. N.B. This later shearing does not affect the intrusive granite dykes in the vicinity (e.g. fig.33) that cut across the bands. South coast of Mátâta nunâ.

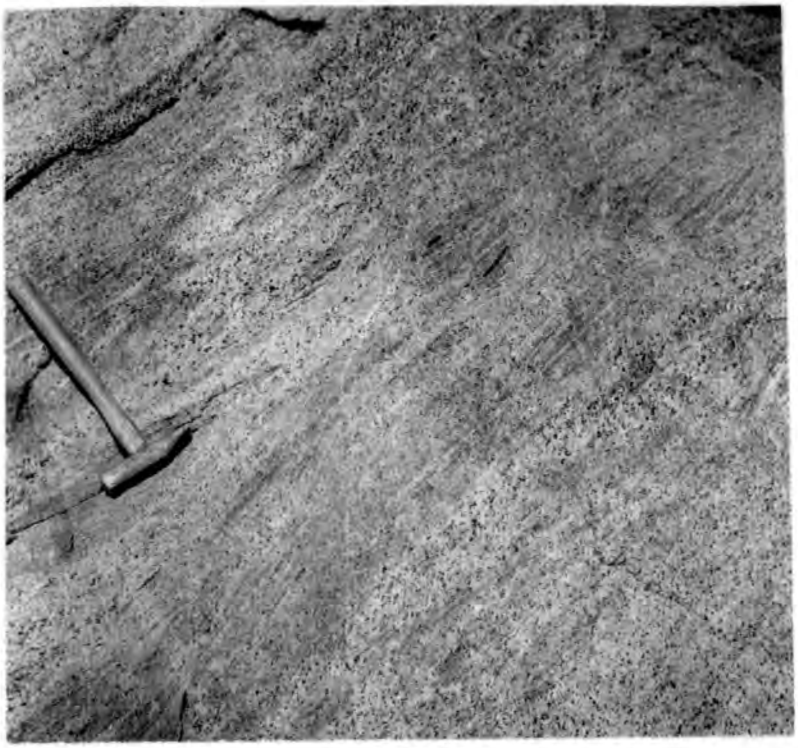

Fig.18. The typical form of the nebulitic gneiss with crude mineral layering and 'ghost' structures. Atertûp ilua.

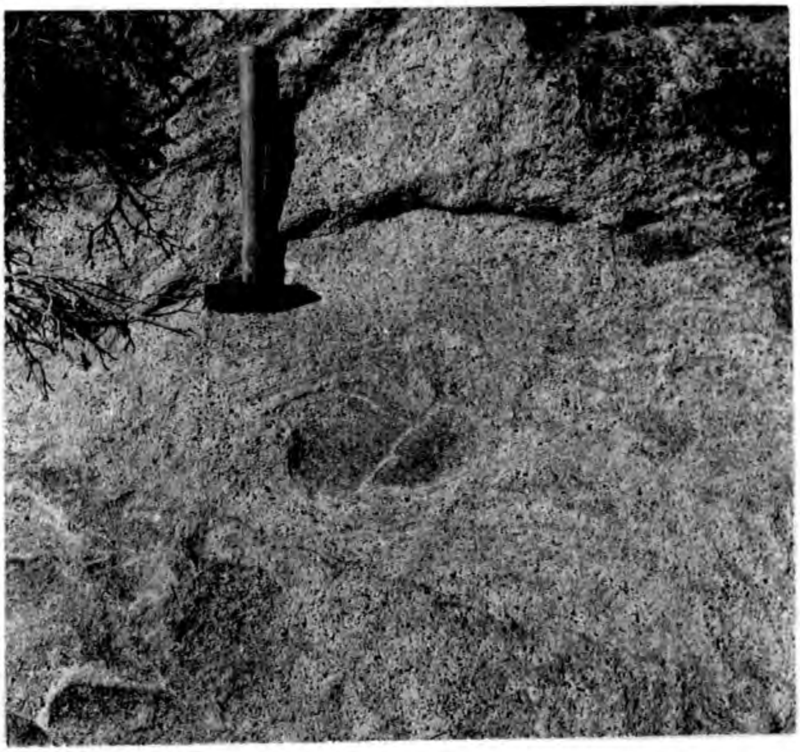

Fig.19. Nebulitic gneiss with the remains of an enclave. Sarfaq - 00/689958.

The banded nebulitic gneiss along the coast of Bredefjord is interpreted as original supracrustal rocks that have been sheared out but incompletely homogenized on granitization. The biotite-hornblende schist is thus the least affected relic of the supracrustal rocks. The megacrysts appear to be confined to certain layers. This may be because other layers were less permiable to migrating material so that it was concentrated in certain layers.

On Mátâta nunâ some of the nebulitic gneiss is in the form of banding like that on the Bredefjord coast (fig.17) or the bands may have been sheared and more basic in composition to give lenses of hornblende rich rock in granite (fig.20). In fig.17 the bands have been cut across by later vertical shear planes on which there has been sinistral movement. If the bands were originally more basic on composition and more competent than the matrix lenses or more basic rock would be formed by the shearing producing a couple on the lenses so giving the sigmoidal shape to the mineral layers within the lenses (fig.20).

The Banded Gneiss on Ûgarmiut

On the western side of the island of Ûgarmiut there is a N.-S. strip where the granite has regular mafic bands (figs. 21 to 23). The dark bands have an average width of about 10 cm with about three times that width of leucocratic granite between. Very occasional feldspar megacrysts are known in the leucocratic granite but have never been seen penetrating the mafic bands. The banding is regular with a consistant strike direction of about 160° and a dip of about 35° to the west. In places there is a weak foliation of the hornblende crystals parallel to the bands. Not all the bands are absolutely regular; a small fold (fig.22) is known in one of them, and the bands are known to sweep around enclaves. Enclaves are rare, but some show rotation and have the appearance of banded meta-

Fig.20. Nebulitic gneiss in which the more basic and competent layers have formed lenses during shearing which produced apparent rotation by the action of a couple. The granitization has been most intense along the direction of the shearing.

This example is rather poor and more mafic than many lenses; many of the lenses are 'ghost' lenses within the light grey, finer grained granite.

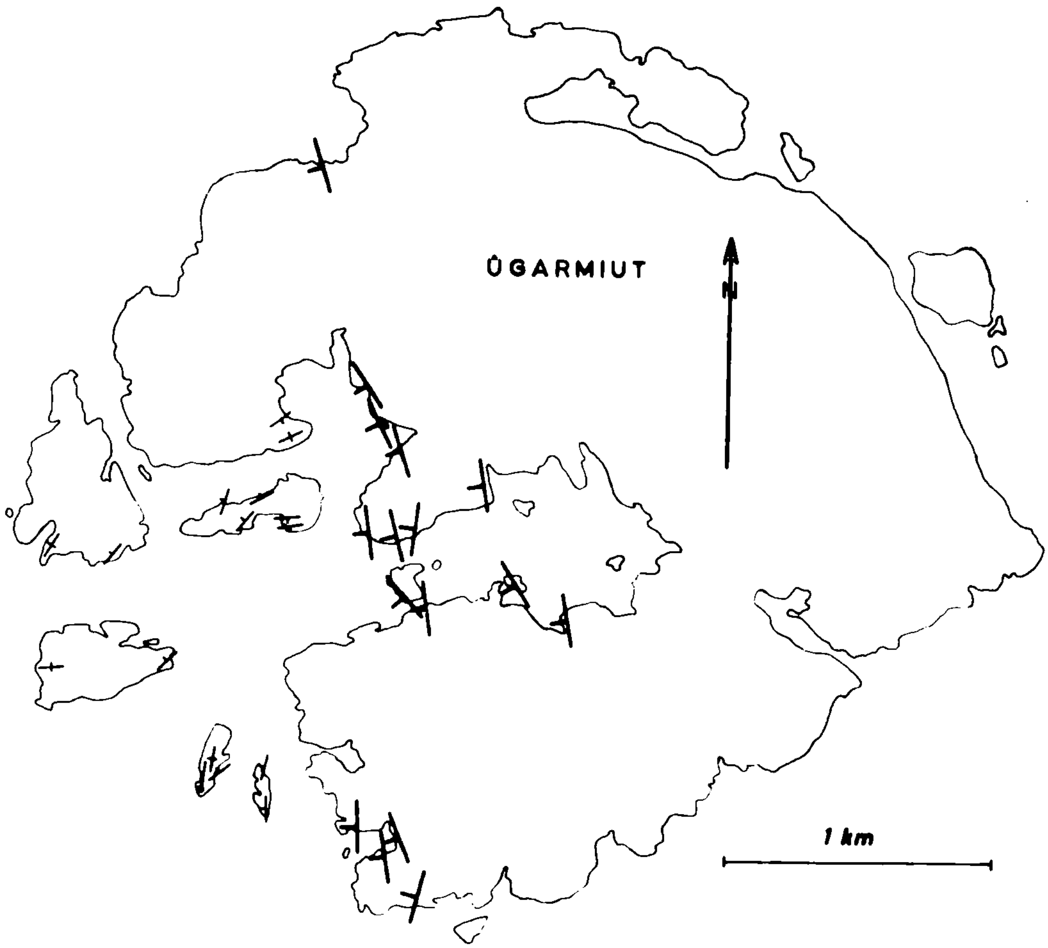

Fig.21. A sketch map of Ûgarmiut showing the area and orientation of the banded gneiss (large structural symbols) and the orientation of the lithological layering in the gneiss and schist to the west (small structural symbols).

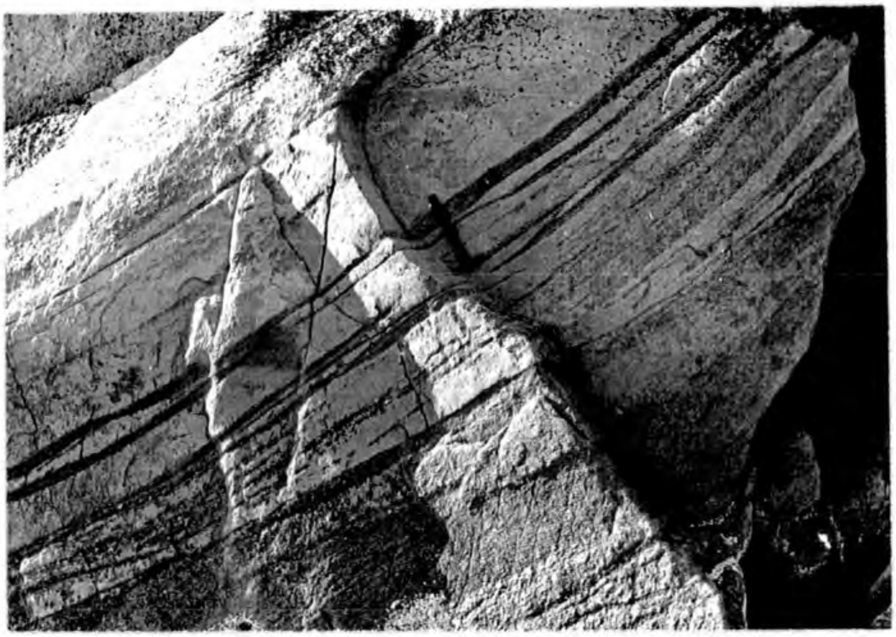

Fig.22. A vertical face with mafic bands in a leucocratic gneiss. They have the same orientation as the bands in fig.23. The length of the hammer shaft is 30 cm and the head sits on a fold in one of the bands. Ûgarmiut - 00/523885.

Fig.23. Mafic bands in the banded gneiss in the S.W. of Ûgarmiut. The bands are regular, striking 160^{0} and a dip of 35^{0} to the west. This banded gneiss can be traced in a narrow north-south strip the length of Ûgarmiut.

sediment (fig.10). Some of the lower bands show slight pinch and swell structure.

The banding is well exposed on a wave splashed area in the S.W. corner of Ûgarmiut (fig.23) and again in the middle part of the bay on the western side of the island. Inland it is not seen at all. On the northern coast, in line with the strike of the bands, there are traces of them but they are not well exposed. On the southern coast of Ûgarmiut, the northern coast of Upernivik and on the island in Ikerasak there are elongated lenses rich in hornblende which are aligned to give a rudimentary banding. On the island in Ikerasak these mafic lenses are associated with nebulitic gneiss which suggests that there may be a connection with the formation of nebulitic gneiss. Banding is also developed elsewhere in the area, e.g. on the north side of Tunua where, whether by coincidence or not, it has practically the same orientation as the bands on Ûgarmiut.

Origin of the bands

There are three possible origins for the bands:

1) shearing
2) original sedimentary or igneous layering
3) metamorphic differentiation

The main features to be considered are the regularity of the banding, the presence in it of rare rotated enclaves that are like meta-sediments in origin, and that 200 m to the west there is a hornblende-biotite schist with a strike nearly at right angles to that of the mafic bands.

It is suggested that the bands are probably due to metamorphic differentiation acting on an area of shearing. The occasional enclaves have acted competently and have been rotated but not themselves sheared.

Other types of banding

Besides the regular mafic banding on Ûgarmiut there are other types of banding elsewhere in the area. Along part of the Bredefjord coast and on Mátâta nunâ there is a nebulitic gneiss which has bands of different grain size and different composition which are frequently very regular. They are discussed in the separate section on the nebulitic gneiss (p.33).

Big Feldspar Granite

The main granite of Qaersuarssuk is a medium to coarse grained grey granite. In the area between Kangerdluarssuk avangnardleq and Bredefjord it is characterized by the presence of large microcline megacrysts (fig.24). This same megacryst-bearing granite occurs on the Bredefjord coast of southern Tugtutôq (Upton, 1962) and on the peninsulas to the east of Qaersuarssuk on the northern side of Bredefjord (Allaart, M.S. maps, 1960). Between the lake 5 and Torssukátak the granite is similar but megacrysts are not quite as abundant and in places it has quite a distinct nebulitic appearance, while along the Bredefjord coast the homogeneous granite passes into a nebulitic gneiss.

The megacrysts are normally in the order of 3-4 cm in length, occasionally reaching 5 cm with zoning rarely seen in the largest of them. A density count of the megacrysts was attempted at one place, giving 9 megacrysts per 100 sq. cm. In the western part of the area the granite is similar but megacrysts are very local and commonly only about 1 cm in length.

Occasionally there is a faint planar orientation of the microcline megacrysts but without foliation of the accompanying dark constituents. This may well be due to slight local directional forces controlling the growth of later forming microcline megacrysts which is not of sufficient strength to impart

Fig.24. Megacrysts in the granite on Ûgarmiut. The concentration is approximately that commonly obtained in the big feldspar granite.

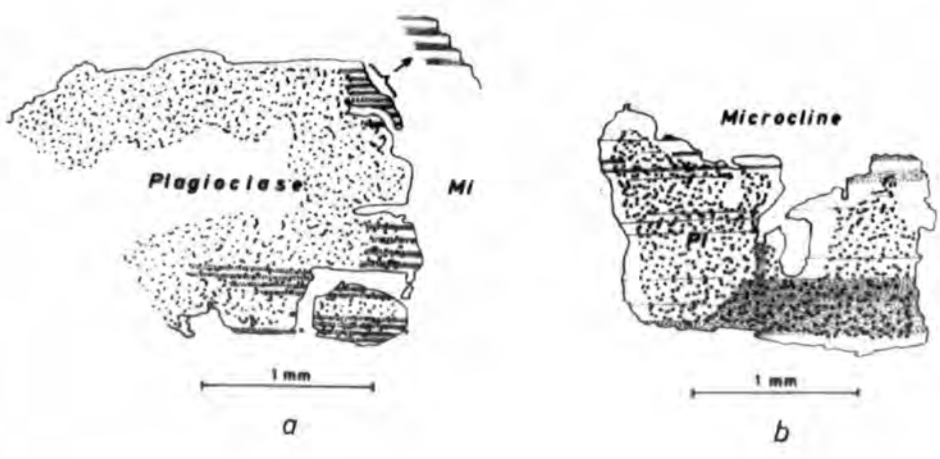

Fig.25. Sketches of two inclusions of plagioclase in microcline showing corrosion by the surrounding microcline. The inner parts of the plagioclase are saussuritized with a clear outer border. Note the differential corrosion in 'a' leading to a step-like edge dependent on the twinning direction. Both drawn from 45201.

a foliation to the granite. Nowhere is the orientation pronounced and no regular regional pattern has been seen in it. In areas where megacrysts are not frequent concentrations of them may occur locally along old shear zones.

In the extreme north-east corner of Qaersuarssuk medium grained megacryst-bearing granite occurs in an area that is largely of a finer grained 'aplitic' granite. This finer grained 'aplitic' granite may be younger than the medium grained megacryst-bearing granite, but it may also be partly incomplete homogenization of material of different composition.

The granite is normally light grey in colour with white megacrysts but near to the zones of dislocation both the goundmass feldspar and the megacrysts are red in colour. The microcline megacrysts seem to be more readily affected than the groundmass feldspar as they are pink when the groundmass feldspar is grey. In places the granite and megacrysts are pink to red even though there is no sign of faulting. The red colour is probably due to oxidation of iron.

The granitic rocks have not been subdivided into different types as the big feldspar granite is believed to be merely a variation of the medium grained biotite-granite, which covers the greater part of the area, with the addition of megacrysts. Most of the granite between Kangerdluarssuk avangnardleq and Bredefjord is big feldspar granite which passes into a nebulitic gneiss along the coast of Bredefjord.

Petrography of the Granite

Petrographically there is little, if any, significant difference between the different varieties of the granite on Qaersuarssuk. The big feldspar granite is characterized by the presence of large microcline megacrysts but the groundmass in which these are embedded is indistinguishable from the granite without megacrysts. Biotite is the dominant ferro-magnesian mineral with or without hornblende but in a few examples hornblende is dominant. The relative proportions of the three main minerals is extremely variable giving types which vary from syenite to granodiorite. To cover all these types the term granite is used <u>sensu lato</u>. Much of the variability is due to the coarseness of the rock; a 2.5 x 3.0 cm thin section not giving the true proportions of the different minerals. Jackson and Ross (1956) recommend a surface for modal analysis of 100 times the area of the largest mineral, i.e. about 300 sq. cm. of flat surface if the megacrysts are to be included. Apart from the inadequacy of sampling for modal analysis there is considerable lack of uniformity in the granite itself. The following are approximate modal percentages (volume percent) of the groundmass constituents of the medium grained biotite-granite each sample being represented by a single thin section, either without megacrysts or with the megacrysts excluded.

	45201	45205	45230	45236	45461	45465
Plagioclase	68%	52	64	52	48	36
Microcline	9	27	9	4	22	32
Quartz	10	15	13	37	23	27
Biotite	10	4	11	6	4	3
Hornblende	1	-	2	0.5	1	+
Sphene	2	-	+	-	-	-
	Megacrystic granite excluding megacrysts				Granite without megacrysts	

Thus the groundmass is a granodiorite but the total bulk composition approaches that of an adamellite. The lack of uniformity in the granite is also seen in the processes of replacement that appear to have taken place. Some examples show all the possible replacement processes; others show none at all; the majority show poor examples of one or two.

Primary accessories

Sphene is the most prominent and abundant of the primary accessory minerals. Many samples show megascopic grains which everywhere show their typical idiomorphic form. It may form anything up to 2% by volume of the total mineral constituents. In one example (45216) the sphene appears to be replacing biotite, while replacement of sphene by plagioclase and microcline is also known.

Apatite, though forming an insignificant proportion of the rock, is present in most examples as tiny idiomorphic crystals. Opaque minerals, also, are ubiquitous though nowhere abundant. They are normally associated with the mafic constituents but appear to be of both primary and secondary origin.

Mafic constituents

Biotite is the dominant mafic mineral throughout the granites, though locally hornblende may be abundant and occasionally dominant. Alteration of the biotite to a chlorite is frequent, of which the most common is penninite. The hornblende may show alteration to biotite. Prehnite is also known within the biotite flakes forcing apart cleavage planes.

The biotite normally occurs as isolated plates but in some cases may be associated with opaque material. Both biotite and hornblende occur as inclusions within microcline megacrysts.

The biotite is a common green variety with α pale yellow to pale green-yellow and γ olive green to yellow-green (rarely brown). The hornblende is also green with α yellow, β dirty green and γ dark green.

There are some examples of replacement of biotite by plagioclase, quartz or ?microcline. In 45230 there is a myrmekite-like texture with quartz vermicules in some of the biotite adjacent to hornblende grains.

Diopside ($\beta \leqslant 1,684$) is known from one sample (45496); a second occurrence is doubtful. It is partly replaced by hornblende which is itself corroded by plagioclase and quartz. The sample was collected from nebulitic granite not far from an occurrence of meta-gabbro on the Bredefjord coast so that it may be a remnant from the granitization of the meta-gabbro body. This is the only known occurrence of pyroxene in the granites of Qaersuarssuk though examples from granites further to the east are known.

Quartz

The amount of quartz in any section varies considerably from nil to the dominant constituent. It may be in grains as large as 3-4 mm in diameter though about 1.6 mm is more general. The large grains frequently show a cracked form and amoeboid shape with highly sutured contacts against other minerals and adjacent quartz grains. In general they show irregular, undulose extinction which shows that most of these large quartz grains are aggregates of grains with similar, but not identidal, orientation. Ljunggren (1954) suggests that these are partly recrystallized aggregates of quartz grains. In some examples there appears to be too much regularity about the extinction though isolated patches of the grain may be different. The impression gained from these rocks is that large grains have been cracked with an undulose extinction caused by strain in the crystals. These quartz crystals are also frequently slightly biaxial. This impression is strengthened by the presence of tiny individual grains of quartz along boundaries between large quartz aggregates and microcline megacrysts or between two microcline megacrysts. These tiny grains are believed to be the result of granulation.

In addition to these large amoeboid aggregates and tiny granular grains there may be moderately small sized grains (0.3 mm across), well rounded, perfectly clear and with a sharp extinction - drop quartz (Härme, 1959 p.45). These may be present within the microcline megacrysts or within the large quartz aggregates. They are believed to be a later generation of quartz (quartz II) and may be due either to complete recrystallization of existing quartz or to replacement. The most marked difference between the quartz of the two generations, apart from the difference in extinction is the difference in outline to the surrounding minerals; quartz I has highly sutured contacts against all minerals and other quartz grains and penetrates between them while quartz II has small grains which are well rounded even when within a quartz I aggregate.

Quartz is known to replace all the other main minerals. Fig.30 shows it replacing plagioclase as long thin protuberances parallel to the polysynthetic twinning. These protuberances have the same optical orientation as the adjacent large quartz grain suggesting that there has been some activation of the quartz. Veins of quartz also cut the large microcline megacrysts.

Quartz I occurs as inclusions within both microcline and plagioclase grains and itself may have inclusions of all other minerals except microcline. The absence of microcline as an inclusion within a quartz grain may be of significance in the quartz I - microcline age relationship. Quartz II grains never contain inclusions.

Quartz may also be abundant as myrmekite but this is discussed later (p.60).

Plagioclase

Plagioclase is present in all the granitic rocks and may be the dominant mineral in a section. Carlsbad and polysynthetic twinning is common. The plagioclase may occur as distinct grains in the groundmass, occasionally as small megacrysts, or as inclusions within the microcline megacrysts. Frequently, but by no means always, those plagioclase grains that abut microcline, either as inclusions within the microcline or as separate grains surrounding microcline, have clear outer rims that are more albitic than the rest of the grain. In many examples the plagioclase, which has a composition of about An_{30}, has been saussuritized so that the outer albitic rims stand out particularly well as they are unaffected by alteration.

Much of the plagioclase, and in particular the plagioclase inclusions within the microcline megacrysts, shows signs of corrosion and replacement by microcline. There are numerous examples which show this of which a few are illustrated as figs. 25-26. The corrosion of the plagioclase by microcline or quartz appears to be affected by its orientation with respect to that of the replacing microcline (high misfit of Voll, 1960 figs. 7a and b). This is clearly so in fig.25a where a set of polysynthetic twins is differently affected resulting in step-like corrosion.

Plagioclase grains included in the microcline megacrysts and those surrounding the megacrysts rarely have a common optical orientation. Occasionally, though, two or more inclusions within the megacrysts will have the same orientation (fig. 27) and are interpreted as originally a single grain that has been partially replaced by microcline.

Lobes of myrmekite into microcline occur in some examples some of which show albitic rims and some show corrosion by the microcline.

Very occasionally a few pieces of clear microcline, always with very fine grid twinning, occur within a large plagioclase grain and always have one of its twinning directions parallel to that of the plagioclase twins (fig.28). These inclusions are interpreted as the early stages of replacement by microcline

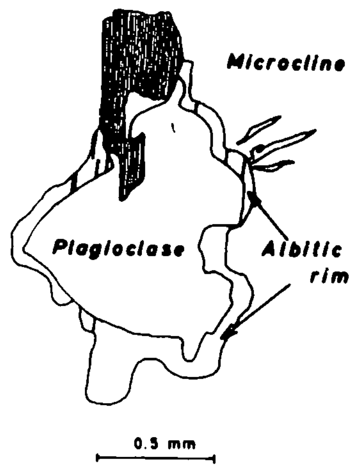

Fig.26. A corroded, clear, albitic rim around a corroded crystal of plagioclase. The whole is an inclusion in a large microcline megacryst. Note the fine twin lamellae confined to the albitic rim (cf.fig.31d). Drawn from 45380.

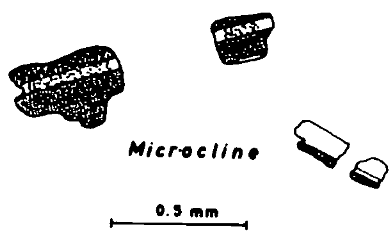

Fig.27. Two pairs of plagioclase inclusions, each pair having exactly the same orientation. Whether or not the pairs are joined in the third dimension does not affect the argument that these are corroded remnants of larger plagioclase crystals. Drawn from 45219.

Fig.28. An illustration of the early growth of microcline in a plagioclase crystal taking the orientation of its host. X-nicols. x 40. Sample 45384.

in the central parts of the plagioclase crystal. Where concordant microcline occurs within plagioclase no albitic rim ever surrounds it.

Occasionally there are large (4 mm) euhedral crystals of albitic plagioclase. A well developed face or two on these crystals is not so unusual (see fig.29) though in many examples it may be grown over by an outer albitic rim that makes the plagioclase crystal anhedral.

Faint zoning occurs rarely in some of the larger plagioclase crystals. The presence of zoning probably means that there has been no recrystallization of these rare zoned crystals of plagioclase as recrystallization would homogenize the grain. Plagioclase throughout all the granites is frequently saussuritized. Embayments of quartz into plagioclase suggest corrosion and replacement of the plagioclase by quartz and the plagioclase may also be veined by quartz (fig.30).

45481 has a large grain of plagioclase which is mainly made up of one grain though there are smaller grains of not quite the same orientation which have been originally a part of the large grain.

Microcline

The microcline occurs both interstitially and as megacrysts in the granitic rocks. The megacrysts may be large and densely packed and have grown at the expense of the earlier minerals, in particular at the expense of plagioclase by a process of potash metasomatism. Many of the larger megacrysts have a single carlsbad twin. Since grid twinning is practically universal there is not considered to be any orthoclase in these rocks. In the hand samples megacrysts may rarely show apparent zoning. No trace of this zoning has been seen in the thin sections though Allaart (oral communication) has zoning due to a zone of perthitic plagioclase.

Inclusions of all the other mineral constituents occur in the megacrysts,

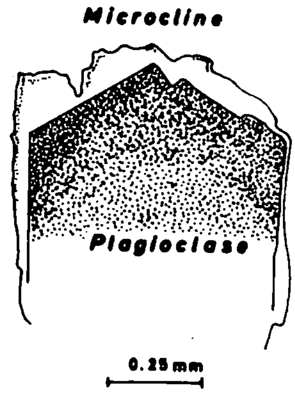

Fig.29. A drawing of a plagioclase inclusion in microcline. The early plagioclase shows crystal faces with an overgrowth of a later formed, clear albitic rim. Drawn from 45201.

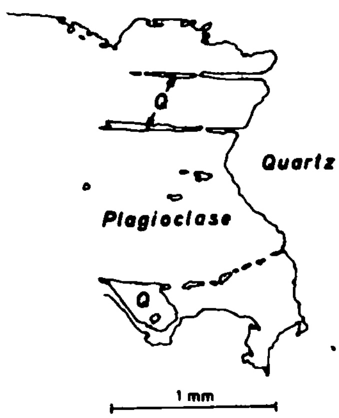

Fig.30. Reactivation of the quartz has lead to quartz veining the plagioclase. Drawn from 45201.

in particular plagioclase and quartz but also occasionally biotite, opaque grains and sphene. These inclusions normally have no relation to the microcline orientation; they appear to be completely random with the possible exception of sample 45385 which is discussed below. The plagioclase inclusions show abundant evidence of corrosion by the microcline.

Lobes of myrmekite form protuberances into the edge of the microcline grains, Rims of albitic plagioclase between microcline and plagioclase grains are common but are by no means ubiquitous.

Perthite is extremely common; vein, film and string perthites. The quantity of albitic perthite in the microcline megacrysts varies considerably, from none to about 35% of a planar surface. No connection is normally discernable between the type, size or positioning of the perthite lamellae and the albitic rims, myrmekite or the inclusions, though there appear to be rare exceptions to this which are described below. The lamellae clearly follow certain crystallographic directions in the microcline.

Occasionally microcline with very fine cross-hatch twinning occurs as 'inclusions' within grains of plagioclase. In these examples the crystallographic orientation of the microcline is related to that of the plagioclase (fig.28). This has been interpreted as an incipient stage of replacement of the plagioclase by microcline. The main characteristic of this microcline is its very fine cross-hatch twinning.

In 45385 cross-hatch twinning, film and vein perthite are well developed. There appears here to be a slight inverse correlation between development of cross-hatch twinning and development of perthite lamellae. Here also within the microcline there are numerous small albitic 'inclusions' oriented so that their polysynthetic twinning is parallel to that of the microcline and such that the dominant set of polysynthetic twins have the same orientation as the albite of the perthite lamellae and in a few instances a connection has been seen between the perthite lamellae and the 'inclusion'. Along the twin plane of the microcline there is the greatest development of albitic 'inclusions' and from these there are quite a few direct connections with the lamellae of the adjacent perthite. As well as the oriented 'inclusions' there are a few plagioclase 'inclusions' of apparent random orientation which bear no known relation to the perthite lamellae. From the shape of the oriented plagioclase 'inclusions' alone it would be argued that the microcline had replaced the plagioclase but taking into consideration the constant orientation of these 'inclusions', their relation to the orientation of the microcline and to the perthite lamellae they appear to have a common origin with the albite of the perthite lamellae. This is possibly an example of the late stage albitization described by Robertson (1959).

The replacing microcline, though starting in one plagioclase crystal, and having its initial orientation controlled by that crystal, eventually replaced not only that crystal but all those surrounding it which are of different orientations so as to give a megacryst larger than any of the original crystals.

Minor constituents

There are few minor constituents which are only occasionally found. They include allanite, zircon, prehnite in the biotite, and haematite. Epidote is quite prominent in some samples which, in most cases, show other features of alteration or proximity to shear zones.

Discussion on the Age of the Megacrysts

The megacrysts occur in abundance in the big feldspar grainte, in the nebulitic gneiss of the Bredefjord coast and occasionally in local concentrations elsewhere. The intrusive granite (p.80) to the east of Uniarîssat and, more particularly, that on Mátâta nunâ, which is believed to be Sanerutian in age, does not have any megacrysts with the exception of the granite dyke cutting the discordant amphibolite dyke on Mátâta nunâ (fig.48 and p.74). The megacrysts in this granite dyke are believed to be derived and incorporated into the mobile granite as they are concentrated along one margin and aligned at an oblique angle to the contact. The 'floating' gneiss block (fig.35) on Mátâta nunâ contains numerous megacrysts in the granitic layers. These granitic layers have been cut by later granitic veins, following shear planes, but these do not contain megacrysts.

In certain places the megacrysts are aligned and the alignment may sweep around enclaves of basic material. Thus the megacrysts have either been present before the deformation of the incompetent granite around the more basic enclaves, or they have grown in place during the deformation. In one example the more competent basic enclave is a deformed amphibilite dyke of unknown age so that the megacrysts are earlier or contemporaneous with the deformation of the dyke.

On the islands of Qeqentat megacrysts appear to be growing across the boundary into an aplitic dyke, but are not present entirely within the aplite. In another locality the granitic veins penetrating an amphibolitic sheet have megacrysts. The latter case suggests the growth of megacrysts during the granitization of the amphibolitic sheet (the age of which is unknown) but the megacrysts are so near to the margins of the sheet that any plastic movement of granite into the sheets could have carried in the megacrysts. The example on Qeqertat suggests that there has been some growth of the megacrysts after the formation of the aplite and amphibolite dykes.

Megacrysts are frequently concentrated along what appear to be old shear zones or zones of deformation in the granite. This suggests that the deformation, leading to movement in certain zones, occurred before the production of the megacrysts and that these zones were passages for the easy transference of material leading to a concentration of megacrysts.

The lack of megacrysts, unfortunately, is no criterion for age as the megacrysts only appear to be present under certain conditions or in certain types of granite e.g. the nebulitic granite which only has megacrysts in certain layers.

The evidence in general suggests a Ketilidian age for the large megacrysts. This does not invalidate any suggestion that they were enlarged or altered under later (Sanerutian) conditions, the existing megacysts acting as nuclei.

Orthoclase or Microcline

Since cross-hatch twinning* in the alkali-feldspar is practically ubiquitous, no crystal being entirely free of such twinning, it is assumed that all the alkali-feldspar is microcline. However, Goldsmith and Laves (1954b p.104) claim, on the basis of crystallographic considerations, that "the typical cross-hatch twinning is a logical consequence of an inversion from a pre-existing monoclinic crystal, and could not have been developed as growth twinning. This indicates that the great majority of microclines were originally monoclinic" and form triclinic microcline through transformation. Laves (1955 p.297) suggests that "probably most of the microclines in magmatic, migmatic and metamorphic rocks have previously been monoclinic potash feldspar." Thus, since all the alkali-feldspar in the Qaersuarssuk granites has cross-hatch twinning it has,

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* polysynthetic twinning after both the albite and pericline laws.

according to Goldsmith and Laves, been primarily monoclinic, and no primary microline exists.

Marmo (1962 p.59-60), however, disputes this conclusion and points out that while heating experiments clearly demonstrate that microcline is transformed to monoclinic sanidine under hydrothermal conditions at 525°C (Goldsmith and Laves, 1954a) the opposite transition on cooling has never been accomplished. Microcline has never been synthesized by direct crystallization (Goldsmith and Laves, 1954a p.15); all attempts have yielded orthoclase. But microcline has been produced by the replacement of albite by potash-feldspar, admittedly without twinning, under hydrothermal conditions (Laves, 1951; Wyart and Sabatier, 1956); i.e. by potash metasomatism.

Furthermore, Marmo (1962 p.60) indicates observations that would also appear to contradict the experimental evidence. As an example he cites the phenomenon seen in synkinematic granites of microcline, of high triclinicity and with good cross-hatch twinning, partly replacing plagioclase. Orthoclase is not known to replace plagioclase in a similar way. This is exactly what is seen in the granite on Qaersuarssuk. The alkali-feldspar in the granite on Qaersuarssuk has not been tested for triclinicity (Goldsmith and Laves, 1954a) but Nesbitt (1961) has carried out X-ray diffraction work on some megacrysts from the granite on the Julianehaab peninsula and has found that all those tested had a fairly high triclinicity. With the exception of one low value of 0.75 the triclinicity is greater than 0.9.

Perthite

The microcline megacrysts are all perthitic to a certain extent, some much more so than others. A few of the interstitial microcline grains have no sign of microscopic perthite, nor have the small pieces of concordant microcline in plagioclase crystals. Vein perthite is by far the most common type. The string perthite always makes a small angle with the vein and film perthite. In 45268 the string perthite is flame-like and frequently reaches to the edge of the grain and may even be more abundant at the edge. Perthite is also known to stop abruptly against a biotite grain or against a twin plane in microcline while a film perthite lamella crosses this plane. The directions of the perthite lamellae on the two sides of the twin plane are different and this is taken as an indication that the direction of the lamellae is controlled by the microcline host. In 45385 polysynthetic twinning is developed in the perthite lamellae.

On a planar surface the perthite lamellae lie with their long axes not quite at right angles to the trace of the twin plane. Rosenqvist (1952 p.81) distinguishes four types of perthite (described and named by Andersen, 1929) which follow certain directions in the microcline: 1) vein perthites, which he says are the commonest type, vary in size, outline and orientation; 2) film perthites form thin films perpendicular to (010) and at an angle of -75° with (001), though they are occasionally found oriented differently; 3) string perthites form regular strings which are parallel to (010) and at an angle of -73° with (001); 4) patch perthites are more irregular than the vein-type lamellae but tend to be oriented in the same direction.

Andersen (1929) recognized the temperature control of perthites and his textural classification represents conditions of ddcreasing temperature. Rosenqvist (1952) has found that there are different rates of diffusion in different crystallographic directions in the crystal and "It seems from the diffusion experiments (using Ra in alkali-feldspar) as if the symmetry of the diffusion ellipsoid decreases with increasing temperature. From these observations it may be concluded that perthite formed at high temperature must be of the string type, at intermediate temperatures of the film, or vein, type, and at low temperatures irregular, of the patch type." (p.85). The experiments also showed that the rate of diffusion was very low but that "diffusion in the solid state may form perthites 0.2 mm in width within a reasonable length of time." (p.86). He has in mind the order of 500 years.

The microcline of the Qaersuarssuk granites is believed to have been formed by replacement of pre-existing minerals, most of which was plagioclase. At the elevated temperature existing during granitization the microcline will hold more sodium in the molecule than at lower temperatures so that on cooling the excess sodium may appear as albitic perthite lamellae.

While this may account for some of the perthite it cannot account for it all. The quantity of perthite in a single microcline crystal may be anything from nil up to 35% of the sectional area of a crystal. This upper limit is far greater than that which can be held in solid solution. Spencer (1937) has shown that up to 30% of the soda component can be held in solid solution at temperatures of 750°C, which is probably considerably above any temperatures existing during granitization (see p.67). Perthite formation has also been explained as due to simultaneous crystallization and by replacement. On p.66 the albitic rims to plagioclase and myrmekite are suggested as being due to more or less simultaneous formation with the replacement of the plagioclase by microcline. If the perthite lamellae had the same origin as the albitic rims connections between these rims and the perthite might be expected. Such connections have been seen but are rare. So that while it is possible that simultaneous crystallization may operate in a few examples it is taken to be the exception rather than the rule.

In a few examples flame-like perthite reaches right to the edge of the crystal or abuts against an inclusion. These perthite lamellae are not considered to be of exsolution origin for the following reasons: 1) vein or film perthite is no less common near them than elsewhere in the crystal so that all the exsolution albite from an area has not been collected into a single large lamella instead of many small spindle lamallae; 2) the perthite lamellae abut right against the edge of the crystal, or against an inclusion, so that they are not equally surrounded by an area from which the albitic material can be collected. These lamellae are therefore considered to be of replacement origin.

Myrmekite

Myrmekite occurs either as wart-like or cauliflower protuberances into the microcline as part of a larger plagioclase grain adjacent to a grain of microcline and always has a crenulated border against the microcline (fig.31). Occasionally the plagioclase of the myrmekite is twinned but commonly there is no twinning. When the myrmekite is part of a larger plagioclase grain the twinning usually continues right through the area of the myrmekite and it is usually impossible to say whether the myrmekite has grown into the plagioclase as a unit, or whether the quartz vermicules are formed by replacement; there is no apparent difference in composition between the part of the plagioclase with the quartz vermicules and that of the rest of the grain.

The proportion of myrmekite in the granite varies enormously; it appears to be scarcer in the plagioclase-rich granites and more abundant in those with microcline (cf. Cheng, 1944 p.140).

In the myrmekite lobes the quartz occurs a long worm-like ramifications or vermicules elongated approximately radially to the plagioclase - microcline border or they may be short, irregular droplets (pear shaped). If it is of the

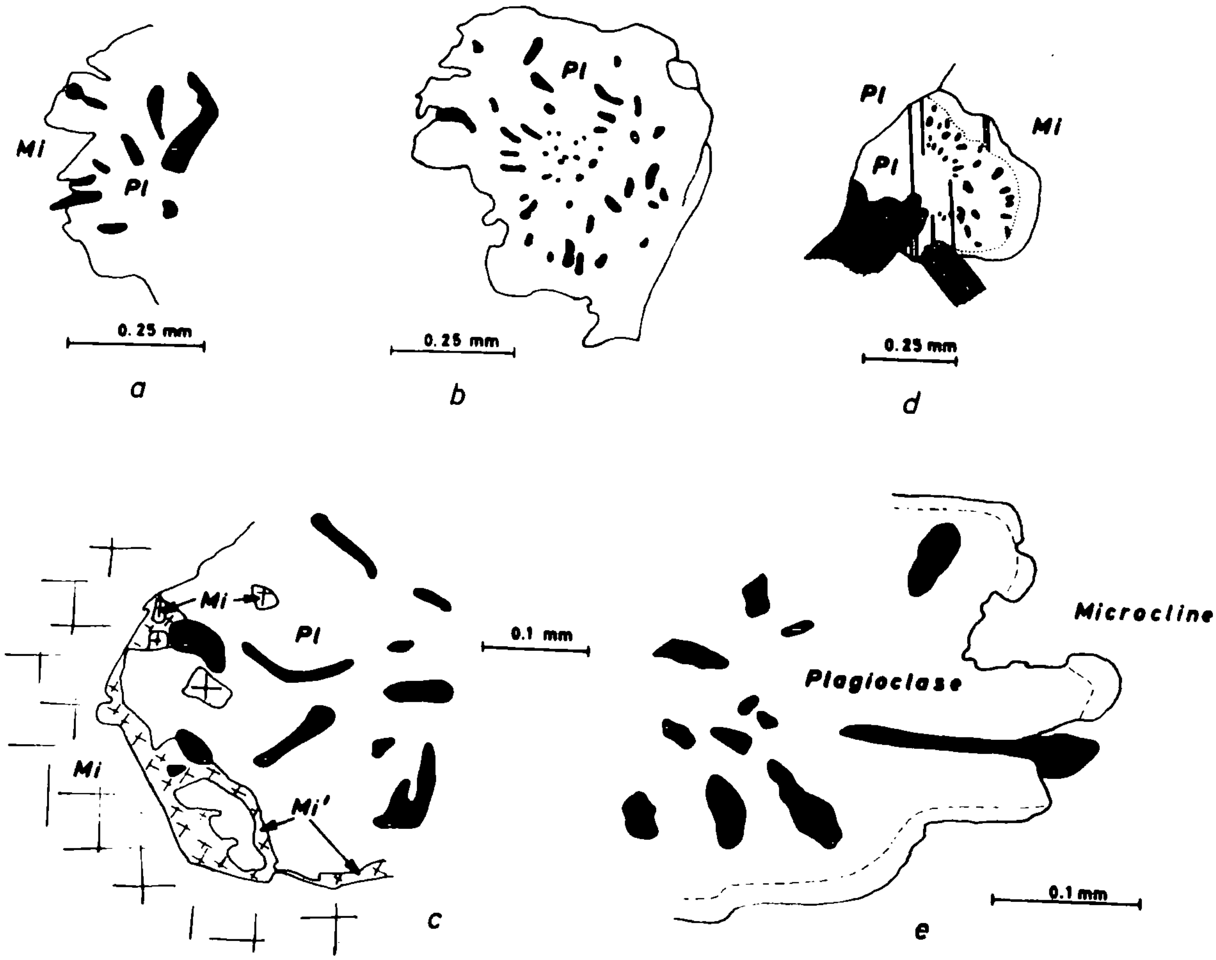


Fig.31. Sketches of myrmekite in the granitic rocks. a, b and e are explainable as corrosion of the myrmekite exposing the quartz which now penetrates into the surrounding microcline in a and e. In c the myrmekite is partly surrounded by a finely twinned microcline (olique crosses) that has a different orientation to the large microcline crystal surrounding the myrmekite (large, upright crosses). In d the twin in the clear rim to the myrmekite does not continue into the myrmekite. For full explanations see the text. Solid black is quartz; Mi microcline; Mi' microcline of different orientation to Mi; Pl plagioclase. a and b drawn from 45304, c and d from 45380, and e from 45284.

droplet form there is often a crude concentricity of the quartz vermicules with larger drops near the margin and finer towards the centre (cf. Oyawoye, 1959 who shows the opposite relationship). The quartz does not always show the same orientation.

A few of the myrmekitic wart-like protuberances into the microcline have albitic rims in the same way as other plagioclase grains abutting microcline (cf. Cheng 1944, p.140). Included grains of plagioclase in microcline may even have vermicular quartz.

The boarders of the myrmekite are normally extensively crenulated. This is believed to be due to corrosion of the myrmekite at a later stage. This corrosion, in some examples, has continued until the quartz vermicules penetrate the microcline (figs. 31a,e). Where a later albitic rim has been added the corroded surface has been repaired so that the quartz vermicules are once again within the plagioclase but they are still recognizable as they cross the boundary from the myrmekite to the albitic rim though many quartz vermicules end abruptly at the boundary. Occasionally the albitic rim may show its own vermicular quartz ~~(fig.~~ (cf. Eskola, 1914, p.27 and Voll.1960, figs. 7a and 7b).

The corrosion and replacement of myrmekite by microcline is possibly best seen in 45380 where there is an outer 'rim' of microcline that is not in the same optical orientation as the main microcline grain (fig.31c). In the same slice there is an indication that the quartz as well as the plagioclase is affected by corrosion as a vermicule, that presumably was at one time entirely filled with quartz, is now partly filled with microcline.

Albitic Rims to Plagioclase and Myrmekite

In some of the granitic rocks there are rims of albitic plagioclase to plagioclase crystals, plagioclase inclusions in microcline and myrmekite where these are adjacent to microcline megacrysts (figs. 29b, 31d, 32). Small concordant pieces of microcline in plagioclase never have albitic rims adjacent to them. These albitic rims are clear and have a sharp, distinct contact with the host plagioclase which is invariably more or less saussuritized. Albitic rims, where present, are normally of equal width following the embayments in corroded plagioclase. They have the same optical orientation as the host plagioclase but where fine lamellae are developed they are finer than the twinning, if any, in the host plagioclase and are not coincident with it. Two examples are known where the albitic rims have a different orientation to the host plagioclase, but are in optical continuity with the perthite. These are discussed below.

There are two possible origins for the rims; by decalcification of the plagioclase, or by addition to the plagioclase at the expense of adjacent microcline.

The formation of the rims by a decalcification process is not considered feasible for the following reasons. 1) The fine twin lamellae in the rims are not coincident with the twin lamellae, if any, in the host plagioclase. 2) In a few examples (fig.29) the albitic rim is added to an euhedral crystal of plagioclase. 3) There is a sharp contact between the host and the rim. These three reasons are consistent with an origin by addition at the expense of the adjoining microcline. The adjoining microcline is a prerequisite for the formation of the albitic rim.

In some cases the albitic rim is of very irregular width. This may be due to uneven growth or it may be due to further corrosion and replacement by microcline. Either explanation is compatible with the explanation presented on p.66 by the oscillation between growth and corrosion of plagioclase. 65

Around some of the myrmekite the rims are less persistent.

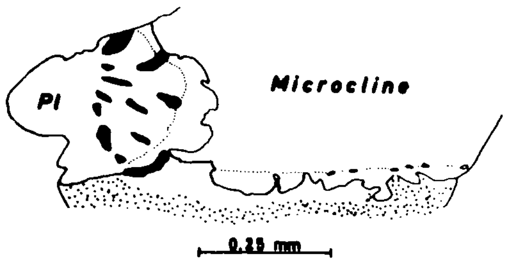


Fig.32. Interpretation: The plagioclase and the myrmekite have clear outer rims possibly slightly more sodic than the rest of the plagioclase (it is hard to tell on this example). The rim to the plagioclase has been corroded by the microcline. The myrmekite appears to have suffered corrosion so that the quartz vermicules were exposed followed by the addition of a sodic plagioclase rim which has suffered later corrosion. There are a number of suppositions made, in particular that the rims are additional and not a decalcification of the plagioclase, but the formation of rims by addition is demonstrated in other thin sections, e.g. figs.26, 29, 31d. Drawn from sample 45328.

Rarely a little vermicular quartz occurs in the albitic rim. There is then a later generation of myrmekite than the main wart-like protruberances.

The relation of the rims to the perthite. The perthite itself is discussed on page 56 57. Apart from a single example, there is no connection between the albitic rims and the perthite lamellae. The single exception known ~~as~~ (45268), is where there is a double rim of which the outer is in optical continuity with the perthite lamellae and has a refractive index slightly higher (i.e. slightly more calcic) than that of the inner rim.

In 45508 where a myrmekite lobe is adjacent to two microcline megacrysts the myrmekite is rimmed against one of the microcline grains by a margin of plagioclase. This marginal plagioclase forms a continuation of the perthite in the microcline suggesting that the perthite has formed, at least the plagioclase margin, after the formation of the myrmekite.

Origin of Myrmekite, Albitic Rims etc.

It has been shown above that the albitic rims are additional and have been formed at the expense of the adjacent microcline. During potash-metasomatism and the formation of microcline at the expense mostly of plagioclase, large quantities of soda will be released which can be locally concentrated along the margins of the plagioclase grains. Whether potash-feldspar will replace plagioclase or the latter replace potash-feldspar depends upon the relative amounts of the potassium and sodium ions. This has been confirmed by the experimental work of O'Neill (1948). Thus, if the removal of soda does not keep pace with the influx of potash conditions will be reached where albite will grow at the expense of the microcline and form rims to the plagioclase. Edelman (1949) gives two equations (I and II p.75) to summarize the process:

$$K + NaAlSi_3O_8 \rightleftharpoons KAlSi_3O_8 + Na$$

$$K + Si + CaAl_2Si_2O_8 \rightleftharpoons KAlSi_3O_8 + Ca + Al$$

As these are reversible equations depending upon the ionic concentrations, the main potash-metasomatism pushes them from left to right replacing plagioclase by potash-feldspar with the release of sodium and calcium ions, while a concentration of sodium and calcium ions pushed them from right to left with the production of albitic rims and myrmekite replacing microcline.

The amount of quartz in the myrmekite is in proportion to the anorthitic content of the myrmekite since the new formed plagioclase requires less silica than the microcline it replaces.

This process of myrmekite formation is then in agreement with the results arrived at by Becke (1908) and Sederholm (1916) without having to postulate both soda- and potash-metasomatism. Where quartz vermicules occur in parts of larger plagioclase grains some of the free calcium ions have probably replaced sodium in the plagioclase with the production of free silica. Both in this case and in the myrmekite once quartz started crystallizing it acted as a nucleus so that droplets or quartz vermicules were formed and quartz is not disseminated throughout the grain.

Thus the production of myrmekite and albitic rims is complementary with the main granitization process involving an introduction of potassium and the removal of sodium and calcium.

Stages of Alteration

1) original plagioclase

2) potash-metasomatism leading to the formation of microcline, first interstitial and later as replacing plagioclase.

3) the formation of microcline from plagioclase led to local excess

soda forming albitic rims or, where the plagioclase was anorthitic, to excess lime and silica giving myrmekite.

4) continuation or renewal of potash-metasomatism with corrosion of further plagioclase including the albitic rims and myrmekite formed earlier.

5) this further led to albitic rims, rarely with excess quartz, to earlier formed myrmekite.

a) at some state there was also unmixing of albite from the microcline to form exsolution perthite, and

b) at not necessarily the same stage, the formation of replacement perthite.

Edelman (1949) suggests that myrmekite was probably formed at low temperatures. Marmo and Hyvärinen (1953) go further and suggest that it is formed under amphibolite facies (ca.400° - 700° according to Rosenqvist, 1952 p.37 and 63) while Kullerud and Neumann (1953) suggest, on the basis of the FeS content in sphalerite, that during granitization in the Rendalsvik area, which they investigated, the temperature was $440 \pm 25^{\circ}$C.

Granitic magma, from experimental work, is not considered to exist below 670° under hydrothermal conditions (Kranck and Oja, 1960; Tuttle and Bowen, 1958). Thus the rocks undergoing granitization were never in a position to be fused. This is probably also valid for the granitic rocks of the Qaersuarssuk area.

The temperatures of granitization mentioned above, according to Rittman, Adams and von Wolff (see Barth, 1952, p.8) are valid at depths of 15 to 20 km. Thus granitization can only take place at shallower depths during orogenic phases when the temperature and pressure have been locally raised.

At a late stage though, during the Sanerution reactivation, locally temperature and pressure must have been sufficiently high, not only for further granitization to take place (the granitization of second period discordant amphibolites) but also for the local mobilization of the granite seen at Uniaríssat and Mátâta nunâ.

Source of Potassium

Marmo (1958, 1962) and Eskola (1932) derived the potassium for potash-metasomatism from sediments as potassium tends to be enriched in clays during sedimentation. Under conditions of regional metamorphism "... pre-existing sediments are transformed into gneiss and granodiorite which lose potassium and silica that elsewhere may cause granitization ..." (Marmo, 1962, p.30).

Aplitic Granite on the High Ground by Lake 230

Across the high ground through lake 230 a slightly pinkish, leucocratic, medium to fine grained rock forms a zone trending N.E.-S.W. It is characterised by the presence of large and prominent quartz grains of 2 mm or larger in diameter; the grain size of the other constituents is somewhat variable, the larger quartz grains being surrounded by smaller grains with an average size of about 0.5 mm. A modal analyses on four of the samples gave the following (per centage volume):

G.G.U. Sample No.	45425	45440	45442	45443	Average
Quartz	30%	34%	35%	32%	33%
Microcline	36 } 69	27 } 65	36 } 63	19 } 65	30 } 66
Plagioclase	33	38	27	46	36
Mica	0.1	0.6	1	2	1
Opaque minerals	1	0.4	0.2	1	0.6
	100%	100%	99%	100%	101%

The total feldspar and quartz contents vary only very slightly. It differs from the granites (qv. p.44 43) in having a higher quartz and a lower total feldspar content. The average content of the principal minerals is practically the same as from a similar rock (45338) on Qeqertarssuaq but in the latter the grain size is smaller (0.3 mm) and many of the rounded quartz grains resemble clastic grains. At Uniaríssat there is a sheared meta-arenite which has a greater variation in grain size and a higher quartz content (45403) (q.v. p.22).

The large quartz grains are amoeboid with slightly undulose extinction, as are also the smaller grains in the groundmass. An exception is that of 45442 which is finer grained and similar to the meta-arenite at Uniaríssat. It shows reddish colour banding but no trace of garnet has been found in the thin sections.

The microcline-plagioclase ratio shows considerable variation. In some sections there are large microcline grains with well developed cross-hatched twinning and vein and film perthite right to the edge of the grain. Inclusions of plagioclase are comparatively common. In other sections plagioclase grains are dominant. In the majority of cases the plagioclase shows turbidity due to sericite shreads predominantly in the centres of the grains while the microcline is always clear.

The mica and opaque constituents are insignificant. The mica is mainly colourless but there is also some pale green to colourless and occasional traces of a green chlorite. The mica may give a weak foliation to the rock and biotite grains parallel to the foliation are known enclosed within large quartz grains showing that the quartz has grown later.

Micro-granite

The northern extremity of Naujatalik is a micro-granite. Micro-granite is also known at the extreme north-east tip of Qeqertarssuaq, and small areas have been differentiated on Igdlaua. The micro-granite is very siliceous and leucocratic, fine grained and with close jointing. On the extreme north-east tip of Qeqertarssuaq it has a sharp contact against the medium grained granite. This granite has small feldspar megacrysts and these continue for 2-3 cm into the micro-granite.

The position in the chronology of this fine grained granite is unknown but may have formed before the growth of the megacrysts in adjoining medium grained granite.

Granitic Pegmatite Dykes with Reference to Aplite Dykes

Neither pegmatite nor aplite dykes are abundant on Qaersuarssuk. Most of the pegmatite dykes appear to occur in the southern part of the area but examples are known throughout the whole area. They have been seen and mapped almost exclusively along the coasts but this is only because inland the exposures are not particularly good.

The pegmatitic and aplitic bodies that occur throughout the region almost certainly have different modes of formation. The pegmatites and aplites are probably largely the result of anatexis and diffusion, particularly those that occur in "pressure shadows", but there are also a few pegmatite dykes, with or without zoning, on which dilation can frequently be demonstrated and that are believed to be products of magmatic injection.

The zoned pegmatites are mostly known from the southern part of the area. In the Nanortalik region, to the south, it has been suggested that the large zoned pegmatites, may be associated with the 'New' Granites (Bridgwater, 1963).

These 'New' Granites are possibly the same age as the intrusive granite dykes on Mátâta nunâ which could therefore explain their regional distribution. The zoned pegmatites reach a maximum width of 40 cm. The majority show normal zoning, i.e. granitoid (aplite), graphitic texture (only rarely developed), pegmatoid (often continuous with the outer zone) and an inner zone of quartz. Slight variations of the normal zonal pattern do occur and quite frequently the quartz core is not developed, or there is only an inner graphitic zone.

In these pegmatite dykes the main accessory minerals are biotite (known in plates up to 3 cm across) and magnetite and occasionally allanite and haematite. One occurrence each of muscovite, monazite and spessartite is known.

The zonal structure of the pegmatites is attributed to crystallization in a closed system within the pegmatitic stage (Quensel, 1957, p.86). The presence of allanite (and monazite) in a dilation pegmatite places it within the type 1 pegmatitic stage of Turner and Verhoogen (1960 p.429) which is believed to have formed at roughly 600-800°C (Quensel, 1957 after Fersman, 1931). Brotzen (1959 p.73) states that most of the graphitic granite formed above 600°C and that the quartz core was brittle at about 300°C.

Pegmatite dykes are later than the aplite dykes where the two have occurred together and both pegmatite and aplite dykes are cut by the mobilized granite on Mátâta nunâ with, at the same place, a single, thin pegmatite dyke later than the mobilized granite.

Many of the aplite dykes, even when parallel sided, are non-dilation dykes. Whether the aplite dykes cut by the mobilized granite at the 'floating' gneiss block are non-dilational it has not been possible to tell. A very large number of the aplitic dykes are flat-lying bodies with irregular margins.

Mobilization in the Granite

In a number of places there is evidence that the granite has been locally mobile. It is well demonstrated in three localities on the southern coast of Mátâta nunâ, and the granite against the meta-sediment to the east of Uniaríssat may also be interpreted as a mobile granite. The three localities on Mátâta nunâ will be described followed by other evidence of mobilization. The granite to the east of Uniaríssat is described separately (p.80).

In the region of the small bay (00/589867) on Mátâta nunâ and along the coast to the west the nebulitic gneiss appears to have been broken up into large blocks, in the order of tens of metres across, and granite intruded between the blocks as dykes. That there has been relative displacement between the different blocks of the country rock is well illustrated (fig.33) on the western side of the bay where a granite dyke 1 m wide separates nebulitic granite of different orientation and lithology, and three pegmatite dykes of different directions on one side of the granite dyke are cut off by the granite dyke and do not reappear on the other side.

In order to ascertain how much movement there might have been between the blocks of the country rock a discordant amphibolite dyke was used as a marker and its orientation measured in the different blocks. This discordant amphibolite dyke is rather further west (00/573860) than what seems to have been the main area of displacement of the country rock but the dyke is cut by the granite in two places and there are other lengths where the dyke crosses small inlets. Where the dyke is continuous the dip is reasonably constant though there is a variation in the strike. Each time the dyke is cut by granite or by

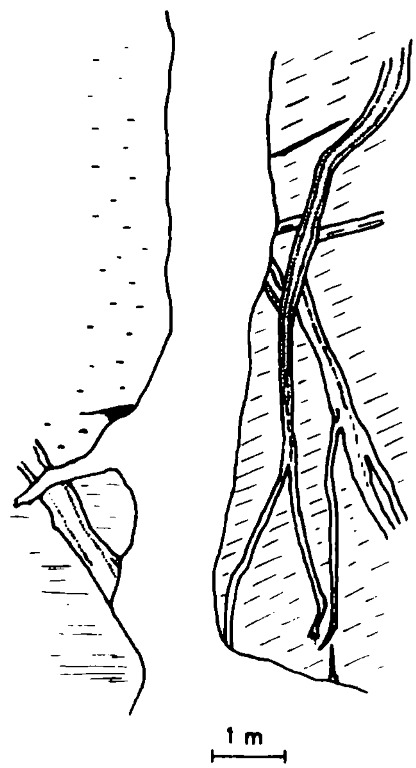


Fig.33. An intrusive dyke of granite (plain) cutting gneiss (represented by dashed lines) and zoned pegmatites (represented by lines of dots within a pair of continuous lines). Bay at 00/589867 on Mátâta nunâ.

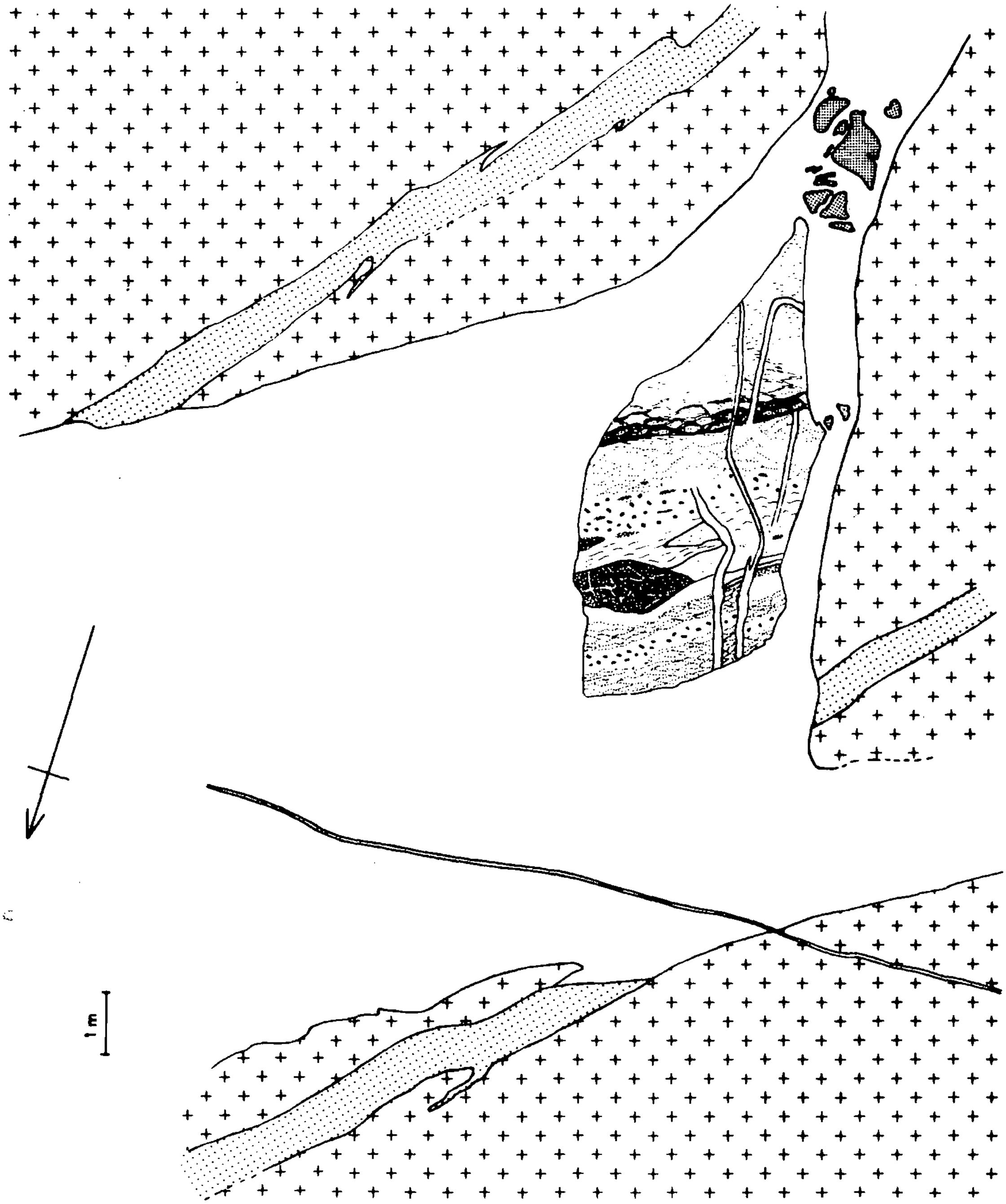
an inlet its dip and strike are different. This is not conclusive but it is suggestive that there has been a certain amount of rotation of the blocks at least about a horizontal axis to change the dip values of the different lengths of the dyke. The strikes within the same length of dyke are too variable to say whether there has been rotation about a vertical axis and the dyke has too many parts missing across inlets to say what sort of lateral movement there might have been except that it cannot have exceeded a few metres.

The discordant amphibolite dyke has been described above as being cut by intrusive granite dykes (figs. 48 & 49). The western granite dyke has a maximum width of two metres and is well marked cutting across the amphibolite dyke and the adjacent nebulitic granite. The second cut through the amphibolite dyke is clear-cut against the dyke but becomes very diffuse against the nebulitic granite as the intruding granite is packed with inclusions. The inclusions are mainly derived from the amphibolite dyke, but there are also inclusions of quartz-diorite and a single inclusion of meta-gabbro.

A third example where granite has been intruded as a dyke between blocks of country rock is found on the eastern side of the small bay on Mátâta nunâ. At this locality three lengths of aplite dyke can all be approximately fitted back to give a single aplite dyke. Sitting between the three lengths of aplite dyke there is a block of gneiss within a homogeneous granite (figs. 34 & 35) that is quite distinctive compared with anything known in the neighbourhood. The outline of the block is sharp and clear-cut, particularly the N.W. and N.E. corners which are parallel and normal respectively to the lithological layering in the block, and the northern corner of the block is particularly sharp. These well defined edges together with the lack of embayment into the gneiss along layers of similar composition to the intrusive granite suggests that there has

Fig.34. A block of gneiss within the mobilized granite. The photograph is taken looking south. The area is shown diagrammatically in fig.35. Only one length of the aplite is visible in the middle distance to the right of the photograph. The boundary between the intrusive granite and the country rock granite is just discernable between the nearer end of the aplite and the hammer and just beyond the far side of the block of gneiss. Bay at 00/589867 on Mátâta nunâ.

Fig.35. A block of gneiss within an intrusive, homogeneous granite (without ornamentation). This intrusive granite cuts an aplite dyke (dotted) and older granite (crosses). A later thin pegmatite dyke cuts across the intrusive granite. Bay at 00/589867 on Mátâta nunâ.


1 m

been very little corrosion of the block and that these are almost the original fracture surfaces.

The gneiss block was extensively granitized before it was emplaced in the intrusive granite. The foliation, picked out and accentuated by thin quartz-feldspathic segregation, the homogeneous layers broken up by later granitic veins, and the more competent bands now occurring as beads of epidote nodules are parallel to more granitic layers in which there are numerous large feldspar megacrysts. Sub-parallel to this layering there are a few thin pegmatite veins. The whole is cut across by a couple of shear planes which contain coarse grained granite. This coarse grained granite along the shear planes appears to be emplaced after the formation of the megacrysts in the conformable layers as no megacrysts penetrate or occur within the cross-cutting granite in continuation of the conformable layers. All the structures of the gneiss are cut off at the edge of the block so that the surrounding homogeneous granite has not played any part in the granitization of the gneiss.

The homogeneous granite that surrounds the gneiss block has a sharp boundary against the surrounding granite which contains a ghost structure and is cut by the aplite dykes. After the emplacement of the granite carrying the gneiss block the granite has been cut by a thin pegmatite dyke. It cannot be said with certainty that the structure of the gneiss block does not fit into the local structure of the nebulitic granite, but all the indications are against this including the difference in degree of granitization.

Further examples of mobilization of granite are found on the N.W. corner of Ajaterfik, which lies on the western side of Ûgarmiut, where there are three small inclusions of bedded meta-sediment within a medium grained homogeneous granite. These have no common orientation, do not show folding within themselves, and none of them fit into the local structural pattern of the island.

The presence of granite veining in the discordant amphibolite dyke at the hut is also indicative of late activity of the granite.

The overall picture obtained is that at a comparatively late period in the history of the basement rocks this area has not been far from the seat of rheomorphism.

Discussion

The granite of the granite dykes was not necessarily emplaced as a magma but rather the nature of the rock had become such that it would flow and act as a fluid. For example, of the two granite dykes cutting the discordant amphibolite neither is of homogeneous granite. One of them has megacrysts along one margin, but it is believed that these were formed earlier and emplaced within the granite of the dyke as megacrysts are not found in the adjacent country rock or in the other granite dyke. It could, of course, be argued that only that margin of the dyke was suitable for migration of material and receptive for the growth of megacrysts. The other granitic dyke cutting the discordant amphibolite is even more heterogeneous with numerous inclusions of a number of different rock types, schlieren and ghost migmatitic structures. If it was intruded as a magma the inclusions would be present in a more homogeneous granite.

The cause of the break-up of the country rock into blocks is not known and why there was no plastic deformation is not understood. There is no other evidence for considerable stress conditions. Fracturing is normally associated with regions of high level in the crust.

The mobilization of the granite is presumed to be Sanerutian. The granite cuts pegmatite and aplite dykes but by the gneiss block it is cut by a thin late pegmatite. It thus comes late in the basement chronology.

The Granite - Meta-sediment Contact to the East of Uniaríssat

Field Relations

To the east of Uniaríssat a sharp contact is seen between the meta-sediment and the granite (figs. 36 & 37) which dips steeply to the north-west in the only place (01/580029) where it is clearly exposed. At this same place there is a 15-40 cm wide intermediate zone which traced westwards disappears. The intermediate zone is well defined from both the granite and the meta-sediment. Between the granite and the intermediate zone the contact is gradational over about 1 cm; between the intermediate zone and the meta-sediment it is knife sharp. The intermediate zone cuts abruptly across the bedding of the meta-sediment (fig. 37) and, on the point, the intermediate zone forms an embayment into the meta-sediment (fig.39).

In a very few places a second intermediate zone, gradational to the first, can be distinguished between the main intermediate zone and the granite. The main intermediate zone is fine grained, light grey in colour with growth of small hornblende crystals. The second intermediate zone is granitic in character with feldspars of the same size as those in the granite but showing foliation parallel to the contacts and a matrix of finer grain size than that of the granite.

Ptygmatic* veins are abundant in the meta-sediment near to the granite and they cut the main intermediate zone. It has not been possible to determine

* Ptygmatic veins are small tortuously folded quartz-feldspar veins where the axes to the folds have <u>no</u> common orientation (cf. Read, 1931 p.110-111; Dietrich, 1959 p.358).

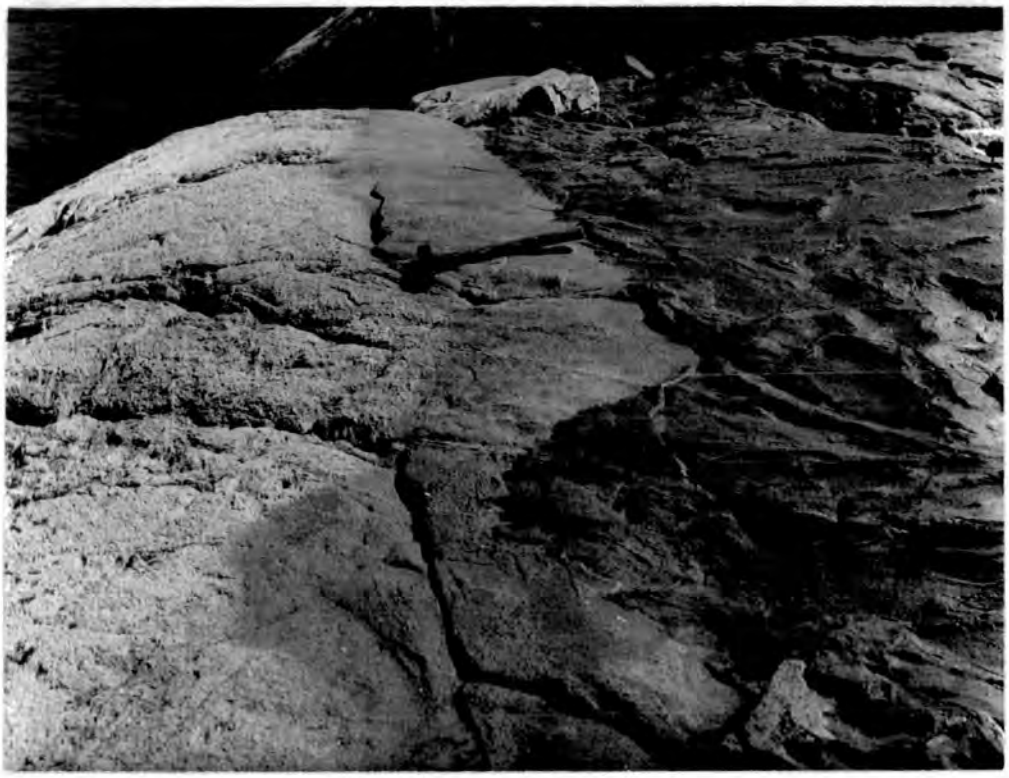


Fig.36.

Figs.36 to 39. The contact between granite and meta-sediment at 01/580029. Note the intermediate zone, about 30 cm wide and the cutting off of the banding in the meta-sediment by this zone in fig.37. In fig.39 the granite is shown embaying the meta-sediment. The epidote veins are cut off by the intermediate zone but the quartz-feldspar veins continue through it and terminate against the main granite (fig.37).

Fig.37.

Fig.38.

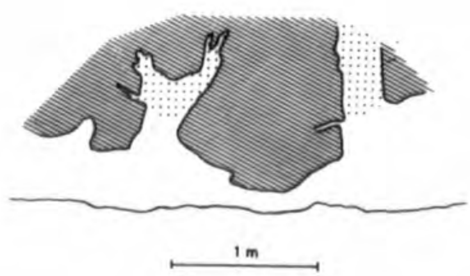


Fig.39.

Ruled is meta-sediment; plain is granite with the intermediate zone between the continuous line across the diagram and the meta-sediment grading into a coarser facies (dotted) in the embayments.

whether this veining comes from, or cuts, the secondary intermediate zone and the granite. Epidote veins, often showing boudinage structure, are also frequent in the meta-sediment. No epidote vein penetrates the intermediate zone. Pegmatite is sometimes present along the contact between the meta-sediment and the main intermediate zone, and where developed it is rich in magnetite.

While the feldspars from the second intermediate zone frequently show preferred orientation those in the granite only show orientation in a few places.

Discussion of the Field Evidence

From the field relations the following features are of importance in the interpretation of the contact. 1) The intermediate zone retains a comparatively constant width following closely the border of the meta-sediment (fig.38). 2) The intermediate zone cuts off the banding in the meta-sediment (fig.37) and no trace of banding has been seen in the intermediate zone. 3) Ptygmatic veins cut the meta-sediment and the intermediate zone.

The evidence is rather scanty for a definite interpretation to be made for as Buddington has said, "One of the difficulties in proving granitization is that nearly all criteria are subject to alternative interpretation" (1959,p.733) The contact can be interpreted in two ways, depending upon the bias of the observer and his interpretation of the emplacement of the granite. There is no independent evidence on the formation or emplacement of the granite.

1) A mobile intrusive granite. If the granite is assumed to be intrusive the intermediate zone could have formed by a mixing of granitic material with meta-sediment which has then acted as a lubricant between the granite and ~~the meta-sediment which has then acted as a lubricant between the granite and the~~ meta-sediment and has flushed out the contact to give the sharp, cross-cutting relationship. The ptygmatic veining is later, the tortuosities of the ptygma

depending upon the relative competencies of the injected material, the host rock and the less ductile adjacent rock which acts as a resister against which the vein buckles (Wilson, 1952).

2) Granite formed by replacement. The granite may have been formed by replacement of a sedimentary or volcanic series of rocks relatively easily granitized leaving the meta-sediment as a resister that has withstood granitization. The intermediate zone may then be interpreted as granitization of the meta-sediment at its margin during a period of reactivation of the granite, the granitization penetrating further into the meta-sediment in places as embayments (fig.39). That granitization may form sharp contacts with the earlier rock is well illustrated in many of the discordant amphibolites where the granitization appears to be structurally controlled within the dyke leaving sharp contacts against amphibolite. It may be argued that the ptygmatic veins were emplaced during deformation. Since there is no evidence of deformation after the formation of the intermediate zone, the ptygmatic veins must have been emplaced before the formation of the intermediate zone and to have survived the granitization of the zone since they had a low granitization potential.

More definite evidence of late local mobilization of the granite is known from Mátâta nunâ. Thus mobilization of granite is known not so very far away so that the formation of the intermediate zone by mixing is feasible during a later reactivation of the granite which may locally have flushed out the contact. The lack of an intermediate zone further to the west along the contact does not affect any of the arguments; reactivation or mobilization may, and probably was, very local.

Discordant Amphibolites

Discordant amphibolites are well represented at three places in the Qaersuarssuk area. They will be described from these places and reference made only to other occurrences when there is any notable variation.

These amphibolites are discordant to the structure in the adjacent rocks and have the character of intrusive dykes which have been later affected by metamorphism and migmatization. They have parallel contacts, apophyses into the country rock and a marginal texture interpreted as a reflection of an original chilled margin. At Uniarís sat the dykes are discordant to bedding in meta-sediments, at the hut on Bredefjord they are discordant to amphibolite bands in the gneiss, and on Mátâta nunâ they are discordant to migmatitic structures. As a group the dykes are in various stages of alteration the least altered retaining a pseudo-igneous texture while the most altered that can be identified as dykes are sheared amphibolites.

In many places on Qaersuarssuk there are examples of amphibolites similar to those to be described which are almost certainly of the same origin but a discordant relationship cannot be demonstrated as they are in a homogeneous rock and many of the criteria that characterizes a dyke have been lost. This also applies in areas where there has been folding and shearing and what was once probably straight and discordant is now parallel to all the other structures in the gneiss. This means that there are a large number of amphibolite bands (e.g. fig. 47) where it is impossible to say whether they were once dykes or whether they are original basic bands or metamorphic differentiates.

Uniaríssat

On the peninsula known as Uniaríssat there is a swarm of amphibolite dykes striking 055° with a discordance of 5° to the bedding of the meta-sediment into which it is intruded (figs. 40 and 41). The dykes have been boudined with the development of pegmatite in the low pressure zones (fig.42) following a foliation of the mafic constituents, particularly marked by the lens-shaped aggregates of hornblende up to 1 cm in length. In some of the dykes the lenses of hornblende are absent from the margins of the dyke. Where present these margins are about 2 cm wide and are regarded as a reflection of an original chilled margin. Apart from the lack of hornblende aggregates in the margin there is no apparent difference in grain size. Most of the dykes are about 30 cm wide. The lengths of these amphibolite dykes are not known as they are only seen on a narrow strip of coast.

The Hut (Bredefjord) by Tûgdlik

On the coast of Bredefjord beside the hut at 00/703948 two periods of discordant amphibolites can be seen (figs. 43 - 45). The dykes of the earlier period were intruded into folded Ketilidian gneisses and nebulitic granite and were followed, after a period of migmatization, by the later dyke which cuts the migmatization of the earlier.

The later period of dyke intrusion is represented by a single dyke (figs. 43 - 46) striking 020°. It is about 60 cm in width with a fine grained margin which probably reflects an original textural difference due to chilling. The central part is coarser grained with porphyroblasts of hornblende. The dyke is broken into blocks which are regular in size and shape, being squarish in section and the width of the dyke and are arranged <u>en bajonet</u> with thin granite veins between them. The dyke probably broke into blocks as it was more

Fig.40. A swarm of discordant amphibolite dykes at Uniaríssat.

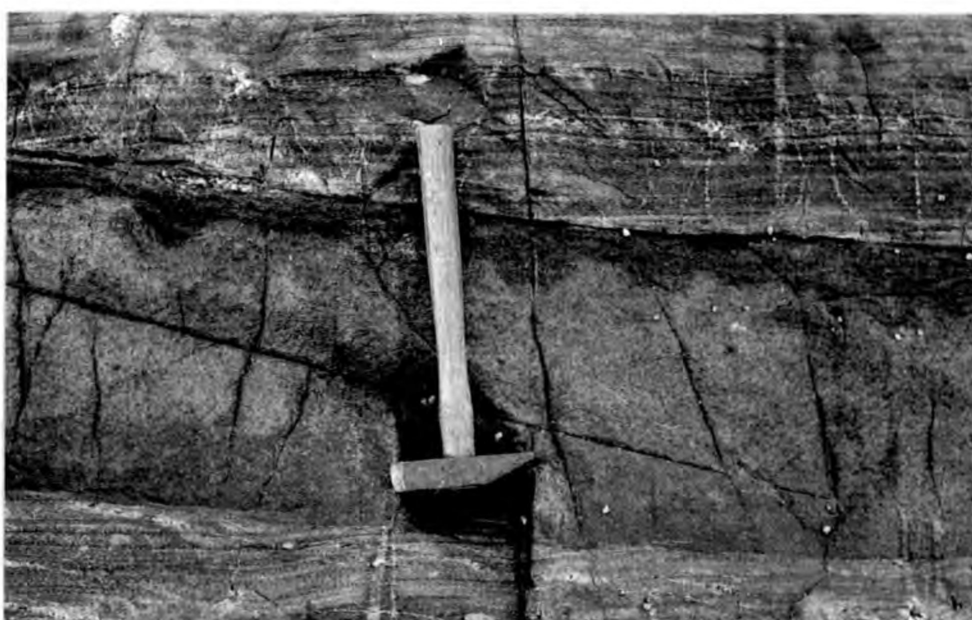


Fig.41. A discordant amphibolite dyke cutting the meta-sediment at Uniaríssat.

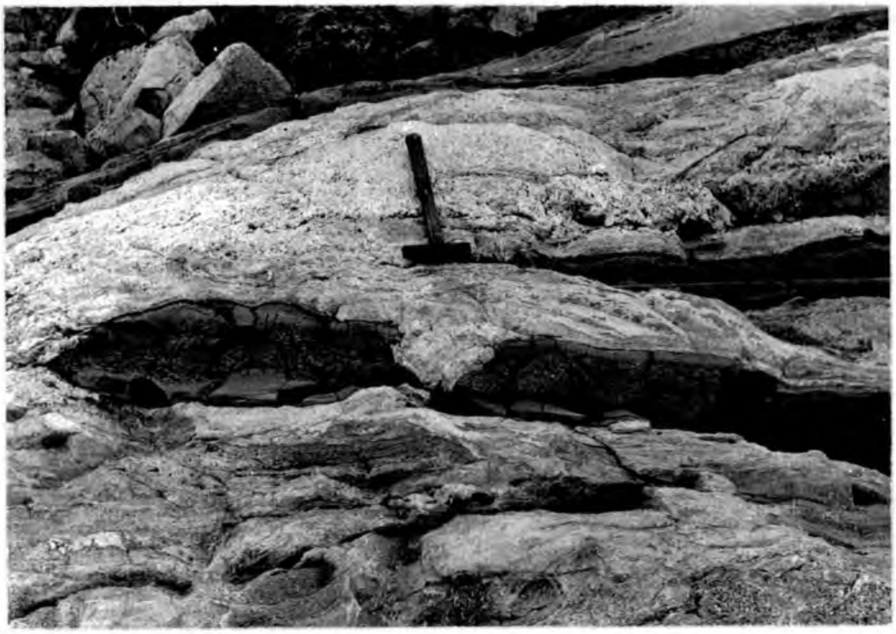


Fig.42. A discordant amphibolite dyke at Uniarı́ssat that has been boudiné and foliated. Note the fine grained margin with the absence of the dark hornblende aggregates.

Fig.43. The later discordant amphibolite dyke at Tûgdlit cutting an amphibolite dyke of an earlier period in the foreground. Note the difference in the style of the migmatization: the earlier affected to a greater extent than the later. 00/703948.

Fig.44.

Figs.44 and 45. The amphibolite dyke of fig.43 cutting an earlier amphibolite dyke at right angles to it. The hammer is lying on the earlier dyke with the shaft parallel to the length of the dyke.

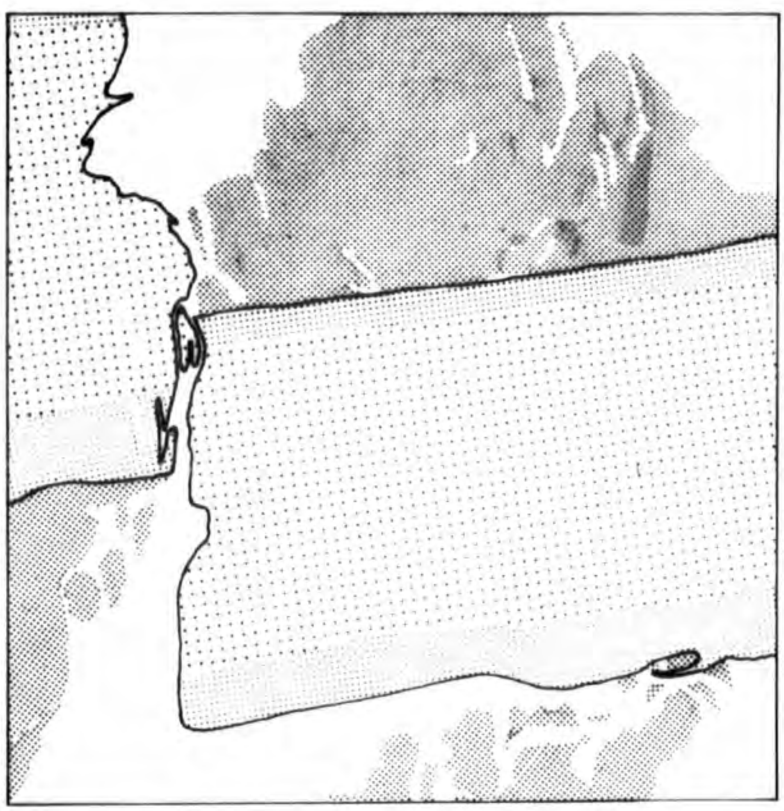


Fig.45.

competent than the granite and the cracks were invaded by granite (figs. 43 - 46). On the basis of the regularity of the blocks it is suggested that the granite and displacement followed old cooling joints in the dyke.

This later dyke cuts amphibolite sheets (figs. 43 - 45) and folded streaks (figs. 46 and 47). The sheets are not folded and since they occur alongside folded amphibolitic streaks they are thought to be dykes emplaced later than the folding. These sheets, of which there are two, have not been affected by folding and have strikes that vary between 070° and 100°. They are affected by migmatization to a greater extent than the later dyke but this cannot be used as a criterion of age as the greater degree of alteration may be due to: 1) a difference in the original composition; the more basic to ultra-basic in composition the more competent the body and the least signs of alteration. 2) a difference in attitude of the amphibolite sheet compared with the migmatitic structures, the greater the difference in attitude the greater the degree of alteration. The later dyke not only cuts the earlier amphibolite sheets or dykes but also cuts the granite veining it so that the two dykes are of different periods.

In the same area there are folded amphibolitic streaks (fig. 47). As these streaks are conformable to the gneiss structure it is not possible to use them for elucidating the geological history of the area: they could be earlier post-Ketilidian or inter-Ketilidian dykes, or they could equally well be the remains of original supracrustal rocks such as lavas or tuffs.

Mátâta nunâ

On the south coast of Mátâta nunâ there is an amphibolite dyke that is important since it is the key to the age relationship of the mobilized granite

Fig.46. The amphibolite dyke of fig.43 cutting amphibolitic streaks. These streaks are continuous with that of fig.47.

Fig.47. An amphibolitic streak concordant with the structure of the gneiss. Since it is parallel to the gneiss structure it is not possible to tell whether it is an earlier dyke or a 'resister' of supracrustal rock. The continuation of this streak is cut by the amphibolite dyke of fig.46.

in that area. This dyke (00/573860) can be traced for nearly 200 m striking 100^{o} and dipping to the north-east along the coast of Bredefjord. It is straight and discordant to the migmatite (fig. 49). The dyke, with an average width of about 80 cm, shows the remains of an igneous texture (fig.60) and in places small aggregates of hornblende. It is cut in two places, at least, by granite dykes (figs. 48 and 49) but, except for a little pegmatite along one margin in one place, shows little sign of granitization.

Other Occurrences of Discordant Amphibolites

Along the coast of Bredefjord south-westwards from the hut there are fairly numerous discordant amphibolites. Many have a direction similar to the later period dyke at the hut and many show the same break-up into blocks separated by granite (figs. 50 and 51) and the presence of margins of different texture (figs. 50 and 59). Hornblende develops as lens aggregates, usually in the central part of the dyke but occasionally the reverse is seen, hornblende aggregates concentrated in the 10 cm margins and scarce elsewhere. Very occasionally, for example in a 60 cm dyke at 00/694940, the hornblende is concentrated only in one margin and scarce in the other and in the central part of the dyke. Where aggregates of hornblende occur small feldspar megacrysts (?relic phenocrysts, cf. fig. 60) are also common.

Normally the lenses of aggregate hornblende in the dykes are elongated parallel to the length of the dyke. Usually though, the dyke only shows a slight discordance to the gneiss but where the dyke has a high discordance, such as at 01/6910 near the inland ice, the elongation of the hornblende aggregates is parallel to the gneiss structure and not to the margins of the dyke.

Frequently the dykes have a low dip, the later dyke at the hut being

Fig.48. The amphibolite dyke on Mátâta nunâ cut across and displaced by an intrusive granite dyke. 00/573860.

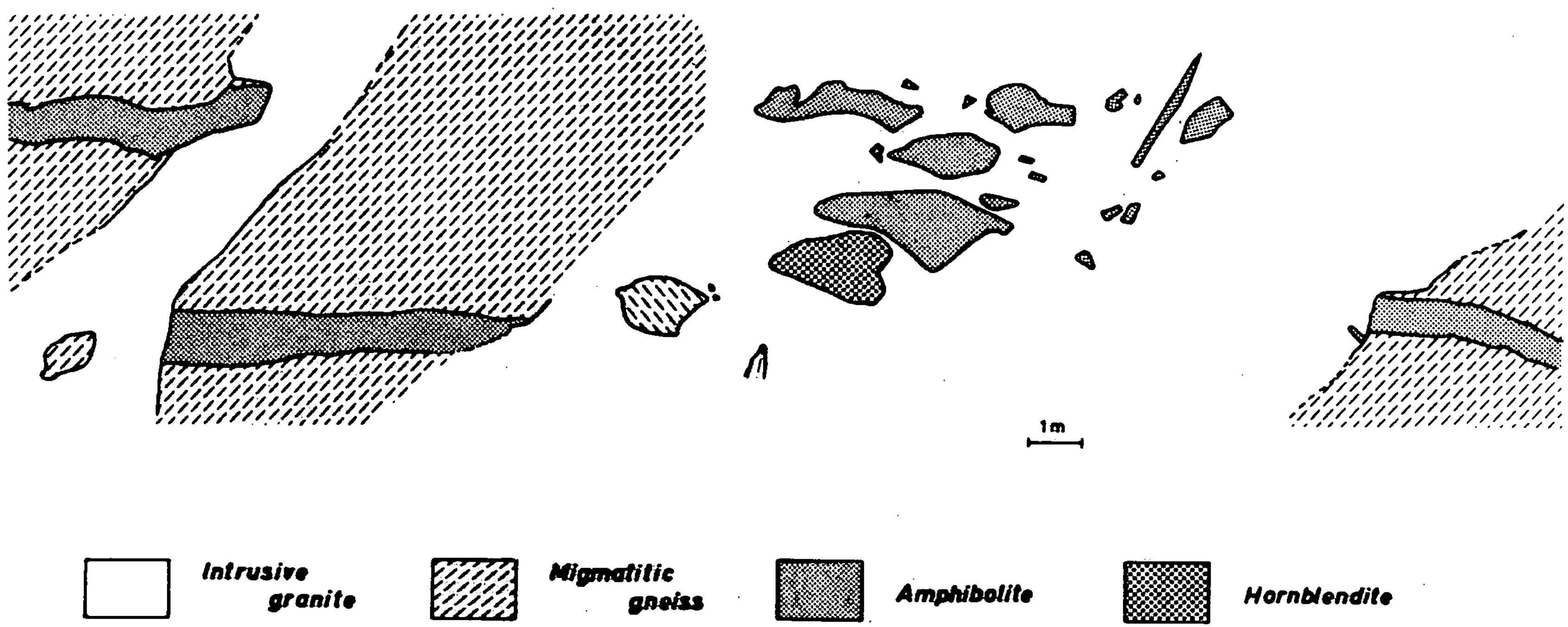


Fig.49. An amphibolite dyke cut across by later intrusive granite with numerous fragments of the amphibolite and other rock types. Bay at 00/589867 on Mátâta nunâ.

Fig.50. An amphibolite dyke on the Bredefjord coast. Note the prominent fine grained margins to the dyke.

Fig.51. An amphibolite dyke on the Bredefjord coast broken up into short lengths. 00/676930.

one of the exceptional vertical dykes. An echelon arrangement is quite common and so it plastic movement in the granite: some of the more extreme examples are illustrated in figs. 52 and 53. Shear folding is best illustrated in a single dyke above the Sermilik glacier (figs. 54 and 55).

The dykes tend to occur in swarms. The swarm at Uniaríssat has already been mentioned (fig. 40); the group of 020° striking dykes along the Bredefjord coast constitute a swarm, and a third group is illustrated as fig.56 by the inland ice.

An inspection of the strikes of the various amphibolite dykes suggests that there are a number of dyke generations. No sort of age relation of generations can be worked out as there are no intersections known. On Mátâta nunâ most of the amphibolite dykes have a strike of 155°-160°, the dyke already described being an exception. A dyke of this general direction at 00/561860 is interesting as it is marginally replaced by aplitic granite (Fig. 57) while the amphibolite still preserves the remains of an original igneous texture. This is also seen at 00/586865 on Mátâta nunâ. A similar feature, but with pegmatite rich in hornblende replacing the dyke, is occasionally seen in the Bredefjord coast dykes. Dykes that are extensively migmatized quite frequently have a sheath of aplite between the dyke and the granite.

There are many examples of amphibolites which are concordant with the granite foliation. These amphibolites present a problem as to whether they are dykes at all, or 'resisters' from original supracrustal rocks.

Petrography

Texturally the dykes show all gradations from those with a strong folation to those that retain something of their original ophitic texture (fig. 60).

Fig.52. An echelon arrangement of an amphibolite dyke in granite. 00/694962.

Fig.53. An amphibolite dyke in a plastic medium. 00/708983.

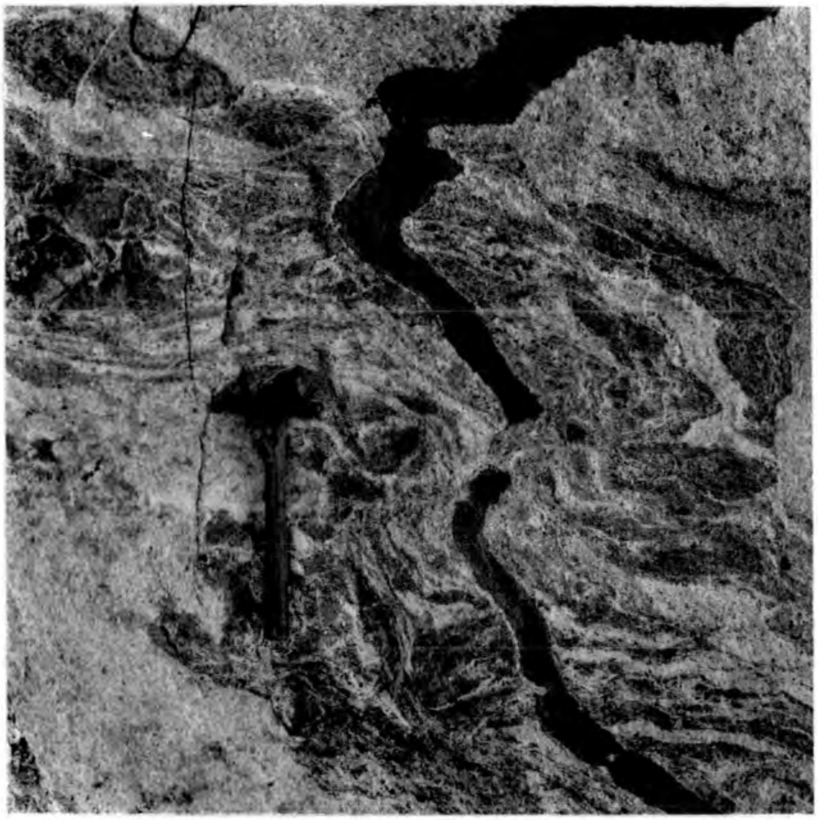


Fig.54.

Fig.55.

Figs.54 and 55. Different parts of the same dyke showing folding. From above the Sermilik glacier.

Fig.56. A swarm of amphibolite dykes by the inland ice.

Fig.57. An amphibolite dyke marginally replaced by aplite. The amphibolite still shows an igneous texture. A small pegmatite vein cuts the aplitized amphibolite dyke. Mátâta nunâ - 00/561860.

Fig.58. Apophyses from the end of an amphibolite dyke. Mátâta nunâ - 00/580863.

In those dykes that retain something of their original texture the greater part of the plagioclase is clear, enclosing numerous small rods of apatite though some of the plagioclase laths are slightly sericitized. Carlsbad-albite twinning of the plagioclase is ubiquitous and normal zoning is frequent. In addition to the plagioclase laths there is normally a crystal or two which is of larger size and always shows strong zoning, with a composition ranging from about An_{34} in the centre to An_{20} on the margin (andesine to oligoclase). The laths have an average length of about 0.2 mm. In 45367, which is much finer grained than the other samples, there are numerous larger laths of plagioclase averaging 1 mm in length, in a groundmass with a grain size of 0.05 mm. These larger crystals are probably the remains of phenocrysts.

Microcline has been occasionally identified as clear interstitial grains and quartz may also occur.

In those dykes that show a stronger foliation of the mafic constituents the feldspar, which is interstitial to the mafic constituents, show considerable dusting due to sericite and epidote. The microcline grains are usually fairly clear of this dusting as are also certain plagioclase grains, suggesting that these have recrystallized at a late stage.

The hornblende, estimated at about 15-30% of the total in those samples with the weakest signs of shearing, occurs as small grains (about 0.2 mm) between the plagioclase laths but there is a tendency for it to form lens-shaped aggregates (fig. 61). The hornblende grains in the aggregates form larger grains than those in the groundmass. The pleochroism shown by the hornblende is fairly constant with α very pale green, β apple green, and γ blue-green.

The other main mafic constituent is biotite which may occur in nearly equal proportion to the hornblende or be very subordinate. It is strongly

Fig.59. A discordant amphibolite on the Bredefjord coast broken up by granite veining. From a colour transparency.

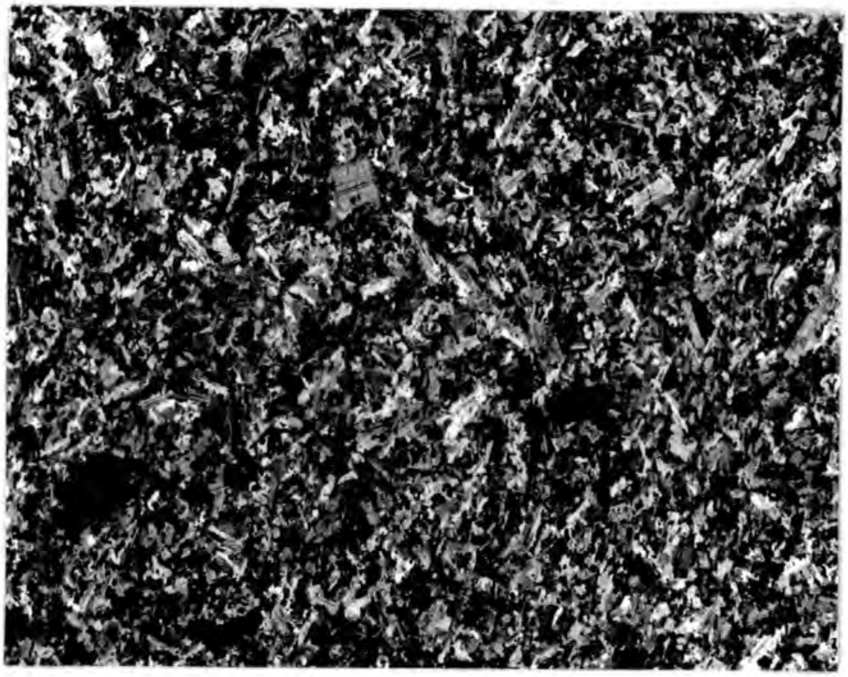


Fig.60. The remains of an ophitic texture in a discordant amphibolite. Sample 45379 from Mátâta nunâ. X-nicols. x 6.7. Photo C.Chaplin.

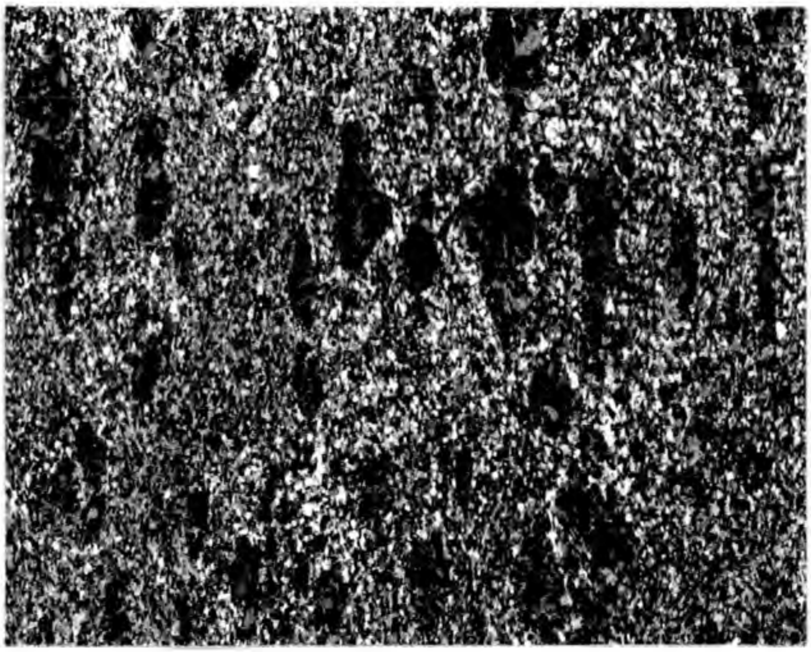


Fig.61. A thin section of a discordant amphibolite where the hornblende forms lens-shaped aggregates. The sample (45342) is taken from the centre of a dyke at Uniaríssat. 1 nicol. x 6.7. Photo C.Chaplin.

pleochroic with α pale straw yellow to γ green-brown to dark brown. It is absent from the hornblende aggregates except for the periphery.

In those dykes with a stronger foliation, e.g. fig. 61, the hornblende forms prominent aggregates with crystals of about 0.4 mm though many of the aggregates are rather diffuse and sometimes include biotite. Occasionally grains of pyroxene are present which do not show signs of alteration. The hornblende and biotite in this dyke have very similar pleochroic colours with α pale yellow rather than the pale green of those described above, and the biotite with γ dirty green rather than brown.

The sample 45376, from the eastern end of Mátâta nunâ (00/564858) which is very similar in hand sample to the meta-gabbros (p110) contains considerable quantities of pyroxene which is being replaced by brown and green hornblende. The hornblende is pleochroic with α pale yellow, β light brown or green and γ brown or green and frequently forms rims around longitudinal sections of pyroxene. Both colours of hornblende frequently occur in the same crystal and there is probably a compositional difference, the green being most common around the edges. Opaque material in this section is scarce and occurs in concentrations of tiny grains often associated with areas of pyroxene as if derived from it.

In general opaque material, in amounts up to 1% to 3%, is disseminated throughout the amphibolite but where there are aggregates of hornblende developed large opaque grains are present in the aggregates while with a foliation of the individual mafic constituents the small disseminated grains almost entirely disappear from the groundmass. A few of the opaque grains show red translucent edges like haematite, but the majority of them are probably magnetite. The occasional larger grains all have reaction rims while in places there are indications that the hornblende is replacing magnetite. Opaque material along cleavage fractures in the hornblende is fairly common. Sphene is comparatively abundant (up to 2%) occasionally associated with the opaque grains but usually independent of them. Where there is marked foliation the prominance of the sphene is greatly reduced. Apatite is known as a minor accessory in some slices.

A vein of epidote crosses one of the slices and epidote is abundant in the slice adjacent to the vein. In the areas where there is epidote there is tremolite (or a mineral between hornblende and tremolite) which has pleochroic colours of pale green, pale blue-green and nearly colourless. The iron seems to have gone into the epidote from the hornblende leaving tremolite.

In those dykes that are less intensely sheared there appears to have been recrystallization of the plagioclase and the sericitization/saussuritization that almost certainly occurred was largely removed. Hornblende and biotite have replaced original pyroxene and sphene has recrystallized and grown, probably with calcium from the plagioclase and titanium from the original pyroxene and ilmenite. Haematite has formed by oxidation of the magnetite.

The two samples (45340 and 54342) from the margin and centre respectively of a dyke at Uniarı́ssat have a strong foliation marked by sub-parallel crystals of biotite and hornblende with lens aggregates of hornblende and rods of opaque material with a random arrangement. The marginal part of the dyke has a well developed foliation due to biotite accompanied by randomly arranged rods of opaque material. Along the boundary of the margin against the inner part of the dyke there are small lens aggregates of biotite, or occasionally of hornblende with a flake or two of biotite. Near to the edge of the inner part there are small aggregates of epidote and some aggregates entirely of opaque grains. The hornblende and biotite crystals of the aggregates are considerably larger in size than those in the groundmass. The aggregate minerals average 0.4 mm while those of the groundmass are long thin flakes reaching about 0.2 mm in length. In the middle of the dyke (45342) the biotite is subordinate to hornblende and opaque material is scarce, entirely absent from the groundmass and occurs only as small disseminated grains in the lens aggregates. In contrast in the margin of the dyke (45340) the opaque material of the groundmass is in randomly arranged rods and that of the lens aggregates is in equidimensional grains of comparable size to the hornblende grains. The amount of opaque material in the lens aggregates varies enormously from a few odd grains to the dominant mineral and even forms small lenses entirely of opaque grains.

The groundmass, apart from the mafic minerals, of both the margin and middle of the dyke, is almost entirely of sericite with epidote and quartz.

The lens aggregates of hornblende throughout the dyke have formed during metamorphism with the constituent hornblende grains in random orientation: the plagioclase was sericitized. The biotite has grown under conditions of shear and sweeps around the lens aggregates but the opaque rods have crystallized after a release of the shear conditions. The shearing may have been most intense along the margins of the dykes, where there is epidote, and the plagioclase of the groundmass in the centre is not as strongly sericitized and occurs as granular grains together with microcline and quartz.

Relationship of the Amphibolite Dykes to the Country Rock

A single amphibolite dyke (00/580863) on the south coast of Mátâta nunâ shows a number of intrusive features. The dyke is straight with a strike of 165° and a width varying between 30 and 50 cm lying in granite. Since it is lying in a fairly homogeneous rock no discordance can be demonstrated. There are joints in the dyke at regular intervals normal to the strike and small parallel joints confined to the margin. No difference in grain size between middle and margin is now apparent and small lens-shaped aggregates of amphibole crystals growing throughout the dyke are elongated parallel to the length of the dyke. Occasional ?inclusions of granite and a single lump of quartz are present in the margin of the dyke, the granite inclusions having the shape of narrow lenses. The dyke is cut across by a pegmatite vein and by a 2 cm wide vein from the surrounding granite, as well as smaller granite fingers, which are continuous with the granite surrounding the dyke. The dyke is discontinuous with apophyses from the dyke penetrating the intervening granite. The form of these apophyses suggests penetration along an early joint system in the granite (fig. 58).

From the features seen in this dyke it is suggested that it was intruded into granite. This supposes that the granite was cool with a joint system of its own and presumably at a fairly high level in the crust. That it was intruded into granite is suggested by the granite inclusions while a joint system is suggested by the straightness of the dykes and the form of the apophyses. This interpretation is supported by the marginal textural difference, interpreted as a chilled margin, shown by dykes on the Bredefjord coast (figs. 45, 50 and 59).

Discussion on the age of the DAs

Watterson in the Kobbermine Bugt area (1963) has recognized three periods of discordant amphibolites. These he has called DA_1, DA_2 and DA_3 to distinguish them from the different generations of discordant amphibolites in the Ivigtut gneisses referred to by Ayrton (1963) and Weidmann (1963) as ADs (amphibolites discordant).

In the Kobbermine Bugt area discordant amphibolites occur in the granite and in the meta-sediments. The DA_1 period of dykes only occurs in the meta-sediment and is cut off by the granite. These dykes are therefore interpreted as being earlier than the granite. If they occur within the granite there is no way to distinguish them from remnants of supracrustal rocks. It is suggested by Watterson that these may be the feeders of the lavas in the volcanic series at the base of the Ketilidian (the Arsuk series of Wegmann (1938) in the Ivigtut area).

The second period of discordant amphibolites (DA_2) occur in the granite, are granitized by the country rock granite and may be folded. A discordance to the foliation in the granite may sometimes be demonstrated but it is not possible to do so in every case.

The third period dykes are not folded and are not veined by the country rock granite but may, and frequently are, cut by aplite and pegmatite dykes. Many of them also have a tendency to be replaced by aplite though this is not a diagnostic feature as aplite is also known to replace second period dykes. A feature that is common in the third period dykes is the S-shaped foliation within the dyke, the margins having a foliation parallel to the contacts. It is suggested by Watterson that these dykes have been intruded into hot country rock granite.

A set of dykes later than all the aplite and pegmatite dykes, yet metamorphosed, has been recognized in the Julianehaab area by Allaart (personal communication) but as these have not been recognized on Qaersuarssuk they will not be further discussed here other than to mention that they are earlier than lamprophyre dykes believed to be of Gardar age. Their age relationship to Gardar dykes of more certain age is unknown other than that similar dykes described by

Bondesen on Tôrnârssuk (1960) are earlier than the first generation of Gardar dolerite dykes.

While this division of the discordant amphibolites is recognizable in certain places in the Julianehaab district elsewhere the diagnostic features are lacking so that it becomes extremely difficult, or impossible, to fit individual dykes into the chronological pattern. The three areas on Qaersuarssuk from which discordant amphibolites have been described will be used to illustrate this.

At Uniaríssat where discordant amphibolites are intruded into meta-sediments there is no age relationship to the granite. They do not show an S-shaped foliation but do show slight boudinage. This suggests that they are not of the third period, but whether they belong to the second or the first period it is not possible to say.

The dyke on Mátâta nunâ and the later dyke at the hut are both cut by granite and neither of them are folded. They could therefore both belong to the second period of dyke emplacement.

At the hut there are two dykes neither of which are folded. They could be 1) of different periods separated by a period of migmatization, or 2) of different generations but belonging to the same period. If the dykes belong to two different periods the later dyke might be expected to cut migmatitic structures in the earlier dyke formed during the intervening migmatitic stage. The evidence for this is inconclusive (figs. 44 and 45). The later dyke is obviously less migmatized than the earlier, but this is no criterion of age, and may be due to 1) a difference in attitude to the foliation direction of the granite, those parallel to it being little affected while those at right angles are shear folded and more strongly affected by migmatization; 2) a difference in composition, and hence competency, of the dykes. But in the two dykes at the hut the granitic veining is parallel to the length of the earlier dyke and cross-cutting the later dyke (fig.43). This does not fit the expected pattern if the migmatization of the two dykes was at the same time. A second migmatization after the emplacement of the later dyke would be likely to destroy any dilational features. The postulation of two periods of dyke emplacement each followed by migmatization, yet later than the folding does not fit into the currently accepted chronology of dyke periods and migmatization that has been worked out in adjacent areas. Different generations of the same period are clearly demonstrated elsewhere (e.g. Iterdlak on the Julianehaab peninsula where three generations are distinguished belonging to the same period (Allaart, personal communication; Nesbitt, 1961)).

Watterson (1963) has pointed out that not all the dykes need be inter-orogenic and gives evidence for the emplacement of the third period discordant amphibolites during a period of renewed activity in the basement. There is an intimate connection between these dykes and their replacing aplite. Aplite both as veins and as wholesale replacement of the dyke is frequent often with the aplite confined to the dyke and not penetrating the granite. A late, and possibly the last, generation in the DA_3 period of dyke emplacement occurs as low dipping sheets. These frequently show cauliflower veining and appear to be more susceptible to aplite replacement than the dykes. Sheets of this type may possibly occur along the Qôrnoq coast of western Qaersuarssuk.

Significance of the Dykes in Chronology

Similar metamorphosed amphibolite dykes were used by Sederholm to distinguish older and younger Archæan granites in south-western Finland (Sederholm, 1926 p. 31-36) and Sutton and Watson (1951) used them to divide the Lewisian gneisses in north-west Scotland.

In west Greenland Ramberg (1948) used the metamorphosed Kangâmiut dolerite dykes to separate two periods of regional metamorphism and migmatization and recently Berthelsen (1961a and b) has tentatively equated the Kangâmiut dykes with the Kuanitic dykes of south Greenland.

To the north of Sermiligârssuk there are fresh dolerite dykes, the Kuanitic dykes. To the south of this fjord what are believed to be the same dykes have been affected by later regional metamorphism and migmatization that has not affected the dykes to the north of it. The dykes mark a division between the Ketilidian rocks into which they were emplaced and a later period of reactivation of the basement, termed the Sanerutian (q.v. p.9).

Meta-gabbro

Field Occurrence

Agmatitic meta-gabbro occurs in a number of places on Qaersuarssuk though only two areas are of any size. These two larger areas are situated one on the high ground to the west of Atertûp ilua and the other in a hollow at the head of one of the small fjords (00/5892) between the two Kangerdluarssuks. There are in addition small occurrences such as in the N.W. corner of Qeqertarssuaq (01/540036) and on the south shore at the entrance to Atertûp ilua, with opposite it on Qeqertaq, a single block, and on the south coast of Mátâta nunâ (00/579862).

Both the larger areas are badly exposed, the one between the Kangerdluarssuks being in low ground with only occasional outcrops. It is partly surrounded on the eastern side by a sheath of diorite. The other area, about 2km west of Atertûp ilua, is better exposed but scantily explored. It appears to be an elongated mass about 500 m in length and 200 m across. The eastern part is veined by 1-2 cm plagioclase-quartz veins while on the western side the veining material is much more abundant with the meta-gabbro occurring as angular blocks which, on the surfaces presented, do not fit back into place.

The other area of note is the 20 m wide strip of meta-gabbro striking N-S. on the southern side of the entrance to Atertûp ilua (00/629895). The northern part is only thinly veined by plagioclase-quartz veins while the southern and central parts are broken into small, angular blocks with a dominant plagioclase-quartz matrix. In areas where the meta-gabbro is only thinly veined there may be channels of the vein material carrying small pieces of the meta-gabbro (fig. 62) which appear to be floating. Where there is thin veining the blocks produced by the veins are all angular and fitting as if broken apart. Southerwards, where the porportion of matrix increases, the blocks are still as angular but no longer fit together in the two dimensional surfaces presented (fig. 63) and there are patches of coarse pegmatite in the matrix.

On the northern side of Atertûp ilua, in the extreme S.E. corner of Qerqertaq, there is a single block of meta-gabbro about 10 metres square. The four margins of the block are distinct and sharp against the granite. It is homogeneous apart from a single thin plagioclase-quartz vein that crosses it. This block is probably an extension of the meta-gabbro strip on the southern side of the fjord, the whole being a broad dyke that has been affected, among others, by the Sanerutian reactivation of the granite.

The meta-gabbro from these areas is coarse grained with large hornblende crystals up to 1 cm in size, and with traces of interstitial plagioclase. The large hornblendes may weather out to give a pitted surface.

Fig.62. A plagioclase-quartz vein in meta-gabbro with disoriented blocks of the meta-gabbro. 00/629895.

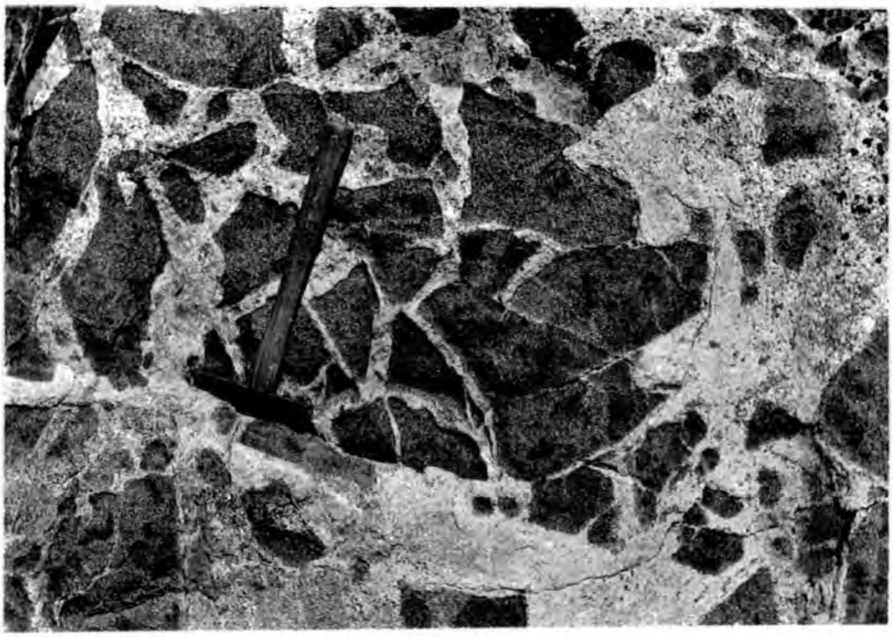


Fig.63. An advanced stage of break up and disorientation of meta-gabbro blocks. 01/538034.

Petrography

The samples from the different areas are very much the same. In only one sample (45503) has olivine been observed; original pyroxene occurs in some but not all, being absent where there is a maximum development of large hornblende crystals. Biotite is universally present.

The hornblende, which has grown at the expense of the original pyroxene, occurs in some slices as large grains up to 1 cm in diameter as well as smaller grains. It is strongly pleochroic with α pale yellow-green to colourless, β apple green and γ light green.

The slice 45503 contains olivine and pseudomorphs after olivine. The presence of olivine and its pseudomorphs, as well as pyroxene, indicates that this is the least altered of all the meta-gabbro samples. The olivine is veined by a fibrous mineral, pleochroic in pale and deep yellow, and rimmed by a carbonate mineral that may be magnesite.

The pyroxene, where it occurs, is in numerous small rounded grains in which some show fine examples of replacement by hornblende. The replacement of pyroxene by hornblende is frequently from the centre outwards, patches of hornblende occurring in the pyroxene. These small rounded pyroxene grains frequently have the cleavage planes accentuated by fine opaque material.

The proportion of plagioclase in the different samples varies considerably, on a rough estimate there being a decrease of plagioclase with increase in hornblende. Where plagioclase is most abundant it has a composition of about An_{27}-$_{36}$. Much of the plagioclase is saussuritized, but in some of the slices there are small perfectly clear grains. Albite twinning is universal and some of the larger grains are zoned.

Biotite only occurs associated with the larger grains of hornblende.

It either grows along the cleavage of the hornblende or forms larger, better formed flakes cross-cutting the hornblende cleavage. The biotite in both positions is pleochroic with α pale yellow and β and γ brown. The cross-cutting flakes of biotite appear to be later and better developed than the biotite in the hornblende cleavage. It is growing at the expense of the hornblende. The biotite has occasionally been altered to chlorite.

The production of biotite from hornblende requires a source of potassium. The plagioclase-quartz veins could have been this source, the potassium going into the production of biotite in the meta-gabbro rather than microcline in the veins.

Apatite occurs as comparatively large grains, in 45509 up to 0.4 mm across. This is also the slice with the largest hornblende content so that there is an apparent increase in size of apatite grains with increase in metamorphism. Apatite occurs in all the other slices but is very much more disseminated throughout the rock. Sphene is an accessory that appears to occur only in 45324.

A small porportion of the biotite in all the slices contains prehnite (cf. Struwe, 1958) growing between the plates and forcing them apart. Occasionally the whole grain containing prehnite is chlorite, but more usually there is only a very thin sheath of chlorite surrounding the prehnite crystal. Opaque material is sparse and confined to the hornblende crystals. Calcite occurs as a secondary, interstitial mineral in 45503.

Discussion

The relations of these meta-gabbro bodies to the main granite is not known. The meta-gabbro is more competent than the surrounding granite so that under orogenic movements it would break up into angular blocks and the spaces that formed filled with pegmatitic material. The pegmatitic veins thus formed do not ramify through the granite in the same way as they do through the meta-gabbro since the granite is more incompetent and ductile and therefore does not break up in the same way as the meta-gabbro. Ramberg (1956) has very good diagrams showing the same type of break-up of ultrabasic and amphibolite inclusions in veined and banded gneisses where the pegmatite veining in the inclusions does not penetrate into the surrounding gneiss (p. 189-190).

The source of the pegmatite and the form in which it was emplaced is not clear. If the pegmatitic material is derived from the surrounding granite then the pegmatite ought to be continuous with the granite as feeder channels. If, though, it is derived from the meta-gabbro itself, in order to obtain almost pure plagioclase-quartz a large amount of mafic material must be removed. But no connection has been observed between the surrounding granite and the pegmatite of the meta-gabbro.

Where the break-up of the meta-gabbro has been more severe small pieces have been rotated so that the two dimensional pattern now presented on an outcrop will no longer fit like a jig-saw puzzle. The pegmatite need at no time have been a fluid injected into open cavities. Low pressure areas (tension cracks) will be filled by plagioclase-quartz by diffusion as soon as they form (cf. pegmatite between boudins). This process requires expansion of the meta-gabbro body which is taken up in the more incompetent surrounding granite.

Summary and History

The masses were intruded as gabbros, or something more ultrabasic, possibly with at least a certain amount of crystal accumulation. They were metamorphosed under amphibolite facies conditions with the production of hornblende and probably saussuritization of the plagioclase. The metamorphism was accompanied or followed by veining which was followed by the production of biotite at a lower facies level. Later prehnite grew between the biotite plates partly at the expense of the biotite.

At no time do the masses appear to have been affected by stress conditions so that they were presumably intruded after the folding of the area but before the latest of the periods of migmatization (veining). The masses would be competent and would not be expected to show the effects of local stresses that affected the discordant amphibolites.

The relation of the masses to the discordant amphibolites is not known.

Amphibolitic (meta-gabbro) masses occur in other areas within the Julianehaab district. To the west Ayrton and Burri (1959) describe them in the Qagassimiut area and further to the east Nesbitt (1961 p.40) describes layering in a meta-gabbro mass on the Julianehaab peninsula. The age of these meta-gabbro masses is uncertain, though that on the Julianehabb peninsula is cut by an amphibolite dyke of uncertain age (Nesbitt, 1961 p.42).

PART III

GARDAR

After the last reactivation (Sanerutian in the basement there followed a long period of erosion before the intrusion of a suite of dykes accompanied by faulting. This period of dyke intrusion of Qaersuarssuk is part of the Gardar period, so named by Wegmann (1938) after the Norse bishopric Garðar where there is now the settlement of Igaliko. The accompaniment of dyke intrusion by faulting allows a dyke chronology to be built up though much of it is rather speculative owing to the scarcity of dyke intersections.

On Qaersuarssuk doleritic dykes are the most widely developed, but there are also lamprophyric, trachy-doleritic and alkali - micro-syenitic dykes. There are no major igneous bodies on Qaersuarssuk.

<u>Chronology of the Gardar Dykes</u>

Dyke intersections in the area are rather scarce but with the aid of the two major directions of faulting which show movements at different times, and on the N.N.W. faults in different directions, it is possible to build up a dyke chronology. The following chronology has been established on Qaersuarssuk, with the oldest at the bottom:

N.N.W. Sinistral wrench faults; - rejuvenated (possibly only local) W.N.W. Sinistral wrench faults - rejuvenated

Northern composite big feldspar dyke

W.N.W. Sinistral wrench faults

North-east olivine-dolerite dyke

N.N.W. Sinistral wrench faults - rejuvenated

Big feldspar dykes (some of the southern dykes); N.E. Dolerite dykes (some)

(N.N.W. Sinistral wrench faults - possibly only local)

Big feldspar dykes (some of the southern dykes); N.E. Dolerite dykes (some)

Micro-syenitic dykes (probably more than one generation)

Nepheline - micro-syenite dyke

N.N.W. Dextral wrench faults

E.S.E. olivine-dolerite dykes

This is in general agreement with the Gardar dyke chronology obtained in the

Qagssimiut area to the west (Ayrton and Burri, 1959) and in broad outline to that obtained in the Ivigtut area to the north-west (Berthelsen, 1957).

The E.S.E. olivine-dolerite dykes are displaced dextrally by N.N.W. faults. No other dykes show dextral displacement on these faults so that the E.S.E. olivine-dolerite dykes are presumed to be the earliest Gardar dykes. Their relation to the W.N.W. fault is not known as they run approximately parallel to it, but it is suggested (p173) that the W.N.W. fault may have been initiated in pre-Gardar times.

The nepheline - micro-syenite dyke is earlier than an accompanying micro-syenitic dyke on the evidence of intersections. Furthermore, the nepheline - micro-syenite dyke is displaced by a greater distance on the W.N.W. fault than the northern composite big feldspar dyke so that it is presumed to be earlier. The relation of the nepheline - micro-syenite dyke to another big feldspar dyke at 00/538925 is definite: the former is proved older on an intersection.

There are a number of micro-syenitic dykes in the area and since it has not been possible to distinguish different generations they are treated as if they all belong to the same generation. As already mentioned the micro-syenitic dyke that accompanies the nepheline - micro-syenite dyke is younger than it, and another micro-syenitic dyke is earlier than a big feldspar dyke at 00/624949 above Naujât tasiat.

The chronological position of the N.E. doleritic dykes is more difficult. On the evidence of displacement by the W.N.W. fault they are earlier than the northern composite big feldspar dyke and at 00/522916 a dolerite appears to have baked the nepheline - micro-syenite dyke.

The N.E. olivine-dolerite dyke causes difficulties on the N.N.W. faults as there is no measurable displacement on them. But these faults appear to die out northwards and so may only cause a crushing in the dyke. This crushing has been assumed in order to keep the chronological position of the dyke in line with the other evidence, principally that of the northern composite big feldspar dyke which is known to cut the N.E. olivine-doleritic dyke but which has not been displaced as far on the W.N.W. fault line.

This northern composite big feldspar dyke shows the minimum displacement along the W.N.W. fault and is therefore assumed to be later than all the other dykes that are affected by that fault. This makes it the latest of all the big dykes.

In two places big feldspar dykes cross one another (00/611938 and 01/647000), and on the Torssukátâ fault there is a suggestion that the two big feldspar dykes crossing the fault may be separated by some sinistral movement. This also applies to two N.E. dolerite dykes. This means that there is probably a number of generations of big feldspar dykes and more than one generation of dolerite dykes.

No mention has been made of the chronological position of the lamprophyre dykes or the single tiny spherulitic dyke. The age of each is discussed under their appropriate headings: probably both are late Gardar.

Earliest Generation (E.S.E.) of Dolerite Dykes

The earliest generation (E.S.E.) of dolerite dykes is represented on Qaersuarssuk by a group of dykes running in a direction approximately W.N.W.-E.S.E. and lying to the south of the W.N.W. fault (map 2): no dykes of this generation are known to the north of this fault. There are three large dykes over 60 m in width and numerous smaller ones most of which lie between the two northern large dykes. The smaller dykes are grouped with this generations, but in most cases their chronological position cannot be proved. To the south of the three large dykes there are three small ones having the same direction as the larger but which can be shown to be later than them. Therefore not all the smaller dykes belong to this generation. The possibility of two generations of these dykes is also seen on Tugtutôq and possibly also on the Julianehåab Peninsula.

The dykes of this generation are cut and displaced dextrally by amounts of up to 450 m by N.N.W. faults. By a comparison of the relative displacement of the dykes by these N.N.W. faults and the very few dyke intersections the three large dykes of this generation can be shown to be the earliest dykes on Qaersuarssuk and hence belong to the earliest generation of Gardar dolerite dykes in southern Greenland (Berthelsen, 1957; 1963).

A characteristic feature of this generation of dykes is the production of large dyke offshoots which may extend up to a kilometre before terminating or rejoining the main dyke. Most of the dykes form pronounced erosion hollows. Where the dolerite is exposed spheroidal weathering is common, while certain of the smaller dykes show prominent jointing and occasionally form distinct step features.

Almost all the dykes, and certainly the three larger dykes, are characterized by the adjacent reddened granite which may extend away from the dyke by as much as 20 m. This same reddening of the granite occurs along faults and lines of shearing and it is presumed in most cases to have been causes by shearing along the margins of these dykes. The dykes themselves, and in particular their margins, are sheared. Where the shearing has been intense there are surfaces with slickensiding and veins of quartz in the dyke. At 00/609904 where a small N.E. dyke crosses the southern of the three larger dykes, a dextral displacement of the small dyke by 4 m can be demonstrated at the southern margin of the large dyke. Since this direction of shearing along the dyke margins is parallel with the W.N.W. fault it is suggested that it is contemporaneous with one of the early periods of movement along that fault.

The majority of the dykes are believed to be vertical. Two exceptions are known: one is the sector of the large dolerite dyke between Kangerdluarssuk avangnardleq and Torssukátâ which dips about 70° to the north; the other is one of the smaller dykes which has a number of characteristics which are not entirely in keeping with the dykes of this generation, and has a steep dip to the south-west.

Coarse pegmatitic areas are only rarely seen in the dykes. Normally they appear to be richer in pyroxene than the normal dolerite but a pegmatite pipe 12 cm in diameter rich in feldspar is also known.

The dykes of this generation are completely lacking in phenocrysts with the exception that at Saputínguit the large dyke appears to contain feldspar phenocrysts; however, here it can be shown that the doleritic material containing phenocrysts was intruded later into the large dyke and chilled against it. The large dyke on Igdlaua also has a number of feldspar aggregates up to 20 cm across which are confined to a band about 2 to 3 m wide. The occurrence of feldspar phenocrysts and aggregates are of interest as they are connected with the problem of the origin of the cognate xenocrysts and aggregates in the big feldspar dykes (q.v. p138).

Petrography

Petrographically there is no difference between the three large dykes. The texture throughout is intergranular though the larger augite crystals are poikilitic. There is a certain amount of difference in grain size with an average plagioclase crystal 1 to 2 mm in length and poikilitic augite crystals up to 7 mm across.

The plagioclase has a composition range An_{28-65} though the average is about An_{45-55}.* A single chemical determination on the bulk feldspar gave

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* values from maximum extinction angles on oriented sections.

$Or_8Ab_{50}An_{42}$.‡ It occurs as laths twinned on the carlsbad-albite and albite twin laws. Where plagioclase fills large interstitial areas, which it does occasionally, it shows twinning laws additional to the two just mentioned (probably pericline twins). Compositional zoning is seen in many crystals but is particularly evident in the large interstitial plagioclase crystals.

The pyroxene occurs both as large poikilitic crystals and as smaller subhedral grains between the plagioclase laths. Most of it is neutral in colour though some of it has a trace of pink. Much of it is of uniform composition, to judge by its extinction, but occasional crystals show distinct compositional zoning.

The average compositions for the three dykes are given below. Within the dykes themselves there is little variation. Even within the southern of the three dykes which includes samples of dolerite-pegmatite and a coarse grained facies as well as the normal dyke rock there is no significant difference in the composition of the main minerals, apart from the absence of olivine in the dolerite-pegmatite.

	Olivine (mol %)	Clinopyroxene (average. atomic %)	Plagioclase (mol %)
Northern dyke	Fa_{52-66} †	$Ca_{40.5}Mg_{31}Fe_{28.5}$	An_{14-48}
Intermediate	Fa_{44-49}	$Ca_{36}Mg_{32.5}Fe_{31.5}$	An_{34-64}
Southern dyke	Fa_{54-64}	$Ca_{38}Mg_{34}Fe_{28}$	An_{23-49}

The intermediate of these three dykes has the lowest iron content in the olivine but the highest iron content in the pyroxene. It also has a higher anorthite

‡ determined flame photometrically by B. Borgen
† X-ray diffraction determination of olivines in mol %. See appendix.

content than the other two dykes and the lowest calcium content in its pyroxene. The higher iron content of the clinopyroxene in the intermediate dyke may be explained by early olivine, probably due to too rapid crystallization, not being kept in equilibrium with its liquid so that it is more magnesium rich than it should be, i.e. the ratio Fe/Mg of the liquid is not consistent with the co-existing olivine so that the clinopyroxene that crystallizes from the liquid does not have the appropriate composition compared to the olivine. Zoning of the olivine crystals would have exactly the same effect but zoning has not been noticed in the olivine of these dykes. This has been discussed by O'Hara (1963) along with the effect of change of temperature and pressure producing a shift in the $\frac{\text{Fe/Mg olivine}}{\text{Fe/Mg pyroxene}}$ in favour of iron concentration in the pyroxene with lower temperature.

Olivine is normally abundant as small anhedral grains. These are commonly clustered together in loose groups, and individually are small in size (0.2 mm across).

Opaque material is abundant as comparatively large grains (0.5 mm), the largest of which are slightly poikilitic to plagioclase and olivine. They are practically always thinly rimmed by biotite that is pleochroic in red and pale brown, the intensity of the colour varying, sometimes within the same crystal. There are rare large biotite flakes which, though they appear to be independent of associated opaque grains are associated with a green chlorite. These green chloritic patches are sometimes associated with serpentinized olivine but appear also to occupy interstitial areas independent of olivine. On the whole there is little late stage deuteric alteration of the minerals.

Apatite occurs in the normal dolerite and is particularly evident in the pyrozene crystals. One sample from the northern of the three dykes contains a little interstitial quartz.

Pegmatitic facies occur within the southern of the three dykes as pods and veins of coarser grain dominated either by plagioclase or pyroxene. Some of these areas lack olivine, others have olivine in approximately the same quantity as the normal dolerite. Where there is olivine it occurs in the same size of grain as the rest of the dolerite even though the other associated constituents are of larger grain size. Apatite crystals occur in the pyroxene of these pegmatitic facies and the opaque mineral occurs as large, intrically skeletal crystals. The feldspar in these patches shows much more alteration than elsewhere.

N.E. Trending Dykes

General Remarks.

A large number of dykes trending approximately N.E. are found between Kangerdluarssuk avangnardleq and Bredefjord. Very few dykes of this trend on Qaersuarssuk are found outside this area. On the northern side of the W.N.W. fault a few are found more to the north-west, but they are a continuation of the main belt after allowance has been made for movement along the fault.

Out of this large number of dykes there are a few that are characteristic and have been more systematically mapped. They are the nepheline - micro-syenite dyke, some of the other micro-syenitic dykes, the big feldspar dykes and the N.E. olivine-dolerite dyke. These are described separately. The remaining dykes are a group of doleritic to trachy-doleritic dykes with or without phenocrysts. The distinction of the big feldspar dykes at times becomes rather artificial so that among these dykes there are some that resemble the big feldspar dykes but have not been included with them because they lack large feldspar crystals.

The age relations among these dykes of similar trend is difficult as interpretable intersections are rare. Of the remainder nothing is known beyond that they all appear to be post earliest (E.S.E.) dolerite dykes and pre-post Gardar dykes.

The dykes are treated, as far as it is possible to do so, in chronological order.

<u>Nepheline - Micro-Syenite Dyke</u>

Field Setting

A single nepheline - micro-syenite dyke is traceable across Qaersuarssuk in an E.N.E. direction. In the south-west it crosses the peninsula jutting into Kangerdluarssuk avangnardleq from the west; a short length of it is mapped on the northern side of inner Kangerdluarssuk avangnardleq; and what is presumably the same dyke is traceable from the head of Kangerdluarssuk avangnardleq across the hill to Torssukátak. To the north-east Allaart (manuscript maps) has mapped it across to Kangerdluatsiaq, while to the South-west Ayrton and Burri (1959) have mapped it on Qagssimiut and adjoining islands. It is thus known for 30 km in a direction 060°.

In the south-west part of Qaersuarssuk it is 5.5 to 7.0 m in width while in the northern part of the island it is known up to 17 m. From the course of its outcrop it has a steep dip to the S.E.

The dyke is light grey in colour and markedly crowded with tabular feldspars up to 2.5 cm in length and 4.0 mm phenocrysts of nepheline. The tabular feldspars are aligned with their <u>b</u> axes horizontal and commonly perpendicular to the length of the dyke (fig. 64). In addition to the phenocrysts there are occasional rounded inclusions of finer grain and of both darker and lighter grey than the dyke. Many of these inclusions are marked by their scarcity of phenocrysts and by the tangential arrangement of tabular feldspars around their margin.

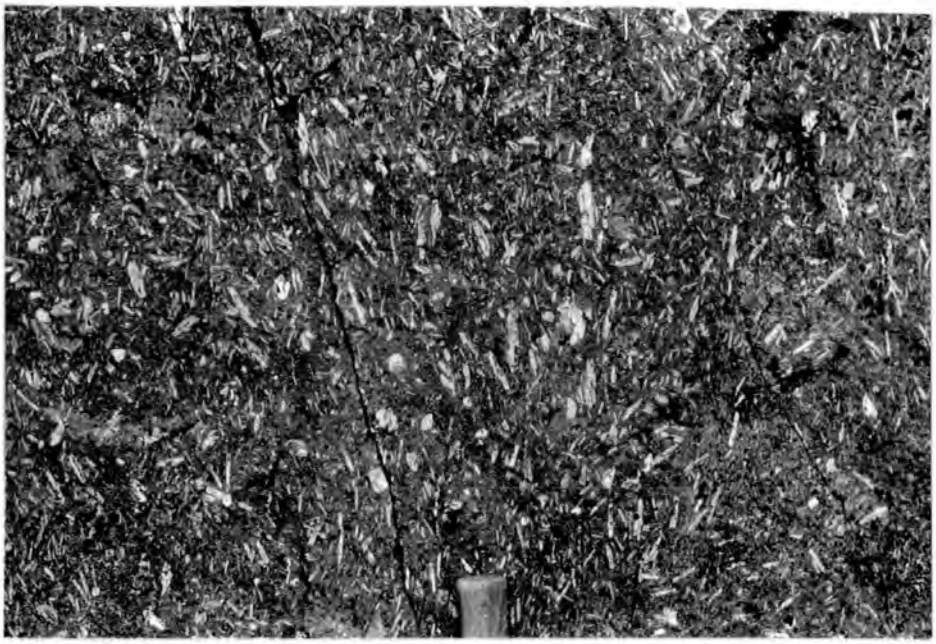

Fig.64. A clean weathered surface of the nepheline - micro-syenite dyke. The white crystals are orthoclase laths, the very small dark crystals are pyroxene (not to be confused with the occasional lichen). 00/534924.

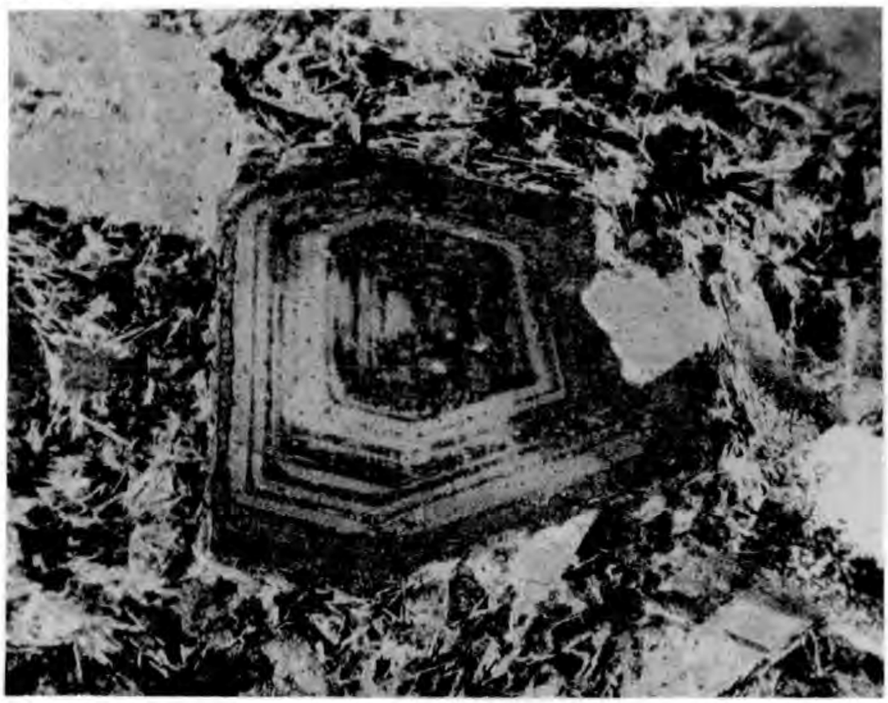

Fig.65. An altered, zoned nepheline in the nepheline - micro-syenite dyke in which the zones are picked out by different alteration products. X-nicols. x 25. Sample 45295.

The inclusions of light grey colour may contain within them other inclusions both darker and lighter grey in colour. These inner inclusions rarely contain phenocrysts of nepheline. They are probably early stages in the differentiation of the dyke magma and pieces of chilled margin reincorporated into the rock at various stages. On Qagssimiut tabular feldspar crystals have been seen in a whorl suggesting eddy currents within the magma.

The margins of the dyke are chilled against the country rock and are without phenocrysts. Radiating crystals of prehnite occur on a joint surface at 01/662016.

The southernmost length of the dyke on Qaersuarssuk is red in colour due to the proximity of later dolerite dykes and some shearing. While the feldspar and groundmass are red the nepheline is green due to chlorite and another secondary mineral pseudomorphing nepheline and frequently showing an excellent zonal texture in it (fig. 65).

Age Relationships

The nepheline - micro-syenite is later than the earliest of the Gardar dolerite dykes but is earlier than a big feldspar dyke (055°), a micro-syenitic dyke (060°) and a dolerite dyke (080°).

In only one place, at 00/531923, is the dyke demonstrably faulted 10 m sinistrally by a N.N.W. fault, but since it is earlier than the big feldspar dyke, which is sinistrally faulted by these N.N.W. faults, the nepheline - micro-syenite dyke is presumably also affected. By using these N.N.W. faults it can be shown that the apparently isolated length of nepheline - micro-syenite dyke on the northern side of inner Kangerdluarssuk avangnardleq is part of the same single dyke.

Petrography

The dyke rock is fine grained with numerous large tabular alkali-feldspars and euhedral phenocrysts of nepheline together with phenocrysts of ægirine-augite rimmed by ægirine and occasional fayalitic olivine grains. These phenocrysts are set in a fine grained trachytic groundmass containing, inter alia, alkali-feldspar, ægirine-augite and a soda-hornblende.

Alkali-feldspar occurs as phenocrysts and is also the matrix to the rock. As phenocrysts it constitutes about 25% of the rock. The phenocrysts are tabular with carlsbad twins and a $2V\alpha$ 53°, hence they are probably orthoclase. They may be homogeneous, perthitic or wholly or partly altered. The perthitic phenocrysts show approximately equal amounts of plagioclase and potash-feldspar (X-ray determination*). The soda-feldspar of the perthite is in strips. The secondary mineral pseudomorphing the tabular feldspar characteristically consists of fibrous sheaths set parallel to the b axis of the feldspar (fig. 66). This secondary mineral is colourless with low relief (R.i <balsam), $\triangle \sim 0.005$, +ive(?) with parallel extinction and length fast (? zeolite). The presence of fresh nepheline with altered alkali-feldspar suggests deuteromorphic alteration. The alteration clearly seems to have started along the margins of the crystal and forms embayments into it. More rarely does it seem to have preferentially followed a cleavage plane across the crystal. It affects equally the homogeneous and pethitic feldspars. Much of the matrix feldspar seems to have been altered in the same way. Both euhedral nepheline and anhedral pyroxene may be included into the tabular feldspars. The ratio of potash-feldspar to albite in the matrix feldspar is about three to one (X-ray determination).

* X-ray determination by M. Danø

Fig.66. Fibrous sheaths of a ?zeolite replacing an alkali-feldspar phenocryst in the nepheline - micro-syenite. The sheaths are parallel to the b axis of the feldspar. X-nicols. x 50. Sample 45457.

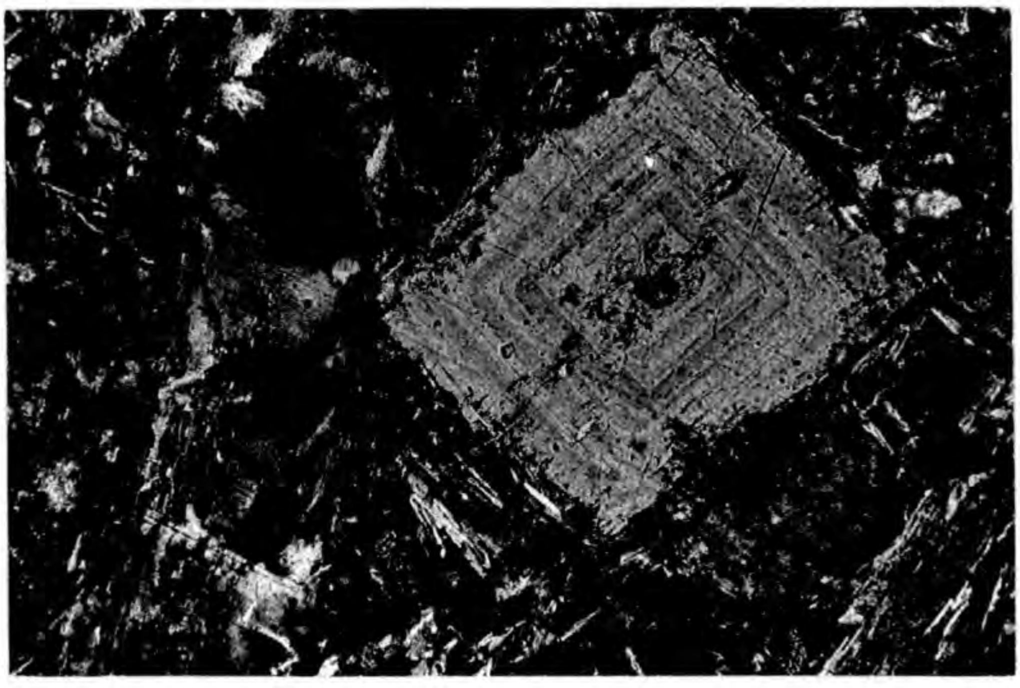

Fig.67. A zoned nepheline crystal in the nepheline - micro-syenite. See text p.131. X-nicols. x 51. Sample 45457.

The nepheline occurs as euhedral to subhedral crystals up to 4 mm across and constitutes something like 13% of the total rock. Regular concentric zoning may be seen in many of the grains, though frequently it is very hard to see. Some very clear zoning is seen in 45457 (fig. 67). The zones show as slight differences in the birefringence. Where the nepheline has been altered the zoning frequently becomes accentuated as their tends to be preferential alteration. In 45256 up to half of a nepheline crystal may be zoned, alternate zones being replaced by a cream coloured fibrous mineral (length slow, Δ~first order red, low relief and approximately parallel extinction). Where alteration is more complete (e.g. 45295 fig. 65) the zones are picked out by a bright green chlorite, with a little epidote, and a colourless to pale reddish-brown aggregate of minerals which may be fibrous (Δ~0.008). Parts of the nepheline may be replaced by a mosaic of colourless grains of Δ~0.005. In 45225 part of the ?nepheline is replaced by a carbonate mineral. Occasional nepheline crystals contain small rounded inclusions with the appearance of devitrified glass.

Zoning in nepheline is due to a variation in the potassium - sodium ratio. The ideal formula has 75% $NaAlSiO_4$ (which corresponds to a composition $Na_3KSi_4Al_4O_{16}$). In addition small amounts of Ca may substitute for Na. A change in the proportions of Na, K (and Ca) only has a very small affect on the birefringence so that the composition cannot be determined optically. Smith and Sahama (1954) have developed an X-ray method and express the composition as the ratio K/(K + Na + Ca). Nepheline and kalsilite form a solid solution series at high temperatures. No free kalsilite has been found in the Qaersuarssuk sample.

An X-ray determination of the bulk K/K + Na ratio for a nepheline crystal gave the following:

Sample	2θ for (21.0)	100 K/K+Na	2θ for (20.2)	100 K/K+Na	Mean (atomic %)
45457	27.26 (mean of three)	15.4	26.69 (mean of three)	15.2	15.3
44390	27.26 (mean of two)	15.4	26.69 (mean of two)	15.2	15.3

The pyroxene in subhedral to anhedral phenocrysts is aegirine-augite rimmed by aegirine and may have inclusions of olivine and primary opaque minerals. The aegirine-augite is pleochroic with α deep green, β green and γ yellow-green. Pyroxene is also abundant in the groundmass where most of the grains are also aegirine-augite rimmed by aegirine though a few are all aegirine.

Some of the slices show phenocrysts of fayalite (Fa_{100}*). These are always rimmed by a narrow margin of opaque material.

An important interstitial mineral is soda-hornblende occurring as wedges between the feldspar laths. It is probably arfvedsonitic from its pleochroic colours (α deep greenish-blue, γ cream-yellowish). Enigmatite (pleochroic deep brownish-red to practically opaque), apatite and opaque minerals are minor accessory constituents. The proportion of opaque material is normally fairly low, but where the dyke has been affected by the proximity of later dykes and shearing there is a considerable amount of interstitial opaque material. This contrasts with 45225 which shows considerable alteration, but is practically devoid of opaque material.

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* The 2θ value for these olivines falls just beyond the limit of the determinative curve for the forsterite - fayalite series at the fayalitic end. This can probably be accounted for by various errors and by substitution. Yoder and Sahama (1957) quote an error of ± 4 mol %. Both Ca and Mn may occur in small quantities in the fayalitic olivines. In the Skaergaard intrusion Wager and Mitchell (1951 p.153) found that the manganese content rises in successively more iron rich olivines. Tephroite also has a lower $2\theta_{(130)}$ value so that a larger than normal amount of manganese may explain the X-ray results obtained.

The dark grey inclusions found in the dyke are of alkali - trachyte without nepheline in the groundmass. It is fine grained with abundant rods of opaque material. The light grey inclusions have a marked texture of radiating feldspars. Biotite is present in inclusions of both colours and is associated mainly with the opaque material. The biotite is strongly pleochroic; α light brown with touches of red-brown, β and γ very dark brown in the light grey inclusions, and α yellow to β and γ brown in the dark grey inclusions. Both are iron-titanium biotite (Hall, 1941). There does not appear to be any aegirine in these inclusions and the pyroxene in the darker inclusions appears to be augite rather than aegirine-augite.

General Discussion

A nepheline precipitated in a cooling magma will continually react with the magma. From a study of the system $NaAlSiO_4$-$KAlSiO_4$-SiO_2-H_2O (Hamilton and MacKenzie, 1960; Hamilton, 1961) it has been found that with falling temperature nepheline in equilibrium with the silicate liquid changes composition in two ways: a) by a change in the Na/K ratio (nepheline becoming richer in potassium), and b) by a change in the Si/Al ratio, Si being raplaced by Al. Hamilton (1961) suggests that in post-magmatic cooling only the Na and K atoms move and that these are exchanged with the alkali atoms in the accompanying feldspar in such a way that the Na/K ratio of the nepheline approaches 3:1, viz. approaches the ideal composition of nepheline $Na_3KAl_4Si_4O_{16}$ (Buerger, 1954).

The nepheline crystals are frequently zoned. The zoning appears to be more prominent or only developed in the smaller crystals; the larger show no signs of zoning. The zoning, though not proved, is almost certainly due to a difference in the Na/K ratio. Although it has not been possible to determine the

Na/K ratio of the different zones the mere presence of zoning indicates that the nepheline has crystallized under varying temperature (and/or pressure) conditions. It is believed that the zoning is oscillatory, though it has not been possible to demonstrate it. Oscillatory zoning would indicate that the nepheline has been moved around from one temperature environment to another in which case there has probably been considerable circulation within the magma before intrusion.

There should be a correlation between the composition of the nepheline and the degree of unmixing of the perthite, i.e. the coarseness of the perthitic intergrowth (Hamilton, 1961),. In the samples examined both optically homogeneous and perthitic orthoclase occur as phenocrysts.

If the phenocrysts set in whorls are correctly interpreted as eddy currents the magma during emplacement must have had a low viscosity.

The nepheline - micro-syenite dyke was intruded early in the Gardar succession of dyke rocks. The Hviddal giant dyke at the eastern end of Tugtutôq is a nepheline- bearing syenite intruded comparatively early in the Gardar (Upton, 1962) but the nepheline-syenite complex of Ilímaussaq is believed to be late Gardar. The Igaliko massif to the E.N.E. has been tentatively suggested as the main source of the alkaline syenite magma to feed the dykes but not sufficient is yet known concerning the age relationships of the alkaline dykes and the massif to make any valid connections.

Micro-Syenitic Dykes

A number of micro-syenitic dykes occur on Qaersuarssuk all trending N.E. to E.N.E. Only short lengths of the dykes are known so that the full extent of the dykes are not known. They have an average width of 8 m but may be anything from 25 cm to 15 m. Since they have a common trend with the other N.E. trending dykes their age relations are hard to determine. A dyke belonging to this group is known to cut the nepheline - micro-syenite dyke and another to be cut by a big feldspar dyke. Some of the dykes appear to have sinistral displacements across N.N.W. trending faults. There are so many segments of dykes without any known age relations that the possibility of these dykes belonging to more than one generation must be borne in mind. Their probable position in the dyke chronology is shown on page 118.

There are at least two types of dyke of which most are alkali - micro-syenitic. These are readily distinguished by the characteristic sheen on a freshly broken surface. In general they form erosion hollows and are characterized by the close jointing giving large flat slabs of rock. These slabs are excellent for building and on the coast old Esquimo graves are frequently found on the dykes. The trachytic texture is usually evident on the surface while a few have phenocrysts of alkali-feldspar. Fresh unaltered dykes are grey in colour but alteration gives them a brown-red colouration.

Petrography

The alkali - micro-syenitic dykes are composed of predominately sodic minerals. The main constituent is an antiperthitic feldspar as tabular crystals 0.3 mm in length with an average bulk composition $Or_{32}Ab_{66}An_{2}$ mol %. These generally have a trachytic to radiating arrangement giving the characteristic texture to the dykes. Many of the laths show carlsbad twinning and most are slightly turbid. The mafic constituent includes any one or more of the three minerals soda-amphibole, alkali-pyroxene and titan-biotite which together form about 20% of the rock. No feldspathoids have been distinguished. In general these dyke rocks appear to be very similar to Brögger's sölvsbergite (Johannsen, 1937; Brögger, 1894).

The most common of the soda-pyroboles is the soda-amphibole. It is strongly pleochroic with the following pleochroic schemes:

α olive green browny green	β brown	γ pale brown
blue-green		colourless
pale green		colourless
blue		pale blue

The brown soda-amphibole with the barkevikitic affinities is the most common and frequently has greener (more sodic) margins as it grades into a more arfvedsonitic type. It is commonly associated with an alkali-pyroxene and occasionally also with a titan-biotite and in a few examples is absent. Characteristically the soda-amphibole occurs in the wedge-shaped interstitial areas between the feldspar laths.

Most, though not all, of the dykes also have an alkali-pyroxene. It varies from a sodic-pyroxene to ægirine; crystals of ægirine and ægirine rims to aegirine-augite are the most common. Ægirine may also form rims to the soda-amphibole. Ægirine occurs as stubby prismatic crystals.

A titan-biotite is present in a few of the dykes. It is pleochroic from α bright red-brown to β and γ dark brown or opaque. It occupies the same interstitial position as the soda-amphibole and appears to have formed contemporaneously with it and both minerals later than the alkali-pyroxene.

Interstitial quartz amounting to 2 - 5% of the total occurs in two dykes. The presence of opaque crystals is variable. Where they do occur they are subhedral crystals of pyrite which are identifiable on a fractured surface.

Many of the dykes have small, 1 mm, phenocrysts of alkali-feldspar, rarely they may be as large as 2 cm long. These phenocrysts contain approximately equal amounts of soda and potash feldspar with an anorthitic content of between 0 and 10% (X-ray determination).

One dyke has a variety of phenocrysts consisting of separate crystals of plagioclase and potash feldspar, pyroxene and aegirine though the latter are mostly altered to a chlorite. Another dyke (45371) has a perfectly circular vùg filled with a carbonate mineral and containing four green fibrous mineral grains of a soda-amphibole (?crocidilite).

Accessory minerals in the dykes are apatite as tiny rods in the feldspar and as little euhedral grains. Sphene is prominent where there is no biotite. Crystallization has been under strong reducing conditions to give pyrite.

One of the dykes belonging to the same type contains numerous spherical to elongated nodules of finer grain than the main rock of the dyke. These nodules are fairly evenly distributed throughout the dyke except along the margins where they are comparatively scarce.

These alkali - micro-syenitic dykes show late stage enrichment in soda and water under increasing reducing conditions. The later minerals also tend to have less silica, with the exception of quartz in two dykes.

From the crystallization sequence the apatite, and the alkali-pyroxenes are early to crystallize while the titan-biotite and soda-amphibole are the last except where there is excess silica.

N.E. Doleritic and Trachy-Doleritic Dykes

These dykes form a group, after the exclusion of certain dykes to be described later, with an average strike direction of 050° and an average width of

10 m, but varying from anything between 50 cm and 50 m. The different dyke types and the composite nature of a few of them makes it almost certain that more than one generation is involved. Intersections among these dykes are entirely lacking. The great majority appear to be vertical but a few show steep dips either to the north-west or the south-east.

Non-porphyritic olivine-dolerites and porphyritic doleritic to trachy-doleritic dyke types are prevalent.

Big Feldspar Dykes

The big feldspar dykes are a group of dykes about 10 to 17 m in width with a general north-easterly strike. They occur mainly in the area between Kangerdluarssuk avangnardleq and Kangerdluarssuk kujatdleq and its continuation to the south-west and north-east. There is an apparent decrease in the number of dykes to the south-west, where there are four, compared to five or six along the south coast of Torssukátak (fig. 68).

These dykes are characterized by the abundance of feldspar crystals and aggregates (figs. 69-72). The true big feldspar dykes have large single crystals, of which the largest seen in the area is 35 cm in length, while the aggregates of feldspar crystals are even larger reaching 190 cm in diameter. From these giant sizes the crystals grade down in size with two maxima, one at 10 to 15 cm and a second at 1 to 2 cm. These smaller feldspar crystals occur along with the giant crystals and also occur in those parts of the big feldspar dykes where the giant feldspars are lacking. In addition there are dykes which appear to lack entirely the big feldspar crystals but have abundant feldspars of the smaller size ranges. In this description of the big feldspar dykes all those dykes having the same type of matrix and numerous large feldspar crystals, of whatever size, ~~have been~~

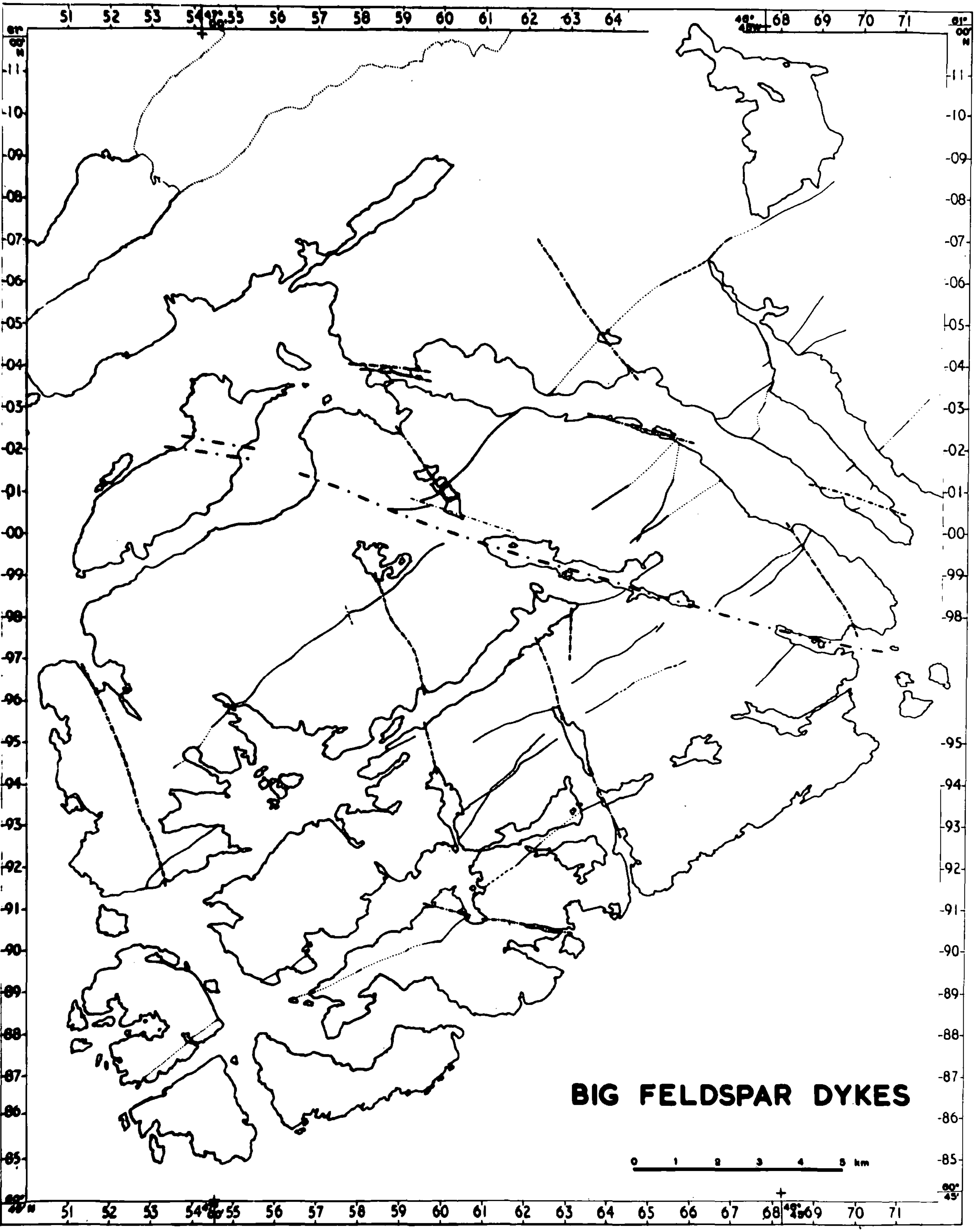
BIG FELDSPAR DYKES
0 1 2 3 4 5 km
51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71
-11- -10- -09- -08- -07- -06- -05- -04- -03- -02- -01- -00- -99- -98- -97- -96- -95- -94- -93- -92- -91- -90- -89- -88- -87- -86- -85-

Fig.68.

Fig.69. A single plagioclase crystal 28 cm in length in a big feldspar dyke. 00/568899 - north side of the entrance to Kangerdluarssuk kujatdleq.

Fig.70. An aggregate of plagioclase crystals in a big feldspar dyke. Hammer length 30 cm. The same locality as fig.69.

Fig.71. A view of the surface of the big feldspar dyke showing the large aggregates and single crystals of plagioclase, and their concentration to the middle of the dyke. Same locality as figs.69 and 70.

Fig.72. The junction in a composite big feldspar dyke between the trachy-dolerite carrying big feldspars in the centre (left) and the micro-syenite margin (right). 01/687002 - Torssukáta.

have been grouped and described together.

The large feldspar crystals are broken and have corroded and rounded corners. They are not considered to have formed in their present positions but to have been picked up and intruded with the magma of the dyke. Since they are allothigenous crystals and are foreign to the rock in which they now occur but are considered to have some genetic relation the term cognate xenocrysts is suggested (cf. cognate xenolith of Billings (1954, p.289) and Holmes (1920, p.63).

A number of the dykes are composite with substantial marginal components of micro-syenite. Although the margins are quite different compared with the 'big feldspar' centres, as they are intimately connected with the central component of these dykes, they are described along with it where appropriate.

The best known of these dykes is the northern composite big feldspar dyke. It has been described separately. The others, belonging to two slightly earlier generations, have been described together with the emphasis laid on the differences to the northern composite big feldspar dyke.

Relation to Faulting and other Dykes

To the south of Kangerdluarssuk avangnardleq the big feldspar dykes are cut by N.N.W. faults. Four of these big feldspar dykes cross the fault through Naujât tasiat along which there has been sinistral movement displacing the dykes by an estimated 150 m. Along this same fault line there has been an earlier movement now showing a dextral displacement of 350 m which affects the early E.S.E. olivine-dolerite dyke that crosses it. The most southerly of these four big feldspar dykes crosses, and is later than, another E.S.E. olivine-dolerite dyke to the north of it.

The northern composite big feldspar dyke is later than the N.E. olivine-dolerite and is not displaced to such a great extent as that dyke by the W.N.W. fault.

In two places big feldspar dykes cross one another. In only one case it is possible to determine the relative ages. But this suggests two different times of emplacement. There is also a suspicion of two generations when matching the big feldspar dykes across the N.N.W. fault through Torssukátâ where one dyke appears to be affected by a sinistral displacement of 50 m and another dyke sinistrally displaced by 200 m.

Thus it appears that these dykes are not all contemporaneous. The northern composite big feldspar dyke is the latest of the Gardar dykes while the other big feldspar dykes probably belong to two earlier generations (see p.118) 16 each with both composite and non-composite dykes.

The Northern Composite Big Feldspar Dyke

A vertical composite big feldspar dyke, of average width 16 m, occurs for 11,6 km across the N.W. of Qaersuarssuk. It is known for at least a further 7,7 km in a N.E. direction to the north of Qaersuarssuk and passes south of Kangerdluatsiaup tasia where Allaart has mapped it.

The dyke, at its maximum known width of 33 m by Kangerdluatsiaup tasia, is made up of a porphyritic central part 27 m in width with non-porphyritic micro-syenitic margins each 3 m wide. At its south-western end the dyke is extremely badly exposed but the micro-syenitic margins appear to continue about 300 m beyond the porphyritic centre.

For the greater part of its length the margins are not seen at all and the centre alone is mappable as coarse black and white gravel, which is formed on weathering, or it may stand out as tors which frequently exhibit onion weathering.

The margins are normally only seen on the coasts.

Relation to other Dykes and Faulting

It is the latest of the Gardar dykes on Qaersuarssuk as it cuts the N.E. olivine-dolerite dyke and is displaced less than any other dyke on the W.N.W. fault (see chronological scheme 116 p118). Its relation to other Gardar activity is not known, in particular its relation to the giant dykes on Tugtutôq which are displaced sinistrally by about the same amount on the same W.N.W. fault.

At 00/552960 it has been slightly displaced sinistrally by a N.N.W. fault and at 00/589988 an E.-W. fault has displaced it dextrally. Besides the sinistral displacement of 1500 m on the W.N.W. fault it is also affected sinistrally by a couple of faults through the lake 30 and again where it crosses Torssukátak it is dextrally displaced 300 m.

Field Description - Central Component

The central part characterizes the dyke in the field. It has an average width of 10 m, is medium grained doleritic crowded with cognate xenocrysts which are broken and have corroded and rounded corners, varying in size from that of the groundmass up to 33 cm in length. The average size of the cognate xenocrysts varies around 1 to 2 cm and 10 to 15 cm. There are a few crystal aggregates, one 30 cm in length occurs on Qaersuarssuk and another of 35 cm was measured south of Kangerdluatsiaup tasia. Towards the north there is a greater tendency for the development of aggregates particularly in the centre of the dyke, but the greater number are single crystals. Typically the cognate xenocrysts have a rudimentary vertical alignment. Towards the edge of the central component the cognate xenocrysts decrease rapidly in size and concentration over about 10 cm.

The larger cognate xenocrysts commonly have rows of dark inclusions parallel to their length which, in some cases, appear to be of the matrix. The great majority of the cognate xenocrysts are badly altered but the centres of some of the larger crystals are fresh and clear. At 00/549959 carlsbad twinning was commonly seen in the crystals as well as polysynthetic twinning which contrasts with sample 45420, collected from the dyke in the northern part of the island, where carlsbad twinning is not seen at all but polysynthetic twinning is clearly seen in the hand samples.

Field Description - Marginal Component

The marginal part is micro-syenitic, about 3 to 4 m wide, light grey in colour and fine grained with a chilled border against the country rock. This marginal component is fairly persistent though it does appear to be lacking in a few places. The outermost metre is normally entirely free of phenocrysts and inclusions; the inner part has 1 cm euhedral to subhedral orthoclase phenocrysts scattered spasmodically through it and dark fine grained inclusions with or without orthoclase phenocrysts. These dark inclusions are elongated vertically, commonly about 7 cm in length but reaching 15 cm, though one without phenocrysts in it was 23 cm in length. Those inclusions carrying phenocrysts appear to be darker than those that are barren.

Contact Relations between the two Components

There is a gradational contact between the two components of the composite dyke. Towards the central component the marginal part increases in grain size, in concentration of the fine grained dark inclusions and in the occurrence of occasional coarser areas. Within the central doleritic component there is a rapid decrease towards the contact in the size and concentration of the cognate xenocrysts over about 10 cm. A few inclusions of the dolerite occur within the micro-syenite near to the contact between the two components and along the contact there are occasionally slightly coarser areas of irregular shape which appear to belong to the central component of the dyke. In the border zone there are also occasional dark minerals surrounded by a rim of feldspar which, on the weathered surface, may be open and contain epidote.

Petrography - Central Component

The central component is fine grained trachy-doleritic, xenocrystic and of doleritic (intergranular) texture. The crystals of augite and biotite have an average size of 0.5 to 0.75 mm while the feldspar crystals are from 4 mm upwards. Plagioclase is by far the most abundant of the mineral constituents amounting to 60 - 70% of the total rock. The mafic minerals are augite, biotite and a few grains of olivine while the ilmeno-magnetite forms a substantial amount. Apatite is a minor constituent.

The plagioclase phenocrysts in 45259 and 45276 show carlsbad and albite twinning. By measuring the composition plane and using van der Kaaden's curves (1951) the plagioclase appears to be of high temperature modification with a composition about An_{51}. The composition obtained from the maximum extinction of oriented lamellae, however, only gave a high temperature value of An_{45}. Many of the plagioclase grains have rims of more sodic feldspar without twinning and often clear when the centres are altered.

The plagioclase from sample 45420 is part of a big feldspar xenocrysts It shows both albite and pericline twinning. The position of the composition

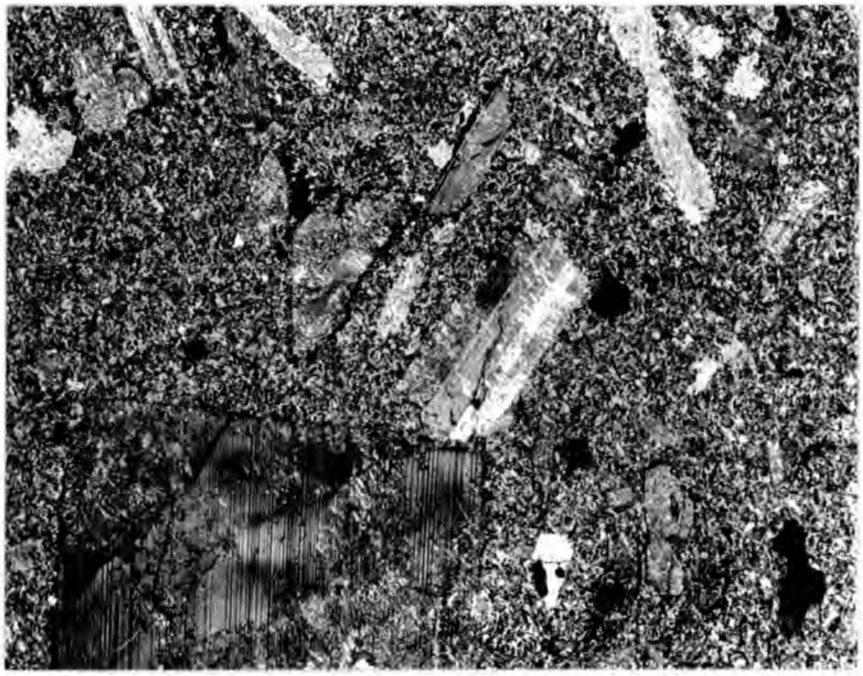

Fig.73. A thin section of a big feldspar dyke showing the plagioclase xenocrysts. X-nicols, x 5.5. Sample 45460. Photo C.Chaplin.

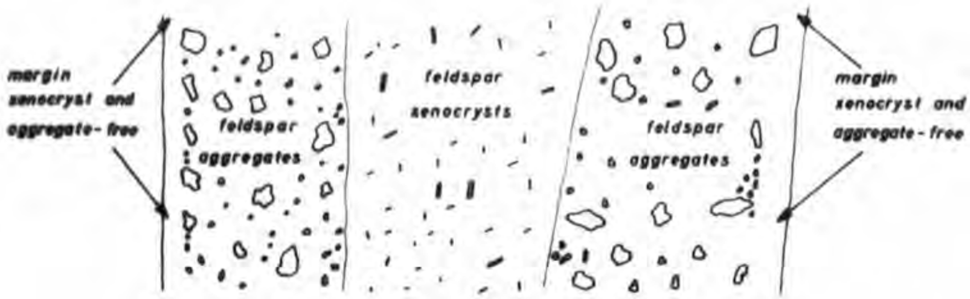

Fig.74. A diagrammatic cross-section of the big feldspar dyke at 00/623951. See text for explanation p.150.

plane was plotted in relation to the optic axes and compared with van der Kaaden's curves (1951) and with the curves of Slemmons (1962)*. The results from adjacent twin lamellae are variable, high temperature forms occurring alongside those with low temperature form. Those showing high temperature optics gave an average value of An_{49}, while those with low temperature optics An_{56}. Bridgwater has found the same variability among other plagioclase xenocrysts that he has measured from these dykes. Results from the measurement of refractive index gave an average value of An_{50}. These values are considerably more albitic than the majority of the large plagioclase crystals in other big feldspar dykes (Bridgwater, 1962). This agrees with D. Bridgwater's suggestion (oral communication) that the plagioclase xenocrysts from more trachytic groundmasses have a lower anorthite content.

The augite occurs as subhedral, colourless, non-pleochroic grains constituting 10 to 15% of the total rock. Biotite is not as abundant as the augite constituting only 8 - 10% of the total. It is pleochroic with α pale yellow β and γ red-brown. Olivine does not occur in all the slices and the few grains that are present tend to be associated together and are rimmed by opaque material and largely altered. In addition there are a number of chloritic areas which may have been olivine. Opaque material, both primary and secondary, forms up to 10 - 15% of the total as small grains and alteration product. The grains are magnetite with very fine exsolved ilmenite lamellae and a little sulphide mineral which is possible chalcopyrite.

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* The results from Slemmon's curves were obtained by D. Bridgewater

Petrography - Marginal Component

The marginal component of the dyke is alkali - micro-syenitic. It has feldspar laths of 1 - 1.5 mm in length which form a crudely radiating texture. There are occasional euhedral phenocrysts of orthoclase about 1 cm in length.

The feldspar is antiperthitic or forms separate crystals of albite and orthoclase. It constitutes about 80% of the total. Its bulk composition is about $Or_{36.5}$ $Ab_{63.5}$ mol %.

Biotite is the main mafic constituent estimated as 4 - 6% of the total. It is interstitial to the feldspar. It is pleochroic with α yellow-brown β and γ deep red-brown but there is a good deal of variation with some red and some dark grey, and occasionally a margin that is pleochroic from a pale yellow to green. It is occasionally intergrown with the soda-hornblende though where soda-horneblende occurs it usually partly surrounds biotite grains. The soda-hornblende is pleochroic in deep blue-green to a dirty green-blue or yellow-green with high dispersion and $\alpha \wedge c$ about 24°, though the extinction is not complete, suggesting that it has arfvedsonitic affinities. Besides surrounding biotite grains it occasionally partly surrounds the grains of soda-pyroxene. The sode-pyroxene occurs as small grains, rarely as long as 1.5 mm,. These are zoned with ægirine-augite centres out to ægirine rims with pleochroism in deep to yellow-green though in some examples the ægirine forms the complete crystal.

The accessory minerals are apatite, ?zircon and opaque material a very little of which is primary.

Other Big Feldspar Dykes

Besides the northern composite big feldspar dyke there are some short lengths of similar dykes between Kangerdluarssuk avangnardleq and Kangerdluarssuk kujatdleq. Attempts to match these dykes across the N.N.W. faults have not been very successful but there are indications that these dykes belong to two generations separated by some horizontal movement along the N.N.W. faults.

A length of big feldspar dyke is known from the entrance of Torssukátâ crossing the high ground to the west of Naujât tasiat in a direction about 040°. It is about 11 m in width increasing eastwards to about 12 - 13 m. This dyke is divisible into three parts; a central part with feldspar xenocrysts, a marginal part with feldspar aggregates and a thin border that is devoid of phenocrysts (fig.74). There are no sharp boundaries between the parts but the feldspar aggregates of the marginal part end abruptly against an imaginary line which is taken as marking the edge of the thin border. This outer border is about 5 cm wide and is micro-syenitic.

A possible south-westerly extension of this big feldspar dyke across Naujât tasiat is a 12 m dyke striking 070° on the northern side of the entrance to Kangerdluarssuk kujatdleq. The largest single crystals and aggregates known on Qaersuarssuk occur in this length of dyke. The large aggregates of feldspar crystals are up to 1.90 m across, e.g. fig.70 , and isolated single crystals are up to 49 cm in length, e.g. fig.69 . These are usually scattered along the length of the dyke (fig.71), the giant crystals and aggregates confined to the centre but smaller crystals and aggregates are abundant right to the margin. Those near to the margin show a strong parallelism, but even those in the centre lie with their long axes parallel to the length of the dyke.

The composite dykes are in the order of 12 m (exceptionally reaching 19 m) in width with margins of 2.5 - 3 m of alkali - micro-syenite. The contact between the two parts is normally gradational over about 5 cm (fig.72) and irregular without signs of chilling. Occasionally large xenocrysts occur just within the xenocryst-free margin or traces of the marginal alkali - micro-syenite in the edge of the central part.

The xenocrysts of the central part frequently, but by no means always, show a vertical alignment. The alkali - micro-syenitic margins are normally free of phenocrysts, but in some examples orthoclase phenocrysts up to 1 cm in length are known.

In a number of cases the composite dykes loose either their margins or centres and end as thin alkali - micro-syenitic dykes or normal big feldspar dykes. Locally there may be an alkali - micro-syenitic margin only on one side.

The composite dyke that ends at Torssukátak (01/687002) has, on its western side, an apophysis into the granite from its marginal part in which there is a block of coarse grained ?syenite about 2 m by 1.25 m (45453).

Petrography

The texture of these dykes is doleritic (intergranular) with a grain size in the order of 1 mm.

The plagioclase xenocrysts are intensely sericitized but in a few examples the centres of the crystals are still fresh. Albite and albite-carlsbad twinning is common and can be seen in hand samples even when sericitized. Within the xenocrysts there are frequently dark inclusions parallel to the length of the crystal. These inclusions contain a variety of minerals, probably derived from the dyke matrix; augite, opaque material, biotite and a great deal of chlorite.

The smaller plagioclase crystals are usually sericitized but may have a clear outer albitic rim that is sometimes finely antiperthitic. The presence the alkali-feldspar suggests that it is a trachy-dolerite.

The mafic material has a tendency to collect in aggregates between the plagioclase laths. The pyroxene is faintly pink in colour (or flesh coloured) but is not pleochroic. The biotite, which rarely occurs without being associated with the large opaque grains, is pleochroic with α colourless, and β and γ deep red-brown. The deep red-brown colour is due to the presence of titanium (Hall, 1941). When it is not associated with the opaque grains it is pleochroic with α yellow β and γ = grey-brown. Olivine, and pseudomorphs after olivine, occurs in some of the slices as small grains which often tend to collect into aggregates. It is a fayalitic olivine. It is always associated with large amounts of opaque material, and may form anything up to 3% of the rock.

The large opaque grains are magnetite with exsolves ilmenite lamallae. Commonly, there are also small amounts of a sulphide mineral which is possibly chalcopyrite. Rarely ilmenite occurs independently of the magnetite. In ~~the~~ many cases the magnetite shows signs of alteration, biotite forming a narrow reaction rim against the plagioclase. The coloured biotite is mainly associated with these grains filling the skeletal pores. The total opaque mineral content is about 10%. Apatite is a prominent accessory occurring mainly as rods in the plagioclase. Chlorite (probably penninite) is common throughout as a secondary product.

Discussion on the Genesis of the Big Feldspars

The large feldspar crystals in this group of dykes are commonly broken and corroded. They are therefore considered not to be in equilibrium with their surroundings but to have formed elsewhere and to have been intruded with the dyke magma.

A melt of basaltic composition on cooling will precipitate calcic plagioclase. If these crystals are not removed from the system they will on cooling, if equilibrium is obtained, become more albitic and will finally reach the anorthite - albite ratio of the initial magma (see Turner and Verhoogen, 1960, fig.5, p.101). If equilibrium is not reached within the crystal it will be normally zoned. The giant crystals in these big feldspar dykes show no signs of zoning. The larger the growing crystal the greater will be the deficiency of material about it involving migration of material from a greater and greater distance. Gentle stirring will always provide fresh magma adjacent to the growing crystals. Thus in order that the giant crystals should grow to a large size there has presumably been a certain amount of movement in the magma so that the material surrounding the growing cystals always retains the same composition, otherwise there will be a depletion in the anorthitic content and zoning will occur.

A similar argument is applicable to olivine and pyroxene crystals, but neither of these minerals occur as large phenocrysts. Top accumulation in a magma chamber has been suggested for the plagioclase aggregates. If this is so, the olivine and pyroxene crystals of greater density will separate out from the areas of vigorous growth in the magma. The large plagioclase crystals must have had a density equal to, or very close to, that of the magma in which they were growing, i.e. about 2.67 gm/cc. If they had a density slightly greater than that of the magma convection currents at depth would probably keep them buoyed up, and if they had a density slightly less than that of the magma they will form a top accumulation of feldspar without other minerals of large size. On intrusion the magma may be more alkaline due to depletion by material already precipitated as plagioclase crystals and will carry with it the top accumulation of plagioclase aggregates. In the syenite near Narssaq Stewart (1960) records an anorthositic sill forming a roof to the syenite and suggests that the xenocrysts in the syenite have fallen from the roof. The anorthosite, however, is not a top accumulation of the syenite as it is earlier and intruded by the syenite.

Gorbatschev (1961) describes dykes very similar to the big feldspar dykes of southern Greenland, under the name of dolerite-porphyrites, from the Eskilstuna region of eastern central Sweden. He considers the anorthosites to be early differentiates of the dolerite magma and ".... have apparently formed by gravitative accumulation of early crystallized plagioclase in the top positions of the magma chamber ..... before being disrupted and displaced by several succeeding surges of the dolerite magma...." (p. 21-22). Also "While some of the anorthositic rocks are merely glomeroporphyric accumulations of plagioclase phenocrysts, others form a breccia .... The contact relations and outline relations of the anorthite fragments and their mutual composition show that the rock had completely solidified previous to being intruded, broken, and carried into its present position by the dolerite."

Bridgwater (1962) at a lecture given at Det V Nordiske ~~Geologiske~~ Geologiske Vintermøde in Aarhus has considered the problem of the anorthositic fragments in the Gardar intrusives throughout southern Greenland. One of the most impressive features of the problem is the immensity of the volume of anorthosite involved - over 50% of a dyke being by no means rare. In eastern central Sweden Gorbatschev records anorthosite making up 90% by volume of a dyke. It is by no means a local phenomenon; anorthositic fragments are known in dykes in an area extending from Nunarssuit to Narssarssuaq and possibly as far as the east coast of Greenland.

The anorthositic fragments in the Gardar dykes appear to belong to the later Gardar dykes, but do not occur in the main Gardar intrusions, which are mainly late Gardar, with two exceptions, one of which is the syenite near Narssaq, which was mentioned above, and the other is the Narssaq gabbro a continuation of one of the giant olivine-gabbro dykes on Tugtutôq. Their general absence from the main intrusions gives rise to speculation concerning the reason for their absence. The density of syenitic magma is almost certainly lower than that of a gabbroic magma and ~~that~~ plagioclase crystals will no longer form a top accumulation. The presence of banding in many of the intrusions may be connected with this. If there is top accumulation of plagioclase there ought to be a corresponding gravitative accumulation of the heavier minerals giving ultra-basic layers. Small areas of ultramafic rocks occur in the Narssaq-Tugtutôq region (Upton, 1962, p.30).

Upton (1962, p.35) invokes two magmas at different depths to explain the greater abundance of anorthositic fragments in doleritic and gabbroic dykes than in syenitic masses, the doleritic magmas lying at a greater depth than the syenitic with the anorthositic material lying in an intermediate position. Although he does not explicitly say so it is implied that this layer was formed by top accumulation in the deeper basaltic magma.

The anorthositic fragments show a difference in the twinning of the plagioclase which appears to be correlated with the magma type in which they are found. According to Vance (1961) plagioclase of igneous rocks tends to have an abundance of carlsbad twinning with primary polysynthetic twins which are wide in relation to the grain size. Plagioclase with this type of twinning (according to D. Bridgwater) is what is normally found in the plagioclase fragments in the gabbros of Tugtutôq but not in the plagioclase fragments from the syenite masses of Isortoq or in the trachy-dolerites of Qaersuarssuk.

Comments on the Composite Relationship

Some, but by no means all the big feldspar dykes on Qaersuarssuk, have considerable margins of alkali - micro-syenite. Composite dykes result either from differentiation in situ, or by intrusion of two separate magmas differing in composition along the same fracture. In all the examples on Qaersuarssuk there is a marked junction between the two types, and occasionally only one of the types forms the continuation of the composite dyke. It is therefore suggested that these dykes were formed from two intrusions of magmas of different composition. The alkali-syenitic marginal part was intruded first and chilled against the granite; this was followed by the central trachy-doleritic part carrying the big feldspars before the marginal part had cooled sufficiently to produce a chill on the central part but after a sufficient amount of solidification of the margin so that the later intrusion is confined to the centre and there has been very little mixing of the two types along their contact. B. Walton (personal communication) mapping in the area to the east of Narssarssuaq has composite dykes in which the central part is chilled against the marginal part. This is the opposite order of intrusion to that commonly found in composite dykes where the alkaline magma normally follows the basic. The presence of two magmas does not presuppose that there were two magma chambers. The two types are probably the result of differentiation from a single common magma and the intrusion has taken material from different levels at different times.

Olivine-Dolerite Dyke

A large olivine-dolerite dyke crosses the western side of Qaersuarssuk in a direction 055°. On the coast of Torssukátak, in the north, it has a width just less than 40 m and increases in width to the south-west until it is about

100 m on the coast of Qôrnoq. This increase in width to the south-west continues on Qârusuarssuk (mapped by Ayrton and Burri) where it reaches a maximum of 200 m before breaking up into a swarm of dykes and diminishing in total width. Similarly to the north-east across to Kangerdluatsiaq (mapped by Allaart) there is a decrease in width to 25 m and possibly the dyke continues still further to the north-east.

For the greater part of its length the dyke forms an erosion hollow across the country with occasional tors of brown-weathering dolerite set in large areas of light brown gravel carrying no vegetation.

The dyke is coarse-medium to coarse grained with very little difference in grain size between the middle and close to the margin. The margin, of only a few centimetres, is fine grained without being chilled against the wall rock. The adjacent granite for 1.5 m is frequently green in colour with interstitial granophyric texture due to partial melting. Further from the dyke the granite may sometimes be red in colour due to shearing during the injection of the magma.

Vertical banding is known in two places formed by the contrast in colour between darker and lighter bands which grade into one another and are about 2 - 4 cm across.

Pegmatite occurs rarely, usually following vertical joints but occasionally has the form of irregular 'pods'.

Age Relations

The dyke is the latest of the Gardar olivine-dolerite dykes on Qaersuarssuk though it is not the latest dyke of the Gardar period as it is cut by the northern composite big feldspar dyke at 01/607019 and is affected by Gardar faulting. It is displaced sinistrally by 2600 m which also, incidently, confirms its pre-big feldspar dyke age as the latter is only displaced 1500 m.

A N.W. fault through lake 30 (01/598016) displaces it about 200 m dextrally. No other faulting can be definitely demonstrated but at lake 230 (00/5899) there is some slickensiding in the dyke and it may well be displaced sinistrally by a N.N.W. fault by a small amount. Further west other N.N.W. faults are traceable up to the dyke and die out beyond. In no case can displacement be demonstrated but the slightly irregular erosion hollows suggest that the dyke may be slightly affected.

The dyke has the same direction, and is therefore believed to be the same generation, as the Giant dykes on Tugtutôq (Upton, 1962) and the large dyke swarm at Qernertulik (N.E. of Bangs Havn) (D. Bridgwater and Pulvertaft, personal communications), both of which are referred to the latest generation of Gardar olivine-dolerite dykes.

Petrography

The dyke is medium-coarse grained with a doleritic to sub-doleritic (intergranular) texture though sometimes the feldspar laths have a tendancy towards a radial arrangement. The main constituents are plagioclase 70%, olivine 9%, augite 6%, ilmenite 6% and biotite 3 vol %. In addition there is apatite and ?pectolite. The secondary minerals include serpentine, epidote and sericite.

The plagioclase is andesine; most of it is twinned on the albite and carlsbad laws. Some of the grains show distince normal zoning. In sample 45305 the plagioclase is more albitic though with a refractive index greater than that of balsam (ca.An_{22}). The plagioclase is all more or less altered to sericite with epidote.

The olivine is the most abundant mafic mineral (9%). It occurs as rounded colourless grains up to about 1 mm in diameter, frequently crowded together as aggregates in the mafic filled interstices between the plagioclase laths. The composition varies between Fa_{49} and Fa_{58} while that of one sample determined optically is Fa_{63}. On alteration crysotile (serpentine) is developed along the cracks in the grains together with a little secondary opaque material. Although it has not been checked this secondary opaque material from the alteration of the olivine is probably magnetite. The main alteration product is bowlingite, a brown slightly pleochroic, fibrous mineral which is in the same optical orientation as the original olivine. In addition in some of the more altered grains there is antigorite, pleochroic in green to yellow-brown, and occasionally also a carbonate mineral.

Augite is subordinate in amount to olivine (6.5%). It is faintly mushroom-coloured to pink and a few of the grains show faint pleochroism. It is interstitial to the feldspar and is sometimes moulded around grains of olivine. The grains are large, tending to be poikilitic in places with inclusions of apatite, biotite, feldspar and opaque material. The mean composition is about $Ca_{40}Mg_{29}Fe_{31}$ (β 1.705-1.714 and $2V_{\gamma}$ 48-54^{o} with persistent values of 48^{o} amongst a majority of grains with a 2V about 52^{o}. It is suspected of containing some titanium.

The biotite in the rock is markedly pleochroic with α very pale yellow (almost colourless where γ is green), β and γ deep red-brown to brown to green. The red-brown colour is suggestive of it being rich in titanium and poor in magnesium (Hall, 1941). It is suspected of having, what for biotite, is an appreciable optic axial angle but no measurements are available. Some of the red-brown flakes have a thin green border portion to the rim separated by biotite of a browner colour.

Large skeletal grains, up to 1 mm in diameter, of ilmenite, and magnetite with very fine exsolved ilmenite lamellae, are abundant. In addition there is fine grained disseminated pyrite with some pyrrhotite. Under high magnification the pyrrhotite is seen to have a little pentlandite and exsolved chalcopyrite. The gaps in the skeletal grains are normally filled, and the grains rimmed against plagioclase, by red-brown biotite, rarely there is sphene.

The principal accessory mineral is apatite. It occurs as little hexagonal grains or occasionally rods. It occurs mainly within the augite but also in the plagioclase.

In 45305 a fibrous mineral fills a few interstices between plagioclase laths. It is possibly ?pectolite. It has a weak birefringence up to yellow of the first order and an extinction angle ca. 5 - 10^{o}, biaxial positive with a refractive index greater than that of balsam. Prehnite occurs in a few of the altered biotites forcing apart the cleavage flakes (Struwe, 1958).

Discussion

Ilmenite is an early precipitate in the dyke which suggests strong oxidizing conditions and that ilmenite was probably in excess over magnetite in the original magma. The presence of biotite suggests that the melt was wet and relatively rich in potash.

The olivine appears to be the first formed mineral followed by the opaque grains though some of these are probably contemporaneous with the olivine. The apatite probably finished its crystallization next followed very closely by the biotite. Apatite very rarely occurs within biotite grains though it is known to do so. The biotite has definitely formed after the completion of the growth of the opaque grains as it fills in the skeletal holes and rims it attacking the magnetite. The biotite probably takes the remainder of the titanium giving it the deep red-brown colour, and the last of the biotite formed when the titanium to iron ration was greately reduced giving the green biotite instead (Hall, 1941). The plagioclase and pyroxene probably crystallized partly contemporaneously though the pyroxene was probably the last to finish.

Pegmatite

The pegmatite is very coarse grained, hypidiomorphic-granular, of plagioclase with augite and ilmenite. Augite crystals in the pegmatite reach 6 cm in length, though the average is about 2 cm. A feature of the small pegmatite pods is the concentration of large bronze-coloured biotite around the rims.

The plagioclase is the dominant mineral of the pegmatite. One sample (45433) is albitic, An_{0-4}* (X-ray determination), while a second (45287), from the same locality, has a bulk composition of $Ab_{73}An_{27}$†. A marked feature of the plagioclase is its irregular twinning (fig. 75). In one large crystal the centre has regular albite twinning but towards the margin it becomes irregular.

The augite forms about 16% of the total. The grains are large and slightly zoned with a composition about $Ca_{44}Mg_{32}Fe_{24}$ ($2V_{\gamma}55^{o}$ and β 1.700).

Ilmenite is abundant in large (up to 2 mm) well developed skeletal grains which constitute 6% of the total (fig. 76). A sample has been examined by Oen Ing Soen which shows that the grains are entirely ilmenite; there are no traces of magnetite. Within the silicates there are two tiny grains of chalcopyrite.

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* X-ray diffraction by M. Danø.

† Flame photometer determination by B. Borgen.

Fig.75. Twinning in the feldspar of the dolerite-pegmatite from the olivine-dolerite dyke. An X-ray diffraction pattern shows no potash-feldspar; all plagioclase ca.An_{0-4}. X-nicols. x 27. Sample 45433.

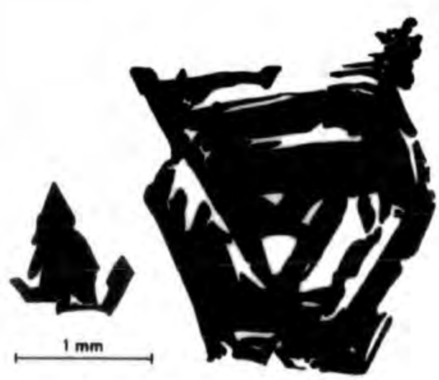

Fig.76. Skeletal crystals of ilmenite in the olivine-dolerite pegmatite. Drawn from 45287.

Sphene (1.5%) occurs associated with some of the ilmenite skeletal grains and this contains needles of ilmenite.

Biotite is the only other main constituent of the pegmatite pods. It is much altered to chlorites, one of which appears to be clinochlore while the other has a slightly higher birefringence and is pleochroic from a pale yellow-brown to colourless. There is a third mineral which marks out the original biotite, dark in colour and appears to have a high birefringence.

Apatite is an accessory mineral with hexagonal grains up to 0.5 mm in diameter.

Spherulitic Dyke

A thin, 40 cm. blue-black dyke with a strike of 060° cuts the nodular micro-syenitic dyke in the north-west tip of Mátâta nunâ and the island in Ikerasak and the same dyke on Upernivik. It is characterized by a well marked spherulitic texture.

Spherulitic dykes are also known cutting the syenite at Kusanga on the Narssaq Peninsula which is comparatively late in the Gardar sequence of intrusions (Stewart, 1960, Ussing, 1912). On Tugtutôq Upton (1962) has described a sodic rhyolite which he has termed comendite. If these spherulitic rhyolitic dykes are contemporaneous they appear to have been intruded late in the Gardar period.

Petrography

The dyke is characterized by its blue-black colour and spherulitic texture (fig.77). The spherulites are rounded, or polygonal where they interfere with one another, with a phenocryst of alkali-feldspar in the centre.

The spherulites are in the order of 6 mm in diameter and are composed of

Fig.77. A thin section of the spherulitic riebeckitic rhyolite. X-nicols, x 9. Photo C.Chaplin. 45537.

Fig.78. Vertical bands in a 2 m wide lamprophyre dyke. 00/705976 - north side of Patdlît.

numerous crystallites with a feathery texture. The extinction within the spherulite forms a unit, extinguishing as a cross parallel to the nicols. Outside the spherulite the feathery texture has a strong flow texture superimposed on it and there is no massive regularity in the extinction. Between the spherulites a carbonate mineral forms a large part of the interstitial material between the crystallites.

The crystallites are opaque under normal illumination but with the use of the condenser are seen to be intensely pleochroic from pale blue to yellow while the small areas of colourless material between the crystallites become pale blue under crossed-nicols and extinguish with a brownish-red colour (riebeckite-arfvedsonite).

The phenocrysts, around which the radiating feathery texture of the spherulites is developed, are in the order of 1 mm in length. They have not been in equilibrium with the magma at the time of intrusion and crystallization as they have rounded corners due to slight absorption.

Comendites have quartz phenocrysts as well as feldspar phenocrysts so that although the dyke is very similar to the comendites its silica percentage is probably too low.

The bulk feldspar of the rock is albite.

Lamprophyric dykes

Lamprophyric dykes, 50 - 80 cm wide occur throughout the area, commonly in swarms but single dykes are also numerous. They are normally vertical with an average strike direction of 055°, but are abundant between 030° and 080°, with

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* X-ray diffraction determination by M. Danø.

examples present in almost any direction. The greatest development of these dykes is in areas of mylonitization and shearing in the granite. The larger dykes in these areas are unaffected by shearing but some of the smaller dykes are slightly affected and may have epidote veins. The dykes are probably intruded towards the close of the period of shearing in these areas but before it is quite finished. Unfortunately these lamprophyric dykes are neither known across lines of dislocation, nor by other Gardar dykes so that their age relations relative to the Gardar intrusive rocks are unknown. On the Julianehaab Peninsula a camptonitic sill "was intruded soon after or late in the alkali dyke sequence and presumably related to a similar source." (Nesbitt, 1961, p.215).

Many of the larger dykes are banded (fig. 78). The bands have a sharp junction between each other and differ in grain size, the presence or absence of white or pink-filled vugs and a dark mineral that weathers out to give a pitted surface.

Petrography

The majority of the lamprophyric dykes are extensively altered. One of the least affected is a dyke from the head of Kangerdluarssuk avangnardleq. The main part of this dyke (sample 45202) is crowded with small phenocrysts (maximum 0.5 mm) of clinopyroxene showing strong compositional zoning and areas up to 2 mm across that are probably pseudomorphs after olivine. Many of these larger pseudomorphed grains are now filled, or partly filled, with a carbonate mineral and it is probable that they are responsible for the vugs on the weathered surfaces. In addition to these phenocrysts there are numerous small insets of a brown amphibole. These amphibole crystals have an elongated form with hexagonal cross-sections. Many are subhedral with imperfections on the long faces which show as round 'inclusions' in the cross-sections. Twin planes parallel to (100) are common, the extinction angle $\gamma \wedge c$ is 13^{o}, and there is a marked pleochroism with α pale yellow, β brown and γ brown. It is probably closely related to barkevikite.

A littie biotite, pleochroic with α colourless to β and γ red-brown, is interspersed with the amphibole.

In parts the groundmass appears to consist of elongated grains of a colourless mineral with the same order of size as the amphibole crystals. These are now extensively replaced by a carbonate mineral but have probably been feldspar laths. Some of the groundmass, though, may be a devitrified glass. Rods of opaque material are common and have the same size as the amphibole cross-sections.

The pseudomorphs after ?olivine consist of cracks across the grain filled with opaque or carbonate material and between the cracks the rest of the space is taken by a fibrous mineral similar to antigorite or, in some parts, wholly or partly by a carbonate mineral.

The marginal part of the dyke has a groundmass that is largely devitrified glass with crystallites of ?plagioclase, strongly zoned phenocrysts of clino-pyroxene and numerous large pseudomorphs after ?olivine; no barkevikite is developed. Some of the pseudomorphs reach 4 mm in diameter.

Other lamprophyre dykes are extremely altered with not much more distinguishable than that they have been very fine grained with phenocrysts. These phenocrysts are normally completely filled with a carbonate mineral. Opaque material is abundant and in a few there are laths of biotite which may show compositional zoning in its pleochroism. These biotite have α near colourless to pale brown, β and γ brown to red-brown, the stronger pleochroic colours occurring on the margins.

One dyke (sample 45350) is of uncertain identification. It is completely crystalline with a groundmass of numerous microclites, showing a flow texture, which have a high relief together with opaque material. In this groundmass are set phenocrysts which are completely pseudomorphed by a carbonate mineral and quartz. Some of these may have been olivine with cracks marked by opaque material and patches of a green, fibrous chlorite; others are hexagonal in outline but completely filled by quartz or a carbonate mineral.

Discussion

Recent studies by Vincent (1953), Ramsay (1955), Challis (1960) Woodland (1962) and Campbell and Schenk (1950) have associated camptonites with the late alkaline fraction of an alkaline olivine-basaltic magma. Earlier studies (Rosenbusch) associated them with alkali-syenite intrusions. Since a parental olivine-dolerite magma has been present in the region, and probably gave rise to the syenitic suite of rocks, the camptonite might be closely associated with either the olivine-dolerite or the syenite. Lack of age relationships does not help the problem. In east Greenland Vincent (1953) has found camptonites associated with Tertiary olivine-dolerites. There is thus also the possibility that the camptonites of Qaersuarssuk are associated with the post-Gardar suite.

All the dykes appear to have suffered late stage deuteric effects, notably the replacement of olivine by carbonate or carbonate-talc in 45202, but in the more extremely altered dykes carbonate has replaced all originally existing mafic minerals.

The phenocrysts of olivine and pyroxene were probably formed early, the pyroxene at least in a magma of rapidly altering composition probably as the result of rapid differentiation of the magma before intrusion. The presence of volatiles is one of the generally recognized conditions for the formation of amphibole (Kennedy, 1936) while the presence of biotite indicates a watery magma.

Petrogenetic Considerations

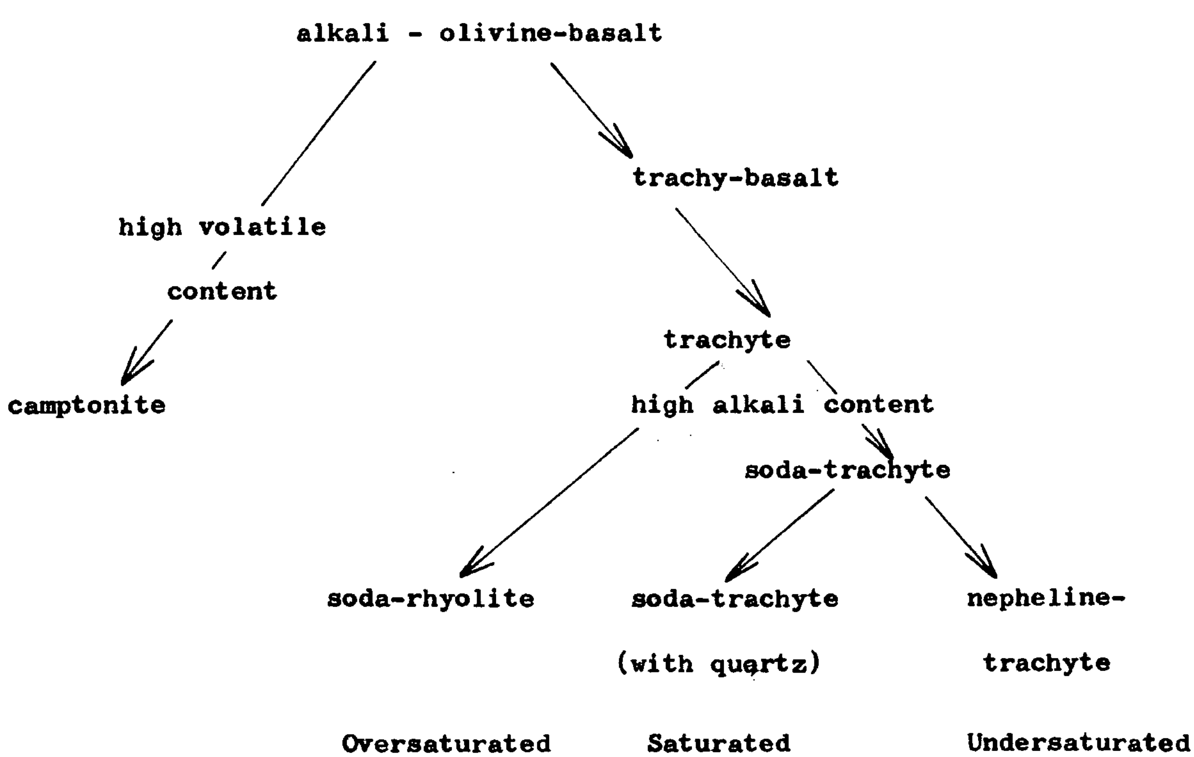
This section is an attempt to draw together the descriptions of the different intrusive magma types into some kind of evolutionary sequence. The earliest dyke rocks in the area are olivine-dolerites. Unfortunately, even though they are the earliest intrusives they need not therefore be the parental magma type. At Grønnedal (Emeleus, 1963), for example, the earliest Gardar intrusives are nepheline-syenites with associated carbonatites.

Qaersuarssuk is but a small part of the area covered by Gardar activity. The intrusive rocks are only represented by dykes which are neither reliable nor form satisfactory bodies in which to see evolutionary sequences. The main outlines of these sequences must be obtained from better known centres. On Tugtutôq, on the southern side of Bredefjord, there is a Gardar extrusive centre that is being investigated at the moment (Upton, 1962). This probably marks the focus of the local differentiating magma chamber that produced the alkaline rock types that are found on Tugtutôq and, to a less extent, on Qaersuarssuk.

Differentiation of alkaline olivine-basalt magma type normally leads to end fractions of trachytic (syenitic) and phonolitic (nepheline-syenitic) composition, the undersaturated condition of the differentiate apparently being inherited from the parent magma (Turner and Verhoogen, 1960, p.394). Olivine-basalts of Gardar age occur in abundance on the Narssaq Peninsula and almost certainly covered a far larger area than their present position restricted to the 'graben' would indicate.

The dyke sequence on Qaersuarssuk (p118), apart from the earliest dykes of olivine-dolerite, is opposite to that normally expected from a differentiating magma; the alkaline undersaturated magma types being intruded before more basic trachy-dolerites and olivine-dolerites. Fractional crystallization, probably at various levels largely independent of one another in space and possibly also in time, may lead to intrusive and extrusive phases in a chronological sequence that departs from the differentiation sequence. Local cupolas may form during intrusion into higher levels in which further differentiation takes place leading to local magma types. The effects of assimilation may also be important in certain areas leading to further local variation.

The following is a very tentative working scheme with the Qaersuarssuk dyke types fitted into the classical differentiation sequence from a parental alkali - olivine-basalt magma.



Gardar Faulting

The topography of Qaersuarssuk is strongly influenced by the zones of dislocation; the fjords from Imartuneq in the north-west to Bredefjord in the south-east trend approximately E.N.E.-W.S.W., and throughout the island there are numerous N.N.W. lines of dislocation all forming valleys and small fjords. The long length of lake 5 and its accompanying valley also marks a large fault. In many cases a topographical feature is present where no actual displacement can be demonstrated.

All the faults in the area appear to be wrench faults displacing cross-cutting dykes; no vertical movement can be demonstrated on any of them due to lack of suitable markers.

Although the E.N.E. fjord directions are the most marked feature nowhere has it been possible to see zones of crushing of this trend, but this may be due to lack of exposure. This direction is also the main trend of the Ketilidian orogeny and the strike of the meta-sediments at Uniaríssat has approximately the same direction.

The N.N.W. Faults

The N.N.W. direction of faulting has a pronounced affect on the topography giving rise to a series of valleys, lakes and small fjords. Along these faults two directions of movement are clearly demonstrated; an earlier dextral and a later sinistral movement separated by the emplacement of a number of generations of N.E. dykes. From what is known of the Gardar faulting elsewhere it appears that this sinistral movement has only been recognized on Qaersuarssuk.

Three of the early E.S.E. olivine-dolerite dykes, each over 60 m wide, are cut in a number of places by N.N.W. faults. These dykes now show dextral displacements on these faults by the amounts given below, but since sinistral movement followed the dextral the original dextral movement after the emplacement of the E.S.E. olivine-dolerite dykes was considerably greater.

Naujât tasiat fault	450 m	
Torssukátâ fault	600 m	(but the course of the dyke here may give a deceptively large figure).
Kigssaviat fault	450 m	
Northern extension of the Tunua fault	450 m	

After the dextral movement on these faults there followed the emplacement of a number of generations of different dyke types (see chronological scheme p.118) in a N.E.-S.W. direction. The dykes were followed by sinistral movement along the same fault lines. The sinistral movement on the faults, with the exception of the Torssukátâ fault, is about 150 m. On the Torssukátâ fault it is possible that there has been two periods of movement, of 150 and 50 m, separated by dyke emplacement, but the division is not entirely proved.

The majority of these faults die out to the north. The northern composite big feldspar dyke is only locally affected by small amounts while to the north of it the N.E. olivine-dolerite dyke, which is earlier than the northern composite big feldspar dyke, shows no displacement. But the course of the dyke is not entirely regular and the valleys following the faults continue across the dyke suggesting that there may have been shattering of the dyke without a displacement of any magnitude.

The initiation of this direction of faulting can only be proved as post-E.S.E. olivine-dolerite dyke, but the rather irregular course and apparent large displacement of a dyke of this generation along the Torssukátâ fault may be due to the dyke following an earlier fracture zone in that direction.

The W.N.W. Fault

A great W.N.W. fault along the lake 5 shows at least two stages of movement, both in a sinistral sense. It is part of an important line of dislocation which can be traced over a length of at least 70 km in a W.N.W.-E.S.E. direction across the Julianehaab District. It is parallel to a number of other faults showing a similar magnitude of sinistral displacement so that they form an important set of faults throughout the whole region. The initiation of movement is unknown. The Laksenæs fault in the Ivigtut region shows sinistral movement before the Sanerutian period (Henriksen, 1960) so that it is quite possible that the fault across Qaersuarssuk was initiated before the Gardar period. However no movement can be demonstrated until after the emplacement of the N.E. olivine-dolerite dyke which is quite late in the dyke chronology. No vertical movement can be demonstrated on the fault but, in common with the Laksenaes fault, there was probably considerable vertical as well as horizontal movement.

After the emplacement of the N.E. olivine-dolerite dyke there was sinistral movement of 1100 m along the fault (based on the assumption that the dyke cut straight across the fault line). This was followed by the emplacement of the northern composite big feldspar dyke which was subsequently displaced 1500 m sinistrally. Thus the fault shows a total sinistral displacement of 2.6 km.

The fault itself appears to be displaced 2 km to the south-west along Bredefjord between Qaersuarssuk and Tugtutôq. The E.S.E. olivine-dolerite dykes, though, do not show any displacement across the fjord, and certainly not of that magnitude. Thus is appears as if the fault is here on echelon.

Dynamics of the Gardar Fault System

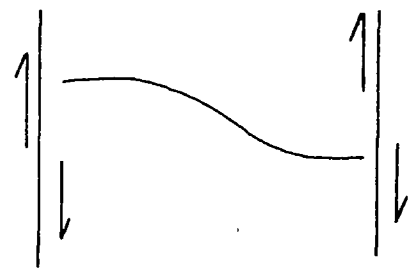
This section is highly speculative as must be any dynamic approach to the problem. Whilst it is suggested that the W.N.W. faults may be old, since a fault in the same direction in the Ivigtut area is old, the faults that can be shown to be the oldest on Qaersuarssuk are the N.N.W. faults. The map 2 shows the N.N.W. faults and their relation to the N.E. dykes.

The salient points are that the N.N.W. faults show transcurrent movement in two directions; an earlier dextral and a later sinistral. It therefore appears that there has been a radical change with time in the forces producing these faults.

With the exception of the early E.S.E. olivine-dolerite dykes the dominant dyke direction is north-east and the majority of these occur between Kangerdluarssuk avangnardleq and Bredefjord. Any discussion of the stress system resulting in faulting must take into account the dykes.

The earliest Gardar stress system recognized in the area is the emplacement of the E.S.E. olivine-dolerite dykes along tensional fractures. This was followed by dextral movement on N.N.W. faults to displace these dykes by minimum amounts of 450 m. These E.S.E. dykes are developed on a regional scale. But E.S.E. tensional opening on a regional scale and dextral faulting on N.N.W. lines appear to be incompatible on the same dynamic system.

One of the E.S.E. olivine-dolerite dykes has a slightly sinuous course in the sector between Kangerdluarssuk avangnardleq and Torssukátâ. If this is assumed to be due to a couple operating between a pair of N.N.W. faults, giving rise to a sinuous tension crack, it would also indicate a dextral movement on the faults.



While this may have operated locally it is not considered in general to have set the course for these dykes.

Small amounts of dextral movement could be explained by scissor faulting or by large amounts of vertical movement when the dykes that are used as markers are not vertical. The fact that these faults die out to the north may suggest considerable scissor faulting. One of the dykes is known locally to dip 70° northwards which means that a downthrow on the north-east side of the fault will give a dextral displacement on the fault relative to the dyke.

The prominent feature of the N.E. dykes on Qaersuarssuk is their abundance in only part of the island. The individual dykes are traceable over considerable distances and their emplacement appears to be quite unrelated to the fault systems. Their regional distribution is also interesting. There is a concentration of dykes on Tugtutôq extending north-westwards over the south-east part of Qaersuarssuk. Further to the north-west they are scarce until on the islands round Qagssimiut where there is a minor concentration and scarce between Qagssimiut and the Isortoq area to the north of Nunarssiut. To the north-east of Nunarssuit there is a great dyke concentration. The two areas of dyke concentration, Tugtutôq and Nunarssuit are also the position of later intrusive centres.

To explain this dyke distribution a flexuring of the crust is suggested with N.E.-S.W. axes in which the dykes follow tensional fractures located along the crests of the flexures (fig.79). The position of the dykes on Qaersuarssuk would then be on the northerly limb of the crest of the flexure along Tugtutôq. While it may completely explain the dyke emplacement on Qaersuarssuk it probably does not completely explain that on Tugtutôq and in the Isortoq area. The main dykes on Tugtutôq are two very large dykes which have features that are the result of more than emplacement along tension fractures. Here forcible intrusion probably with stoping has occurred (Upton's map, 1962). Bridgwater (1959) has evidence of stoping in some dykes in the Isortoq area and in one place the upper termination of a large dolerite dyke which is explained as being forcibly intruded.

Nearer to the Nunarssuit intrusions within the same suite of dykes there are dykes that follow a rather sinuous course. These have suggested to Pulvertaft (Harry and Pulvertaft, 1963, p.17) that the dykes have partly followed tensional fractures resulting from a regional couple.

Flexuring of the crust with N.E.-S.W. axes due to N.W.-S.E. compression could lead to the development of N.N.W. sinistral faulting and could interdigitate in time with N.E. dyke intrusions (fig.80). Slight dextral movement might be expected along the complementary fault direction, E.S.E. and shows as shearing along the edges of the dykes in that direction which is such a marked feature of those dykes. A possible 4 m dextral displacement of a N.E. dyke across the edge of an E.S.E. olivine-dolerite dyke is also known.

Two marked directions in the area are the E.N.E. fjords and the W.N.W. fault line. These two directions could be considered as complementary shear

Fig.79. A diagrammatic cross-section between N.E. of Nunarssuit and Tugtutôq to illustrate the suggested flexuring of the crust with accompanying dyke intrusion along the crests of the flexures in a N.N.E. direction.

Fig.80. The fault directions resulting from N.W.-S.E. compression and tension along the crests of the flexures produced (after Moody and Hill, 1956).

Fig.81. The fault directions resulting from E.-W. compression (after Moody and Hill, 1956).

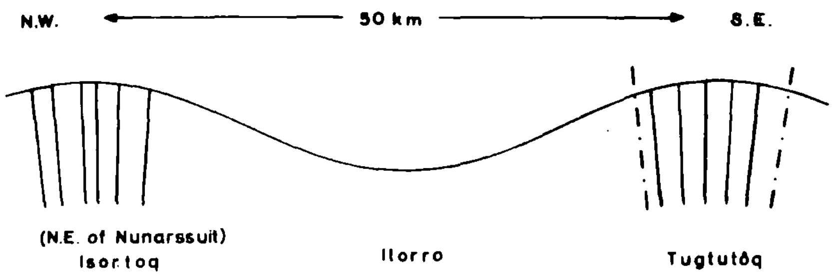


Fig.79.

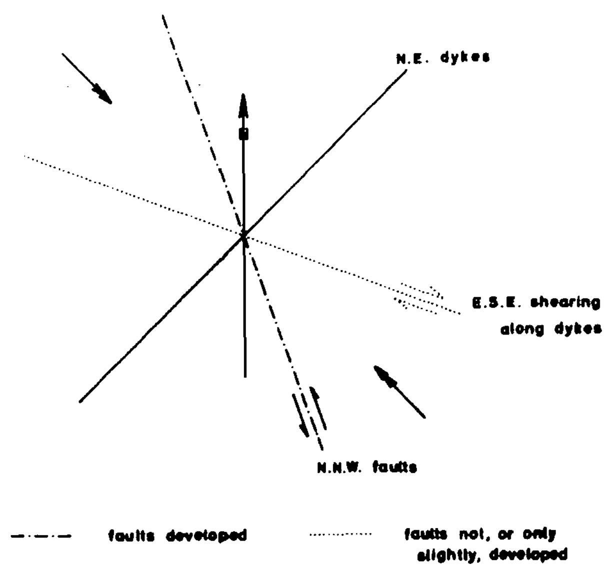


Fig.80.

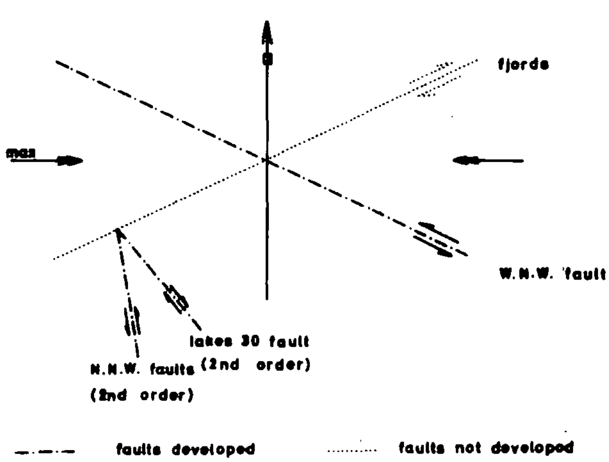
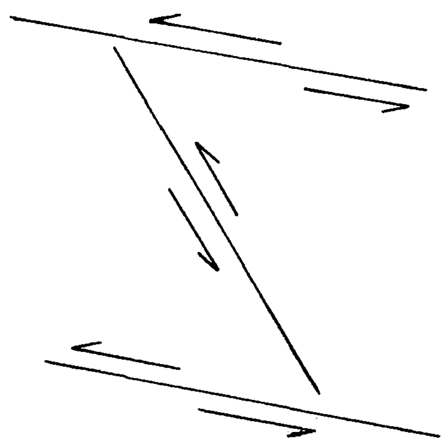


Fig.81.

directions resulting from E.-W. compression. Displacement of any magnitude is only known to occur along the W.N.W. fault. As a result of considerable displacement along two or more of these W.N.W. faults (a second is considered to run to the south of Qaersuarssuk) sinistral movement could occur on a wrench shear fracture system in a direction N.N.W. (second-order wrench faults)- fig.81. Dextral movement along the lakes 30 fault could also be explained by a second-order fault. Second-order faults would be expected to terminate at the master fault. If this fracture system was already developed from an early stress system renewed activity would be very likely to occur.



The suggested stress systems are open to the valid criticism that forces from more than one direction are involved.

<u>Comparisons with Labrador</u>

Kranck (1953) describes briefly various olivine-dolerite dykes on the coast of Labrador between Domino Run and Hopedale. In the Aillik-Makkovik area, which is about 100 km north-east up the coast from Hamilton Inlet, there are "steep diabase dykes of several generations ..... At least two, and probably three, generations of diabase can be recognized, of which the older intrusions are pure black and the younger weather brownish. The latter form two large dykes, at least 200 feet thick [60 m] striking across Aillik Bay." (p.19). From his map these trend E-W. There are also younger lamprophyre dykes in this area, though in other areas that he mentions lamprophyre dykes are mainly older than the dolerite dykes. Olivine-dolerite dykes also occur on Smokey Archilelago, at the entrance to Hamilton Inlet, and are particularly numerous around Indian Harbour where many reach a thickness of several hundred feet (p.12). Again, from his map these trend N.E. to E.-W.

No dyke directions are given in the text, but from the map dykes in the Aillik-Makkovik area are shown E.-W, N.-S. and N.N.W. while further north up the coast to the area of Hopedale dykes up to 14 km in length are known in a direction N.E. No indication is given of their relative ages, nor their sizes.

In his comparisons with other parts of Canada on p.37, he tentatively suggests a "Keweenawan age or still younger (Tertiary?)". These dykes might rather be correlated with the dolerites of Gardar age in Greenland, but without more knowledge of the age relations and directions of the Labrador dykes little more can be done.

Part IV

POST-GARDAR

Post-Gardar Dolerite Dykes

General Statement

Two dykes of fresh olivine-dolerite on Qaersuarssuk are later than all the other dykes and are unaffected by faulting. Both are characterized by their vertical banding. The northern of the two dykes has a general direction of 100° swinging to 120° on the eastern side of Qaersuarssuk and to 130°, with a dip of 70° to the south-west, on the extreme western side. To the west the same dyke can be traced across Qârusuarssuk, and to the south-east a banded olivine-dolerite can be traced across Tugtutôq Lille Ø where it swings round to have a south-east direction (Ayrton and Burri, 1959, and Upton, 1959 MS maps).

To the south of this dyke there is a second banded dolerite dyke which has a general direction of 110°, and approaches very close to the northern one on the Bredefjord coast. It is traceable inland for just over one kilometre and is considered to be an offshoot of the northern dyke. There is some evidence that this southern dyke is multiple.

A 2.5 m fresh olivine-dolerite dyke dipping 30° W.S.W. is present in the northern part of Upernivik. Its chronological position is uncertain other than that it is later than an E.N.E. micro-syenitic dyke. It could be a post-Gardar dyke judging by its freshness. Columnar jointing in it is well developed.

Regional Aspect

On Qârusuarssuk, due west of Qaersuarssuk, two sets of post-Gardar dykes are recognized; an earlier running N.W. and nearer the glacier N.N.W.;

and a later which runs approximately east - west. The dykes of the later generation are less common than those of the earlier. This later generation runs more or less parallel to the first generation of Gardar dolerites (the E.S.E. olivine-dolerites) and are apt to be confused with them unless they cut Gardar dykes (Ayrton and Burri, 1959).

Westwards towards Nunarssuit both sets of dykes are recognizable.

To the south-east on Tugtutôq a single 4-5 m post-Gardar olivine-dolerite dyke traverses the late Gardar complex (Upton, 1959; 1962 map).

To the north, in the Ivigtut area, there are two principal swarms of unfaulted and fresh N.N.W. olivine-dolerite dykes parallel to the coast. On Tôrnârssuk E. Bondesen (personal communication) has separated two generations. One of these dykes cuts the ring dyke at Kûngnât which, without positive evidence, is referred to the latest Gardar (Upton, 1960, p.16). J. Muller (personal communication) distinguishes a total of four generations and places the dykes described here in the last generation.

Age of the post-Gardar Dykes

There is no direct evidence for the age of the post-Gardar olivine-dolerite dykes. They are separated off into a separate group as nowhere are they affected by faulting which cuts Gardar dykes. Swarms of them occur up the coast as far north as Frederikshaab and similar dykes occur on the east and south of Disko Bugt. It has therefore been suggested (Berthelsen, 1961b p.334) that they are of the same age as the Plateau basalts of Disko Bugt. These overlie plant-bearing sediments which are referred to the Lower Palaeocene (E.Koch, 1959) while layers of ash occur as low as the Coniacian (Upper Cretaceous) so that incipient volcanic activity began at the end of the Mesozoic, (cf. possible Upper Cretaceous dolerite sills in Vestspitzbergen (Harland, 1961 pp.105-107)).

If these dykes are Tertiary in age it increases the area of the Thulian or Brito-Arctic Volcanic Province into southern Greenland in addition to the considerable areas of Plateau basalt that occur in eastern and western Greenland and the extreme eastern tip of Baffin Island (Kidd, 1953).

Field Description

The main dyke can be traced with fair certainty over a distance of 26 km. The average width across Qaersuarssuk is 34 m. At its western end the dyke dips 70° to the south-west and a similar dip is seen on the eastern side of Kangerdluarssuk avangnardleq. The short length of the southern banded dyke also has a possible southerly dip.

Throughout its length the northern dyke is characterized by prominent light and dark bands which are best observed on the weathered surfaces. The light bands, which are narrower than the darker, are about 5 cm wide but examples up to 15 cm are found. There are all shades of colour reflecting the mineral composition from white to dark; sometimes the transition is abrupt. While on a vertical surface the bands are very regular (figs. 82 and 83) on a horizontal surface they are by no means constant in direction (fig. 84): one set of bands may cut across another and in one case such a set have been seen to turn into a whorl. Normally the vertical banding occurs throughout the dyke but in places it is seen only near the margins.

At 00/560924 three 'channels' (fig.85) each about 30 cm across and within a few metres of one another are interpreted as late slumping along troughs (fig.86). Pegmatite is locallized along the edge of the structure and occurs

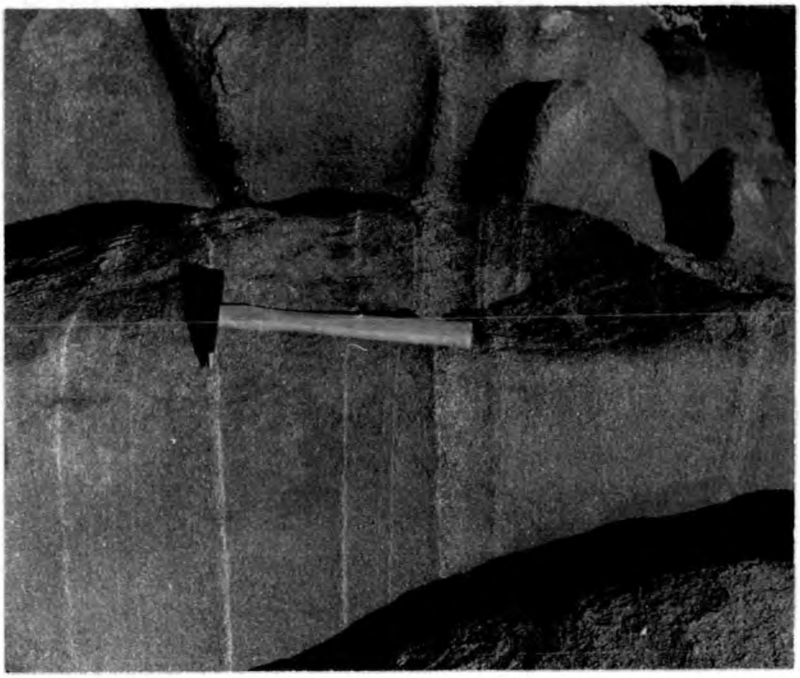


Fig.82. Light bands on a vertical surface of a post-Gardar olivine-dolerite dyke. Hammer length 30 cm. 00/533929.

Fig.83. Regular light and dark bands in a post-Gardar olivine-dolerite dyke. A pegmatite pipe to the right of the hammer shows a cross-section on the horizontal surface below. 00/619887.

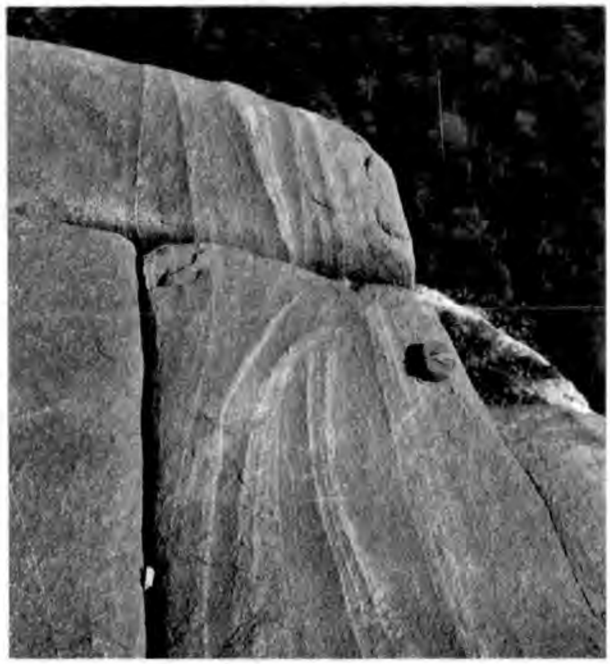


Fig.84. Light and dark bands on a horizontal surface of a post-Gardar olivine-dolerite dyke. Note the way that one set of bands cuts across another. Hammer length 30 cm. 00/582912.

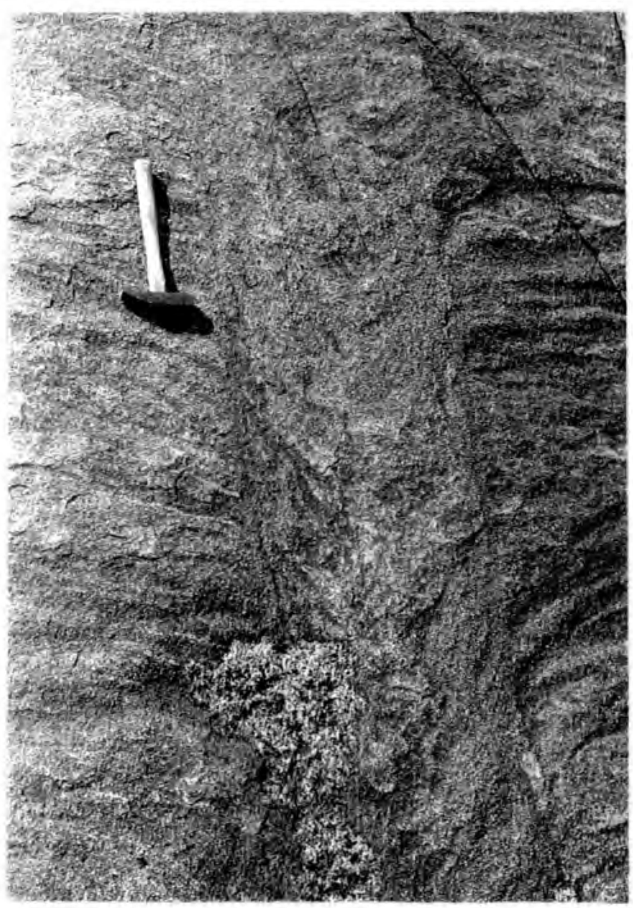


Fig.85. Late movement of material in a 'channel' normal to the length of the dyke. The structure peters out towards the camera.

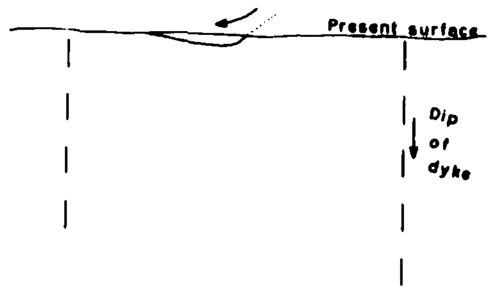


Fig.86. An interpreted cross-section of one of the troughs (fig.85) of late slumping in the post-Gardar dolerite dyke.

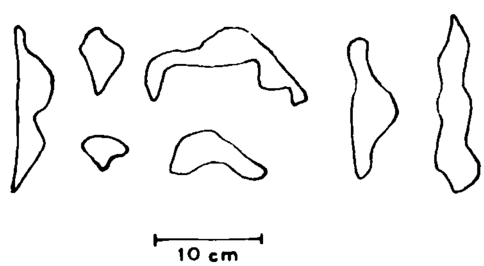


Fig.87. Representative cross-sections of the vertical pipes of dolerite-pegmatite in the post-Gardar dolerite dyke. Drawn from field sketches at the same locality as fig.83.

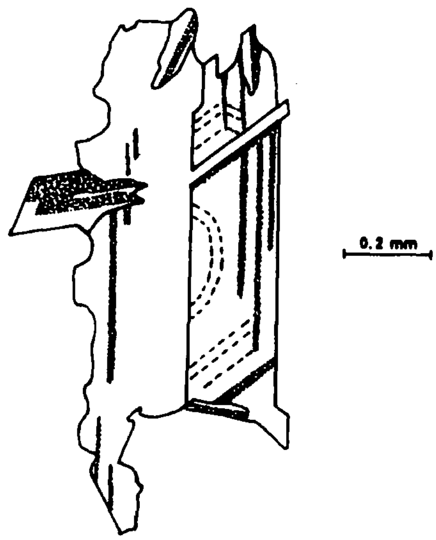


Fig.88. A crystal of plagioclase from the post-Gardar dolerite dyke showing two generations of growth. The earlier crystal is zoned (marked by dashed lines) and broken along a twin plane; the later growth is without zoning. Drawn from 45497.

nowhere else in that sector of the dyke.

The dyke has a fine grained margin of 15-20 cm against the granite. Within 2-3 m of the margin there is a number of light grey, well rounded, fine grained inclusions of dolerite and granite up to 8 cm in length. The dolerite of the dyke is chilled against the granite inclusions. The darker, finer grained doleritic inclusions are probably earlier solidified pieces reincorporated into the mobile material.

Vertical pipes of dolerite-pegmatite occur in the dyke (fig.83). They are coarse grained and poor in mafic constituents with variable cross-sections commonly about 10 cm in diameter (fig.87). The pegmatite has a few macroscopic (ca. 3 mm) plates of bronze-coloured biotite and occasionally zeolites.

The southern banded dolerite dyke is very similar to the main dyke to the north, differing mainly in its smaller size, being only 11 m in width decreasing westwards to 6 m where last seen, and in the slight evidence for multiple intrusion. The margins of 1.5 m are of coarser grain compared to the rest of the dyke, and have a slightly different weathering colour. The junctions between the margins and the interior are fairly sharp. Within the central part there are both coarser and finer portions with the finer grained occurring as rounded inclusions in a coarser matrix.

Discussion on the Origin of the Vertical Banding

The vertical banding is a characteristic feature in the northern dyke but it is not a general characteristic of post-Gardar dolerite dykes elsewhere. On a vertical surface all the bands are very regular without divergence from the vertical but on a horizontal surface there is considerable cross-cutting of one group of bands by another (fig. 84). The bands near to the centre cut those nearer to the margins indicating that not all the magma was intruded at the same time and that the central part is later than the marginal. The multiple intrusion of magma into the dyke may suggest that it was a feeder dyke to higher levels. This does not imply that it fed surface lavas; indeed there is no evidence for such lavas. The dark and light bands may be explained as changes in differentiation taking place at depth producing intrusions of slightly differing compositions with crystallization in from the walls, and the scouring out of channels parallel to the walls (fig. 84).

Petrography

Where there is no banding the dyke is comparatively uniform. An average modal analysis of three slices of normal dolerite, to the nearest volume percent, is given in the first column.

		Normal dolerite	dark band	light band
Plagioclase	(50-59%)	56%	56%	70%
Augite		19	20	12
Olivine (plus pseudomorphs after olivine)		6	4	3
Opaque minerals		8	9	5
Biotite		8	7	6
Apatite		2	3	3

Modal analyses on two adjacent light and dark bands in the dyke gave the figures in the second and third columns. The mode of the dark band is very close to the mode of the normal dyke while the light band shows a distinctly higher plagioclase content and lower content of mafic minerals. The apatite content of the banded portion of the dyke appears to be slightly higher than elsewhere and there is a fractionally greater amount of apatite in the dark band compared to the light which is not shown in the figures presented.

The dyke is completely holocrystalline with a grain size in the order of 0.3 - 1.0 mm being different in different parts of the dyke. The texture throughout the dyke is practically the same with randomly oriented laths of plagioclase and interstitial augite as aggregates of grains or as small poikilitic grains penetrated by plagioclase laths. There is no difference in texture between the bands but the crystals of the light band do have a slightly smaller average grain size than those in the dark bands; 0.4 mm in the light bands compared to 0.5 mm in the dark. In the bands the longer plagioclase laths are proportionally wider while in the greater part of the dyke they have a stumpier form.

Albite twinning in the plagioclase laths is practically universal and carlsbad twinning is extremely common while pericline twinning has occasionally been seen in the larger laths. All the crystals are strongly zoned with a composition range of An_{28-41} and one value as low as An_{17}*. Values as high as An_{50-56} have however been obtained by extinction angle methods on the U-stage. There are cases, e.g. fig. 88, where early zoned plagioclase crystals have probably been broken along a twin plane and a later twin has grown without zoning. This may indicate a tendency towards crystallization of the plagioclase laths in two generations.

The plagioclase is very much more sodic than in post-Gardar dykes from

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* Compositon from R.I. values on cleavage flakes. See appendix.

further north. J. Muller has found that the plagioclase becomes less basic the younger the dyke generation (personal communication). He has not studied any of the latest generation, to which the dyke on Qaersuarssuk belongs, so that the very sodic plagioclase of these dykes follows the trend that Muller has determined on the other generations.

The presence of rare, tiny, interstitial grains of quartz or alkali-feldspar is suspected but not proved. There are a few examples of late stage interstitial fibrous zeolites.

The pyroxene occurs as crystal aggregates of augite between the plagioclase laths or as single crystals which are partly interstitial and partly poikilitic with penetration of narrow plagioclase laths so that much of the pyroxene has crystallized contemporaneously with the plagioclase. These pyroxene crystals are commonly in the same order of size as the plagioclase laths. The grains show slight zoning so that there is a variation in the composition. The compositional range is about $Ca_{42.5}Mg_{29.5}Fe_{28}$ to $Ca_{35.5}Mg_{26.5}Fe_{38}$. The composition of the pyroxene from the pegmatite falls within this range, with the difference that it has a lower magnesia content. The $2V_{\gamma}$ values from individual grains within the same slice also show considerable variation though they tend to fall into two groups; those about 48^{o} and those about 52^{o}. All the pyroxene is faintly pink which is suggestive of it being slightly titaniferous.

Olivine, though an essential constituent, is not abundant being as low as 3% of the total (including those pseudomorphs that are definitely after olivine). Due to its small size and alteration it has been difficult to obtain its composition. Values of Fa_{42} and Fa_{55}* have been obtained. It tends to be

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* determined optically on a single crystal each.

extensively altered into green serpentine minerals including antigorite, and possibly also clinochlore and brown xylotile.

Biotite occurs both as a primary and a secondary constituent. As a secondary mineral it forms a reaction fringe surrounding the opaque minerals against plagioclase. Since it only fringes those parts of the opaque grains against plagioclase, reaction between the opaque grains and the interstitial liquid did not begin until comparatively late in the cooling history and after the pyroxene had crystallized. However, the greater portion of the biotite is primary in plates of approximately the same size as the plagioclase and pyroxene. It is strongly pleochroic with α very light brown-yellow, β and γ deep red-brown. The 2V is relatively large, estimated at about 15°. The strong pleochroic colours suggest that it has a high titania and low magnesia content (Hall, 1941). Very occasionally the biotite is slightly poikilitic.

The opaque mineral occurs as skeletal or subhedral grains of magnetite with exsolved ilmenite lamellae. It tends to be closely associated with the aggregates of pyroxene and olivine and is frequently intimately associated with the biotite.

Apatite is invariably present as long slender acicular crystals with six-sided prismatic cross-sections of about 0.2 mm diameter.

In the finer grained portion from the centre of the multiple southern dyke there are phenocrysts of plagioclase and pyroxene (up to 1 mm and 0.5 mm respectively) with a few opaque crystals in a very fine grained groundmass (0.03 mm) consisting of clinopyroxene, biotite and opaque grains in a plagioclase matrix.

Dolerite-Pegmatite

Dolerite-pegmatite mostly occurs in vertical pipes but occasionally as small irregular bodies (e.g. as in fig. 85). It is relatively coarse with subhedral feldspar and clino-pyroxene crystals up to 6 mm in length. The intersticies are filled partly with clinopyroxene and amphibole but mainly with fine grained minerals of late stage crystallization.

The feldspar is alkaline in large (commonly 5 mm) subhedral to euhedral crystals most of which appears to be potassic with narrow rims of sodic feldspar. The position of these rims onto the euhedral crystals is suggestive of them being additional and not a later replacement by sodic feldspar. These sodic rims show considerable zoning and there is also very slight zoning in the main euhedral crystals. The composition of the bulk feldspar is about $Or_{46}Ab_{45}An_{9}$ mol %.

The clinopyroxene shows greater idomorphic habit in the dolerite-pegmatite than in the rest of the dyke. A granophyric-like intergrowth with the alkali-feldspar is common indicating contemporaneous crystallization with the feldspar. The crystals tending towards an idiomorphic habit show strong zoning which is apparent from their colouring, very pale pinkish centres grading out to narrow light green margins. In contrast the subhedral crystals show only the faintest trace of zoning.

The clinopyroxene has started crystallizing early with a tendency towards idiomorphic crystals followed closely by contemporaneous crystallization of pyroxene and feldspar forming the granophyric-like intergrowth. The later pyroxene was thus protected from the residual liquids which zoned the exposed leaving the protected pyroxene completely untouched. The pyroxene has a composition about $Ca_{40}Mg_{23}Fe_{37}$.

Amphibole normally forms separate crystals but may also rim the zoned clinopyroxene crystals. The amphibole is pleochroic with α yellow-brown, β greeny-brown and γ bright green to greenish-brown, while some of the outer parts are bluish-green and probably a sodic variety. The optic axial angle about α is about 64°.

The biotite is strongly pleochroic with α yellow-gold or red-brown to β and γ deep red-brown to almost an opaque red so that, like the biotite of the main rock, it is titaniferous. The biotite is associated with most of the mafic minerals and has grown at the expense of some of the pyroxene. Ilmenite is the main opaque mineral either as separate grains or as fine ilmenite lamellae exsolved from magnetite. Very little magnetite remains, most of it being replaced by a dark red-brown finely aggregated mineral part, at least, of which is a titaniferous biotite. Apatite is common throughout the pegmatite and is present within all the mafic minerals. Sericite is abundant as an alteration product of the feldspars. There is also a colourless, fibrous interstitial mineral that is probably a zeolite (uniaxial, positive, R.I. $>$ balsam, very weak birefringence, length slow with parallel extinction).

The dolerite-pegmatite represents a post-injection differentiate of the normal rocks when the crystallization was well advanced.

The pipes of the dolerite-pegmatite were drilled through the main rock or kept open in the crystallizing rock until an advanced stage in the crystallization and differentiation of the main rock. In these pipes there collected the post-injection differentiate of the normal rock. That the pipes were not a conduit for the upward movement of late stage residual liquids is probably evident from the lack of hydrothermal alteration both in the dolerite-pegmatite itself and in the normal rock surrounding the pipes.

Turrell (1928) suggested that the formation of dolerite-pegmatite was a filter press action though Walker (1953, p.56) considering the strength of the augite-plagioclase framework, considers that filter-press action is not a factor in the formation of dolerite-pegmatite.

The normal differentiation expected in a pegmatite of an olivine-dolerite is for the plagioclase to be more sodic and the pyroxene to be richer in iron with possibly the presence of an amphibole compared to the normal dolerite (Walker, 1953; Walker and Poldervaart, 1949 p.663). In the pegmatite described here the feldspar is alkaline and the amphibole is a sodic variety. Thus it is considerably alkaline in composition with camptonitic affinities. According to Hatch, Wells and Wells (1949, p.349) lamprophyre with a sodic-amphibole (often barkevikite) is normally associated with syenites such as nepheline-syenite. That this is not always the case has been shown by Vincent (1953) in dykes of Tertairy age from the Skaergaard area of East Greenland. In the coastal swarm of dykes he has demonstrated a genetic link from normal dolerites through oligoclase-dolerites to camptonites which have almost certainly all arisen from the same parental basaltic magma. The camptonites are the result of crystallization and filter press action both of which would be applicable for a pegmatite.

The pegmatite, to judge from its mineral assemblage is enriched in sodium and water.

APPENDIX

Optical Determinations

The composition of the zoned plagioclase was obtained from maximum γ and minimum α refractive index determinations either on (001) cleavage flakes or on mounted grains in random orientation. The anorthite percentage for the cleavage flakes was obtained from Tsuboi's curves (1923) and for the mounted grains from Hess's curves (1960). In some cases maximum extinction angles were measured on albite twins cut normal to (010) and occasionally by the measurement of extinction angles in combined albite-carlsbad twins. The anorthite percentage for these was obtained from curves reproduced in Tröger (1959, p.111).

Optic axial angles were determined by direct measurement about the acute bisetrix on a 5-axis U-stage and were corrected using Kleeman's nomogram (1952). Refractive indices of olivine were not determined but a β value consistent with the 2V was used in the correction. The composition of the olivine from its 2V was obtained from Kennedy's curves (1947) reproduced in Tröger (1959, p.37).

The β refractive indices of the pyroxenes were determined using a variable wave-length method at constant temperature and a standard glass (Micheelsen, 1957). It was determined on either (100) or (001) parting planes when the isogyre of the interference figure is E.-W., as described by Hess (1960 p.11), so that β is N.-S. The pyroxene composition, in atomic percent, was obtained from $2V_{\gamma}$ and β R.I. on Hess's curves (1949).

X-Ray Determinations

The nepheline composition was determined by X-ray diffraction after the method described by Smith and Sahama (1954). The composition is quoted as the ratio 100K/K+Na.

The composition of olivine, unless otherwise stated, was determined by X-ray diffraction after the method described by Yoder and Sahama (1957). These authors give an accuracy of 4 mol %.

All X-ray determinations were carried out by M. Danø of the Mineralogy Museum, Copenhagen.

Chemical Determinations

These were all carried out by B. Borgen of the Geological Survey of Greenland, Copenhagen.

K_2O and Na_2O were determined flame photometrically: CaO was determined titrametrically.

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